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Zuverlässigkeitsanalyse elektronischer Systeme am Beispiel des neuen strahlungsresistenten Stromumrichterkontroller für den Large Hadron Collider

Reliability analysis of electronic systems on the example of the new radiation tolerant power converter controller for the Large Hadron Collider

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Prevessin, April 2016 Volker Schramm

Abstract

At the European Organization for Nuclear Research (CERN), several particle accelerators are operated in terms of research within the field of particle physics. To be able to operate the largest accelerator of all those, the circular Large Hadron Collider (LHC), magnetic fields are used to influence and accelerate the particles as intended. These magnetic fields are created by various power converters, each controlled by a specific Function Generator Controller (FGC). For the controller version which is used in the LHC (FGC2), a new version is currently being developed and is planned to be installed during 2017. This so-called «FGClite» will be deployed in radiation areas, where the FGC2 showed weaknesses in terms of performance due to radiation induced failure.

In the framework of this work the *electrical* reliability of the FGClite is treated. An independent study was carried out regarding the *radiation* reliability [1], which is outside of the scope of this study.

A comprehensive electrical reliability analysis, which tries to predict the failure rate and also to distinguish between potential failure modes, is presented in the following thesis. The main part of the thesis concerns a reliability prediction based on the US Military Standard, a Failure Modes and Effects Analysis (FMEA) and a Fault Tree Analysis (FTA). The preliminary predicted failure rate which contains pessimistic safety values gets further expanded and specified upon by the FMEA and FTA. This allows a detailed prediction for the FGClite reliability and availability in the environment of its operation in the LHC to be made.

The second part of this work, compares the FGClite predictions with real operational data from the FGC2. As a conclusion the predicted results are expanded, and a possible extrapolation to the performance of the FGClite is given.

Kurzfassung

Die Europäische Organisation für Kernforschung betreibt mehrere Teilchenbeschleuniger im Sinne der Forschung im Bereich der Teilchenphysik. Um den größten Beschleuniger, den Large Hadron Collider (LHC), zu betreiben werden Magnetfelder benutzt um die Teilchen wie beabsichtigt zu beeinflussen und zu beschleunigen. Diese Felder werden von verschiedenen Stromumrichtern erzeugt, die ihrerseits von einem speziellen Function Generator Controller (FGC) gesteuert werden. Um die aktuelle Controllerversion des LHCs (FGC2) zu ersetzen wird im Moment eine neue Version entwickelt, deren Installation 2017 geplant ist. Dieser sogenannte «FGClite» wird in Strahlungsbereichen eingebaut, in denen der FGC2 Zuverlässigkeitsschwächen in Bezug auf Strahlungsausfälle aufwies.

Im Rahmen dieser Arbeit wird die *elektrische* Zuverlässigkeit des FGClite behandelt. Eine separate Studie wurde in Bezug auf die *strahlungstechnische* Zuverlässigkeit [1], welche in dieser Arbeit nicht betrachtet wird, ausgeführt.

Eine umfassende Analyse der elektrischen Zuverlässigkeit, welche versucht die Ausfallrate zu prognostizieren, als auch zwischen potenziellen Ausfallarten zu unterscheiden, wird in der folgenden Thesis beschrieben. Der Hauptteil präsentiert eine Zuverlässigkeitsvorhersage nach dem US Military Standard, eine Ausfallarten- und Auswirkungsanalyse (FMEA) und eine Fehlerbaumanalyse (FTA). Die vorläufig prognostizierte Ausfallrate, welche pessimistische Sicherheitswerte beinhaltet, wird in der FMEA und der FTA weiter ausgeführt und spezifiziert. Das erlaubt es eine detailierte Vorhersage für die Zuverlässigkeit des FGClite und dessen Verfügbarkeit in der Umgebung des LHCs zu präsentieren.

Der zweite Teil dieser Arbeit vergleicht die FGClite Vorhersagen mit realen Betriebsdaten des FGC2. Schlussfolgernd werden die vorherigen Ergebnisse eingebunden und eine mögliche Extrapolation der Ergebnisse für den FGClite wird präsentiert.

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Symbols, Abbreviations and Indices

Symbols

Symbol	**Meaning**	**Unit**
AF	Acceleration factor	-
b	Weibull shape parameter	-
d	Number of degrees of freedom	
E	Energy	eV; J
E(T)	Expected value	-
E_a	Activation energy	eV
F(t)	Failure probability function	-
f(t)	Failure Density Function	-
H^+	Cationic form of atomic hydrogen	-
k	Boltzmann's constant (8.617×10^{-5})	eV/K
K	Experimentally determined electric field constant*	nm/V
m	Mass	kg
MTTF	Mean Time To Failure	h; a
P	Power	W
R(t)	Reliability function	-
t	Time	s
T (1)	Lifetime	h; a
T (2)	Random variable (Statistics)	-
T (3)	Temperature	°C; K
T (4)	Characteristic lifetime	h; a
V	Voltage	V
v	Velocity	m/s; km/h
Var(T)	Variance	-
X	Thickness of stressed dielectric*	nm
$\lambda(t)$	Failure rate	fpmh; FIT
π_x	Factors for component characteristics and operating conditions (MIL-HDBK 217F)	-
$\sigma(1)$	Standard deviation / Scale parameter (Normal distribution)	-
$\sigma^2(T)$	Variance	-
χ^2	Chi-Square-Distribution	-

* Used only in combination as a fraction K/X

Symbol	**Meaning**	**10^n**
T	Tera	10^{12}
G	Giga	10^{9}
M	Mega	10^{6}
k	Kilo	10^{3}
c	Centi	10^{-2}
m	Milli	10^{-3}
µ	Micro	10^{-6}
n	Nano	10^{-9}
p	Pico	10^{-12}

Abbreviations

Abbreviation	**Meaning**
AB	Analogue Board (FGClite)
AC	Alternating Current
ADC	Analog-to-Digital Converter
AFT	Accelerator Fault Tracking
AIAG	Automotive Industry Action Group
ALICE	A Large Ion Collider Experiment
ATLAS	A Toroidal LHC Apparatus
BoM	Bill of Materials
CB	Communications Board (FGClite)
CCC	CERN Control Centre
CCE	Converter Controls Electronics (section at CERN)
CERN	European Organization for Nuclear Research (originally: Conseil Européen pour la Recherche Nucléaire)
CL	Confidence Level
CMS	Compact Muon Solenoid
CPLD	Complex Programmable Logic Device
DAC	Digital-to-Analog Converter
DC	Direct Current
DCCT	Direct Current Current Transducer
DGQ	Deutsche Gesellschaft für Qualität (German Society for Quality)
DoD	Department of Defense (United States)
DSP	Digital Signal Processor
EDMS	Engineering & Equipment Data Management Service (CERN Server)
ESD	ElectroStatic Discharge

FCC	Future Circular Collider
FGC (2/lite)	Function Generator/Controller (version 2/version lite)
FIT	Failure In Time (failures/10^9 hours)
FMD-91	Failure Mode/Mechanism Distributions (1991)
FMEA	Failure Modes and Effects Analysis
FMECA	Failure Modes, Effects and Criticality Analysis
FPGA	Field Programmable Gate Array
fpmh	Failures per million hours
FRAM	Ferroelectric Random Access Memory
FTA	Fault Tree Analysis
GUI	Graphical User Interface
HL-LHC	High Luminosity LHC
IC	Integrated Circuit
ID	Identification
IOB	Input/Output Board (FGClite)
LEP	Large Electron-Positron Collider
LHC	Large Hadron Collider
LHCb	Large Hadron Collider beauty
LINAC	Linear Accelerator
MB	Main Board (FGClite)
MIL-HDBK	Military Handbook (Department of Defense, United States of America)
MIL-STD	US Military Standard (Department of Defense, United States of America)
MLCC	MultiLayer Ceramic Chip capacitor
MTBF	Mean Time Between Failure
MTTF	Mean Time To Failure
MTTFF	Mean Time To First Failure
N/A	Not Available
NASA	National Aeronautics and Space Administration
OpAmp	Operational Amplifier
PB	Power Board (FGClite)
PCB	Printed Circuit Board
PLD	Programmable Logic Device
PROM	Programmable Read-Only Memory
PS	Proton Synchrotron
PSB	Proton Synchrotron Booster
R	Reliability
R2E	Radiation To Electronics
RAC	Reliability Analysis Center
RadDIM	Radiation tolerant Diagnostic Interface Module
RPN	Risk Priority Number
RWB	Reliability Workbench (Isograph Ltd.)
SPS	Super Proton Synchrotron
SRAM	Static Random Access Memory

TCP/IP	Transmission Control Protocol/Internet Protocol
TE-EPC	Technical Department – Electric Power Converters group (CERN)
VDA	Verband Der Automobilindustrie (German Association of the Automotive Industry)
VDI	Verein Deutscher Ingenieure (Association of German Engineers)
XB	Auxiliary Board (FGClite)

Indices

Index	**Meaning**
a	Activation
b	base
C	Capacitance
C60+C61	Capacitor number 60 and 61
CL	Confidence level
d	Degrees of freedom
E	Environment
m	mean
meas	Measured
op	Operating/Operation
p	Part
Q	Quality
ref	Reference
S	System
SR	Series Resistance
stress	Stress
T	Temperature
test	Test
V (1)	Voltage
V (2)	Voltage Stress

1 Introduction

In the framework of this work a reliability analysis for the new development of the «Function Generator Controller lite» (FGClite) power converter controller of the Large Hadron Collider at CERN is carried out. This thesis begins with a short introduction to CERN, its accelerator complex and the function of the FGClite within this complex. Next, a reliability prediction following the US Military Standard, a Failure Modes and Effects Analysis and a Fault Tree Analysis are presented. Operational data of the predecessor FGC2 controller is analysed and a comparison to the generated data of the analysis is introduced. Finally, conclusions are made concerning the potential electrical reliability of the FGClite in the LHC.

1.1 The European Organization for Nuclear Research (CERN)

The European Organization for Nuclear Research was founded in 1954 close to Meyrin, in Switzerland. With currently around 2 200 staff members and several thousand visiting scientists working in various fields, the main objective is the research in particle and high-energy physics by operating and exploiting a wide variety of particle accelerators. The biggest of those accelerators is the LHC, which is also the largest single machine in the world. Housed in a circular tunnel with 27 km in circumference, installed 50 to 175 m underground, protons are injected into two adjacent pipes, where dipole magnets are used to guide particle beams in a counter-rotating circular orbit, and radio-frequency systems are used to accelerate these beams. At four intersection points, the so-called experiments or detectors ATLAS, ALICE, CMS and LHCb, the beams can be merged to bring them into collision. By recording data of these particle interactions, as well as constantly increasing the collision energy up to planned 14 TeV (7 TeV per each beam), scientists intend to understand the fundamentals of physics and the universe we live in. [2]

For many different kinds of scientists CERN is in a lot of ways a unique place around the world, especially in the field of particle physics. To become such a place inventions like the World Wide Web or Nobel Prize winning discoveries, like the W and Z bosons or the Higgs boson, contributed a lot. This will still be the case in the future, as there is a vast amount of still-open questions about our universe, its origins and what it is made of. A more specific example in the near future is the research in the field of the Supersymmetry theory [3].

1.2 The Accelerator Complex

To be able to operate, the LHC is dependent on other machines which pre-accelerate the particles before they are injected into the LHC. For this main purpose as well as many others CERN currently operates a total of eight different accelerators. In order to give a short introduction to the physics and technology behind these machines, this chapter only picks the few accelerators which form the chain towards the LHC.

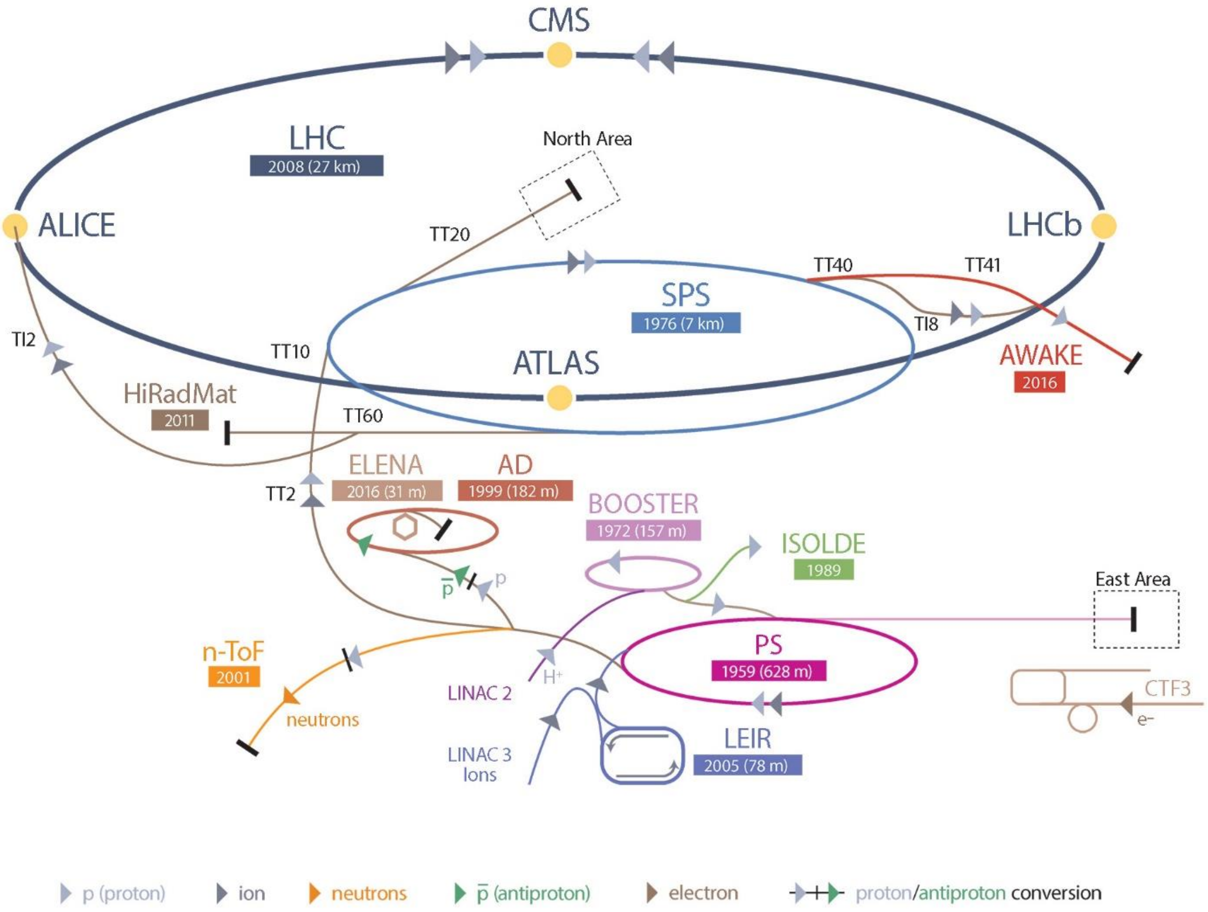


Figure 1-1 : The CERN accelerator complex [4]

The journey of the particles starts at the lower part of figure 1-1 where an H^+ symbol represents the source of particles. In the case of proton experiments, pure hydrogen gets released in the vacuum of the so-called Duoplasmatron, a metallic cylinder which breaks the gas into protons and electrons using an electric field. Afterwards, the protons continue through other electric fields produced by the magnets of the LINAC2 (LINear ACelerator) and reach when exiting 31.4% of the speed of light, which is equivalent to an energy of 50 MeV. Through the following circular accelerators Proton Synchrotron Booster (PSB), Proton Synchrotron (PS) and Super Proton Synchrotron (SPS), the protons, when accelerated referred as particle beams, reach an energy of 450 GeV when they get injected into the LHC. At highest, the particles currently reach in the LHC a world record collision energy of 13 TeV (6.5 TeV each beam) equal to 99.999 999 % of the speed of light and 6 930 times their rest mass according to the theory of relativity by Einstein. With a kinetic energy of 336 MJ, a nominal beam is then comparable to a 1 800 kg car at a speed of 2 150 km/h. [5, 6]

In the future an upgrade of the LHC is planned to create the High-Luminosity LHC (HL-LHC) [7]. Within this framework it is planned to increase the collision energy of the LHC up to 14 TeV and increase the rate at which collisions are produced by maximising the so-called luminosity, which is a measure of the production of physics. Beyond the HL-LHC, studies are ongoing to build another class of accelerator, the Future Circular Collider (FCC) [8], which could be located in an underground tunnel of approximately 80 to 100 km in circumference and could use the LHC as an injector.

2 The FGClite Project

The FGClite project was launched within the framework of CERN’s «Radiation To Electronics» (R2E) project which itself was founded in the year 2007. Having the mandate of «evaluat[ing] the risk of failures due to radiation in the control equipment installed in the underground areas of the LHC machine» [9], R2E started the FGClite project in the end of 2008. Its goal is to replace the currently running FGC2 controller, because radiation tests in September 2008 indicated, and second tests in 2011 [10] revealed, that this version of the module will most probably cause an unacceptable unavailability for the LHC machine as the radiation increases at higher LHC beam energies and in particular for the upcoming HL-LHC, planned to start its operation in the year 2024. In total, approximately 1 750 FGC2s are currently installed in the LHC. Of these around 1 094 controllers are intended to be replaced by FGClite modules [1]. The first replacement of around 700 modules is planned by February 2017.

Originally the development of the first Function Generator/Controller (FGC) started in 1996. Figure 2-1 shows the FGC evolution leading to the in the LHC used FGClite, showing its most recent prototype. Several other versions exist, such as the FGC3, but for simplicity these are not shown.

Figure 2-1 : Function Generator Controller evolution: FGC (left), FGC2 (middle), FGClite (right)

2.1 Function of the FGC

Giving a short introduction to the FGCs function, it is a module controlling different types of power converters which are delivering the current for CERN’s particle beam influencing magnets at different machines and accelerators. Integrating a voltage source and current measurement devices, the controller provides «various services including function generation, current regulation and state control» [11].

More specifically an LHC power converter consists of the three main parts which are shown in figure 2-2: A voltage source, a current transducer and an FGC2 controller which will be replaced by the FGClite.

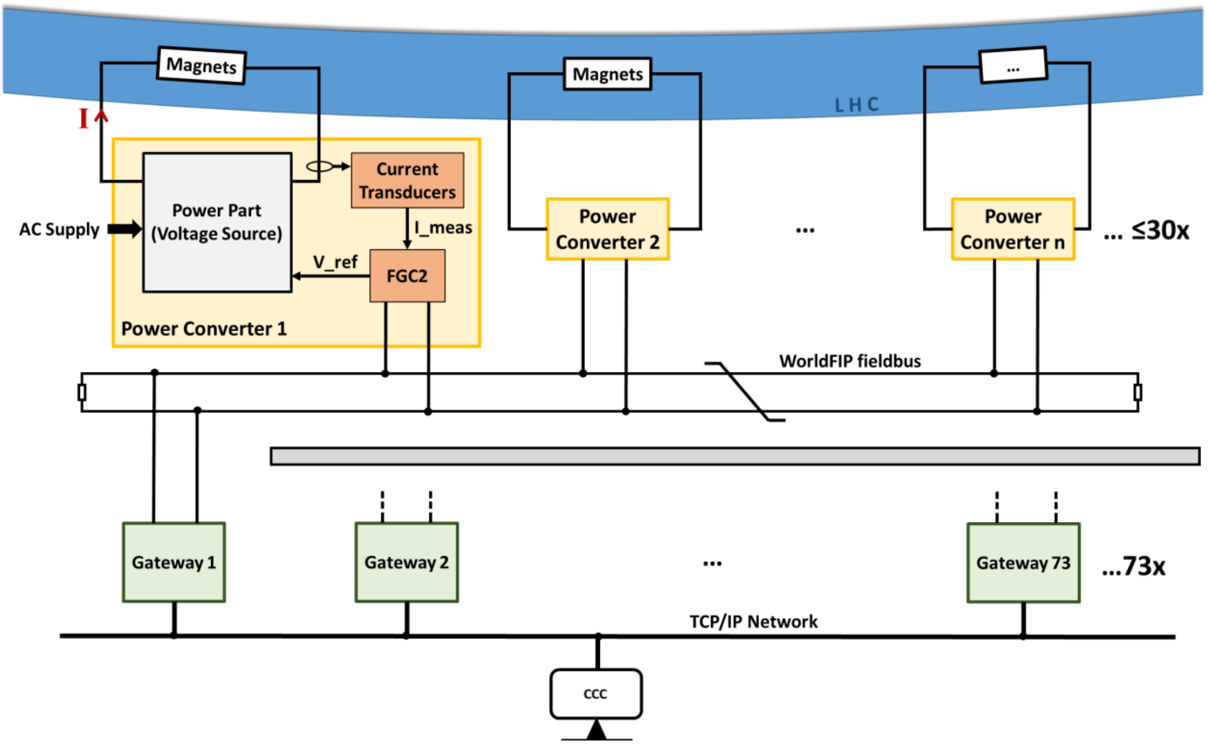


Figure 2-2 : Function of the FGC in the LHC

As displayed, the power part externally receives an alternating current (AC) supply which it converts into direct current (DC) delivering it to the magnets of the LHC. Connected to this circuit, a regulation loop taking current measurements (I_meas) is integrated which uses two high-precision DC Current Transducers (DCCT). Receiving these measurements, as a voltage depending on the converter between either -10 V and 10 V or 0 V and 10 V, in both cases proportional to the output current of 0 to 100 %, the FGC processes this information and provides the power part the needed reference voltage (V_ref). In the FGC, the received voltage signal gets converted by an Analog-to-Digital Converter (ADC) into a digital value. Afterwards, this information gets compared to a reference value and the reference voltage for the voltage source is calculated. The reference voltage then gets sent again as a signal between -10 V and 10 V to the voltage source by using a Digital-to-Analog Converter (DAC). [12]

The controller is connected over a WorldFIP fieldbus to a gateway which itself is controlled by CERN's machine operation in the CERN Control Centre (CCC). In total in the LHC there are 73 gateways connected over a TCP/IP network to the CCC, with each gateway hosting up to a maximum of 30 FGCs over the WorldFIP bus. This makes it possible to control the power converters and to analyse their performance in centralised and coordinated manner.

2.2 The FGClite Development and its Strategy

The most significant weakness of the FGC2 is its radiation tolerance, which is why the main focus of the FGClite development was to address this by improving its reliability under radiation. First goals were defined to design «as simple as possible» (referred as «lite») by moving «all the processing out of the FGC and into the gateway» additionally using new technologies in form of the «NanoFIP» fieldbus interface and the new «Mugef» (FGCD) software [13]. This objective led to a significant reduction of electrical components which implement this processing, for more information see chapter 4.1. For all remaining components suspected to behave different under radiation, a comprehensive design flow to qualify them for the radiation environment was developed [1]. From another point of reliable performance, the new design, with the various changes, also required a concept which has electrically, at least, the same reliability as the demands defined as well as the achieved for the FGC2. These demands set a highest maximum of 40 FGC2 failures per year which lead to a stop of the LHC operation, a beam dump. With an expected «maximum of 10 radiation induced failures per year of operation for all installed FGClite systems that lead to a beam dump of [the] LHC […] » [1] a first target of 30 electrical failures remains [14]. This gives the mandate for the reliability analysis performed in this work, however 30 failures per year means a rather large loss of LHC operational time. It would mean 7.5 % of LHC missions would be aborted due to failures of power converters [14]. In addition, no failures of other power converter parts were assumed in this calculation. For these reasons the reliability requirements should achieve better than 30 + 10 yearly failures, which is the baseline. These higher requirements are introduced in chapter 3.2.2 in the scope of an introduction to reliability basics. It should be noted that the development of the FGC2 did not consider any reliability analysis.

Under these objectives, the FGClite was developed in parallel to analysis and consideration of the electrical reliability and implementation of changes related to that. In the first half of the year 2016 the production of the FGClite was launched. This final module version consists of six different Printed Circuit Boards (PCB) and hosts an additional seventh PCB called the Radiation tolerant Diagnostic Interface Module (RadDIM) which is functionally not necessarily a part of the FGClite. Mechanically, everything is installed in a «6U» wall mount rack as for the FGC2, compare figure 2-1, middle. The different PCBs are the Main Board (MB), the Communications Board (CB), the Auxiliary Board (XB), the Power Board (PB), the Input/Output Board (IOB) and the Analogue Board (AB). Pictures can be found in the appendix and the full schematics on the CERN intern «EDMS» server [15, 16, 17, 18, 19, 20]. The functional implementation of the PCBs and their interaction can be seen in the architecture diagram of figure 2-3 with five boards (blue) which are plugged into the MB and the external RadDIM which is plugged into the XB. A more detailed view on the component level of the architecture follows in chapter 3 together with the included appendices.

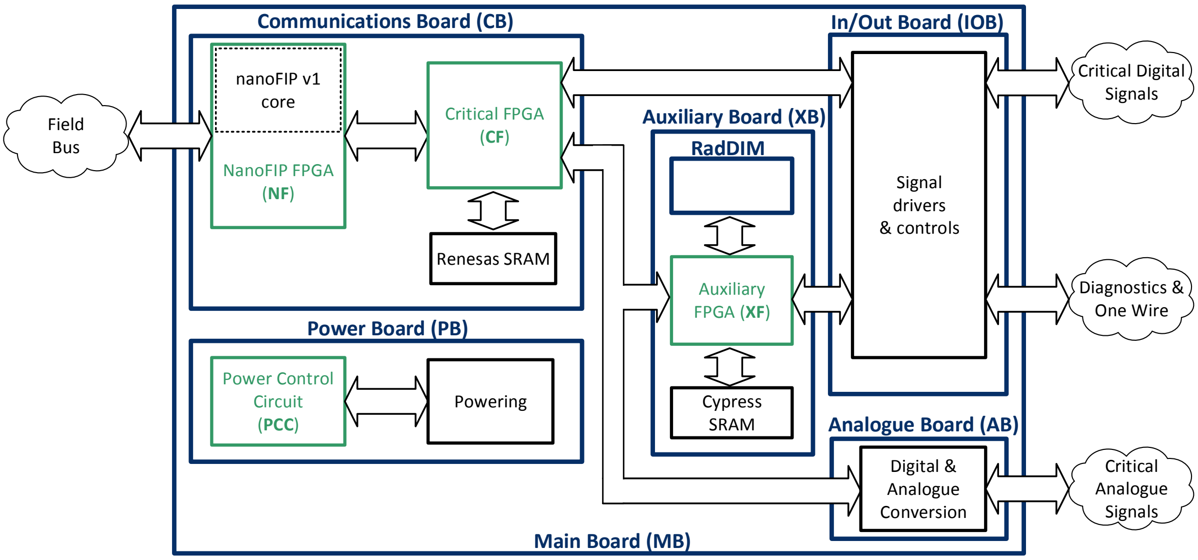


Figure 2-3 : FGClite board architecture [21]

3 Reliability Analysis of the FGClite

This main chapter is divided into five sections. Starting with a short introduction to the reliability theory, the used methodology and reliability specifications for the FGClite, it explains the method for reliability prediction following the US Military Standard [22, 23], «MIL-STD» in the following, a Failure Modes and Effects Analysis (FMEA) and a Fault Tree Analysis (FTA) and concludes with a presentation of the overall results. This and also the following chapter 4 only perform analyses for the electrical reliability of the FGClite, the unreliability due to radiation effects and the radiation tolerance are not covered in this thesis, hence in the following the term «reliability» is only to be considered as electrical reliability.

3.1 Reliability Introduction

To start this section an introduction to the mathematics and definitions behind reliability engineering is given. Outlining this within the next three subsections, the reliability theory is reduced to only important basics and methods which are actually used in this work. For a more comprehensive introduction to reliability engineering please have a look at the used resources [24, 25]. Noteworthy is also that the attempt of this chapter is to explain these basics in a short, understandable and acceptable extent, which is the reason why more specific theory is content of the following work when needed.

3.1.1 Definition of Reliability

According to the VDI 4001 guideline of the Association of German Engineers (VDI) [26, 24], reliability is defined as:

> *« The probability that a product does not fail under given functional and environmental conditions during a defined period of time »*

Applying this definition to a system like the FGClite, means that the module needs to provide its function for at least the required lifetime, see chapter 3.2, in the defined environment of its installing region(s) in the LHC, with a certain minimum, rather high, probability. Taking this probability the reliability $R(t)$ of all 1 094 in the future installed FGClites can be specified using a probability distribution and the failure rate λ, see next chapter. In basic terms the reliability is the fraction of still operational units divided by the number of total units after a certain time period and therefore a unit displaying a probability as a percentage. For 2 observed failures out of 100 identical units running a certain period of time, R would be 98 % for that timeframe.

3.1.2 Basics of Reliability

The Reliability Function

As indicated in the previous chapter the reliability of a component, module, product or system is defined within the function *R(t)* in the interval {*R(t)* ∈ ℝ | 0 ≤ *R(t)* ≤ 1}:

$$\mathrm{R}(t) = 1 - F(t) = \frac{f(t)}{\lambda(t)} \tag{3.1}$$

Deriving to the first part of the equation the failure probability *F(t)* is used describing a function behaving in opposite to *R(t)*, see figure 3-1. The definition of *F(t)* includes the failure density function *f(t)*, see figure 3-2, which is used to describe the distribution of failures over time, described later in the chapter:

$$F(t) = \int_0^t f(t)dt \tag{3.2}$$

$$f(t) = \frac{dF(t)}{dt} \tag{3.3}$$

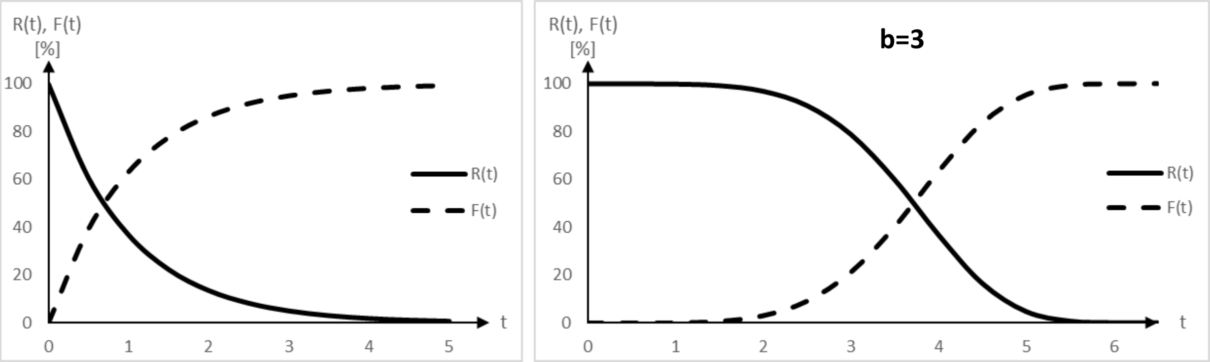


Figure 3-1 : *R(t)* and *F(t)* for an exponential- (left) and a Weibull-distribution (right)

When looking at the second part of equation (3.1), the often used failure rate can be specified as total number of failures of a component, module or system divided by the sum of total time passed per each device, equivalent to the reliability difference of the new system (*R(t)*=1) and the system after Δ*t*, divided by the time passed:

$$\lambda(t) = \frac{Total\ Number\ of\ Failures}{\sum t_{Device}} = \frac{R(t)-R(t+\Delta t)}{\Delta t * R(t)} = \frac{f(t)}{R(t)} \tag{3.4}$$

The unit of *λ(t)* is $\frac{1}{t}$. Often it is expressed in failures per million hours (fpmh). For electronic components the designation Failure In Time (FIT) is commonly used expressing failures per 10^9 hours. 1 FIT is equivalent to 1 failure in 10^9 hours.

When several different components are used in series, meaning one component failure causes immediately a system failure, each component failure rate can be summed up to get the failure rate of the whole system:

$$\lambda_{System}(t) = \lambda_1(t) + \ldots + \lambda_n(t) \qquad (3.5)$$

It is important to mention, that another function known as the hazard rate *h(t)* or instantaneous failure rate exists describing the failure rate for Δt approaching zero. Explicitly *h(t)* describes the «failure rate as the interval length [Δt] approaches zero», while *λ(t)* «is defined as the ratio of probability that failure occurs in the interval [Δt], given that it has not occurred prior to t_1, the start of the interval, divided by the interval length». Therefore equation (3.1), respectively the last equals sign in (3.4), need to be handled with care outside the framework of this thesis. Nevertheless, for this work *λ(t)* is used as a universal designation for the failure rate as explained above. [25]

A third way of representing the failure rate is the Mean Time To Failure (*MTTF*) using the mean time t_m which describes the approximate mean of the times to failure in the graph of *f(t)*. For the exponential distribution, described in the following subchapter, $R(t_m)$ is equivalent to a value of 36.8 % and the *MTTF* can be referred as the reciprocal value of *λ(t)* displayed in hours.

$$t_m = \frac{t_1 + t_2 + \cdots + t_n}{n} = \frac{1}{n}\sum_{i=1}^{n} t_i \qquad (3.6)$$

$$MTTF = \frac{1}{\lambda(\mathrm{t})} \qquad (3.7)$$

Thus, the *MTTF* describes the mean lifetime of non-repairable units. A slightly different designation for such a value is the Mean Time Between Failure (*MTBF*), when a system being used gets repaired after each failure and then starts its *MTBF*-time again from zero. In this context, also the Mean Time To First Failure (*MTTFF*) is used to describe the time until the first failure after the new system gets deployed.

The statistical basics and additional information to derive to the average value of t_m and the *MTTF*, defining the expected value *E(T)*, the standard deviation σ and the variance $\sigma^2(T)$, respectively *Var(T)* are not explicitly described in this framework. Further information can be found in [24].

Reliability Distributions and the Bathtub Curve

To describe the occurrence of failures over time for different failure mechanisms, a large number of distributions displaying the failure density function *f(t)* exist. For the reliability assessment of electronic components in their «useful life» period (Figure 3-3), commonly the exponential distribution is used. It assumes a constant failure rate for these systems (Figure 3-2, left) and that failures occur randomly in time. Thus, this subchapter concentrates on the exponential distribution as well as the more comprehensive Weibull distribution. For further information about other distributions, like the very common normal distribution (Figure 3-2, right) please refer to [27].

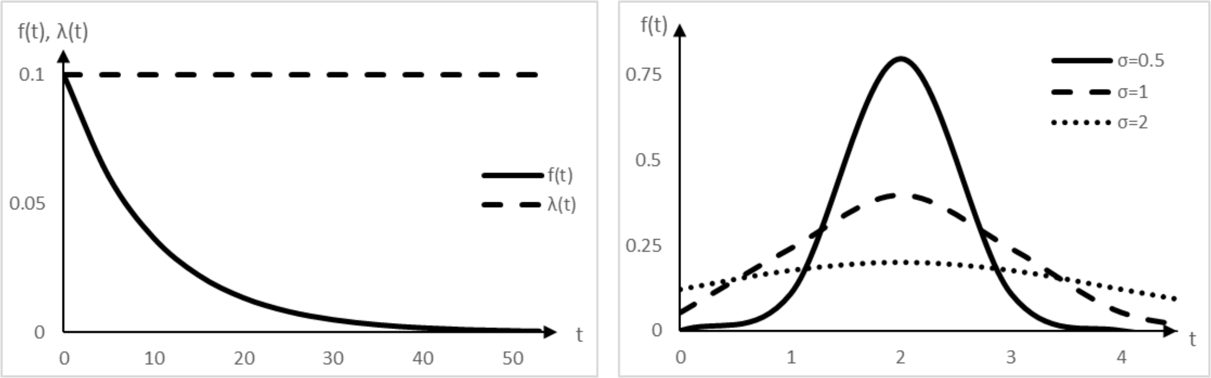


Figure 3-2 : *f(t)* and *λ(t)* of the exponential- (left) and *f(t)* of the normal distribution (right)

As it can be seen in the left diagram of figure 3-2, the failure density function for the exponential distribution forms an exponentially decreasing curve. Having the constant failure rate, the number of failures in one time unit, e.g. 1 hour, decreases together with the decreasing total number of still functional units. For example, the total number at the beginning of the runtime is 100 units and *λ(t)* has the constant rate of 0.01 failures per hour representing the average number of failures within one time unit. This rate leads to an average loss of 10 units after 1k hours leaving 90 functional units. After another 1k hours, 9 units or another 10 % will fail due to the constant failure rate with 81 functional units remaining. Exemplarily continuing this would lead to the failure of the last still functional unit after 44k hours (*n(44k h)* = 44) on average:

$$Functional\ Units(\ n(t)\ ) = 100 * (1 - 0.1)^{n(t)} \tag{3.8}$$

$$= 100 * 0.9^{44} = 0.97\ units < 1\ unit$$

If approximating a function for the data points of this example, equations for the exponential distribution can be defined in compliance to (3.1) until (3.4):

$$R(t) = e^{-\lambda t} \tag{3.9}$$

$$F(t) = 1 - e^{-\lambda t} \tag{3.10}$$

$$f(t) = \lambda * e^{-\lambda t} \tag{3.11}$$

$$\lambda(t) = \lambda \tag{3.12}$$

Being applicable for the useful life period with the constant failure rate, the exponential distribution serves to predict average values like the *MTTF*. However, this period excludes failures caused by e.g. faulty production or aging effects as corrosion. The occurrence of these failures can be illustrated by the well-known bathtub curve in figure 3-3 which uses the Weibull distribution as a function. The curve got its name having a symmetrical bathtub shape which is divided into three parts:

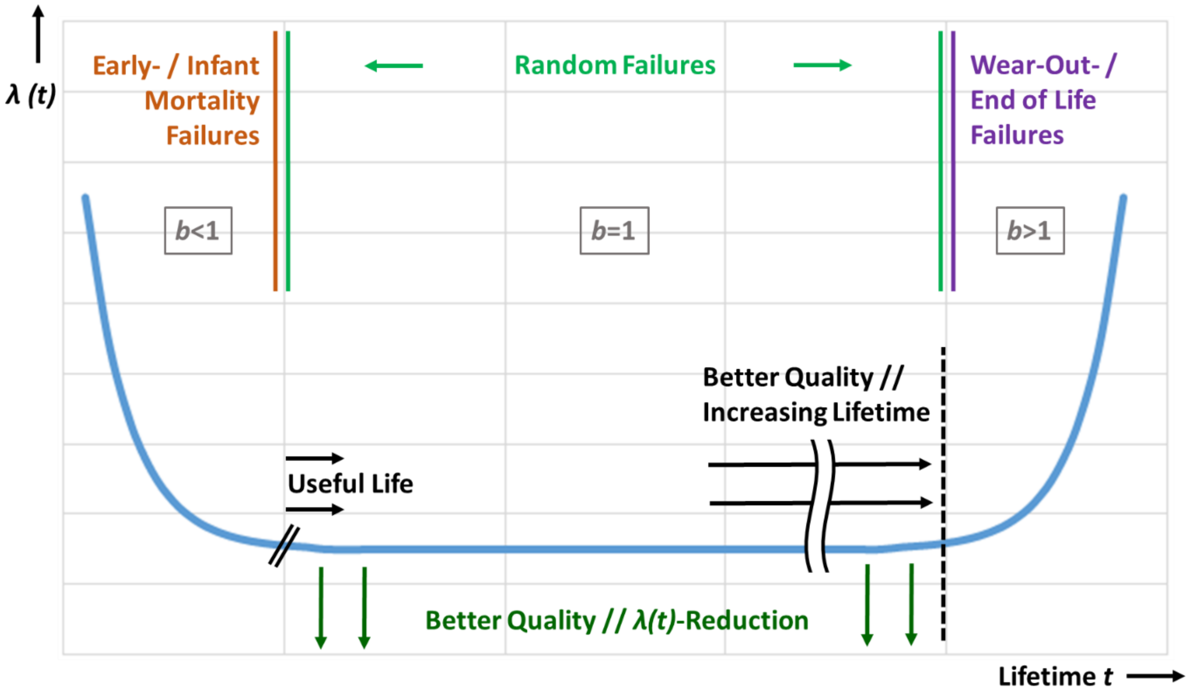


Figure 3-3 : The Bathtub Curve

With $\lambda(t)$ on the ordinate and a horizontal time axis, the «bathtub» shows the failure rate over time for a component or system after the first installation. The three different parts of the curve display three occurring failure possibilities a component or system could lose its function of, the early- or infant mortality failures, random failures in time and wear-out- or end of life failures:

- Infant mortality failures have a decreasing failure rate. They are mostly caused by defects created during the production process, like material defects, design flaws and assembly- or process errors etc. For example, infant mortality failures for a capacitor could be a material defect like a dielectric defect shorting the capacitor, a design flaw like a wrong component choice leading to an operation close to or higher than the rated voltage which causes a failure or an assembly error like a bad soldering contact opening after a short time of operation.
- Random failures have a constant failure rate occurring in the useful life period. They have very various failure modes and their randomly happening occurrence cannot be predicted, however using probability theory their constant rate can be computed.
- Wear-out failures increase the failure rate when the product has been running for a certain time and when the lifetime is approaching to the maximum. Causes for these failures are mostly aging effects like wear or material depletion.

For electronic systems, the bathtub curve is widely applied integrating countermeasures for each of the three parts to reduce the failure rate and increase the reliability and availability of a system. Countermeasures for infant mortality failures are for example tests like the burn-in to remove defective systems and to analyse the failure modes to continually improve the design. To reduce the impact on the availability of a system caused by random failures, a well prepared usage or maintenance documentation can be created. Countermeasures against wear-out failures can be lifetime tests or the usage of higher quality components to increase design safety margins and hence the average lifetime (compare appendix of chapter 3.3.3). Obviously, wear-out failures cannot be avoided without changing components or the system. Their appearance in time can only be delayed. Thus, a common strategy is to predict or recognize by constant failure analysis the start of the failure rate increase and exchange the system or the relevant components at the beginning of the slope. As well, based on test results, a preventive maintenance strategy can be implemented, which exchanges components or systems prior to the calculated time of failure.

To not only display the middle part of the bathtub curve the Weibull distribution can be used serving for all three parts by using a shape parameter called b. This single parameter is variable allowing to adapt the density function. Thus, the above defined equations (3.1) until (3.4) for the Weibull distribution are:

$$R(t) = e^{-\left(\frac{t}{T}\right)^{b}} \tag{3.13}$$

$$F(t) = 1 - e^{-\left(\frac{t}{T}\right)^{b}} \tag{3.14}$$

$$f(t) = \frac{b}{T} * \left(\frac{t}{T}\right)^{b-1} * e^{-\left(\frac{t}{T}\right)^{b}} \tag{3.15}$$

$$\lambda(t) = \frac{b}{T} * \left(\frac{t}{T}\right)^{b-1} \tag{3.16}$$

The variable T, the scale parameter, represents the characteristic lifetime being the mean of the distribution and equivalent to the time where 63.2 % of all installed systems have failed, compare $F(t)$ in figure 3-4.

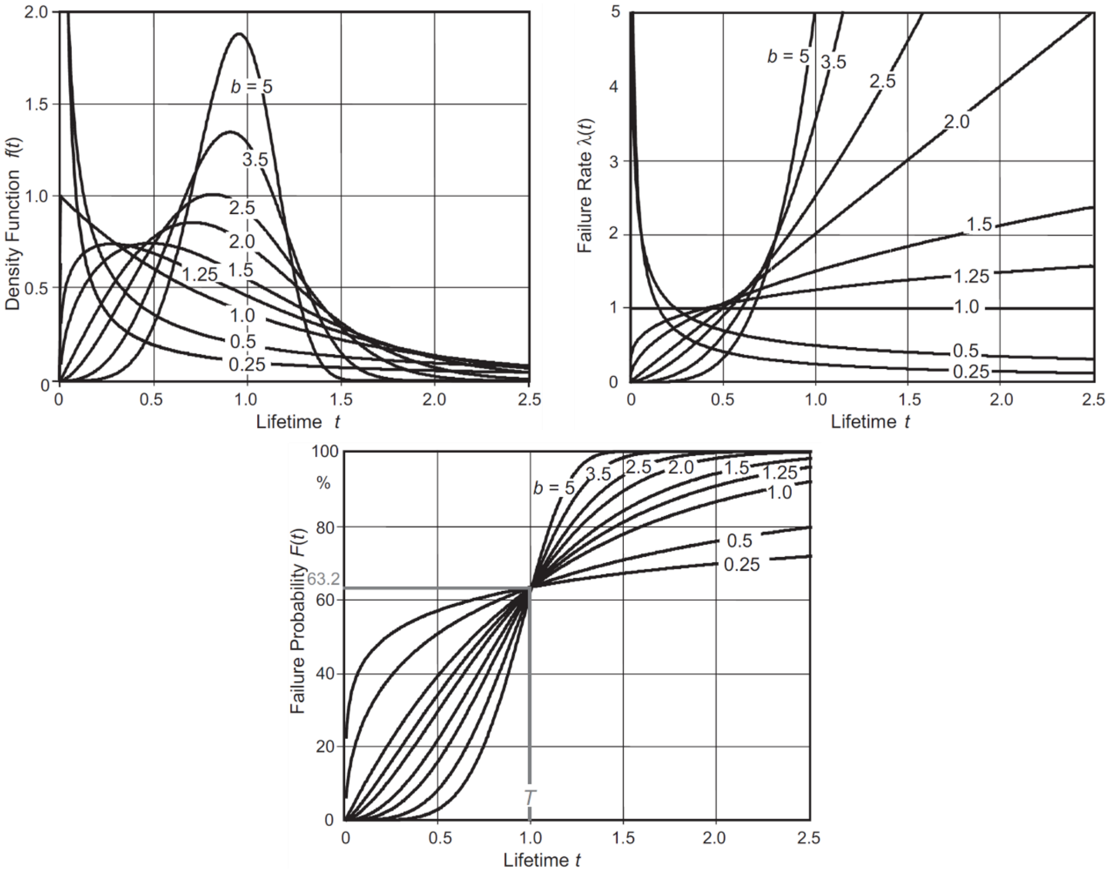


Figure 3-4 : *f(t)*, *λ(t)* and *F(t)* of the Weibull distribution for different shape parameters *b* [24]

The diagrams display *f(t)*, *λ(t)* and *F(t)* for different shape parameters. On the top right diagram it is easily recognizable that a constant failure rate complies with $b = 1$. For this shape parameter the Weibull distribution represents the exponential distribution in the middle part of the bathtub curve. For $b < 1$ the failure rate is decreasing over time, why such values can be used to describe the first part of the bathtub curve. To describe the third part of wear-out failures with the increasing failure rate the shape parameters with $b > 1$ are applicable. As a result of being able to represent constant, increasing and decreasing rates, the Weibull distribution is a universal tool to characterize the occurrence of failures over time which follow mechanisms like displayed in figure 3-3.

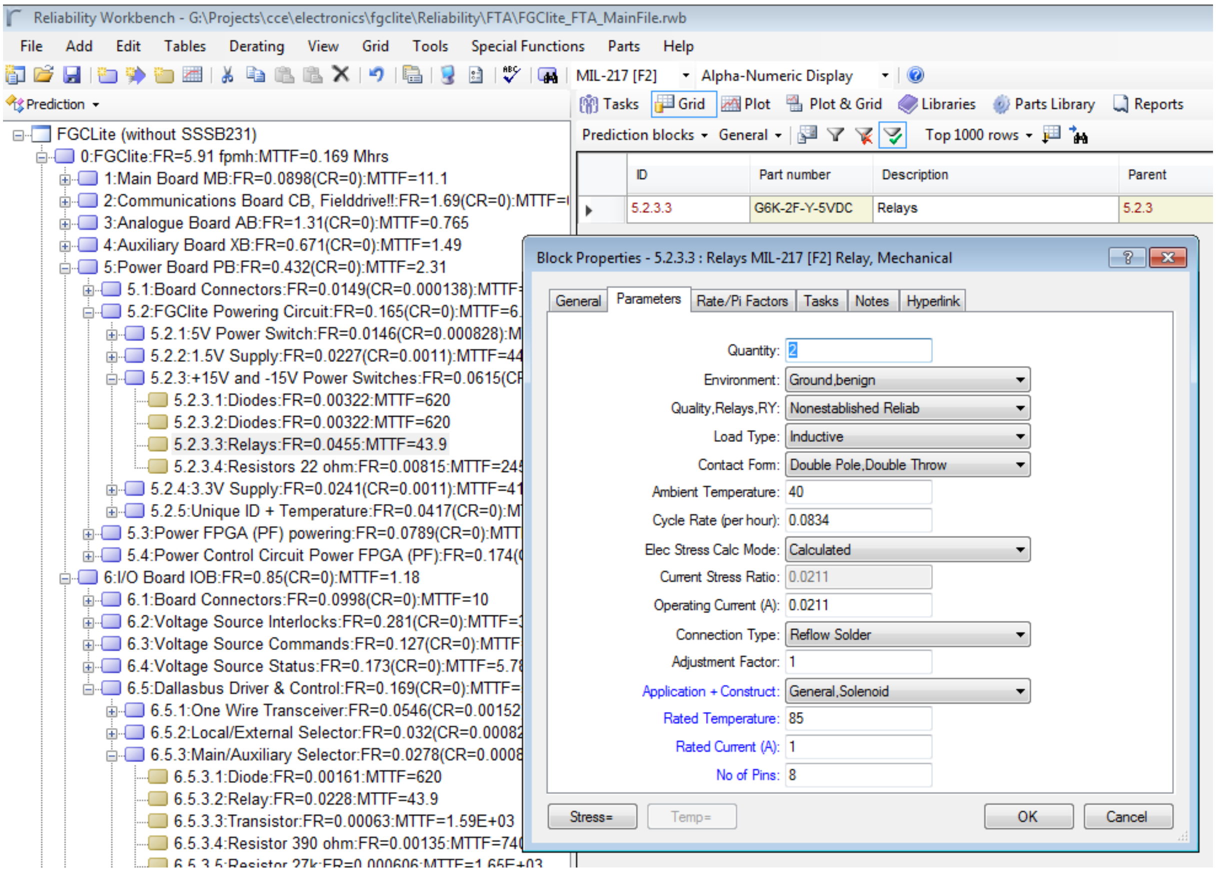
The Confidence Level

Regarding once more the simple calculation of chapter 3.1.1 where a reliability *R(t)* of 98 % was stated for 2 failed units out of 100 within one test period, it could happen in a second identical test that no unit, or 3 or even 10 units, fail. Having these events the reliability would change to $\frac{198}{200}$, $\frac{195}{200}$ or $\frac{188}{200}$, respectively 99, 97.5 or 94 %, which are not representing the first result of 98 % anymore. And obviously the result can change again in a third or fourth run, until n-runs. However, when taking all results into account, it approximates closer and closer to an average value. To express the probability of the correctness of such a mean value, the confidence level (CL) is used. It describes the probability that a random variable is within a certain range around the expected value *E(T)* or *MTTF*, meaning the precision of the estimation. It is the range where with a certain probability expressed by the confidence level, the variable is situated after performing a hypothetical infinite number of retesting. For example a confidence level of 90 % means that in 90 out of 100 cases the observed values are in that range. The confidence level demonstrates that in reality an infinite number of tests, equivalent to a confidence level or a certainty of 100 %, is in reality not possible. Commonly used values for the confidence level are 60 %, 90 %, 95 % and for high precision or redundant systems in parallel sometimes 99 %.

3.1.3 Methodology and Software

To execute the reliability analysis of the FGClite a methodology according to the «Electronic Reliability Design Handbook» of the United States Department of Defense [25], «MIL-HDBK 338B» in the following, is used. In particular, and mainly executed within this work, the mentioned reliability *MTTF* prediction, FMEA and FTA were performed after the principles described in the book chapters 6.4.5, 7.8 and 7.9. A detailed explanation of these methods follows in the according chapters later in this work.

Concerning the digital execution and documentation of the work done, almost entirely the software «Reliability Workbench» version 12.1.2.0 by the company Isograph Ltd [28] was chosen having an available license at CERN. In the case of the presented reliability analysis, this software allowed to integrate the whole FGClite project using various software modules, especially the presented prediction, FME(C)A and FTA module. Powerful features were the already integrated Military Standards allowing a quick failure rate calculation, the useful component integration and the interlinking of components and circuits, provided by a Graphical User Interface (GUI). On higher levels, very handy was the converting of information and results between the different modules or the import of data from «Microsoft Excel» (Excel), for example, as well as the export of the generated data as reports or to Excel. To give an outlook, this one created main file containing all reliability analysis data of the FGClite will be of tremendous value in the future. It can serve for many different purposes, like for example an information database or a starting point for needed improvements, a more comprehensive analysis or a new development and many more.



Reliability Workbench - G:\Projects\cce\electronics\fgclite\Reliability\FTA\FGClite_FTA_MainFile.rwb

FGCLite (without SSSB231)
0:FGClite:FR=5.91 fpmh:MTTF=0.169 Mhrs
1:Main Board MB:FR=0.0898(CR=0):MTTF=11.1
2:Communications Board CB, Fielddrive!!:FR=1.69(CR=0):MTTF=
3:Analogue Board AB:FR=1.31(CR=0):MTTF=0.765
4:Auxiliary Board XB:FR=0.671(CR=0):MTTF=1.49
5:Power Board PB:FR=0.432(CR=0):MTTF=2.31
5.1:Board Connectors:FR=0.0149(CR=0.000138):MTTF
5.2:FGClite Powering Circuit:FR=0.165(CR=0):MTTF=6
5.2.1:5V Power Switch:FR=0.0146(CR=0.000828):M
5.2.2:1.5V Supply:FR=0.0227(CR=0.0011):MTTF=44
5.2.3:+15V and -15V Power Switches:FR=0.0615(C
5.2.3.1:Diodes:FR=0.00322:MTTF=620
5.2.3.2:Diodes:FR=0.00322:MTTF=620
5.2.3.3:Relays:FR=0.0455:MTTF=43.9
5.2.3.4:Resistors 22 ohm:FR=0.00815:MTTF=24
5.2.4:3.3V Supply:FR=0.0241(CR=0.0011):MTTF=41
5.2.5:Unique ID + Temperature:FR=0.0417(CR=0):M
5.3:Power FPGA (PF) powering:FR=0.0789(CR=0):MTT
5.4:Power Control Circuit Power FPGA (PF):FR=0.174(
6:I/O Board IOB:FR=0.85(CR=0):MTTF=1.18
6.1:Board Connectors:FR=0.0998(CR=0):MTTF=10
6.2:Voltage Source Interlocks:FR=0.281(CR=0):MTTF=
6.3:Voltage Source Commands:FR=0.127(CR=0):MTTF
6.4:Voltage Source Status:FR=0.173(CR=0):MTTF=5.7
6.5:Dallasbus Driver & Control:FR=0.169(CR=0):MTTF=
6.5.1:One Wire Transceiver:FR=0.0546(CR=0.00152
6.5.2:Local/External Selector:FR=0.032(CR=0.0008
6.5.3:Main/Auxiliary Selector:FR=0.0278(CR=0.000
6.5.3.1:Diode:FR=0.00161:MTTF=620
6.5.3.2:Relay:FR=0.0228:MTTF=43.9
6.5.3.3:Transistor:FR=0.00063:MTTF=1.59E+03
6.5.3.4:Resistor 390 ohm:FR=0.00135:MTTF=74
6.5.3.5:Resistor 27k:FR=0.000606:MTTF=1.65E+03

ID	Part number	Description	Parent
5.2.3.3	G6K-2F-Y-5VDC	Relays	5.2.3

Block Properties - 5.2.3.3 : Relays MIL-217 [F2] Relay, Mechanical

Quantity: 2
Environment: Ground,benign
Quality,Relays,RY: Nonestablished Reliab
Load Type: Inductive
Contact Form: Double Pole,Double Throw
Ambient Temperature: 40
Cycle Rate (per hour): 0.0834
Elec Stress Calc Mode: Calculated
Current Stress Ratio: 0.0211
Operating Current (A): 0.0211
Connection Type: Reflow Solder
Adjustment Factor: 1
Application + Construct: General,Solenoid
Rated Temperature: 85
Rated Current (A): 1
No of Pins: 8

Figure 3-5 : Isograph Reliability Workbench screenshot for a relay of the FGClite prediction

3.2 Reliability Specifications for the FGClite

To classify the dependability, which contains the safety, availability as well as the reliability and maintainability of the LHC operation, several aspects of these different fields and each little part of the enormous machine need to be regarded detailed and carefully. For the FGClite as a part of the LHC power converters this means defining at first a system border for which reliability requirements need to be specified. Afterwards, results can be generated step by step and system by system to calculate a power converter reliability, availability and eventually values for the LHC dependability can be derived.

3.2.1 Definition of the System and its Operation Conditions

As the first step of the analysis, the FGClite was defined with all its inputs and outputs. In the next step the «black box» approach of system theory [29] was used, where figure 3-6 shows the defined system border. To summarize this system, it contains the six PCBs with all components mounted on them which are listed in the bill of materials. This means that neither the cassette and used screws etc., nor the opposite gender connector of the power converter or the RadDIM board, or any other component is part of the system being studied. Continuing this approach it also implies that the power converter- and the RadDIM interfaces are always fully functional. To keep the straight line of solely six PCBs included, it implies that the two mounted male RadDIM connectors on the XB are part of the system, although they do not have any influence on the FGClite reliability assuming the always fully functional interface.

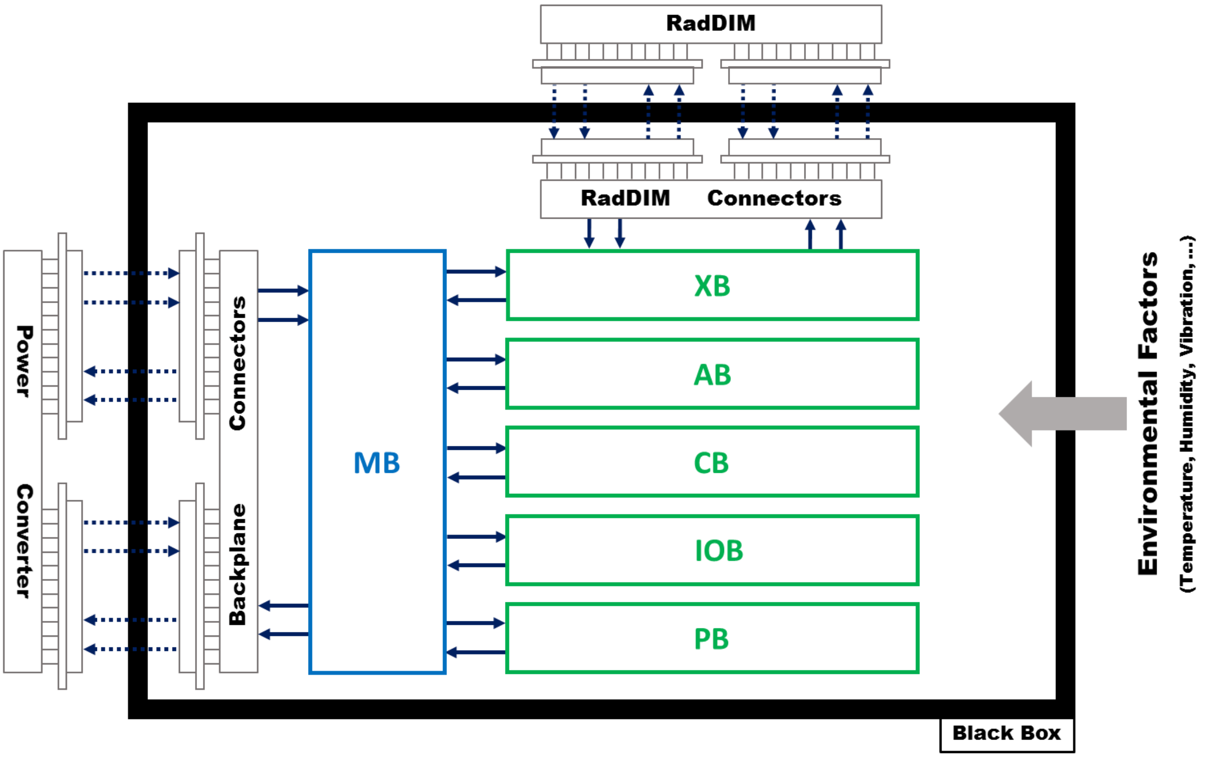


Figure 3-6 : Definition of the black box for the FGClite reliability analysis

As already indicated above the MIL-STD is used for the execution of the reliability analysis and will be further executed in the following chapters. In accordance to the standard, statistical as well as environmental conditions are set like the following:

- Default confidence level: 90 %
- Failure rate in fpmh (failures per million hours)
- At installation the whole system is considered as new (no failure rate reduction caused by burn-in and reception procedures) and correctly installed
- During operation no failures due to undefined environmental influences are considered, compare chapter 4.3.2.
- Environment definition after the Military Handbook 217F: ‘Ground, benign’ (disregarding radiation effects)
- Default connection type: ‘Reflow Solder’
- Default different component qualities: ‘Low Quality’, ‘Nonestablished Reliability’ or ‘Commercial or Unknown’
- Repair mode: ‘Non-Repairable’
- Maximum ambient temperature in all LHC installations: 40 °C

- No temperature stress expected for all components (The calculated heat dissipation of the FGClite is sufficient to maintain a temperature below 40 °C; No fan is needed)
- No voltage stress expected for any component
- An additional Connection Rate (CR) of Reliability Workbench replaces the failure rate of component connections on the PCB

It is important to note the environment is defined as «ground, benign», meaning that radiation induced failures are not part of the analysis. In connection to chapter 2.2 the component irradiation testing for the FGClite is finished to date and tests with the whole module started and will be completed in 2016 [1, 30]. When failure rates for both electrical and radiation induced failures are available, they can be combined to derive to the complete failure rate of the FGClite. Also noteworthy is that for the connection type, reflow soldering and for the different component qualities lowest standards are set to be used by the software by default. If components use other solder processes or have higher quality standards it was changed manually for each single part.

After defining all these conditions an RWB-model named «FGClite» was created including all default information.

3.2.2 Reliability Requirements

With the start of the project in the end of the year 2008 reliability requirements for the FGClite were defined. On one hand the required lifetime was set to «outlast the LHC [HL-LHC]» [14], meaning between 20 and 25 years of operation, depending on the installation date and the planned runtime of the machine. On the other hand a minimum failure rate for the second part of the bathtub curve was defined for yearly operation including, as displayed in chapter 2.2, radiation tolerance as well as electrical reliability. For the electrical requirements, the maximum 30 failures per year which lead to a beam dump were further specified and reduced. The first approach was to consult the FGC2 standards «with an MTBF of 1’000’000 hours» [12] at a confidence level of 90 %, remarking that this *MTBF* definition of the year 2005 is including failures caused by the radiation levels at that time as well, and also remarking that it was not derived from a reliability analysis. Simply operational power converter controller experiences of the in the same tunnel, prior to the LHC installed Large Electron-Positron Collider (LEP) accelerator were taken and applied. On the basis of this very high and challenging *MTBF*, however not fully applicable value, the next step transferred the minimum goal of 30 failures per year for the electrical reliability to a required predicted *MTTF* of **200k hours** prior to installation. More precisely this means for 1 094 units a number of 29 electrical failures during a normal operating year (5 340 hours; compare chapter 3.5.2). This set limit is meant to be seen as the highest acceptable failure rate knowing, on one hand, that a prediction after the MIL-STD uses a pessimistic approach containing a lot of safety margins, compare chapter 3.2.1 and 3.3. On the other hand experiences of the, in a lot of ways, more complex FGC2 show a much better *MTBF* in real operation, see chapter 4. These circumstances led to the last step which reduced the failure rate, by a chosen division factor of three, establishing a development goal of maximum ten electrical failures per normal operational year of the LHC for all installed FGClites:

$$\boldsymbol{\lambda_{\text{electrical}} \overset{!}{\leq} \text{10 failures/year}}$$

This rate is equal to the following *MTBF* requirement:

$$\mathbf{MTBF_{FGClite,\ electrical} \overset{!}{\geq} 950\,000\ hours}$$

3.3 Prediction

When doing a reliability analysis of electronic systems, a so-called «prediction», also «*MTTF* prediction», is often the first step and should be started in the early phases of the product development process, growing and being adapted together with the design. Like mentioned in chapter 3.1.2 the failure rate of a system containing several components can be summed up, when the components are integrated in series with each component failure leading to a system failure. For predicting an *MTTF*, this rule becomes an approach to estimate the system reliability stating that each failure would lead to the system failure, even if in reality it would not. Thus this quantitative method serves on one hand as a basis for further reliability analyses and, on the other hand, to get a first lower benchmark for the later reliability of the design, however only predicting it. Obviously, design weaknesses can reveal from a prediction and be improved at that time, saving a lot of time and costs avoiding later iterations.

3.3.1 Used Data Sources

To predict the failure rate of each single component of a system either tests need to be performed or failure- and lifetime data, e.g. from the field, must be available to guarantee a minimum lifetime under defined operating conditions with a certain probability following the reliability definition of chapter 3.1.1. To get such data, standards exist defining test methods and/or summarizing test and field data.

The Military Handbook 217F

One of the most extensive data collection contains the United States Military Handbook 217F, «MIL-HDBK 217F» in the following. It includes comprehensive failure rate models for many different electric and electronic components based on «the best available data at the time of issue» [23]. With this data computed base failure rates λ_b are listed for different components and component styles or applications. These base failure rates serve as the basic coefficient in a multiplication resulting into the part failure rate λ_p. The other multipliers are called π-factors which are also listed in tables or can be calculated using provided formulas. They represent the component characteristics as well as the operating and environmental conditions. Equation (3.20) in the following displays such a multiplication.

Unfortunately the last revision of the MIL-HDBK 217F took place in the year 1995. Nevertheless, there is until now no adequate and commonly accepted replacement, which is why it is still used and thus the best data source for the prediction of this work. As an example of using the handbook, one of many points of criticism is the enhancement in technology of electronic components and thus the out-of-date safety margins in the failure rates anymore. This however does not necessarily mean that the factors of the used formulas which are often based on physical effects are obsolete.

Reliability Testing

For component failure rates which cannot, or only with a lot of effort, be calculated after the MIL-HDBK 217F, or where other and newer approaches result into at least same dependable but better failure rates, it is worth to perform lifetime tests. The majority of these tests are performed for complex, mostly semiconductor devices and generally integrated circuits (IC). Tests such as Highly Accelerated Lifetime Testing (HALT), Early-Life-Failure (ELF) or High-Temperature Operating Life (HTOL) exist with each for different reasons. To derive to a predicted FIT value of a component very often HTOL is performed as an accelerated life test. At higher temperatures and higher applied voltages than in usual operation, the aging process of the component shall be accelerated. This makes it possible to simulate the lifetime with only testing in a relatively short timeframe. As a result the predicted failure rate can be calculated for the defined operating conditions, depending on the different test parameters, after the following equation:

$$\lambda_{op} = \frac{\lambda_{test}}{AF_T * AF_V} \tag{3.17}$$

The equation uses the resulting failure rate λ_{test} of the HTOL test after equation (3.4) and converts the different test and operation conditions by using the so-called temperature acceleration factor AF_T and the voltage acceleration factor AF_V. In general, an acceleration factor represents the ratio between test- and lifetime. For example a factor of 50 means that one hour of testing is equal to 50 hours of real operation. Most referred to the JEDEC industry standard, AF_V is calculated using a specific model like the following, and AF_T uses the Arrhenius Equation: [23, 31]

$$AF_V = e^{\left[\frac{K}{X} * (V_{stress} - V_{op})\right]} \tag{3.18}$$

$$AF_T = e^{\left[\frac{Ea}{k} * \left(\frac{1}{T_{op}} - \frac{1}{T_{test}}\right)\right]} \tag{3.19}$$

K = Experimental determined electric field constant (thickness/V)
X = Thickness of stressed dielectric
V_{stress} = Applied stress voltage

V_{op} = Operating voltage
E_a = Activation energy (eV)
k = Boltzmann’s constant (8.617×10^{-5} eV/K)
T_{op} = Operating temperature (K)
T_{test} = Testing temperature (K)

3.3.2 Creating the Reliability Workbench Model

Having the scope in chapter 3.2.1, the prediction analysis starts with creating a hierarchy for the project. With the FGClite project block on the top layer, up to four lower levels, plus the last component level, are used to define the systematic hierarchy. Illustrated in purple in figure 3-7, systematic blocks continue on the second level as «System Blocks» for the six PCBs of the FGClite. The following «Subsystem Blocks», «Schematic Blocks» and rarely used «Sub-Schematic Blocks» represent different functional and sub-functional schematics and circuits of each board, compare chapter 2.1. Taking this hierarchy the prediction continues with going through the schematics and Bill of Materials (BoM) of all FGClite boards and integrating each component and the relevant information into the hierarchy obtaining block failure rates being summed up for all hierarchy blocks.

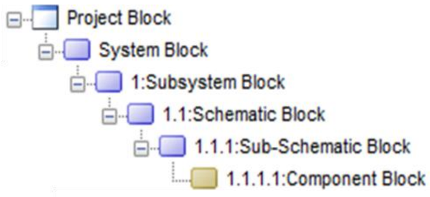


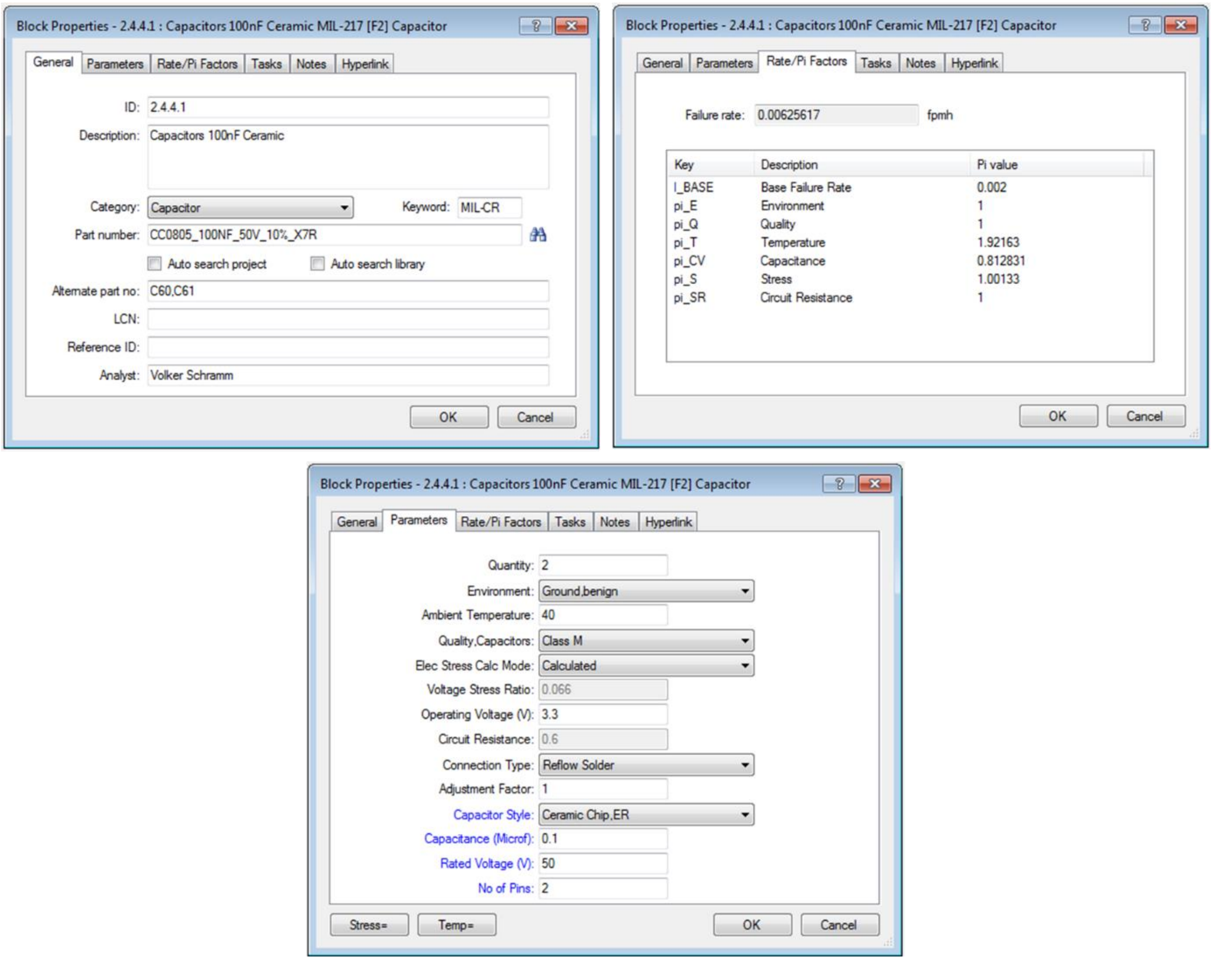
Figure 3-7 : Exemplary used prediction hierarchy in RWB

For most passive components, the integrated GUIs which follow the MIL-HDBK 217F were used to enter the specific data of each component. To pick one example figure 3-8 shows the interface for a capacitor on the CB. When creating the component block and choosing its category, the software automatically sets the default values for environment, quality etc. and assigns an ID for the hierarchy tree. Within six tabs the component information can be entered starting with the «General» tab to name the component, to choose a category and to give it a unique part-, respectively an alternate part number. In the «Parameters» tab the component characteristics and its operating conditions, like the rated and operating voltage, are entered or set default values can be changed like in this example the higher quality class «M» of the capacitor. For this specific Multilayer Ceramic Chip (MLCC) capacitor the style «Ceramic Chip, ER» is chosen. If all necessary parameters are complete the «Rate/Pi Factors» tab displays the failure rate of the component or in this case the summed up value for two summarised capacitors. For this example the equivalent MIL-HDBK 217F calculation can be found on page 10-1 [23] and results into the displayed failure rate for the quantity of two capacitors:

$$\lambda_{C60+C61} = 2 * \lambda_p = 2 * \lambda_b \pi_T \pi_C \pi_V \pi_{SR} \pi_Q \pi_E \tag{3.20}$$

$$= 2 * 0.002 fpmh * 1.9 * 0.81 * 1.0 * 1 * 1 * 1 = 0.0062\ fpmh$$

The last three tabs can be used to add tasks, notes or a link to the component data. Especially the «Notes» tab was used a lot in this prediction to add explanations, justifications or extra information about the component and the failure rate calculation.



Block Properties - 2.4.4.1 : Capacitors 100nF Ceramic MIL-217 [F2] Capacitor

ID: 2.4.4.1
Description: Capacitors 100nF Ceramic
Category: Capacitor
Keyword: MIL-CR
Part number: CC0805_100NF_50V_10%_X7R
☐ Auto search project ☐ Auto search library
Alternate part no: C60,C61
LCN:
Reference ID:
Analyst: Volker Schramm

Block Properties - 2.4.4.1 : Capacitors 100nF Ceramic MIL-217 [F2] Capacitor

Failure rate: 0.00625617 fpmh

Key	Description	Pi value
l_BASE	Base Failure Rate	0.002
pi_E	Environment	1
pi_Q	Quality	1
pi_T	Temperature	1.92163
pi_CV	Capacitance	0.812831
pi_S	Stress	1.00133
pi_SR	Circuit Resistance	1

Block Properties - 2.4.4.1 : Capacitors 100nF Ceramic MIL-217 [F2] Capacitor

Quantity: 2
Environment: Ground,benign
Ambient Temperature: 40
Quality,Capacitors: Class M
Elec Stress Calc Mode: Calculated
Voltage Stress Ratio: 0.066
Operating Voltage (V): 3.3
Circuit Resistance: 0.6
Connection Type: Reflow Solder
Adjustment Factor: 1
Capacitor Style: Ceramic Chip,ER
Capacitance (Microf): 0.1
Rated Voltage (V): 50
No of Pins: 2

Figure 3-8 : GUI for an RWB component block (Capacitor)

Apart of the MIL-HDBK 217F standard, other components like semiconductor devices or oscillators are created choosing «Custom - No Stress» from the category pull-down menu. For all those components, reliability reports were requested from the manufacturers performing the above illustrated lifetime testing. A short example of such a report is shown in the appendix. For these custom blocks the failure rate is entered manually, which is why the conversion of the possible different confidence levels, testing temperatures and applied voltages was done manually in an extra Excel table if needed. To convert different temperatures of manufacturer data equation (3.19) from the chapter above was used and for converting different confidence levels the following equation:

$$\lambda_{new\ CL} = \lambda_{old\ CL} * \frac{\chi^2{}_{new\ CL,d}}{\chi^2{}_{old\ CL,d}} \qquad (3.21)$$

Herein the fraction uses values which are calculated after the Chi-Square distribution (χ^2) for different numbers of occurred test failures. These failures define the distribution's degrees of freedom *d*. Having this number the values for the two coefficients were integrated from the following table 3-1.

Table 3-1 : Chi-Square distribution; χ^2 - values at various confidence levels [31]

Failures	Degrees of Freedom	99%	95%	90%	80%	70%	60%	50%
0	2	9.21	5.99	4.61	3.22	2.41	1.83	1.39
1	4	13.28	9.49	7.78	5.99	4.88	4.04	3.36
2	6	16.81	12.59	10.64	8.56	7.23	6.21	5.35
3	8	20.09	15.51	13.36	11.03	9.52	8.35	7.34
4	10	23.21	18.31	15.99	13.44	11.78	10.47	9.34
5	12	26.22	21.03	18.55	15.81	14.01	12.58	11.34
6	14	29.14	23.68	21.06	18.15	16.22	14.69	13.34
7	16	32.00	26.30	23.54	20.47	18.42	16.78	15.34
8	18	34.81	28.87	25.99	22.76	20.60	18.87	17.34
9	20	37.57	31.41	28.41	25.04	22.77	20.95	19.34
10	22	40.29	33.92	30.81	27.30	24.94	23.03	21.34

Applying the two methods, it was possible to find or calculate data for each FGClite component with only one exception for the obsolete «SSSB231» integrated driver circuit. This so-called «FIELDRIVE» [32] was produced by the company Alstom in combination with the WorldFIP, a further development of the Factory Instrumentation Protocol (FIP), a field bus standard widely used at CERN. Unfortunately Alstom stopped the support of the WorldFIP technology, which is why CERN insourced a lot of the technology. However, for most of the WorldFIP hardware, this means that only a few components, with already future planned applications, still exist thus making reliability testing impossible. As a consequence, it is decided for the FGClite prediction model, due to the fact of only having one component without data, to separate the SSSB231 from the prediction giving it a failure rate of zero. In addition, it is not possible to assign the rather complex component an adequate estimated failure rate. Either it could be much too high putting a wrong safety margin and corrupting the prediction model, or it could be too low creating an unacceptable and not dependable *MTTF*. Of course this approach creates the risk of having a highly unreliable component leading to not meeting the requirements, nevertheless mentioning it at this point, this risk is considered and justified. In addition, at CERN there is no knowledge of a highly unreliable performance of the widely used SSSB231, which is also installed in the FGC2. In order to avoid future misunderstanding, the omission is also clearly marked in the model.

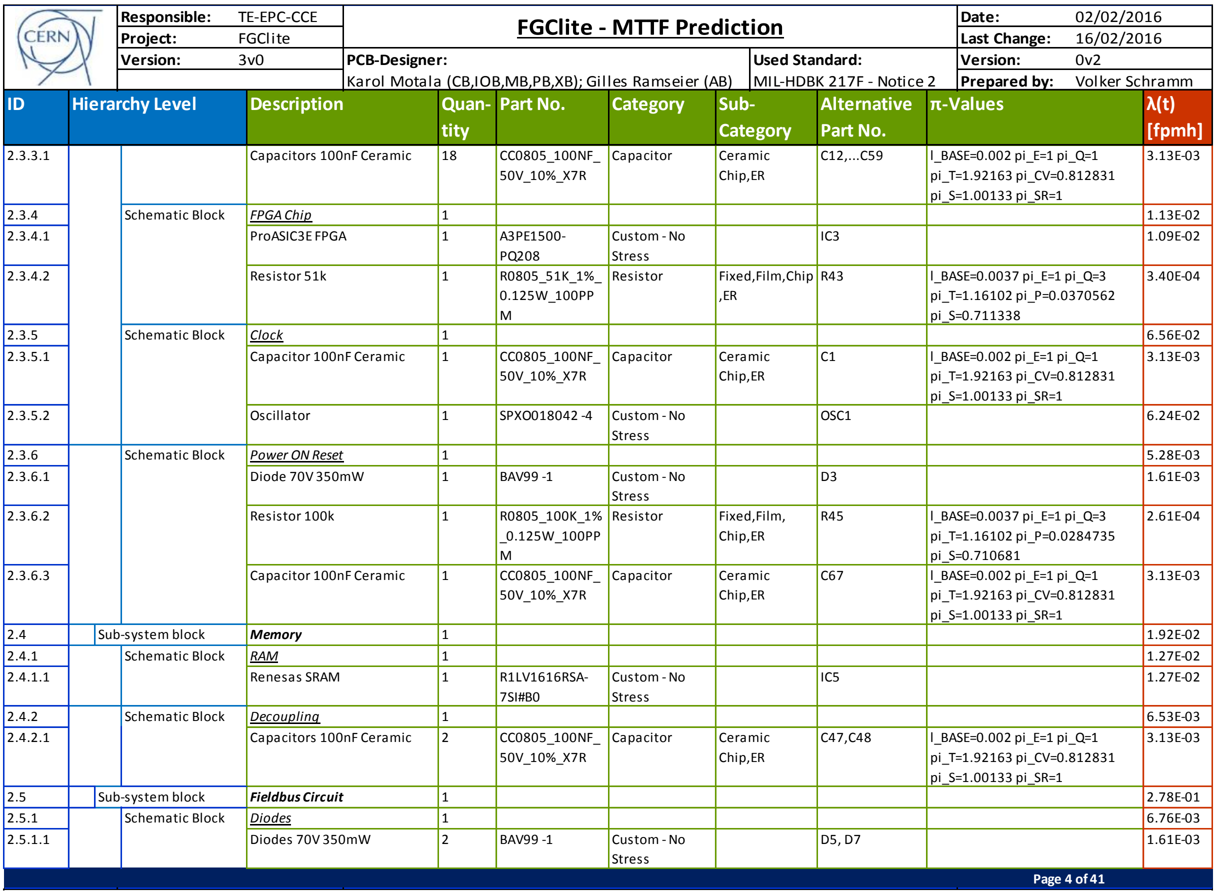
As a last remark, components which are not used during operation, such as connectors for diagnostics and especially spare circuits designed for a possible later use, were integrated in the model but adjusted to a non-existent failure rate of zero. The input of the zero failure rate was not done until the results of the following FMEA proved that potential failure modes of these are actually not leading to any system effects and failures, see chapter 3.4.

Having the final model, it consists of 1 009 parts in total, 804 passive components and 205 integrated circuits. To sort this the RWB model uses 112 systematic blocks.

3.3.3 Results of the Prediction

Once the time consuming work of defining each single component is done, the model offers various possibilities to analyse, process and further develop the generated information. To not only summarize these results in the RWB file, a report was created and exported containing all necessary information within a table, also offering the possibility to print it. A small extract of the CB system block shows table 3-2. The whole report can be found in the appendix. Effort has been made to display the data as clear and comprehensive as possible using three different colours. The first column contains the given ID numbers of the RWB software which start with a «2» in the case of the CB and the second column displays this created hierarchy on three levels for system, sub-system and schematic blocks. In green different component information including the MIL-HDBK's π-values is shown. In the last column the failure rate is displayed for blocks as well as components, while an *MTTF*-value was supressed. If needed it must be generated from the RWB file, respectively converted manually.

Table 3-2 : MTTF prediction report (extract)



Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - MTTF Prediction

PCB-Designer: Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)
Used Standard: MIL-HDBK 217F - Notice 2

Date: 02/02/2016
Last Change: 16/02/2016
Version: 0v2
Prepared by: Volker Schramm

ID	Hierarchy Level	Description	Quan-tity	Part No.	Category	Sub-Category	Alternative Part No.	π-Values	λ(t) [fpmh]
2.3.3.1		Capacitors 100nF Ceramic	18	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C12,...C59	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00133 pi_SR=1	3.13E-03
2.3.4	Schematic Block	*FPGA Chip*	1						1.13E-02
2.3.4.1		ProASIC3E FPGA	1	A3PE1500-PQ208	Custom - No Stress		IC3		1.09E-02
2.3.4.2		Resistor 51k	1	R0805_51K_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R43	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0370562 pi_S=0.711338	3.40E-04
2.3.5	Schematic Block	*Clock*	1						6.56E-02
2.3.5.1		Capacitor 100nF Ceramic	1	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C1	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00133 pi_SR=1	3.13E-03
2.3.5.2		Oscillator	1	SPXO018042 -4	Custom - No Stress		OSC1		6.24E-02
2.3.6	Schematic Block	*Power ON Reset*	1						5.28E-03
2.3.6.1		Diode 70V 350mW	1	BAV99 -1	Custom - No Stress		D3		1.61E-03
2.3.6.2		Resistor 100k	1	R0805_100K_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R45	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0284735 pi_S=0.710681	2.61E-04
2.3.6.3		Capacitor 100nF Ceramic	1	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C67	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00133 pi_SR=1	3.13E-03
2.4	Sub-system block	***Memory***	1						1.92E-02
2.4.1	Schematic Block	*RAM*	1						1.27E-02
2.4.1.1		Renesas SRAM	1	R1LV1616RSA-7SI#B0	Custom - No Stress		IC5		1.27E-02
2.4.2	Schematic Block	*Decoupling*	1						6.53E-03
2.4.2.1		Capacitors 100nF Ceramic	2	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C47,C48	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00133 pi_SR=1	3.13E-03
2.5	Sub-system block	***Fieldbus Circuit***	1						2.78E-01
2.5.1	Schematic Block	*Diodes*	1						6.76E-03
2.5.1.1		Diodes 70V 350mW	2	BAV99 -1	Custom - No Stress		D5, D7		1.61E-03

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MTTF Results

The main results of the prediction analysis are clearly the different *MTTF*s of the subsystems and components with the single value for the whole FGClite on top:

$$\mathbf{MTTF_{FGClite} \geq 198\ 379\ hours}$$

This result approximately matches the target of 200k hours from chapter 3.2.2. For hypothetical full 8 766-hour years of operation this *MTTF* corresponds to 22.63 years. For the number of 1 094 later installed modules this means:

$$\boldsymbol{\lambda} \mathbf{\leq 48\ failures/year}$$

Remarking again this is only the predicted failure rate (MIL-HDBK 217F) for the useful-life period of the bathtub curve and the SSSB231 drive is not included. The following analyses show that the real failure rate will most probably be better. However, relying on the different used standards and under the above presented assumptions, it can definitely be stated that the real *MTTF* will not be worse than ~200k hours.

Most Critical Components and Blocks

Continuing the results analysis, the most as well as the least reliable components, circuits and boards can be determined. The following two figures display the most critical components and functional circuits or PCBs. Both figures display the current state of the development and may not include improved failure rates during the execution of this work anymore. This does only mean improved rates as a result of functional analyses, not of design improvements. Figure 3-9 reveals that there are five highly critical components having a failure rate higher than 0.15 fpmh. Unfortunately it was not possible, or did not make sense, to change them during the development. The failure rate of the three pushbuttons as well as the transformer, D-Sub and Tyco connectors need to be regarded carefully because they all use the calculation method of the MIL-HDBK 217F and therefore might have too high safety values for current modern technology or their specific applications. Besides that, special care needs to be taken for the DAC and the optocoupler due to both having a relatively high failure rate derived from HTOL-testing. Looking into the test reports, both components performed the testing with no failures, but the manufactures carried out a low total device testing time:

- MAX5541CSA+: Total device hours = 15 360 hrs (Sample size = 80; T = 135 °C; E_a = 0.8 eV) [33]
- HCNR200-300E: Total device hours = 260 000 hrs (Sample size = 320; T = 125 °C; E_a = 0.43 eV) [34]

On top for the optocoupler, it is commonly known that optoelectronic devices do not comply with nowadays reliability standards of semiconductor devices. The reason for this is the much smaller production numbers of these devices and therefore a lower development budget [35].

On side note, both components strongly performed their radiation test qualification. The DAC, as well as the optocoupler, both exceeded five times the requirement of the Total Ionizing Dose [36, 37]. For the requirement of Displacement Damage, the optocoupler revealed weaknesses, while this effect is not of importance for the DAC's radiation performance. For the optocoupler, this is however solved over a rotation strategy of FGClites, which are installed in regions of different radiation levels. In addition, the optocoupler's functionality is not used in the regions with the highest radiation levels. For the testing, the optocoupler performed the best out of five tested devices [38].

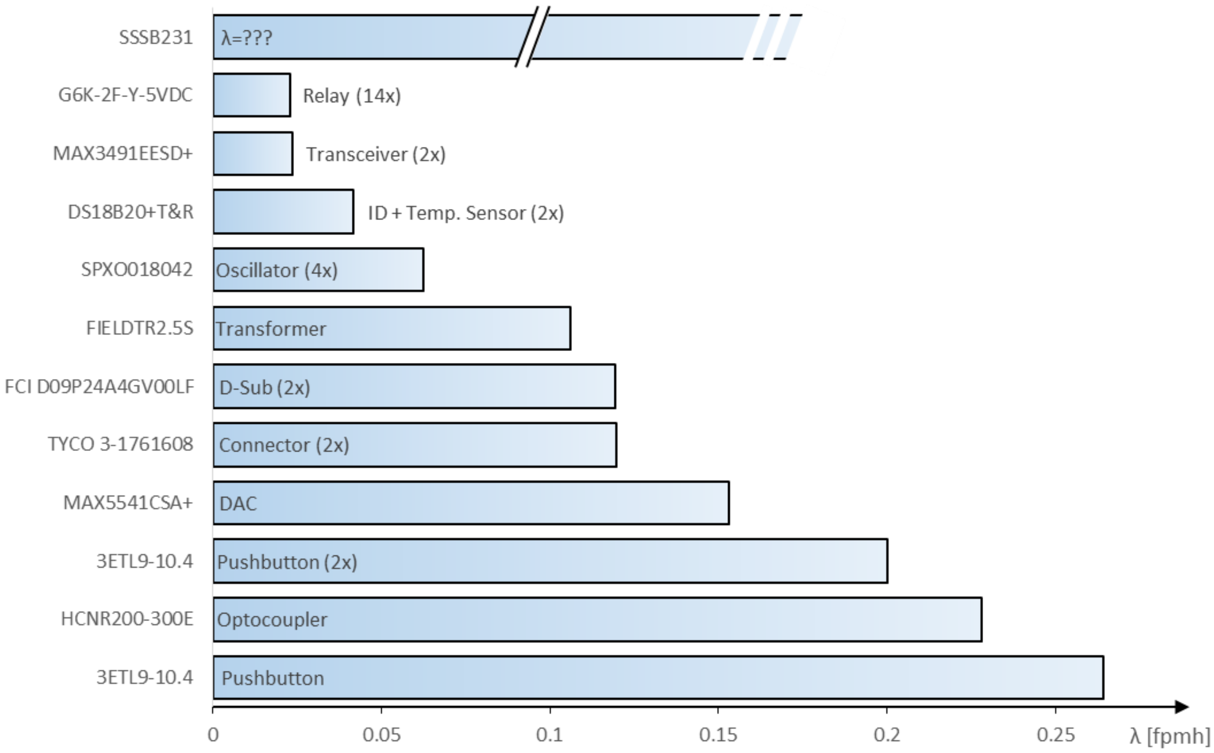


Figure 3-9 : Highest component failure rates

Figure 3-10 shows the highest block failure rates of the model with the six boards marked in green, subsystem blocks in blue and schematic blocks in orange. As it can be seen, the CB is the least reliable PCB followed by the AB and the Front Panel subsystem on the CB containing the three pushbuttons. This result is not surprising when looking at the amount of 211 components on the CB and even 324 on the AB. Reliability improvements in design should normally start in or on top of these blocks while single component improvements should start with high failure rate components.

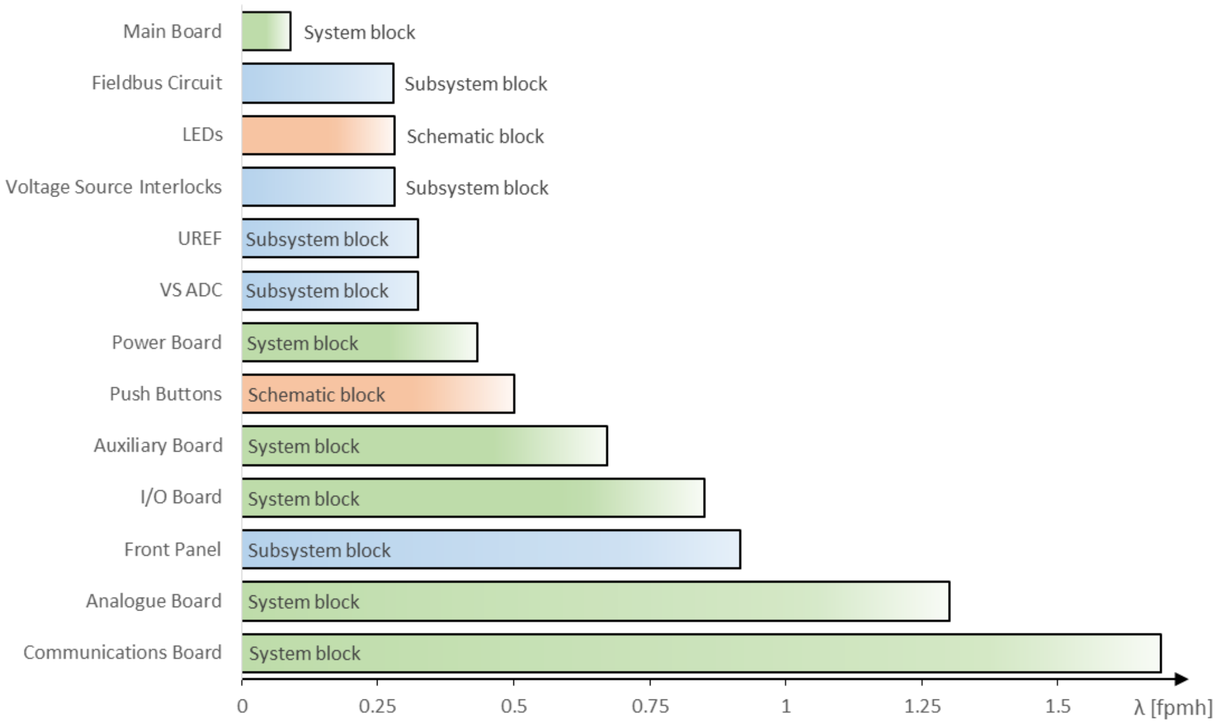


Figure 3-10 : Highest block failure rates

Integrated Reliability Improvements

During the execution of this work several reliability improvements were integrated into the final FGClite design. This includes design changes as well as component changes or upgrades. The following list presents and describes all improvements executed in connection to the results of the prediction. In this connection, it is hard to illustrate the effect which each improvement has in a common way, or by a common factor. This is especially owed to the variety of improvements as well as their interaction in many cases. Thus, an extra added cell describes the effect in each case as quantitatively as possible. A qualitative method to assess such improvements is introduced in chapter 3.4. The component improvements are ranked starting with the most significant improvement.

Table 3-3 : Integrated reliability improvements

Improvement	Description
Components:	
- Upgrading capacitor quality	After MIL-HDBK 217F computations, the MLCC capacitors at the FGClite operating conditions generally resulted in a high failure rate. As a consequence of this, it was decided to change all MLCC capacitors to automotive quality after the AEC-Q200 qualification standard of the Automotive Electronics Council [39]. Advantages of this decision are many more performed qualification tests and therefore a proficient component reliability. It was decided to set a military quality class of «M» which reduces the failure rate by a factor of 3. Even though the computations stated an even better reliability, this decision was made to keep the models' conformity to the other components calculated after the MIL-STD. [40]

	Effect: The summed up failure rate of all MLCC capacitors got reduced by 66 % from 4.2 fpmh to 1.4 fpmh [41]. This is equal to a reduction of around 35 % of the FGClite failure rate at the time of improving.
- Changing PCB connectors	The used Harting DIN 41612 inter-board connectors and the two male backplane connectors were changed to ERNI performance class 1 connectors of the same norm. Harting could only provide customized MIL-HDBK 217F calculations. ERNI was the only contacted manufacturer which had calculations based on testing (partly after the norm IEC60603-2), see [42].
	Effect: The summed up failure rate of all connectors got reduced by over 80 % from 0.5 fpmh to 0.086 fpmh. This is equal to a reduction of over 4 % of the FGClite failure rate at the time of improving.
- Upgrading capacitor ratings	Several capacitor voltage ratings were too close to the maximum applied voltage on the capacitors during operation, which is why ratings were changed, towards a higher voltage, to improve the reliability.
	Effects: Several smaller effects. The most significant change was on the AB. Five 10 µF capacitors (CD56, CD62 to CD65 [20]), which operate at maximum 5 V, got changed from a voltage rating of 6.3 V to 25 V. This reduced each failure rate by 68 % from 0.0156 fpmh to 0.0049 fpmh.
- Upgrading resistor ratings	A few resistor power ratings were too close to the maximum dissipated power of the resistors during operation. The ratings were changed to a higher more reliable rating.
	Effects: Several smaller effects. A significant example can be given for the RadDIM analysis: For two 100 Ohm resistors the failure rate got reduced by 57 % from 0.01 fpmh to 0.0043 fpmh. Operating at a voltage of 3.3 V, the maximum dissipated power was for these resistors at 87 % of the rated power of 0.125 W. It got increased to 1 W. [42]
Design:	
- Changing PCB layouts	The board layout was changed from version 2, to the final version 3, which includes the above described six boards with the passive MB. Version 2 only contained an AB, CB and a rather complex non-passive MB which got split into the three boards IOB, PB and XB.
	Effect: Gains of the new design are the good distribution and modularity, the similarity to the layout of the well running and experienced FGC2 and an easier testing procedure of each board before installation.
- Adding pin-redundancies	After the version 3 iteration a high number of connector pins were integrated and several pin redundancies were added.
	Effect: Minor effect on the failure rate due to already low connector failure rates, however important related to the results of the FMEA and FTA, see in chapter 3.4.2 and 3.5.1. Related to chapter 3.5.1, it is important to mention that redundancies cannot be considered as such for all potential pin failure modes.

Not all design improvements are exclusively connected to the results of the prediction. They were also implemented based on additional and best knowledge, however all as a result of the prediction analysis and discussions related to that.

For all component improvements an illustration how such quality upgrades increase the lifetime can be accessed in the appendix.

3.4 Failure Modes and Effects Analysis (FMEA)

Following the predictions, an FMEA, which uses the created prediction structure as a base, was prepared. The Failure Modes and Effects Analysis was developed in the 1960s by the National Aeronautics and Space Administration (NASA) of the United States for the Apollo program [24]. As a usually qualitative method of reliability engineering, it serves to identify potential failure modes, their potential causes and resulting effects of a regarded system, to make a risk assessment and as required to perform mitigation actions. An FMEA as in this work should be performed after these five steps:

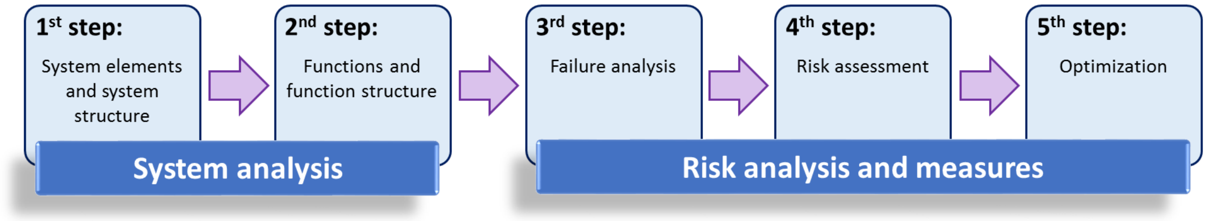


Figure 3-11 : Steps to perform an FMEA after [24, 43]

Executing all this, the core of an FMEA is its form sheet to be filled in, where many variations do exist. Obtaining such a specific form for each present case, a project or a whole company policy, at first the type of the FMEA needs to be distinguished, which is for this work on the component level the «Design FMEA», whilst the second type is the «Process FMEA». Extended to a more functional and systematic level, standards also use the designations of a «System FMEA Product» and «System FMEA Process» [24, 44]. Consequentially this work executes a System FMEA Product regarding both the component and system level, especially when making use of the FMEA later in chapter 3.5. To create an individual layout of a form sheet, different norms and standards can be consulted. Table 3-4 shows a form of the VDA 4.2 standard of the German «Verband Der Automobilindustrie».

Table 3-4 : FMEA form sheet after VDA 4.2 [24, 44]

<table>
<tr><td rowspan="2"></td><td colspan="9" rowspan="2">FMEA
System</td><td>Number:</td></tr>
<tr><td>Page:</td></tr>
<tr><td colspan="5">Type/Model/Fabrication/Load:</td><td colspan="2">Item Code:
State:</td><td colspan="3">Responsible:
Company:</td><td>Created:</td></tr>
<tr><td colspan="5">System-No./System Element:</td><td colspan="2">Item Code:
State:</td><td colspan="3">Responsible:
Company:</td><td>Created:
Modified:</td></tr>
<tr><td>Potential Effects</td><td>S</td><td>Potential Failure Modes</td><td>C</td><td>Potential Causes</td><td>Preventive Actions</td><td>O</td><td>Detection Actions</td><td>D</td><td>RPN</td><td>Responsibility:
Compl. Date:</td></tr>
<tr><td colspan="11">System Element:</td></tr>
<tr><td colspan="11">Function:</td></tr>
<tr><td rowspan="4"></td><td rowspan="4"></td><td rowspan="4"></td><td rowspan="4"></td><td rowspan="4"></td><td colspan="6">Initial State:</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="6">State:</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

The columns on the left serve to analyse each component, functional part or assembly of the examined system recording every potential failure mode(s), the resulting effect(s) and the potential cause(s). It is essential, that no system part, failure mode, effect or cause is missed or neglected. Upon completion, a risk assessment follows which evaluates the severity (S) of the effect for the whole system, the likelihood that the failure cause occurs (O) and the probability of detecting (D) the cause or mechanism of the potential failure before it occurs on three different scales in each case from 1 to 10. These rankings enable then to assess the overall risk using the Risk Priority Number (RPN), which multiplies the three values.

$$RPN = S * O * D \qquad \{RPN \in \mathbb{R} \mid 1 \leq RPN \leq 1000\} \qquad (3.22)$$

The rankings are scaled from 1 representing the best case to 10 representing the worst case, which is why low RPNs constitute a well designed and developed system. In connection to chapter 3.1 this equation also serves as a definition of the term risk represented by the three influencing factors.

After this first part of the analysis, the second deals with actions to improve the system. Having the different RPN-, but also single high severity-, occurrence- and detection rankings, it is easy to identify the biggest design weaknesses and to know where to start. In table 3-4 these measures are documented in two columns divided into preventive- and detection actions. In general it is only possible to lower the occurrence or detection ranking, because the severity is a fixed value of the failure mode which can only be lowered when applying changes in the functional design. Nevertheless, the FMEA identifies these potential weaknesses. Simple examples are, for instance, the installation of a redundant component to reduce the occurrence ranking and depending on the FMEA type the integration of a run-in test prior to the system installation to detect manufacturing errors or a checking strategy to detect potential failures or causes during operation.

Concluding the above, the FMEA is an analysis which is growing during the product development from the early design stages until the finalisation of the product and then becomes a powerful documentation to refer to and further complete during the whole lifetime of the product. Furthermore, an important remark at this point is the large amount of detailed and inevitable accurate work. Depending on each specific system such an analysis might also become sophisticated making it necessary to sometimes customize and adjust the general given guidelines of the different standards and directives. The following FMEA illustrates these points in some cases.

3.4.1 FMEA of the FGClite

For the FGClite's reliability analysis the FMEA serves besides the above described to further specify the already executed prediction. On this base it uses the prediction hierarchy and adds to each block on the component level the generic failure modes. The software RWB provided a converting facility to execute this. To generate a customized FMEA methodology for the specific electronic system of the FGClite, many changes to the methodologies of the different standards have been applied. As closest standards this FMEA refers to, the MIL-STD 1629A [45] and the MIL-HDBK 338B can be named.

Project Definitions

To define the customized methodology table 3-5 lists and summarizes all set determinations as well as general assumptions made.

Table 3-5 : Determinations and Assumptions for the FGClite FMEA

	Description
General:	All general conditions as described in chapter 3.2.1.
Actions:	Already performed actions are integrated in RWB, but not in the report, compare chapter 3.4.2.
Components:	Only components from the BoM are included, as described in chapter 3.2.1.
Effect levels:	Only two levels of effects are used. If initial effects cause several sub effects, they are additionally filled into the initial effect column, see later in this chapter.
Failure causes:	All failure causes are considered as «random failure». The whole analysis is based on the assumption that the installed lifetime of the FGClite starts after excluding all infant mortality failures and ends before wear-out failures appear, thus ranging in the second part of the bathtub curve. Measures to guarantee this are executed [46].
Failure modes:	The failure modes for all considered components were taken either from the MIL-HDBK 338B or the «Failure Mode/Mechanism Distributions» (FMD-91) of the American «Reliability Analysis Center» (RAC) [47]. For very few components some failure modes were summarized in terms of simplification to less specific, more general modes.
Immediate effects:	If a failure mode can result into several immediate effects, always a pessimistic approach was used which takes the worst case result on the higher effect levels.

In order to define classes for the risk assessment rankings custom scales were used to enhance the analysis. For the severity, the top system level was set to the FGClite's operation in connection to the LHC operation. Hence, the six following classes are defined:

- 1 = No Effect
- 2 = Scheduled Maintenance Required
- 3 = Immediate Maintenance Required
- 4 = False/Unrequested Beam Dump
- 5 = Destructive Damage FGClite
- 6 = Missed Beam Dump Request

The highest severity exists when the FGClite misses a request to dump the circulating beam. In this case other safety systems, like e.g. the Beam Loss Monitor [48], need to provide their function to request and finally dump the beam. This unwanted event is directly affecting the reliability of the accelerator protection system in addition to reducing the LHC's beam availability. A loss of availability is also the case for the rankings 3 to 5, whilst a required scheduled maintenance can be executed during a planned technical stop of the whole accelerator and therefore is not influencing any LHC operation. A destructive damage of the FGClite cannot miss a beam dump request but will lead to a controlled dump stopping the LHC operation. Additionally the tunnel needs to be accessed to change or repair the FGClite before the accelerator gets refilled. The same applies for a required immediate maintenance with the difference, that the current run will be finished before accessing the tunnel. In the case of a false or unrequested beam dump, the operation also stops and depending on a successful power cycle of the FGClite afterwards it is possible to immediately restart operation or in a worse case it is necessary to repair or change the module.

As pointed out, the probability to detect potential failures or causes usually applies to failures being detected during the development of a product or during its operation before they occur. For the electronic system of the FGClite, actions to detect potential failures which can occur prior to installation are already taken [46, 49], for this reason only random in time failures are assumed. Presuming only these randomly occurring failures this leads to the modified detection ranking of the four following categories defining the likelihood to detect the specific failure in combination with the resulting effect(s). The generated information of this classification is a powerful aid to analyse and improve the efficiency of the modules' maintenance, respectively repair strategy which is directly connected to the LHC availability. Thus, a direct connection to the *RPN* is applicable. Depending on the likelihood, the detection gets executed constantly or periodically by the installed software or more unlikely over manual data analysis.

- 1 = Definitely detectable (Constant automatic)
- 2 = Most likely detectable (Periodic checking program)
- 3 = Unlikely detectable (Manual data analysis)
- 4 = Not detectable

To define the occurrence ranking, simply the component failure rates from the prediction were used. To create conformity with the severity and detection, especially looking towards potentially needed improvements in the future (Figure 3-16), it was decided to set a maximum of four rankings classifying the component level. In addition, the analysis function of RWB offers the possibility to extend the computing of the occurrence-, severity- and detection ranking as well as the *RPN* on higher hierarchy levels, why the occurrence is the only scale which can be extended on these levels. For the severity and detection of this extended computation, RWB always uses the highest rating of each block.

- 1 = Remote (<0.01 fpmh)
- 2 = Low (≥0.01 fpmh)
- 3 = High (≥0.05 fpmh)
- 4 = Very high (≥0.2 fpmh)
- [5,6] = ≥1 fpmh, ≥10 fpmh

As already pointed out, the scales do not reach the highest number of 10. Additionally they also do not have the same range, which makes it difficult to rely on a standard, yet it is not very complicated to adapt for analysis, see next chapter. The circumstance that the severity scale is longer moves more importance towards this ranking influencing the *RPN* stronger. This intended fact especially emphasizes the *RPN*-significance of the higher severities (4 to 6). In the following risk assessment in chapter 3.4.2 this impact is further illustrated.

Preparation and Execution

To execute the FMEA on the basis of the prediction hierarchy, the board designers which have the most knowledge of the design and its functions were consulted. At this point a special thanks to Gilles Ramseier, Miguel Cerqueira Bastos and the most to Slawosz Uznanski for the help to prepare the FMEA.

After first presenting an approach, then discussing and developing a specific methodology all components were exported from the RWB prediction to Excel and to each, generic failure modes were assigned. This failure modes data of the FMD-91 «was collected from a variety of sources […] compiled from failure analysis reports, DoD [Department of Defense] maintenance data and published materials» [47].

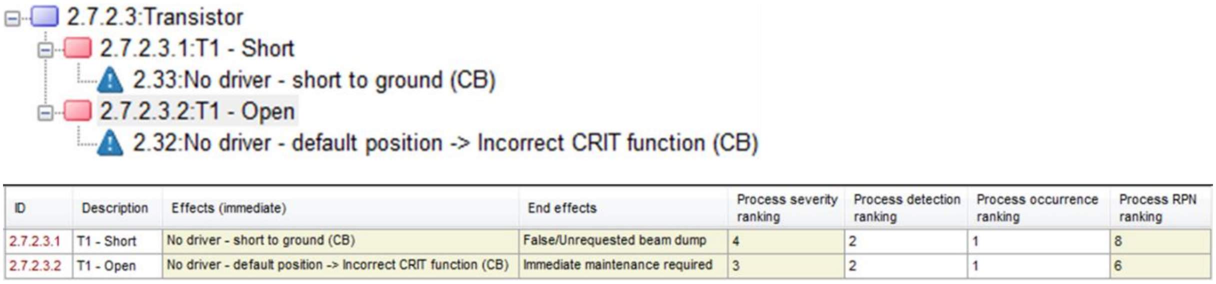
Table 3-6 : Example of potential failure modes and apportionments for a relay after the FMD-91 [25, 47]

Relay	Fails to Trip Spurious Trip Short	.55 .26 .19

In addition two columns for effects and two others for a severity and a detection ranking were added to the Excel file. For unification, simplification and reasons of the RWB model implementation, it was decided to reduce the layers of effects to a bottom and top level. In the case of several sub-effects the integration was executed within one cell using a flow structure.

Creation of the RWB Model

Once the Excel files were filled, the data was taken and integrated into the FMEA hierarchy of RWBs FMECA-module. As shown in figure 3-12, to each component block the associated failure modes (red block) and immediate effects (blue triangle) were integrated together with the detection and occurrence rankings. The occurrence rankings were entered manually by using the relevant component failure rate. On a higher level the corresponding six different end effects with the severity ranking were added and linked to the lower level effects.



2.7.2.3:Transistor
  2.7.2.3.1:T1 - Short
    2.33:No driver - short to ground (CB)
  2.7.2.3.2:T1 - Open
    2.32:No driver - default position -> Incorrect CRIT function (CB)

ID	Description	Effects (immediate)	End effects	Process severity ranking	Process detection ranking	Process occurrence ranking	Process RPN ranking
2.7.2.3.1	T1 - Short	No driver - short to ground (CB)	False/Unrequested beam dump	4	2	1	8
2.7.2.3.2	T1 - Open	No driver - default position -> Incorrect CRIT function (CB)	Immediate maintenance required	3	2	1	6

Figure 3-12 : RWB FMEA: Transistor T1 on the CB

For the block with the ID 2.7.2.3, the FMD-91 provided two different failure modes for the concerning transistor T1 on the CB. It can fail either in a short or an open circuit. As indicated above, already the FMD-91 summarizes failure modes. E.g., for the failure mode of an open circuit obviously the base-emitter line, the collector-emitter line or the emitter itself can open. This has been taken into account during the execution of the FMEA, which is the reason why for all cases always the worst effect was noted down. Using this transistor as an example, figure 3-13 shows the extract of the schematic.

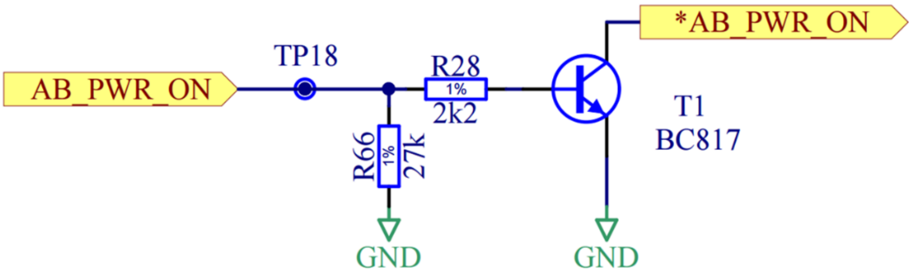


Figure 3-13 : Schematic for the transistor T1 on the CB

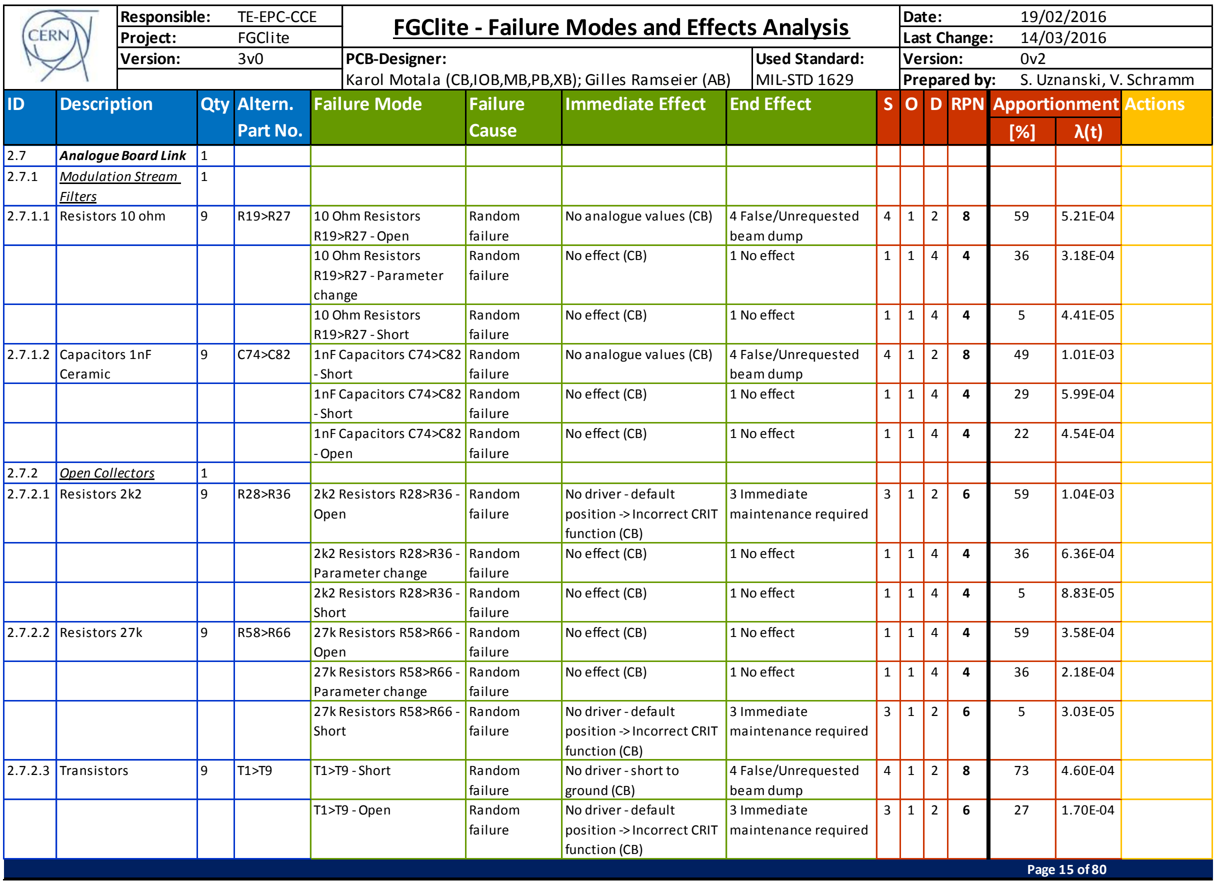
Taking the failure mode of a short circuit, the worst effect is a constant short between the collector and the emitter pulling down the signal «AB_PWR_ON» to the ground. The loss of this signal leads, in the worst case, to the end effect of a «False/Unrequested beam dump» which has a severity ranking of 4. Such a transistor failure can be detected by a periodic checking program. The lifetime test failure rate after HTOL testing of 0.63 FIT (NXP - BC817) equals an occurrence ranking of 1. For the second general failure mode of an open transistor the worst effect would be an «Incorrect CRIT function» leading to the end effect of «Immediate maintenance required».

Additionally to this FMEA, which uses the *RPN*, a second RWB file was created by deleting the three *RPN* rankings and replacing them with so-called failure mode apportionments of the FMD-91. This additional quantitative method uses failure mode ratios like in the last column of table 3-6 which are summing up to in total 100 % for all possible failure modes together. As described above this data was determined of different sources. It is not provided that this data matches the reality in each specific case, p. 7-190 [25], neither are safety margins included when having the maximum value of 100 %. Nevertheless, the FMD-91 is based on a big amount of data and is, in terms of comprehensiveness, the best available data. In addition, by later multiplying the apportionment factors to the component failure rates, which contain safety margins and represent the definitions of the chapters 3.1.2 and 3.2.1, the risk of deviation is reduced. Moreover, the following only uses the apportioned failure rates to analyse the six end effects by summing up many different component rates. It is probable that this fact compensates wrong values in either direction of deviation and, in addition, for different specific applications.

3.4.2 Results of the FMEA

With the two FMEA files prepared, it is possible to link and analyse the data in RWB. As a first step, a report as for the prediction was prepared which merges the results of both files into one table. Table 3-7 shows an extract, the full report can be accessed in the appendix.

Table 3-7 : FGClite FMEA report (extract)



Responsible: TE-EPC-CCE	**FGClite - Failure Modes and Effects Analysis**		**Date:** 19/02/2016
Project: FGClite			**Last Change:** 14/03/2016
Version: 3v0	**PCB-Designer:**	**Used Standard:**	**Version:** 0v2
	Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)	MIL-STD 1629	**Prepared by:** S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment [%]	λ(t)	Actions
2.7	***Analogue Board Link***	1												
2.7.1	*Modulation Stream Filters*	1												
2.7.1.1	Resistors 10 ohm	9	R19>R27	10 Ohm Resistors R19>R27 - Open	Random failure	No analogue values (CB)	4 False/Unrequested beam dump	4	1	2	**8**	59	5.21E-04	
				10 Ohm Resistors R19>R27 - Parameter change	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	36	3.18E-04	
				10 Ohm Resistors R19>R27 - Short	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	5	4.41E-05	
2.7.1.2	Capacitors 1nF Ceramic	9	C74>C82	1nF Capacitors C74>C82 - Short	Random failure	No analogue values (CB)	4 False/Unrequested beam dump	4	1	2	**8**	49	1.01E-03	
				1nF Capacitors C74>C82 - Short	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	29	5.99E-04	
				1nF Capacitors C74>C82 - Open	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	22	4.54E-04	
2.7.2	*Open Collectors*	1												
2.7.2.1	Resistors 2k2	9	R28>R36	2k2 Resistors R28>R36 - Open	Random failure	No driver - default position -> Incorrect CRIT function (CB)	3 Immediate maintenance required	3	1	2	**6**	59	1.04E-03	
				2k2 Resistors R28>R36 - Parameter change	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	36	6.36E-04	
				2k2 Resistors R28>R36 - Short	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	5	8.83E-05	
2.7.2.2	Resistors 27k	9	R58>R66	27k Resistors R58>R66 - Open	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	59	3.58E-04	
				27k Resistors R58>R66 - Parameter change	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	36	2.18E-04	
				27k Resistors R58>R66 - Short	Random failure	No driver - default position -> Incorrect CRIT function (CB)	3 Immediate maintenance required	3	1	2	**6**	5	3.03E-05	
2.7.2.3	Transistors	9	T1>T9	T1>T9 - Short	Random failure	No driver - short to ground (CB)	4 False/Unrequested beam dump	4	1	2	**8**	73	4.60E-04	
				T1>T9 - Open	Random failure	No driver - default position -> Incorrect CRIT function (CB)	3 Immediate maintenance required	3	1	2	**6**	27	1.70E-04	

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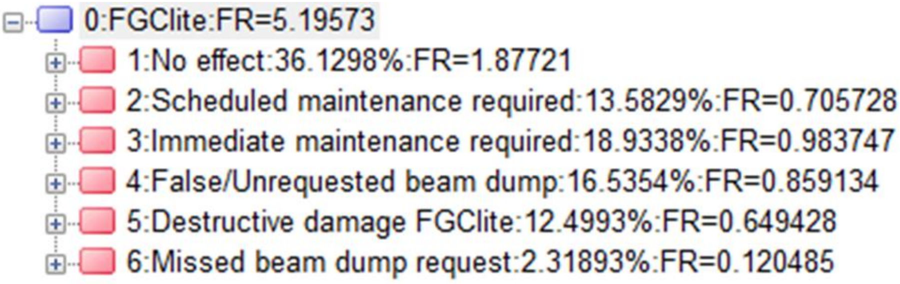
Divided into four different colours, the most left columns are displaying the components in the hierarchy. The columns in green contain the generic failure modes, causes and the two effect levels. In red the *RPN* with its factors is given plus the apportionments of the second file with the resulting proportion of the failure rate in fpmh per single component. The most right column in yellow is representative for the right half of table 3-4 to enter improvement actions like described in the 5th step of figure 3-11. Even though many improvements were realized during the reliability analysis of this work, actions are not yet integrated in the files, because at the time of the creation of the current FMEA version all improvements were already implemented. The RWB prediction module does contain these changes. This work closes up at that point of executing an FMEA, why performing additional actions would be a task for a continuation of this work (see example in figure 3-17), or rather another design iteration of the recent FGClite version 3.

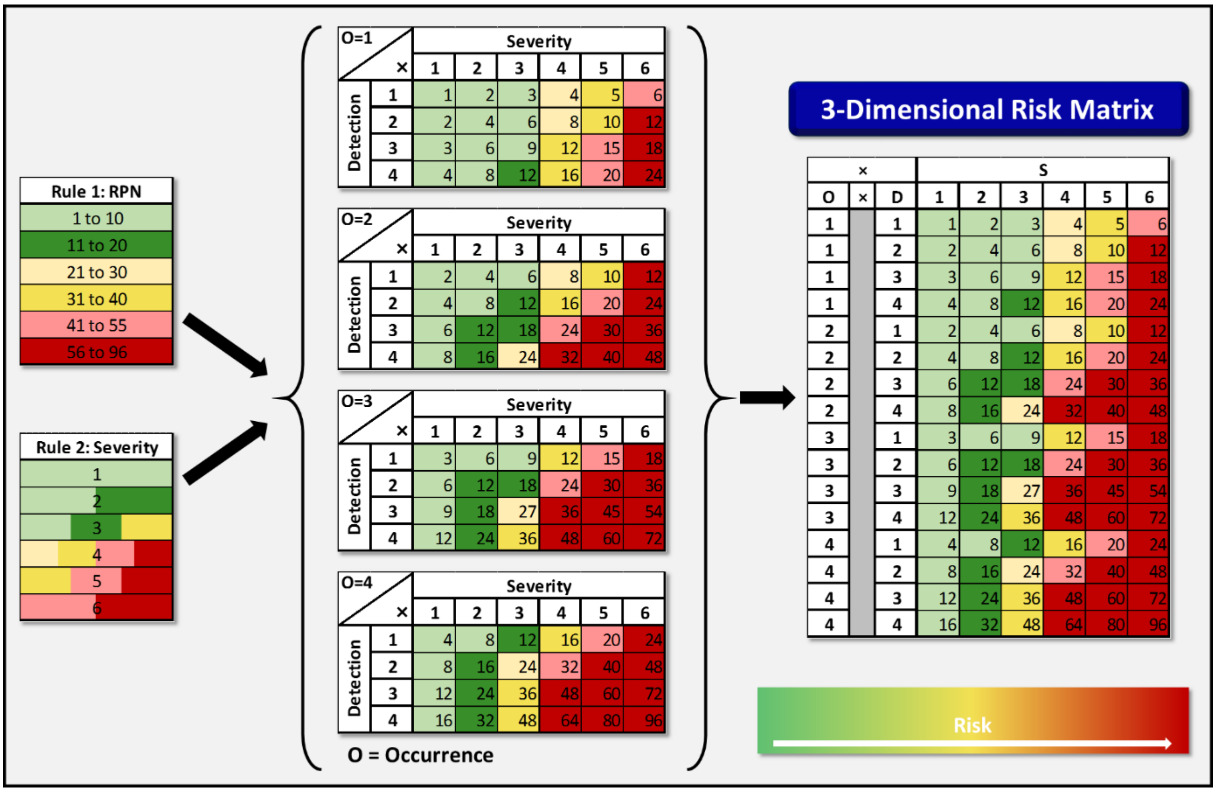


```
0:FGClite:FR=5.19573
    1:No effect:36.1298%:FR=1.87721
    2:Scheduled maintenance required:13.5829%:FR=0.705728
    3:Immediate maintenance required:18.9338%:FR=0.983747
    4:False/Unrequested beam dump:16.5354%:FR=0.859134
    5:Destructive damage FGClite:12.4993%:FR=0.649428
    6:Missed beam dump request:2.31893%:FR=0.120485
```

Figure 3-14 : Failure rate apportionment results for the FGClite end effects

When using the failure mode apportionments under the above assumptions a beneficial result can be generated for the top level effects. For each effect, RWB sorts all failure modes leading to it and calculates the associated ratio and failure rate. For example this results into statistically 2.3 % of FGClite electrical failures which cause a missed beam dump request. Looking at the consequence of this effect being a reduced safety protection, this value can, and should, be reduced in future developments. To present one more example, the predicted *MTTF* of chapter 3.3.3 can be redefined by only taking into account failures which lead to an effect. This reduces the failure rate by an amount of 36 % and results into the specific *MTTF* of a little more than **300k** hours. More specific interpretation and other usage of these information in terms of availability follows in chapter 3.5. It is also to be noted, that the red coloured blocks in figure 3-14 represent effects. The wrong labelling is a reason of the software's implementation.

By further extracting and compressing the FMEA data, a commonly used so-called «Risk Matrix» was created. In the intended case, a two-dimensional matrix uses the severity and occurrence ranking from 1 to 10 on two coordinate axes neglecting the detection probability. In the three traffic light colours distributed from the coordinate origin region in green over a yellow region around the line which is connecting the two axes maximums finishing with the rest in red, the rising risk is displayed in the same direction, compare figure 3-15. Since 2011 a new approach referred as the «Ampelfaktor» (German: word-for-word «traffic light factor») is developed which adds a detection axis in ten units as third dimension. [50, 51]
Taking the fact of different ranking scales and weightings in the FGClite FMEA into consideration, a custom three-dimensional matrix was developed which gives the advantage of tuning the matrix specifically for this project.



Rule 1: RPN
1 to 10
11 to 20
21 to 30
31 to 40
41 to 55
56 to 96

Rule 2: Severity
1
2
3
4
5
6

O=1		Severity					
	×	1	2	3	4	5	6
Detection	1	1	2	3	4	5	6
	2	2	4	6	8	10	12
	3	3	6	9	12	15	18
	4	4	8	12	16	20	24

O=2		Severity					
	×	1	2	3	4	5	6
Detection	1	2	4	6	8	10	12
	2	4	8	12	16	20	24
	3	6	12	18	24	30	36
	4	8	16	24	32	40	48

O=3		Severity					
	×	1	2	3	4	5	6
Detection	1	3	6	9	12	15	18
	2	6	12	18	24	30	36
	3	9	18	27	36	45	54
	4	12	24	36	48	60	72

O=4		Severity					
	×	1	2	3	4	5	6
Detection	1	4	8	12	16	20	24
	2	8	16	24	32	40	48
	3	12	24	36	48	60	72
	4	16	32	48	64	80	96

O = Occurrence

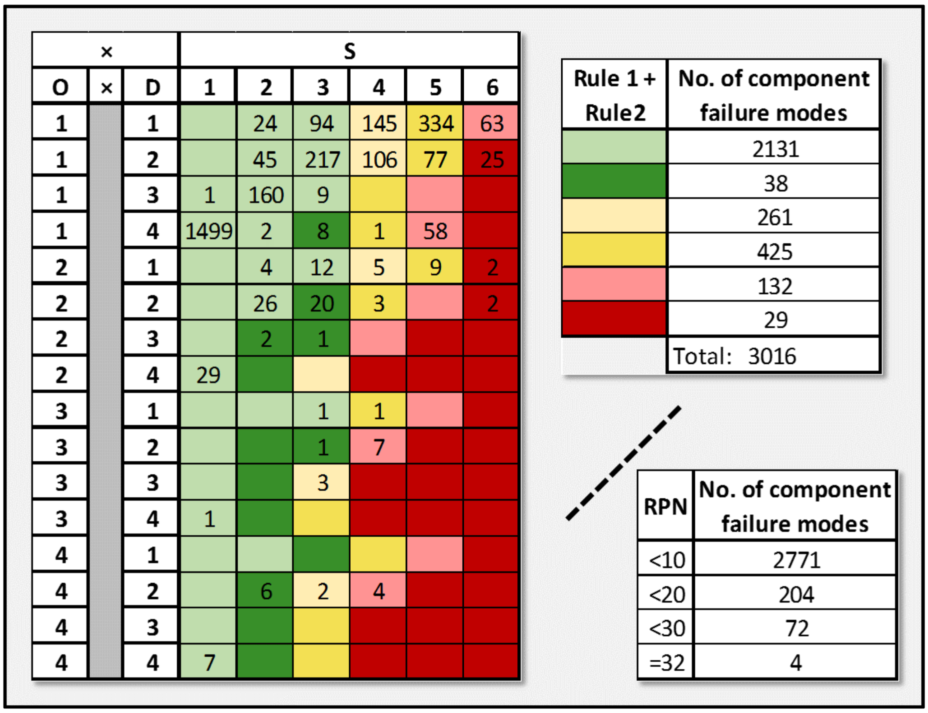
3-Dimensional Risk Matrix

×			S					
O	×	D	1	2	3	4	5	6
1		1	1	2	3	4	5	6
1		2	2	4	6	8	10	12
1		3	3	6	9	12	15	18
1		4	4	8	12	16	20	24
2		1	2	4	6	8	10	12
2		2	4	8	12	16	20	24
2		3	6	12	18	24	30	36
2		4	8	16	24	32	40	48
3		1	3	6	9	12	15	18
3		2	6	12	18	24	30	36
3		3	9	18	27	36	45	54
3		4	12	24	36	48	60	72
4		1	4	8	12	16	20	24
4		2	8	16	24	32	40	48
4		3	12	24	36	48	60	72
4		4	16	32	48	64	80	96

Figure 3-15 : Creation of the 3-dimensional risk matrix

This matrix is constructed by adding a detection axis to the occurrence axis which is then combined into one axis by directly multiplying the two evaluations. The most powerful aspect within this method is the integration of two rules to evaluate the magnitude of the risk. It can even be expanded to a third rule. The first applied rule 1 distributes six ascending risk colours to different ranges of the *RPN*. The nonlinear progression at higher values is owed to the *RPN* calculation of multiplication. To give an example, equation (3.22) can be used to calculate a simple average *RPN* by multiplying the middle of each ranking scale 5*5*5 = 125. However, this designated average does not represent the middle of the *RPN* scale reaching until the maximum of 1000. In the FGClite FMEA, even the highest *RPN* value (see figure 3-16) only reaches the fourth lowest colour stage of this rule. The second rule only assigns colour ranges to the different severities chosen by means of the end effect. For example, a severity of 6 has a minimum risk of the second highest colour category. When afterwards merging this first rule with the second, the colours of the lowest detection rank were taken for each severity column and occurrence rank (Figure 3-15, middle) and compared with rule 2. If the lowest detection colour referred to a lower risk than set in the range of rule 2, the risk was changed to the lowest colour of the range and the higher detection fields were also increased by that difference. The inverse applied for lowering rows of high detection rankings. This second rule additionally emphasizes the intended bigger impact of higher severity rankings, illustrated in chapter 3.4.1, in the framework of this risk assessment. A further illustration of how to derive to the matrix applying the two rules can be found in the appendix.

After the creation of the matrix, it was completed by summing up all component failure modes which have the rankings of the concerning cells. In figure 3-16 it can be seen, that more than half of the failure modes (1 537) are located in the no effect column (S = 1). As these failure modes have no effect on the system level, they will not be analysed, nor mitigated further on. The reason that nearly all failure modes in this column cannot be detected is owed to the definition stipulating that if there is no end effect occurring it obviously cannot be detected. Furthermore, 72 % of the failure modes have a green and 23 % a yellow risk which can be postponed for the first iteration of the analysis. The red coloured failure modes are of high importance as they affect the LHC availability at the time of failure. At the beginning, special care needs to be taken for the 29 dark red failure modes, especially the four with an occurrence ranking of 2, and the, more often occurring, eleven bright red with a severity of 4. In future developments, these *RPN*s need to be reduced respectively eliminated at first. It is also positively remarkable, that the highest risk failure modes have a detection as well as an occurrence ranking of 2 or smaller.



×			S					
O	**×**	**D**	**1**	**2**	**3**	**4**	**5**	**6**
1		1		24	94	145	334	63
1		2		45	217	106	77	25
1		3	1	160	9			
1		4	1499	2	8	1	58	
2		1		4	12	5	9	2
2		2		26	20	3		2
2		3		2	1			
2		4	29					
3		1			1	1		
3		2			1	7		
3		3			3			
3		4	1					
4		1						
4		2		6	2	4		
4		3						
4		4	7					

Rule 1 + Rule2	No. of component failure modes
🟩	2131
🟩	38
🟨	261
🟨	425
🟥	132
🟥	29
	Total: 3016

RPN	No. of component failure modes
<10	2771
<20	204
<30	72
=32	4

Figure 3-16 : Filled 3-dimensional risk matrix and RPN distribution

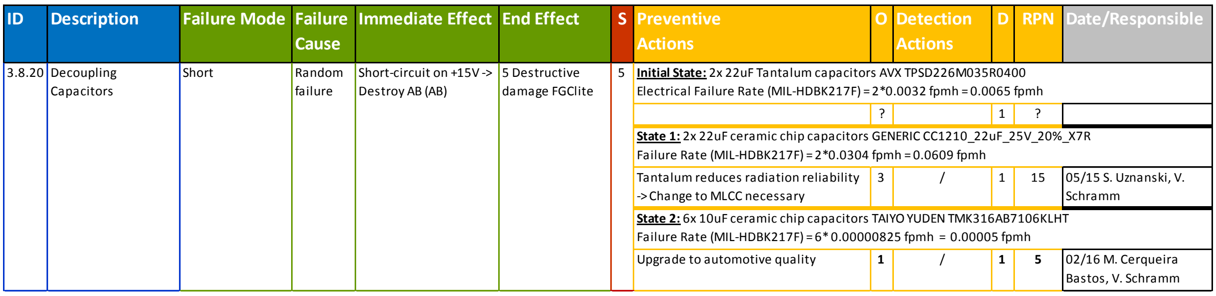
Table 3-8 displays the mentioned critical failure modes scaling the priority of processing them downwards. It can be seen that the most severe boards are the CB and the IOB. Together with the MB and the PB they are the only boards which can cause a missed beam dump request. The second last column of the table also shows the minor importance of the *RPN* which is presently discussed by many experts (VDA, AIAG, DGQ; p. 52 [50]). In connection to this, it should also be mentioned that in this thesis the *RPN* is adapted a lot, especially by the applied severity rule, and that it is not fully relying on any standard, thus the reason why only a vague statement can be made at this point.

Table 3-8 : Highest risk failure modes

ID	Description	Qty	Failure mode	Immediate effect	Severity/End effect	O	D	RPN	Risk
2.2.1.6	Relay	1	RL1 - Fails to trip	Fails to reset (CB)	6 Missed beam dump request	2	2	**24**	
2.3.4.1	ProASIC3E FPGA	1	ProASIC3E IC3 - Broken	No critical FGClite functions (CB)	6 Missed beam dump request	2	2	**24**	
6.2.2.7	Relay	1	RL4 - Fails to trip	No powering failure (IOB)	6 Missed beam dump request	2	1	**12**	
			RL4 - Short	No powering failure (IOB)	6 Missed beam dump request	2	1	**12**	
2.2.1.5	Diode 70V 350mW	1	D1 - Short	Fails to reset (CB)	6 Missed beam dump request	1	2	**12**	
2.5.4.4	Resistor 10k	1	10k Resistor R15 - Short	No fd power cycle (CB)	6 Missed beam dump request	1	2	**12**	
6.2.2.3	Transistors	2	T23,T24 - Open	No powering failure (IOB)	6 Missed beam dump request	1	2	**12**	
6.4.1.2	Resistors 10k	7	10k Resistors R3...R48 - Short	No Status -> Missed beam dump request (IOB)	6 Missed beam dump request	1	2	**12**	
6.4.1.5	Resistors 4k7	7	4k7 Resistors R2...R51 - Open	No Status -> Missed beam dump request (IOB)	6 Missed beam dump request	1	2	**12**	
6.4.1.8	Capacitors 100nF Ceramic	7	100nF Capacitors C26...C37 - Short	No Status -> Missed beam dump request (IOB)	6 Missed beam dump request	1	2	**12**	
2.2.1.3	Push-Button Switch	1	PB2 - Sticking	Spurious power cycle (CB)	4 False/Unrequested beam dump	4	2	**32**	
			PB2 - Short	Spurious power cycle (CB)	4 False/Unrequested beam dump	4	2	**32**	
2.2.1.4	Push-Button Switch	1	PB3 - Sticking	Spurious reset (CB)	4 False/Unrequested beam dump	4	2	**32**	
			PB3 - Short	Spurious reset (CB)	4 False/Unrequested beam dump	4	2	**32**	
2.3.5.2	Oscillator	1	OSC1 - No operation	No communication (CB)	4 False/Unrequested beam dump	3	2	**24**	
2.5.2.2	Fieldtransformer	1	TR1 - Open	No communication (CB)	4 False/Unrequested beam dump	3	2	**24**	
			TR1 - Short	No communication (CB)	4 False/Unrequested beam dump	3	2	**24**	
2.5.3.1	Straight D-Sub	1	J4 - Open	No communication (CB)	4 False/Unrequested beam dump	3	2	**24**	
			J4 - Poor contact/Intermittent	No communication (CB)	4 False/Unrequested beam dump	3	2	**24**	
			J4 - Short	No communication (CB)	4 False/Unrequested beam dump	3	2	**24**	
2.6.7.2	Oscillator	1	No operation	No communication (CB)	4 False/Unrequested beam dump	3	2	**24**	

To finish this chapter, an outlook for a potential continuation is presented giving one example of an already improved outcome of the entire presented reliability analysis up to this point. Initially the AB, for which the development was done by another section included the use of two 22 µF tantalum capacitors. This fact was discovered during the executed analysis of this work, and the capacitors were changed to 22 µF ceramic chip capacitors, since tantalum gets activated in a radiation environment, which leads to radioactive waste. This can lead to a failure and hence reduces the FGClite reliability performance in radiation. After this change, the two 22 µF capacitors were changed together with the automotive quality upgrade to each time three 10 µF components resulting into an *RPN* of 5 for all six components.

An exemplary implementation into the customized FMEA report could look like the following:



ID	Description	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	Preventive Actions	O	Detection Actions	D	RPN	Date/Responsible
3.8.20	Decoupling Capacitors	Short	Random failure	Short-circuit on +15V -> Destroy AB (AB)	5 Destructive damage FGClite	5	**Initial State:** 2x 22uF Tantalum capacitors AVX TPSD226M035R0400 Electrical Failure Rate (MIL-HDBK217F) = 2*0.0032 fpmh = 0.0065 fpmh					
								?		1	?	
							State 1: 2x 22uF ceramic chip capacitors GENERIC CC1210_22uF_25V_20%_X7R Failure Rate (MIL-HDBK217F) = 2*0.0304 fpmh = 0.0609 fpmh					
							Tantalum reduces radiation reliability -> Change to MLCC necessary	3	/	1	15	05/15 S. Uznanski, V. Schramm
							State 2: 6x 10uF ceramic chip capacitors TAIYO YUDEN TMK316AB7106KLHT Failure Rate (MIL-HDBK217F) = 6* 0.00000825 fpmh = 0.00005 fpmh					
							Upgrade to automotive quality	**1**	/	**1**	**5**	02/16 M. Cerqueira Bastos, V. Schramm

Figure 3-17 : Example to perform and fill in actions

3.4.3 Designers Feedback

At this point a short feedback of the designer executing the FMEA is presented. It shows his personal opinion about the whole reliability analysis within this work and especially points out the seen profit of performing an FMEA.

> *« Performing the MTTF prediction and the FMEA gave us an insight in the possible failure modes of the new system during the design phase. The important feedback was a complete list of failure modes but the most valuable is the possibility to rank failures in terms of 1) occurrence rate and 2) visibility on the system level. The failure occurrence rate allowed us to improve on the overall system reliability by changing the most unreliable parts or mitigating the effect on the design level using redundancy. The ranking of failures visible on the system level causing unavailability of a function for operations allowed us to estimate system availability for LHC operations and to adapt the maintenance strategy during operations of the accelerator. Outcome of this research demonstrates the use of such tools in the future design of high-reliability and high-availability electronic systems for the accelerator control/protection. »*

(Dr. Slawosz Uznanski, FGClite project leader)

3.5 Fault Tree Analysis (FTA)

When carrying out a reliability analysis like the above, performing a Fault Tree Analysis can be an optional, yet in many cases necessary, step to ensure and/or improve the quality of a product. Developed in 1962 by H. A. Watson for the US Air Force and early after used by the avionic (Boeing, 1966) and nuclear power industry (1970s), it is a deductive method to display undesired states or functionalities of a system together with potential events leading to such a fault state. Looking at the product development process, this information is very beneficial, the earlier it is available to avoid additional costs, time delay, work or design iterations, and to enhance the product quality. Hence, an FTA should be started as early as possible, to profit the most of its failure preventive concept. Commonly, it is executed during or after the execution of an FMEA, which should as well start in the early design phases, yet it can be executed without the existence of an FMEA. In contrast to the classical FMEA, it uses a top-down approach and can be realized both qualitatively and quantitatively. An FTA usually starts on the highest system level defining so-called top events. In the following step, it moves down to the next lower system level and defines possible failures, which can lead to the top events. This step can be repeated several times, but can also be finished on a certain level, when the already generated results are sufficient to reduce the amount of work. To connect each lower level to the upper, the FTA uses a tree structure with the top events equal to the top branches. All failure events leading to a higher event are branched using Boolean logic (see p. 70 [24]). With different gates which connect one or several events, Boolean operations are performed to determine the occurrence of each upper event. Some of those can be for example an «AND» operation if both failures need to happen to cause the upper event, an «OR» operation if one event is sufficient or a «NOT» operation which negates the input event. [24, 25]

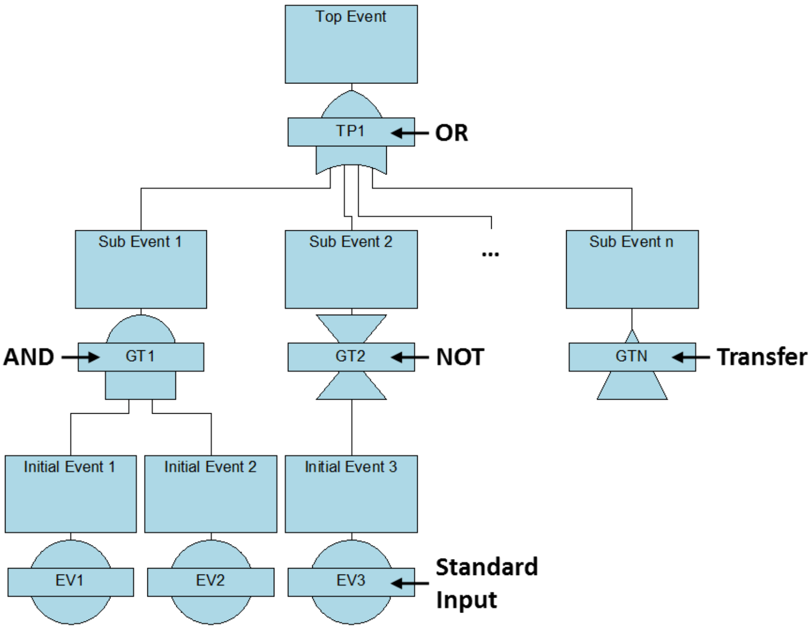


Figure 3-18 : FTA gate symbols in RWB

To execute an either qualitative or quantitative FTA, the following steps should be executed. Similarities to the FMEA can be seen, which is why both methods are compatible to each other and thus can be integrated into the other.

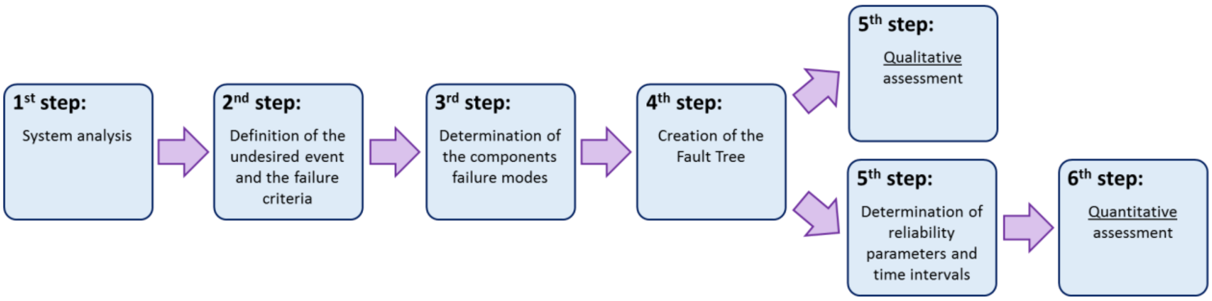


Figure 3-19 : Steps to perform a qualitative/quantitative FTA, after [52]

3.5.1 FTA of the FGClite

With the first three steps of an FTA being already performed during the *MTTF* prediction and FMEA, and the mentioned compatibility to the FMEA, it was straight-forward to create the fault tree. From the FMEA module, the converting facility of RWB was used to create a first version of the tree which already included a large amount of data. Part of this were six top events as the former six end effects. The one branch of «no effect», which was obviously not presenting a fault state, got deleted leaving five remaining top events, compare table 3-9. Additionally, the conversion included a quantitative assignment which was only possible on the basis of having the extra failure mode apportionments integrated to the FMEA, since otherwise it would be necessary to perform the lower 5th step of figure 3-19. With this comprehensive basis, the FTA was only modified in two ways. On the one hand, redundancies were integrated by changing the by default converted OR-gates to AND-gates, and on the other hand the illustrated hierarchy in figure 3-20 was integrated. This means that it is distinguished between failures of a PCB and the interfaces in the form of connectors between them on different levels of significance. The significance is not particularly represented in the tree model, however regarding all failure modes and effects of each pin (pin hole) for all inter-board connectors and the backplane connectors (960 in total) more detailed and separately, does result into an enhanced model for these parts. It can be compared to a more and more narrowing bottle increasing the importance of dependability up to the FGClite's «bottleneck» represented by the backplane connectors where every controller signal is transferred. It is certainly fundamental to mention that a single component failure can still cause the worst case event, however regarded as total unit of components an average failure is of less significance.

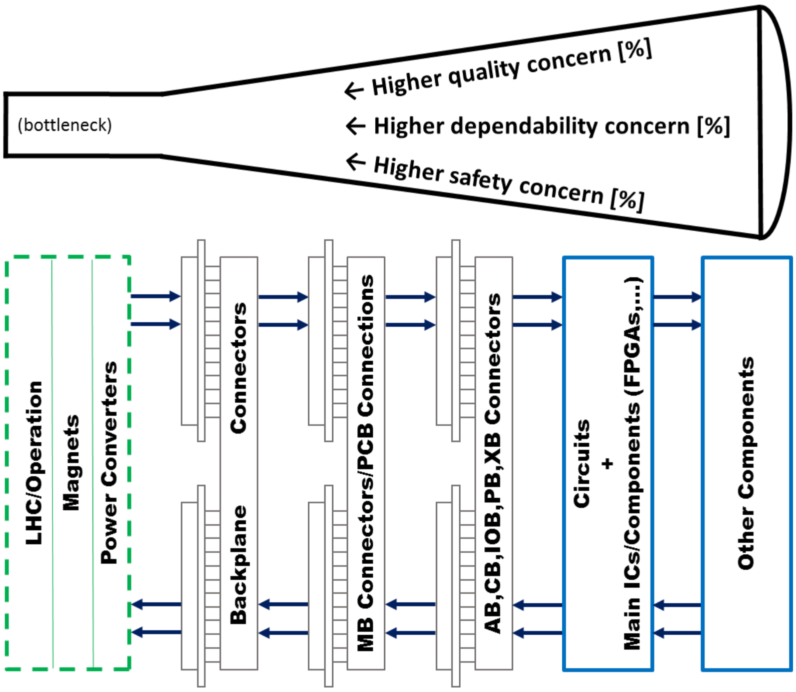


Figure 3-20 : Bottleneck illustration of the FGClite functional chain

This all retroactive strongly justifies the decision to improve the connector quality and to use pin redundancies. However concerning this the FTA also revealed that for some failure modes pseudo pin redundancies do exist. This is for instance the case when a «redundant» power pin fails in a short circuit which destroys the FGClite and leads to a false beam dump. For example, there are three PB connector pins for a voltage of 1.5 V which therefore have no redundancy for this failure mode. On the contrary, if one fails for example with an open connection, the remaining pins (triple redundancy) are still functional and provide the power. No upper effect will occur which is the reason that redundancy exists. All such cases are accordingly integrated to the RWB model (compare figure 3-22).

The after all finalised fault tree model consists of 1 067 gates with 3 737 inputs on different levels and 2 671 primary events. Figure 3-21 illustrates the graphical extent of the model which includes all five top events.

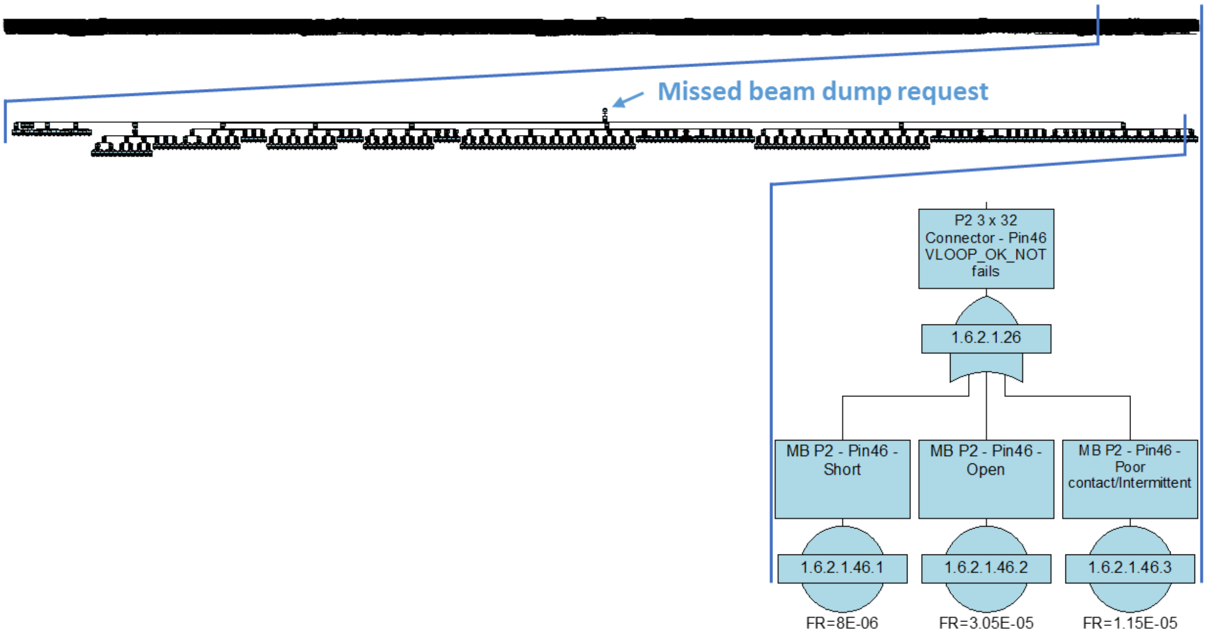


Figure 3-21 : Complete fault tree with five top event branches

3.5.2 Results of the FTA

Regarding again the massive extent of the FTA and the amount of similar data to the FMEA, this work is not including a report of the analysis. This chapter only presents the main results whereas for supplementary data the RWB file needs to be consulted (EDMS server [41]). Representatively for all the content, the smallest top event branch which is actually of high importance for the generated results is shown in figure 3-22. To be able to compress it onto one page all transfer gates which are shown contain collapsed data on a hidden page and only a few are expanded until the initial event.

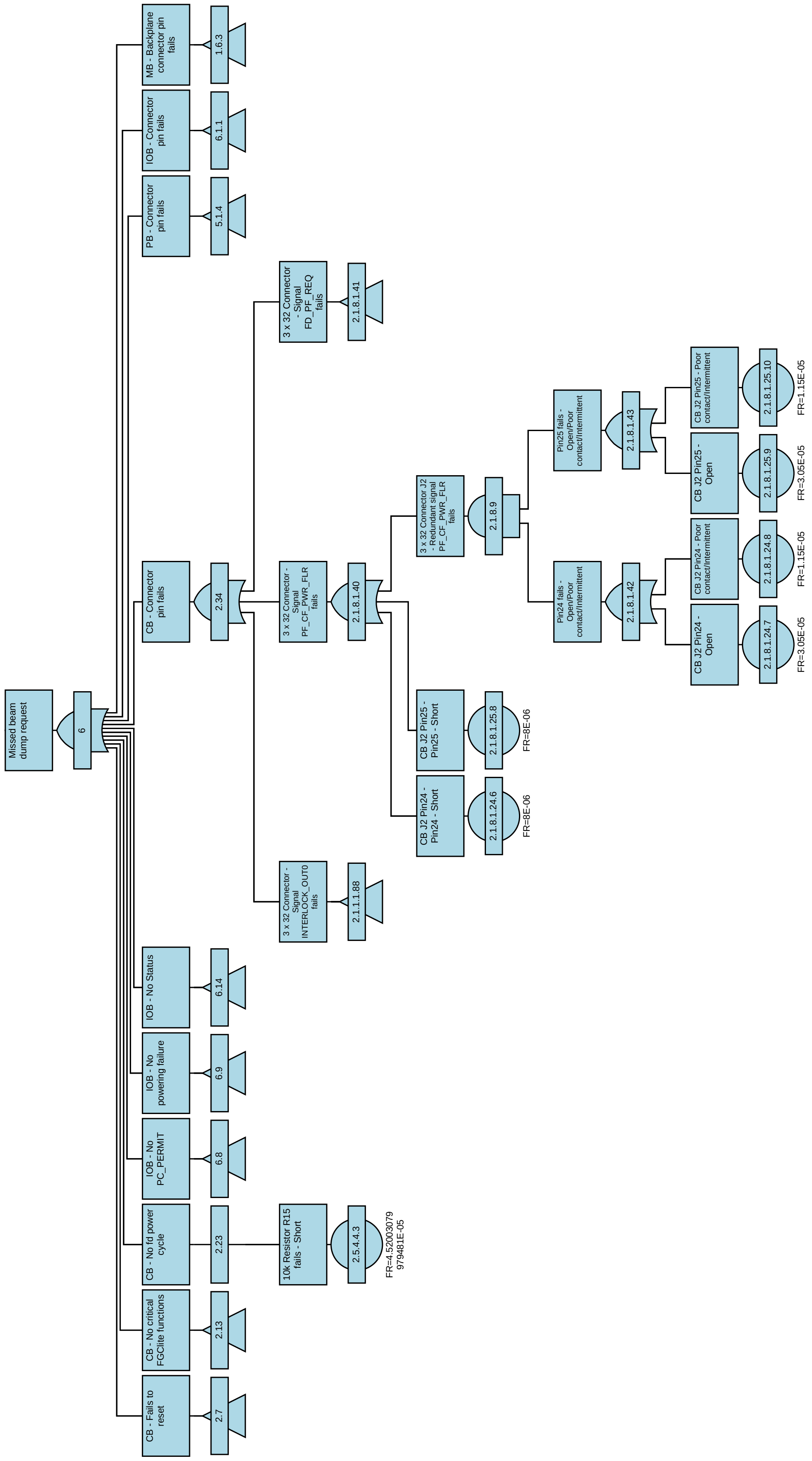


Figure 3-22 : Extract of the fault tree top event «Missed beam dump request»

It can be seen that ten different fault events on the next lower level can cause this top event of the highest severity. To present additional information, 270 failure modes of in total 51 different components, whereas 52 pins out of six FGClite connectors can result into a missed beam dump request. Out of those it is not necessarily the case for 70 redundant failure modes and 34 either fully or partial redundant pins. For the other bigger branches such statistics are not provided because the results would be of minor interest compared to the amount of work. Unfortunately, the RWB software, or rather the methodology of integrating the data into the model does not allow to exclude this data in a non-manual way.

As the above shows, in some manners such system analyses reach their limits when trying to interpret each part in detail and on top the correlations between parts without any systematic aid. The integration into RWB and the gained computing power therefore helped a lot which led to the possibility of predicting an availability, as well as many other parameters, of the FGClite and the different top events. Adding up to chapter 3.1.2 the term of availability needs to be defined at this point:

> *« Availability [A(t)] is the probability that a system is in a functional condition at the time t or during a defined time span, under the condition that it is operated and maintained correctly »* [24, 53]

For this definition RWB computed the inverse unavailability *Q(t)* for every branch of the fault tree by taking the assigned local failure rates. This was executed again under the assumption that the result is only valid for the second part of the bathtub curve which excludes a repair work of the maintenance term in the above definition. Only full replacements after a failure of the module are considered for maintenance. Accordingly the following relations were used (p.146,147 [54]):

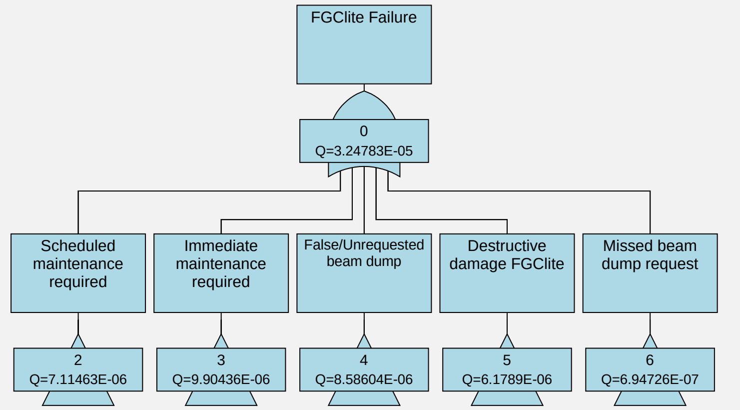
$$A(t) + Q(t) = 1 \tag{3.23}$$

$$Q(t) = F(t) = 1 - e^{-\lambda t} \tag{3.24}$$

The main availability results are summarized in the following table together with the output of an RWB analysis for four different regarded periods of time. To calculate the overall availability for several modules in the lower half of the table the following equation was used for a number of *n* components in series (p. 259 [55]):

$$A_s(t) = \prod_{i=1}^{n} A_i(t) \tag{3.25}$$

Table 3-9 : FTA availability results for the FGClite



t_1 = 10 h fill

t_2 = 2x10 h fill (1 LHC day)

t_3 = 168 h (1 week)

t_4 = 5340 h (2016 scheduled LHC year)

* No effect failures are excluded

		$A(t_1)$ [%]	$A(t_2)$ [%]	$A(t_3)$ [%]	$A(t_4)$ [%]
FGClite operation (1 unit):	- without any technical fault*	99.99675	99.99350	99.94541	98.28059
	- without scheduled maintenance case	99.99929	99.99858	99.98805	99.62080
	- without immediate maintenance case	99.99901	99.99802	99.98336	99.47250
	- without false/unrequested beam dump	99.99914	99.99828	99.98558	99.54255
	- without destructive damage FGClite	99.99938	99.99876	99.98962	99.67059
	- without missed beam dump request	99.99993	99.99986	99.99883	99.96291
	- without a beam dump	99.99845	99.99691	99.97403	99.17785
	- without interruption of the LHC schedule	99.99746	99.99493	99.95740	98.65469
FGClite operation (1094 units):	- without any technical fault*	96.50920	93.14028	55.02286	0.00000
	- without scheduled maintenance case	99.22468	98.45537	87.74269	1.56647
	- without immediate maintenance case	98.92231	97.85623	83.35723	0.30699
	- without false/unrequested beam dump	99.06508	98.13890	85.40168	0.66314
	- without destructive damage FGClite	99.32631	98.65716	89.26479	2.70601
	- without missed beam dump request	99.92403	99.84811	98.73127	66.64059
	- without a beam dump	98.32293	96.67399	75.26638	0.01196
	- without interruption of the LHC schedule	97.26331	94.60152	62.73995	0.00004

The availability $A(t_1)$ for the shown 10-hour-fill is in many ways the most important availability value. It reflects the probability that during this time the FGClite will not cause any failure. From this column the lowest two cells represent valuable data for the simultaneous operation of all controllers which will be installed in the LHC. In words this means that a 10-hour-fill will be completed without any beam dump caused by the FGClite with a probability of 98.32 %, and that with a probability of 97.26 % there will be no interruption of the LHC schedule, omitting a scheduled maintenance event for this case. The second column represents the probability for a successful day of operation, where usually two LHC fills are planned. The third column gives additional information for a hypothetic whole week of constant operation and the fourth column displaying $A(t_4)$ is computed for an estimate value of an average LHC operational year. Even though this average year effectively does not yet exist with the young operational history of the LHC, disturbed by many interruptions, a time of 5 340 hours (267 days) has been taken using data of the planned LHC schedule 2016 [56]. This time only excludes days of a technical stop and assumes the execution of two 10-hour-fills per operational day. The actual time should be much lower and thus the availability values of this column better. In regards to a safe operation, even for this long period and 1 094 operational units, a missed beam dump request will not appear with a probability of 66.64 %.

By reversely computing the *MTTF* from the FTA unavailability results, applying the equations (3.24) and (3.7), a value of **308k** hours results. This value uses $A(t_1)$ from the table above, respectively $Q(t_1)$. As in the FMEA, this excludes failure modes, which lead to no effect, and additionally considers the integrated redundancies from the FTA, as well as assigns a failure rate of zero to non-used pins of the PCB connectors. In the FMEA, the failure rate of these pins was taken as a whole connector failure rate. Compared to the FMEA, this additional model accuracy adds 6 700 hours onto the FMEA *MTTF* of exactly 301.3k hours. This is equal to more than 2 % of improvement.

4 Reliability Comparison with the FGC2 and Investigation of Failure Data

This chapter presents a powerful addition to the FGClite reliability analysis following the MIL-STD which predictively analyses a design without having real operational experience of the specific system. Having such data available for the FGC2 predecessor module, the following shows an analysis of this information and integrates it into the previous results. In addition to the later reliability evaluation, first design differences to the FGClite and a retroactive *MTTF* prediction is presented for the FGC2.

It is important to mention, that the following results do not rely completely on a standard anymore and should be regarded separately to the previous chapter. In many ways this chapter must be seen detached from the above as a distinct second part of this work. Depending on the intended purpose, these results should be handled separately.

4.1 FGC2 Design Differences to the FGClite

As described in the second chapter, the reason for developing the FGClite was that radiation performance of the FGC2 exhibited weaknesses, which would be critical for the upcoming LHC availability at higher beam energies. Aside from that, the FGC2 is a well-designed and reliable converter controller. Thus, the main goal of the new development was to simplify the FGC2, by moving microcontrollers and their digital signal processing away from the module to the gateway, performing radiation testing for the used electronic components chosen and qualifying their use to provide highly available gateway/FGClite communications [57]. The main differences are: The FGC2 consists of two microcontrollers, one Digital Signal Processor (DSP), 18 various memories and 13 Programmable Logic Devices (PLD). The FGClite in contrast only uses four PLDs (FPGAs) and two memories (SRAMs) within these component categories, compare figure 4-1. As for total components used, the FGC2 consists of only 837 while the FGClite uses 1 009 components (Listed BoM-data). Other differences are not covered by this work and the following analysis, but might promise valuable outcomes when dealing with them, especially after operational data of the FGClite will be available. Despite the difference, from the system architecture stand point, the FGClite is very much like the FGC2 implementing all the same electronic functionalities.

4.2 FGC2 Prediction

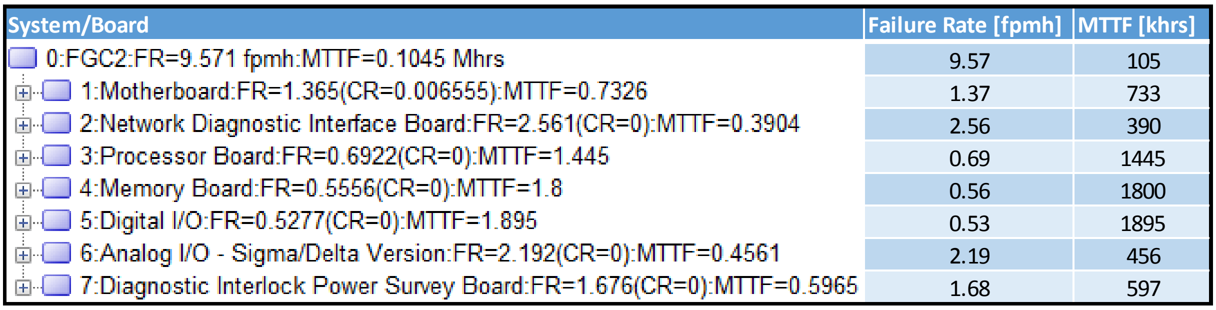
Following the exact same methodology as for the *MTTF* prediction of the FGClite presented in chapter 3.1.3, a prediction for the FGC2 was as well prepared in RWB. The finished model of the FGC2 resulted into the following predicted *MTTF* value under the below presented assumptions:

$$\mathbf{MTTF_{FGC2} \geq 104\ 483\ hours}$$

Just as for the FGClite, the same integrated driver circuit «SSSB231» is mounted in the FGC2, which is why equally a failure rate of zero was assigned. In addition for the two used optocouplers «TLP124» by the Toshiba Corporation no reliability data could be found, which is why the failure rate of the FGClite optocoupler «HCNR200-300E» was assigned. These measures exclude any effect such different devices could cause from the comparison.

For the seven different FGC2-boards, the concerning failure rates are shortly presented in the following table. An inclusion of a prediction report as for the FGClite is not part of this work. To access additional information the RWB files need to be accessed (EDMS server [41]).

Table 4-1 : Predicted failure rate of the FGC2 and its boards



System/Board	Failure Rate [fpmh]	MTTF [khrs]
0:FGC2:FR=9.571 fpmh:MTTF=0.1045 Mhrs	9.57	105
1:Motherboard:FR=1.365(CR=0.006555):MTTF=0.7326	1.37	733
2:Network Diagnostic Interface Board:FR=2.561(CR=0):MTTF=0.3904	2.56	390
3:Processor Board:FR=0.6922(CR=0):MTTF=1.445	0.69	1445
4:Memory Board:FR=0.5556(CR=0):MTTF=1.8	0.56	1800
5:Digital I/O:FR=0.5277(CR=0):MTTF=1.895	0.53	1895
6:Analog I/O - Sigma/Delta Version:FR=2.192(CR=0):MTTF=0.4561	2.19	456
7:Diagnostic Interlock Power Survey Board:FR=1.676(CR=0):MTTF=0.5965	1.68	597

An analysis of the sub-schematic is as well mostly neglected in this work, however it is part of the RWB model. As for additional information in relation to chapter 4.1 as well as for the following comparison, an illustration of the failure rates for the mentioned different components is presented in figure 4-1. It can be seen that for these device categories the controller reliability increased a lot. For the used FPGAs, this can easily be seen which can also reflect an improvement in technology. It needs to be added that both FGClite SRAMs are used for either radiation performance or radiation recording, which is why electrical reliability needed to play a minor role for selecting them [58].

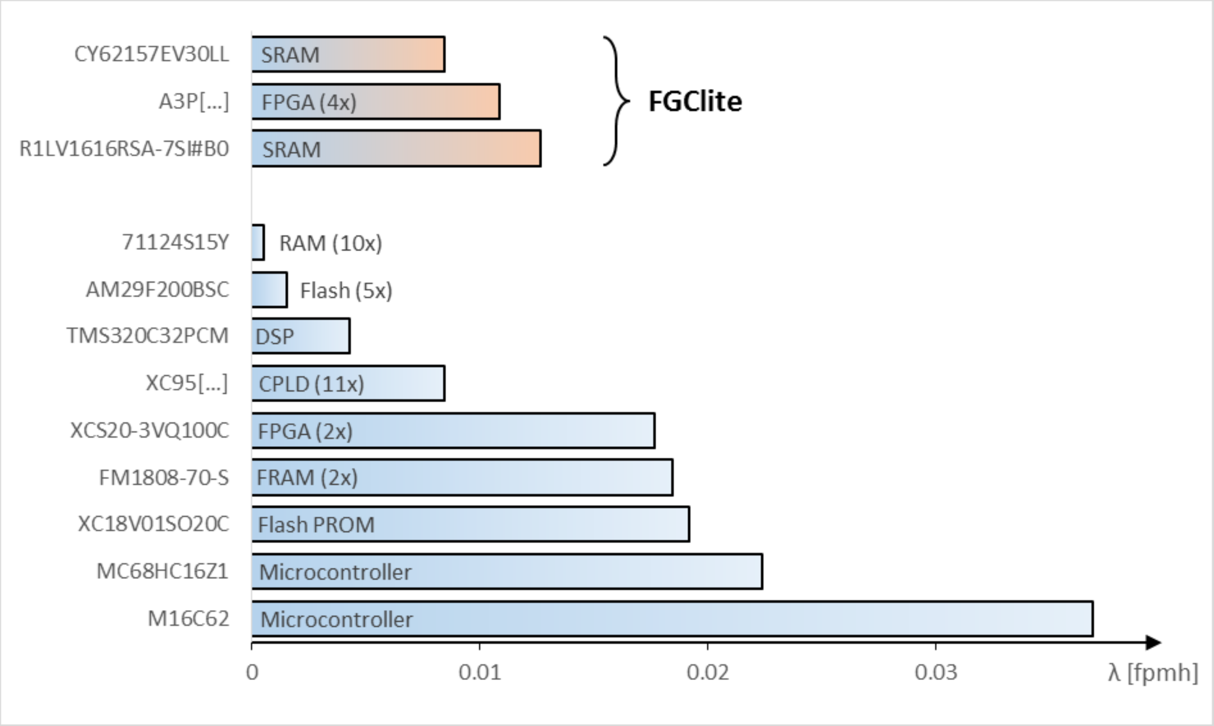


Figure 4-1 : Failure rates for memories and logic devices of the FGClite and FGC2

4.3 FGC2 Operational MTBF

To derive to the operational failure rate of the FGC2, this chapter presents and analyses the repair respectively failure data of all FGC2s in operation and specifies their runtime in the LHC. This makes it possible to assess the particular failure rate of the module broken down to the operation time. Of course also the failure rate for the whole lifetime is presented.

4.3.1 Runtime

To get the time during which the FGC2 was in operation in the LHC, the Accelerator Fault Tracking (AFT) system of CERN [59] was consulted. This tool provides failure as well as additional data of LHC systems from the year 2010 on, which is sufficient for this failure rate assessment. Even though the LHC first started its operation in September 2008, it needed to shut down until 2010 as a result of a magnet quench on the 19th September 2008 [60]. To exclude the required runtime data from the AFT, its cardiogram was used where an availability of the displayed beam energy was set equal to a powered FGC2, see figure 4-2 in green. Whenever the energy went down to 0 TeV for a day or longer, this time was subtracted from the yearly runtime.

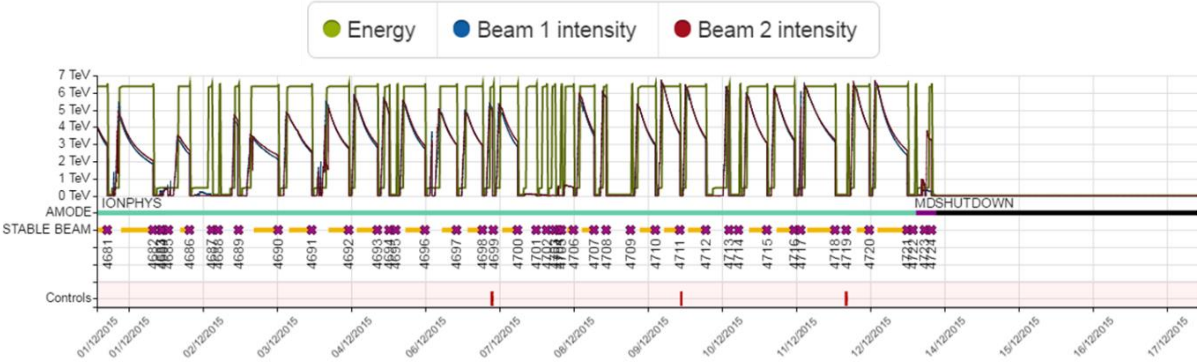


Figure 4-2 : Extract of the AFT Cardiogram

It cannot be guaranteed that this approach of taking data completely represents the runtime of the FGC2, but it closely reflects the actual use of the controller. Unfortunately, exact sources do not exist. The extracted runtime data is shown in table 4-2 with in total 1 347 days of operation in the regarded timeframe. The low numbers of operational days in 2013 and 2014 are a reason of the so-called «1st Long Shutdown», where the LHC operation stopped for maintenance and consolidation.

Table 4-2 : FGC2 Runtime data from 2010 until February 2016

Year	Operational days	Source
2010	290	AFT
2011	264	AFT
2012	265	AFT
2013	38	AFT
2014	169	AFT
2015	309	AFT
≤ 10/02/2016	12	AFT
	Total: **1347**	

4.3.2 Failure Data from Repairs

To receive failure data of the FGC2 during operation in the above timeframe, the CERN intern «TE-EPC Database» [61] of the Electric Power Converter group was used. This extremely comprehensive and helpful data source logs all operational failures or issues of power converting systems at CERN that are under the supervision of this group. In this massive amount of data, it was unfortunately not possible to exclude directly the logbook data for all FGC2 failures in the LHC. Nevertheless, another database of the tool contains repair data for the power converter modules which can be used alternatively.

A point of criticism for taking this repair data directly as failure data can be that the reparation date is not representing the date of failure. However, for the regarded long timeframe of over six years with a restart of the operation in 2010 only failures occurring towards the beginning of 2016 can be missed, if any. This would only marginally influence the following results and justifies the use of this data herein.

Repair Data

To exclude the repairs, the database was searched for each part number of the FGC2 module itself and the containing PCBs. This allowed to gather all repairs, because not always the concerning barcode was scanned for the specific repaired board. In the following several repair entries for different non-electrical issues were supressed, which led to a table shown in the appendix. Such entries are for example software problems as a cause of failure, or repair checks of an actually fully functional unit. In addition for every failed FGC2 the installing region was checked, which was for all the LHC. In the end, the table only contains hardware repairs or equally electrical failures with in total 42 repairs performed between 2010 and February 2016. The following tables summarize the results.

Table 4-3 : FGC2 failure statistics and failure distribution from 2010 until February 2016

Designation	Barcodes	Failures
FGC2 Generic Cassette	HCRFMBA___[...]	17
FGC2 COD Cassette	HCRFMCA___[...]	14
FGC2 SAR-400 Board	HCRFBGA___[...]	5
FGC2 SD-350 Board	HCRFBFA___[...]	3
FGC2 NDI-150A Board	HCRFBBB___[...]	2
FGC2 MEM-250 Board	HCRFBDA___[...]	1
		42

Fault	Occurrence	Fault	Occurrence
PLD (Xilinx)	2 (+10)	Via	2
Resistor	3	DAC	1
Transistor	3	Diode	1
ADC	2	OpAmp	1
Connection	2	Pushbutton	1
RAM	2	PCB (general)	4
Solder	2	Other	5

The appended table contains genuine data of the database. Because not always all columns were filled, an additional column was added to be able to complete the fault statistics.

Repair Data Analysis

This work does only include a short analysis of the FGC2 failures, especially in connection to the *MTTF* results of each component after the MIL-HDBK 217F or accelerated lifetime testing results. At this point, some notable facts, but for the whole previous as well as following work important determinations, are listed. The list was prepared without any claim of comprehensiveness.

Table 4-4 : Notable points of the repair data analysis

Item	Description
Transistors/ Diodes	For different transistors low predicted failure rates of manufacturer HTOL testing (> 2 FIT) are not matching the three occurred failures. With a failure rate proportion of only 0.1 % of the entire FGC2 failure rate the total of ten transistors should only cause 0.04 failures out of the 42 which occurred. In contrary, for all used diodes with failure rates of up to 59 FIT (ESD protection diode), the single occurred fault is really closely matching the prediction.

PLDs	The twelve PLD failures, especially the ten of the Xilinx CPLD strongly justify the decision to move out such components from the FGC also from the electrical reliability point of view by only regarding the black box of the controller. Nevertheless, or rather especially, attention needs to be paid for the four remaining FPGAs of the FGClite. Also here the observed failure rate is much higher than the predicted. This could partly be explained by the big amount of pins these ICs have which can lead to connection/solder failures. These failures are not necessarily component failures but could have been registered as such during the reparation. In RWB the Connection Rate of chapter 3.2.1 tries to cover this.
Connection Rate	The CR should cover the two via and two solder failures, however comparing the RWB data to 42 failures in total, only 0.5 should be of such failures.
Several Components	With certain deviations the resistor, ADC, connector, RAM, DAC, OpAmp and pushbutton failures reflect the prediction results with each having rather high predicted failure rates or a large used number. • For connectors this justifies the decision to improve their quality in the FGClite • For the DAC it is an indicator to take special care about the used FGClite DAC (other than FGC2) with the fourth highest predicted component failure rate • For pushbuttons with a really high failure rate the profit of an FMEA can be highlighted, because only a manual reset was the effect of the failure (see appended table)
Capacitors	For the really high predicted failure rate of capacitors, it is conspicuous, that no failures occurred, except one during the run-in of the FGC2 (accessible in the database). A very likely explanation is that for the investigation and logging procedure of failures for the TE-EPC Database, capacitor failures are not detected as such. For example, an open filtering capacitor can lead to an unfiltered signal towards an IC which causes a failure there or only gets detected at this place and not further investigated. Similarly a short capacitor can lead to a destruction of another component which is recorded instead and a change of capacitance cannot be detected, unless special procedures are implemented.
Other	A last point aside of all military calculations are the two logged repairs in the appended table on the 04.03.2010 and 28.08.2013. One was a mill chip on a CPLD and the other was simply a too small diameter of a drilled hole in the case. These failures affect the operation and are part of all statistics as well as the following analysis, but not considered in any analysis executed above. In future analyses, it can be considered in the FMEA or as an additional global factor in the prediction, however it is nearly impossible to accurately predict their occurring probability and to capture their wide variety. When executing a maintenance strategy such experiences are of great support.

For the transistors and PLDs, being the only categories which performed worse than predicted, an explanation can be, as used for the capacitor data. For instant, capacitor failures which were not discovered as such could have led to the PLD or transistor failures. Especially for PLDs with many capacitors used in their periphery, this explanation can be realistic. To confirm this, further studies should be performed.

4.3.3 MTBF

To calculate the operational electrical *MTBF* of a single FGC2 with the above data, the number of devices is needed, which also got excluded from the TE-EPC Database and resulted into 1 744 installed units in March 2016. This makes it possible to calculate the MTBF like the following:

$$MTBF_{FGC2,op} = \frac{No.\ of\ Units * t_{op}}{No.\ of\ Failures} = \frac{1744 * 1347d}{42} = 55\,933\ d \qquad (4.1)$$

In hours this *MTBF* would mean 1 342 392 hours, however taking only the time of two 10-hour-fills per day, the *MTBF* is 1 118 660 hours. Even though the execution of two completed LHC missions per day is not at all realistic, the 55 933 days represent exactly the reality of the operational days. This will most probably be the same in the future. On top, it is necessary to mention, that this *MTBF* does not include any aging effects which happen when the FGC2 is unpowered, especially during the period of the 1st Long Shutdown. The complete *MTBF* from September 2008 on is approximately 2.7M hours. This uses a time of 2 700 days of 24 hours but is not of big interest for this work.

To calculate the associated failure rate equation (3.7) can be used when replacing the *MTTF* by the *MBTF*. This is only possible under the assumption that in the regarded timeframe no second failure occurred for repaired and reinstalled units. For one component, this was unfortunately the case, but ignoring this fact for the failure rate calculation can only deteriorate the rate which in this case would put an extra small safety value on the results of the following. Therefore, the following equation is completely valid in the framework of this work.

$$\lambda_{FGC2,op}(t) = \frac{1}{MTBF_{FGC2,op}} = 1.79 * 10^{-5}\ \frac{Failures}{d} \qquad (4.2)$$

4.4 Operational MTBF in Comparison to the MTTF Predictions

In the above two chapters a predicted *MTTF* as well as an *MTBF* of real operation was presented which can be set equal to an *MTTF* with the considerations made for equation (4.2). Under this assumption, this chapter tries to combine the results of the two *MTTF* predictions with the *MTBF* data to give a more exact estimation for the future electrical performance of the FGClite. This could be considered as the evaluation of how conservative the prediction methodology is compared to the operations of the system.

Firstly, a closer look at the FGC2 results is necessary as it is where both values are available. The *MTBF* for 20 hours of operation per day is more than ten times better than the predicted *MTTF*. This massive difference can and needs to be explained in the following three ways:

1) The average real operational time per day was definitely lower than 20 hours but cannot be specified. This would lead to a lower *MTBF* for this consideration.

2) The last update of the MIL-HDBK 217F took place in the year 1995. Therefore, the difference also reflects the improvement in the quality of components and technology since then. To mention again this does not necessarily mean that the used approaches and formulas of the handbook to derive to a failure rate are obsolete.

3) Safety margins are used by the MIL-HDBK 217F calculations as well as by manufacturers which provided lifetime data. Therefore, the predicted *MTTF* only represents the minimum most pessimistic value.

4) During the *MTTF* prediction as well as the other analyses, a conservative approach was favored. This included maximum estimations of operation time, ambient temperature, applied voltages, or dissipated power. Therefore, also for this point, the predicted *MTTF* only represents the minimum most pessimistic value.

Looking now at the two predicted *MTTF*s the FGClite has a value which is 1.9 times higher than the one of the FGC2. This means the predicted reliability is roughly twice as good.

Taking this further, the factor can be applied on the operational data of the FGC2 by hypothetically assuming that the operation of the FGClite will proceed similar to the FGC2 and that design differences do not influence the electrical reliability. At this point, it is neither possible anymore to rely on any standard, nor to produce precise numbers nor to make a statement that the following results definitely match the reality. Nevertheless, the following data can certainly give a direction of the reliability progression between the FGC2 and FGClite for the topics dealt within this work and is also of high value for future reliable designs and especially analyses executed after the MIL-STD. Using equation 4.2 this would mean for a normal day of operation an extrapolated failure rate for 1 094 installed FGClites of:

$$\lambda(t) = \lambda_{FGC2,op}(t) * \frac{1}{1.9} = 9.42 * 10^{-6} \ \frac{Failures}{d} \tag{4.3}$$

To give a final prediction for the future electrical reliability performance of the FGClite, in context to this comparison it is favourable to exclude the component improvements mentioned in table 3-3 of the predicted *MTTF*. In terms of reproducibility it puts an additional safety margin on the value and sets the two *MTTF* predictions on a more identical level, because no design analysis to improve the reliability of the FGC2 was executed. In addition, it takes potential effects of the design differences in chapter 4.1 into consideration. This leads to a predicted FGClite *MTTF* of 121 265 hours and therefore a derating factor of 1.16 instead of 1.9, resulting into a modified equation for the above (4.3):

$$\lambda(t) = \lambda_{FGC2,op}(t) * \frac{1}{1.16} = 1.54 * 10^{-5} \ \frac{Failures}{d} \tag{4.4}$$

This is equal to the following *MTTF* for two 10-hour-fills per day and would also mean the following number of electrical failures per normal scheduled year of operation for 1 094 controllers:

$$\mathbf{MTTF_{FGClite,\ comparison} \geq 1\,296\,089\ hours}$$

$$\mathbf{\lambda_{FGClite,\ comparison} \leq 4.5\ failures/year}$$

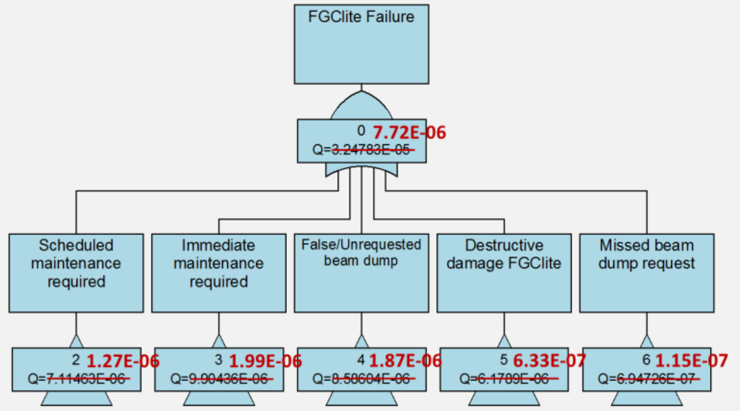
With roughly 1.3 million hours for realistic operation conditions (20-hour-day), this *MTTF* prediction as a result of the comparison, which needs to be seen separated to a MIL-STD prediction, exceeds the requirement of 950k hours (24-hour-day) from chapter 3.2.2. Also for extrapolating to a 24-hour-day the requirement is met. The result also relativizes the predicted *MTTF* result after the MIL-STD of chapter 3.3.3 which is marginally lower than the set requirement of 200k hours. Expressing the *MTTF* in operational days as in (4.1), it is equal to 64 800 days.

4.5 Conclusion and Revised Results of the FTA

Thus, a positive recommendation based on the presented analyses can be given for the future operational reliability of the FGClite. The minimum requirement of **200k** hours of *MTTF* is met within the specified *MTTF* of more than **300k** hours following the FMEA and FTA, revealing failures and failure modes which do not affect the reliability. By extrapolating from the FGC2 prediction and failure data, the target of maximum **10** electrical induced failures per year is also met for the FGClite. For this estimation, a safety factor of higher than 2 resulted from the comparison.

In addition, the presented results for the predicted availability of the FGClite(s) in table 3-9 can be adapted to the *MTTF* of roughly 1.3 million hours as a result of the comparison. For this uprated *MTTF* a $Q(t_1)$ of 7.72E-06, equal to an $A(t_1)$ of 99.992 %, results by applying the equation (3.24) in combination with (3.7). To generate the other cell values this unavailability was taken and combined with the ratio of each specific cell and $Q(t_1)$ (3.25E-05) of table 3-9. To present the above given examples, this means that for this estimation a 10-hour-fill will be completed without any beam dump caused by the FGClite with a probability of 99.71 %, and that with a probability of 99.50 % there will be no interruption of the LHC schedule. During a whole scheduled year like 2016, a missed beam dump request will not appear with a probability of 93.49 %. At this point it is mentioned again that this table can only be seen as an estimation, based on hypothetically assuming that the operation of the FGClite will proceed similar to the FGC2 and that design differences between the controllers do not influence the electrical reliability.

Table 4-5 : Rescaled availability results for the comparison



t_1 = 10 h fill
t_2 = 2x10 h fill (1 LHC day)
t_3 = 168 h (1 week)
t_4 = 5340 h (2016 scheduled LHC year)

* No effect failures are excluded

		A(t_1) [%]	A(t_2) [%]	A(t_3) [%]	A(t_4) [%]
FGClite operation (1 unit):	- without any technical fault*	99.99923	99.99883	99.99013	99.68837
	- without scheduled maintenance case	99.99987	99.99975	99.99786	99.93222
	- without immediate maintenance case	99.99980	99.99960	99.99666	99.89403
	- without false/unrequested beam dump	99.99981	99.99963	99.99686	99.90055
	- without destructive damage FGClite	99.99994	99.99987	99.99894	99.96623
	- without missed beam dump request	99.99999	99.99998	99.99981	99.99384
	- without a beam dump	99.99974	99.99948	99.99561	99.86080
	- without interruption of the LHC schedule	99.99954	99.99908	99.99227	99.75545
FGClite operation (1094 units):	- without any technical fault*	99.15947	98.72292	89.76717	3.28897
	- without scheduled maintenance case	99.86104	99.72227	97.69093	47.62671
	- without immediate maintenance case	99.78265	99.56577	96.41073	31.35051
	- without false/unrequested beam dump	99.79604	99.59249	96.62822	33.67069
	- without destructive damage FGClite	99.93079	99.86163	98.84368	69.10855
	- without missed beam dump request	99.98739	99.97478	99.78831	93.48658
	- without a beam dump	99.71439	99.42960	95.30883	21.78566
	- without interruption of the LHC schedule	99.49766	98.99786	91.88841	6.86540

5 Conclusion and Outlook

Conclusion

After performing a comprehensive reliability analysis, structured in four main parts, a positive feedback concerning the reliability of the FGClite design can be given. Within the first three analyses, an *MTTF* prediction, an FMEA and an FTA, either no big reliability influencing design weakness revealed, or if, it got corrected to enhance the design. For these reasons, the in the future operating FGClite is looking towards a well reliable performance after the definitions and requirements presented in chapter 3.2. Adding up to all this a failure data analysis of the predecessor module generated additional valuable information and evidence for the prior results.

More in detail, the fulfilled different requirements are first represented by a predicted *MTTF* of roughly 200k hours after the MIL-STD. This pessimistically predicted value got improved by a more comprehensive analysis within the FMEA, which revealed amongst many other outcomes that 36 % of all potential component failure modes have no effect on the required performance. This increased the *MTTF* to specific 300k hours. Furthermore developing a custom risk matrix on the basis of the *RPN*, the FMEA offered the possibility to rank the risk of each failure mode. This is equal to a ranking which represents the workflow to start improvements in terms of increasing the design reliability. In the following FTA, the FMEA results were taken, revised and implemented in Boolean logic gates of a fault tree with five top event gates or branches, equal to five end effects of the FMEA. On one hand this further specified the *MTTF*, and on the other led to the possibility of presenting the availabilities of all installed FGClites for different operation periods, as well as for different failure tolerances. Closing up with the analysis of operational data of the former FGC2 showed, that this in many ways more complicated controller has a much better *MTBF* than its predicted *MTTF* which got computed after the exact same methodology which was used for the FGClite. In the framework of a comparison, this allowed to determine a deration factor to adapt onto the FGClite results and led to a predicted *MTTF* of more than one million hours. Equal to less than five controller failures per usual operational year of the LHC this prediction is on the one hand of tremendous amount because it takes real data of a very similar system into account. On the other hand such a prediction unfortunately cannot fully rely on the earlier used standards anymore.

Outlook

For the soon upcoming installation of the FGClite, the design is already frozen for any change. Unless the final prototype testing or the reception and burn-in testing reveal significant weaknesses, the FGClite is planned to be deployed in the LHC tunnel in February 2017. The developed burn-in testing strategy has been outside the scope of this work but was developed in parallel to this analysis. In the near future an investigation into the results of the burn-in testing could confirm the reliability prediction, thus improving the results of the failure data analysis. To perform this, and other future tasks within the FGClite project and reliability engineering, the cooperation with the IMA of the University of Stuttgart is planned to be carried on. Such tasks should definitely include the continuation of the FGC2 analysis. More in detail those tasks, as well as others on a broader scope, are:

- Preparation of an FMEA and an FTA for the FGC2 to emphasize, as well as to investigate, the differences, and especially, their particular effects on the system
- Extension of the FGC2 failure data analysis in terms of total component numbers and changes in comparison to the FGClite
- Analysis of the burn-in testing and of the operational performance to determine the failure rate, its constant progression or increase
- Inclusion of predicted reliability results of the FGClite radiation testing [1]
- Inclusion of external factors like the reliability of software, powering or communication into the model

In a broader view, the methodology presented in this thesis could be used as a constantly edited and improved standard at CERN to enhance the reliability of electronic systems during the design process and later determine their reliability in the installed system. On an even bigger scope, the reliability and availability of the LHC, or even the whole accelerator chain, can be exactly determined as soon as all systems are analysed, which should also include the software architecture(s). Latest at this point, the RWB software of Isograph becomes an essential tool to execute and connect everything. As a second outcome, the available data can be combined with operational data to enhance and update the MIL-HDBK 217F and especially create a more exact custom approach for CERN systems, with specific CERN data. This could also integrate the efforts done by the R2E group to determine the influence of radiation on the reliability of electronic systems.

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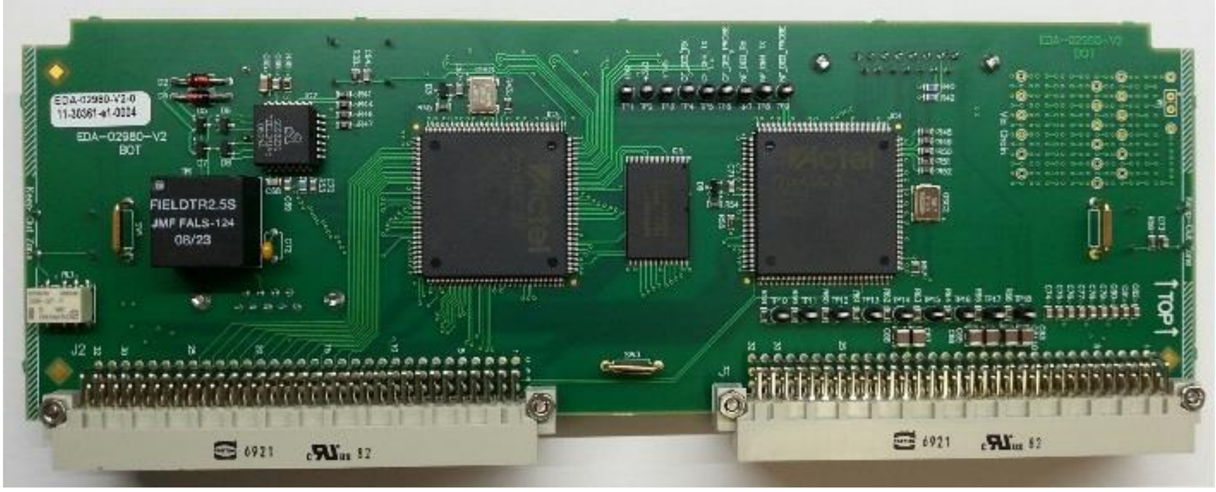
2.2 The FGClite Development and its Strategy

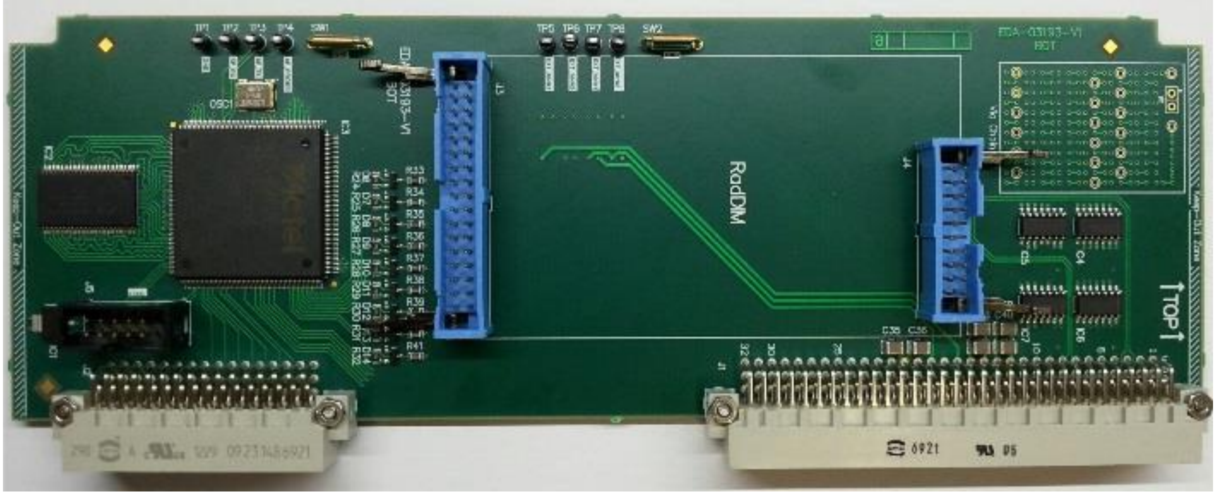
- **Board Pictures:**

FGClite Main Board (MB):

FGClite Communications Board (CB):

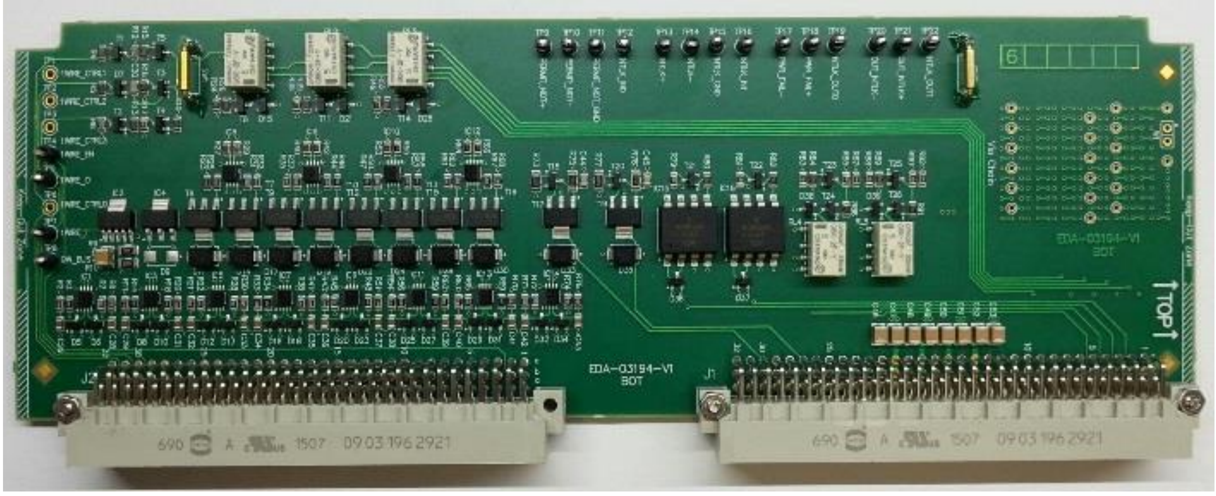


FGClite Auxiliary Board (XB):

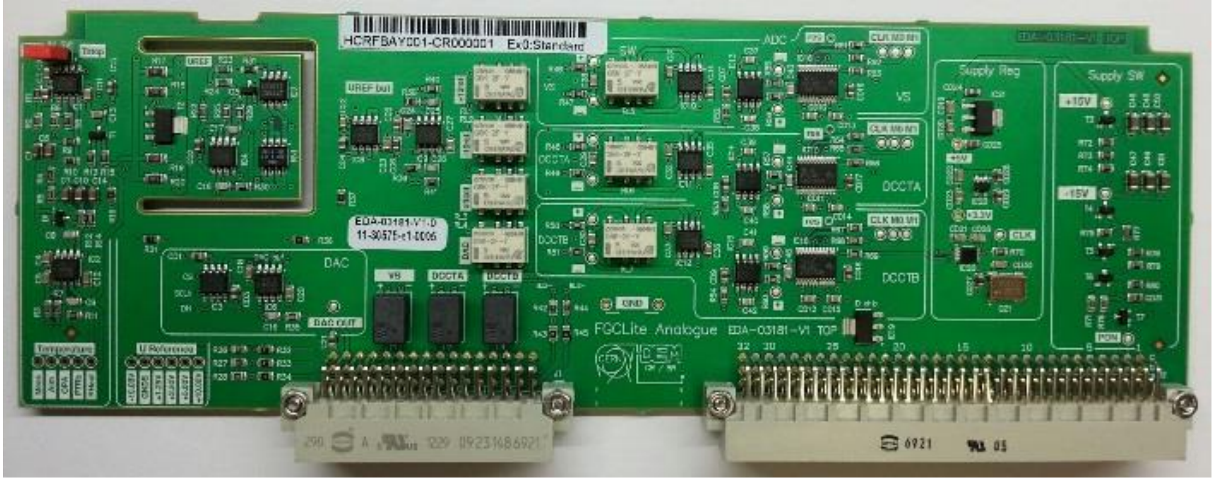


FGClite Power Board (PB):

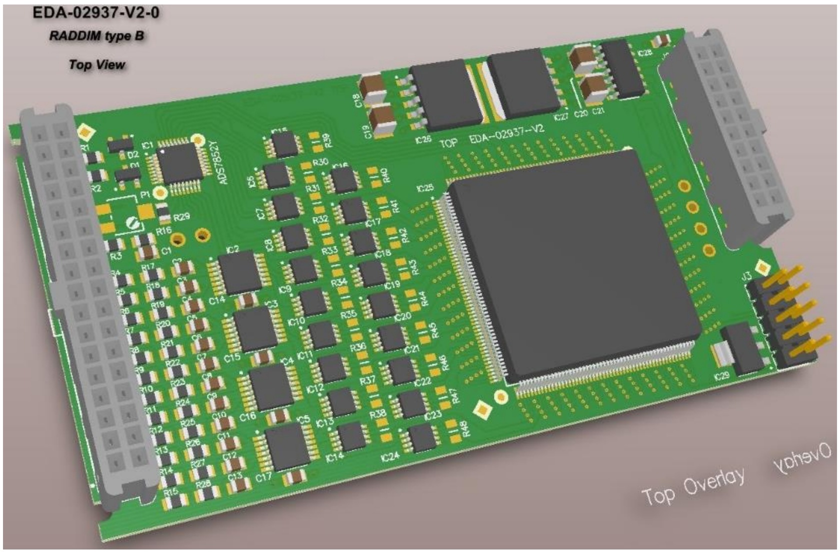
FGClite Input/Output Board (IOB):

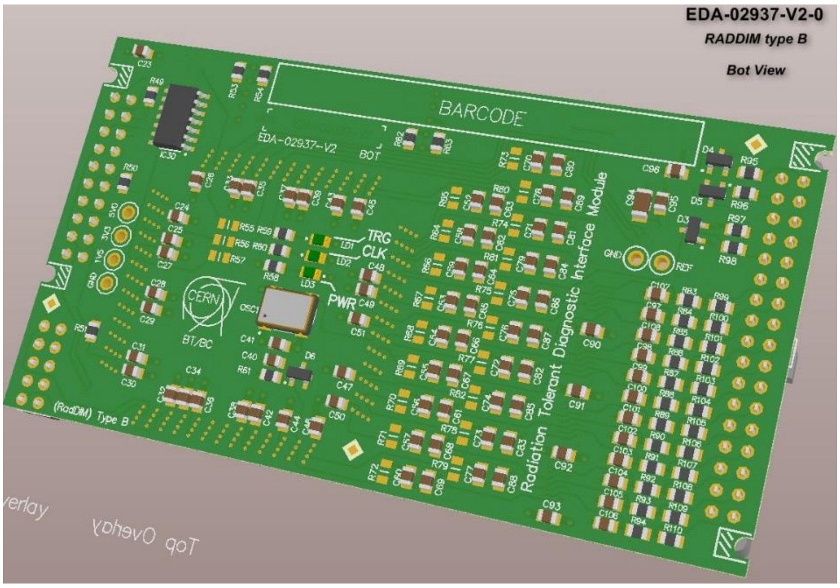


FGClite Analogue Board (AB):



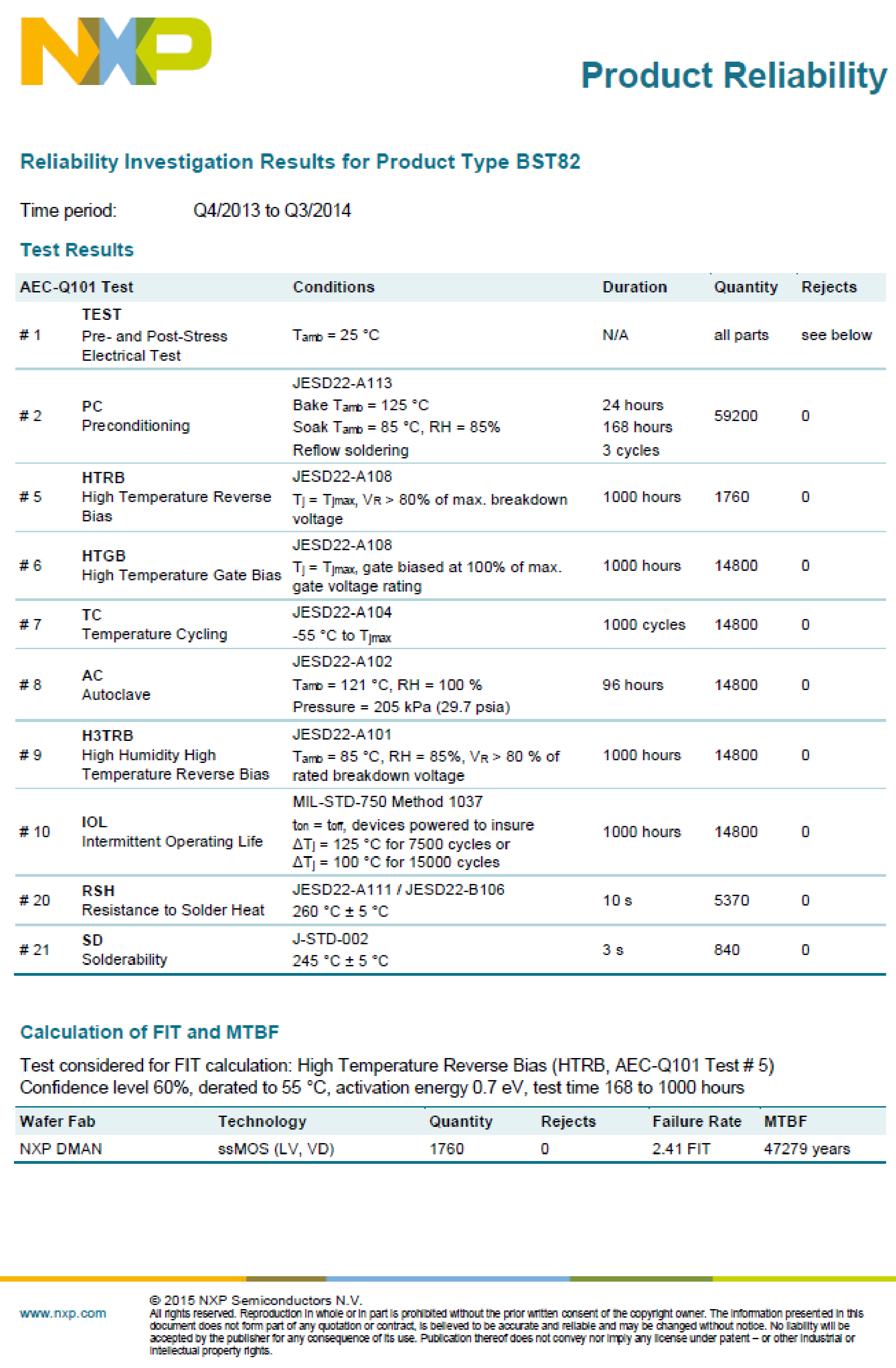
Radiation tolerant Diagnostic Interface Module (DIM):





3.3.2 Creating the Reliability Workbench Model

Exemplary reliability report from NXP for the Field-Effect Transistor «BST82»:



Product Reliability

Reliability Investigation Results for Product Type BST82

Time period: Q4/2013 to Q3/2014

Test Results

AEC-Q101 Test		Conditions	Duration	Quantity	Rejects
# 1	**TEST** Pre- and Post-Stress Electrical Test	T_{amb} = 25 °C	N/A	all parts	see below
# 2	**PC** Preconditioning	JESD22-A113 Bake T_{amb} = 125 °C Soak T_{amb} = 85 °C, RH = 85% Reflow soldering	 24 hours 168 hours 3 cycles	59200	0
# 5	**HTRB** High Temperature Reverse Bias	JESD22-A108 T_j = T_{jmax}, V_R > 80% of max. breakdown voltage	1000 hours	1760	0
# 6	**HTGB** High Temperature Gate Bias	JESD22-A108 T_j = T_{jmax}, gate biased at 100% of max. gate voltage rating	1000 hours	14800	0
# 7	**TC** Temperature Cycling	JESD22-A104 -55 °C to T_{jmax}	1000 cycles	14800	0
# 8	**AC** Autoclave	JESD22-A102 T_{amb} = 121 °C, RH = 100 % Pressure = 205 kPa (29.7 psia)	96 hours	14800	0
# 9	**H3TRB** High Humidity High Temperature Reverse Bias	JESD22-A101 T_{amb} = 85 °C, RH = 85%, V_R > 80 % of rated breakdown voltage	1000 hours	14800	0
# 10	**IOL** Intermittent Operating Life	MIL-STD-750 Method 1037 t_{on} = t_{off}, devices powered to insure ΔT_j = 125 °C for 7500 cycles or ΔT_j = 100 °C for 15000 cycles	1000 hours	14800	0
# 20	**RSH** Resistance to Solder Heat	JESD22-A111 / JESD22-B106 260 °C ± 5 °C	10 s	5370	0
# 21	**SD** Solderability	J-STD-002 245 °C ± 5 °C	3 s	840	0

Calculation of FIT and MTBF

Test considered for FIT calculation: High Temperature Reverse Bias (HTRB, AEC-Q101 Test # 5)
Confidence level 60%, derated to 55 °C, activation energy 0.7 eV, test time 168 to 1000 hours

Wafer Fab	Technology	Quantity	Rejects	Failure Rate	MTBF
NXP DMAN	ssMOS (LV, VD)	1760	0	2.41 FIT	47279 years

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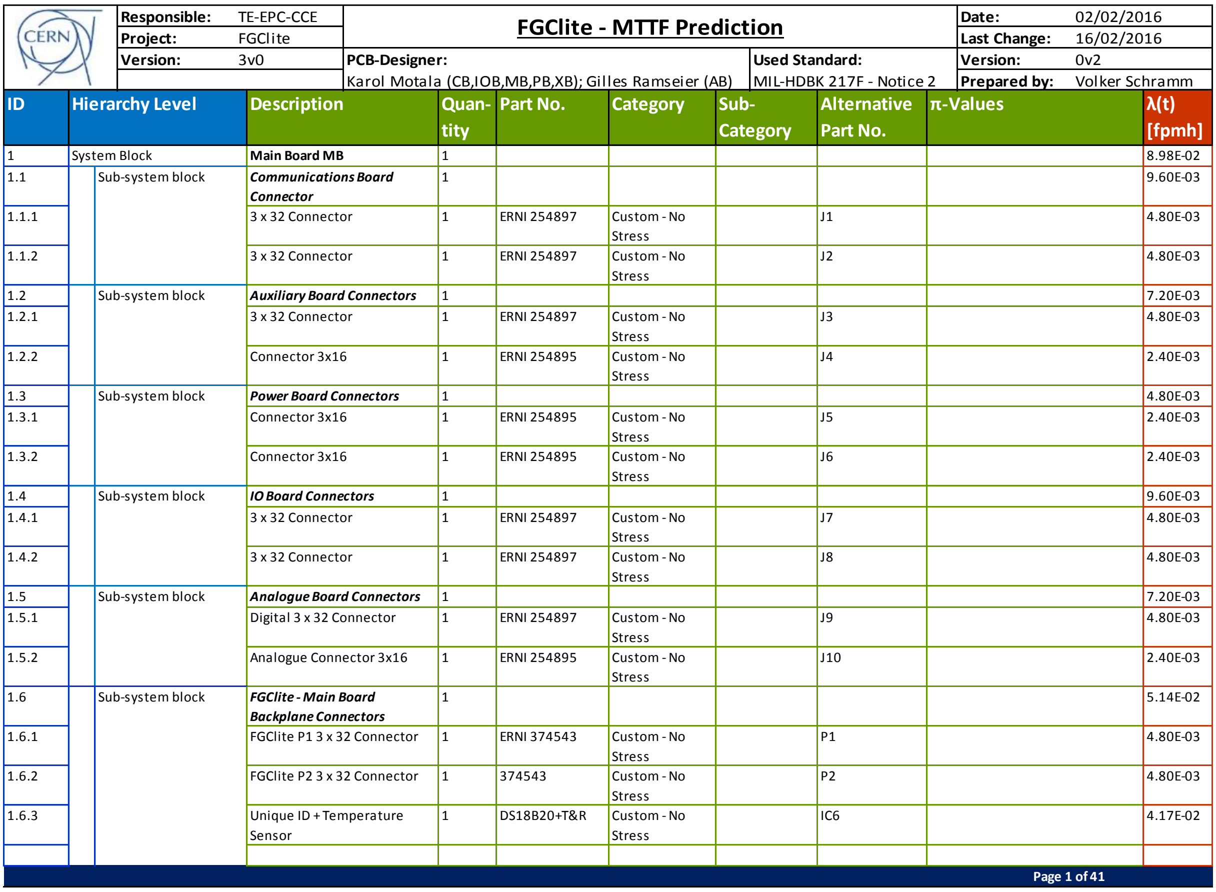
3.3.3 Results of the Prediction

MTTF Results



FGClite - MTTF Prediction

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0
PCB-Designer: Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)
Used Standard: MIL-HDBK 217F - Notice 2
Date: 02/02/2016
Last Change: 16/02/2016
Version: 0v2
Prepared by: Volker Schramm

ID	Hierarchy Level	Description	Quan-tity	Part No.	Category	Sub-Category	Alternative Part No.	π-Values	λ(t) [fpmh]
1	System Block	**Main Board MB**	1						8.98E-02
1.1	Sub-system block	***Communications Board Connector***	1						9.60E-03
1.1.1		3 x 32 Connector	1	ERNI 254897	Custom - No Stress		J1		4.80E-03
1.1.2		3 x 32 Connector	1	ERNI 254897	Custom - No Stress		J2		4.80E-03
1.2	Sub-system block	***Auxiliary Board Connectors***	1						7.20E-03
1.2.1		3 x 32 Connector	1	ERNI 254897	Custom - No Stress		J3		4.80E-03
1.2.2		Connector 3x16	1	ERNI 254895	Custom - No Stress		J4		2.40E-03
1.3	Sub-system block	***Power Board Connectors***	1						4.80E-03
1.3.1		Connector 3x16	1	ERNI 254895	Custom - No Stress		J5		2.40E-03
1.3.2		Connector 3x16	1	ERNI 254895	Custom - No Stress		J6		2.40E-03
1.4	Sub-system block	***IO Board Connectors***	1						9.60E-03
1.4.1		3 x 32 Connector	1	ERNI 254897	Custom - No Stress		J7		4.80E-03
1.4.2		3 x 32 Connector	1	ERNI 254897	Custom - No Stress		J8		4.80E-03
1.5	Sub-system block	***Analogue Board Connectors***	1						7.20E-03
1.5.1		Digital 3 x 32 Connector	1	ERNI 254897	Custom - No Stress		J9		4.80E-03
1.5.2		Analogue Connector 3x16	1	ERNI 254895	Custom - No Stress		J10		2.40E-03
1.6	Sub-system block	***FGClite - Main Board Backplane Connectors***	1						5.14E-02
1.6.1		FGClite P1 3 x 32 Connector	1	ERNI 374543	Custom - No Stress		P1		4.80E-03
1.6.2		FGClite P2 3 x 32 Connector	1	374543	Custom - No Stress		P2		4.80E-03
1.6.3		Unique ID + Temperature Sensor	1	DS18B20+T&R	Custom - No Stress		IC6		4.17E-02

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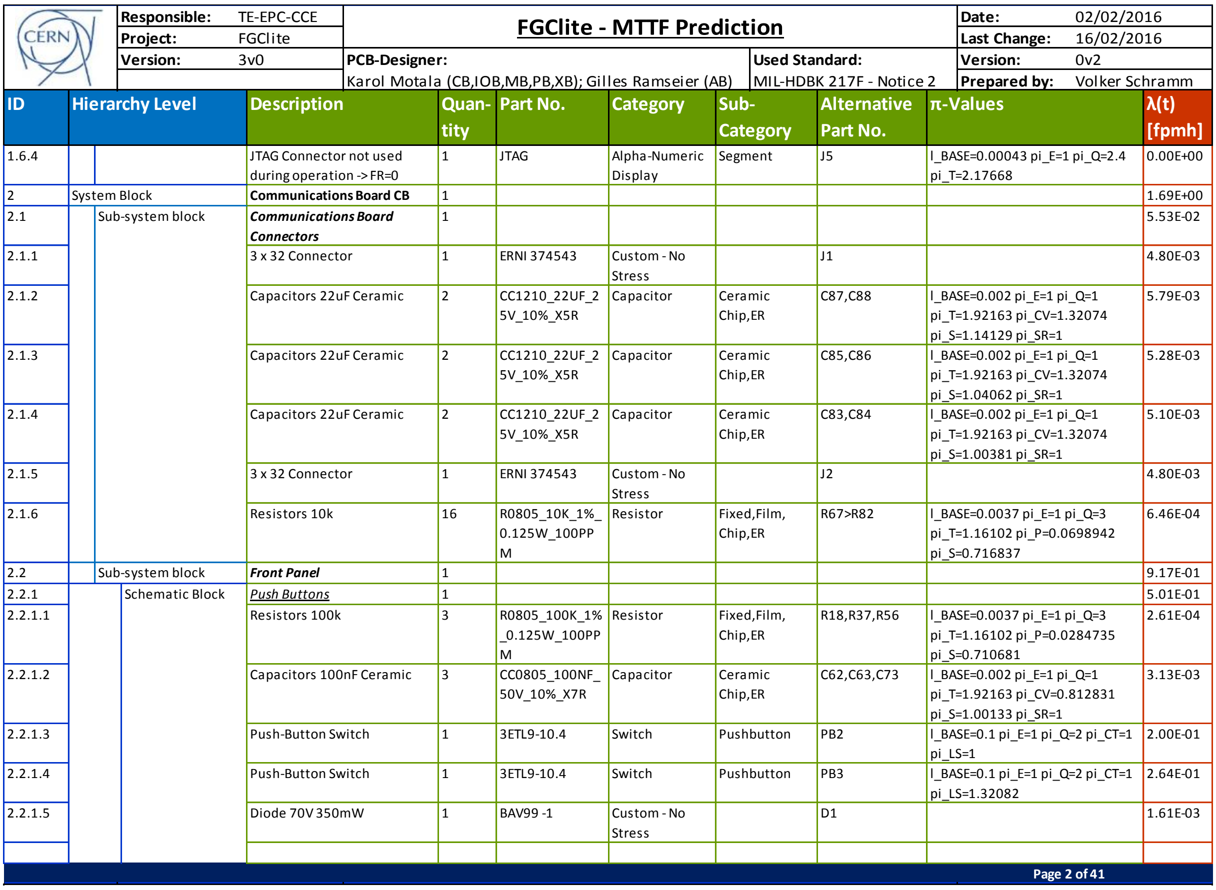

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - MTTF Prediction

PCB-Designer: Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)
Used Standard: MIL-HDBK 217F - Notice 2

Date: 02/02/2016
Last Change: 16/02/2016
Version: 0v2
Prepared by: Volker Schramm

ID	Hierarchy Level	Description	Quantity	Part No.	Category	Sub-Category	Alternative Part No.	π-Values	λ(t) [fpmh]
1.6.4		JTAG Connector not used during operation -> FR=0	1	JTAG	Alpha-Numeric Display	Segment	J5	l_BASE=0.00043 pi_E=1 pi_Q=2.4 pi_T=2.17668	0.00E+00
2	System Block	**Communications Board CB**	1						1.69E+00
2.1	Sub-system block	***Communications Board Connectors***	1						5.53E-02
2.1.1		3 x 32 Connector	1	ERNI 374543	Custom - No Stress		J1		4.80E-03
2.1.2		Capacitors 22uF Ceramic	2	CC1210_22UF_25V_10%_X5R	Capacitor	Ceramic Chip,ER	C87,C88	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1.32074 pi_S=1.14129 pi_SR=1	5.79E-03
2.1.3		Capacitors 22uF Ceramic	2	CC1210_22UF_25V_10%_X5R	Capacitor	Ceramic Chip,ER	C85,C86	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1.32074 pi_S=1.04062 pi_SR=1	5.28E-03
2.1.4		Capacitors 22uF Ceramic	2	CC1210_22UF_25V_10%_X5R	Capacitor	Ceramic Chip,ER	C83,C84	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1.32074 pi_S=1.00381 pi_SR=1	5.10E-03
2.1.5		3 x 32 Connector	1	ERNI 374543	Custom - No Stress		J2		4.80E-03
2.1.6		Resistors 10k	16	R0805_10K_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R67>R82	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0698942 pi_S=0.716837	6.46E-04
2.2	Sub-system block	***Front Panel***	1						9.17E-01
2.2.1	Schematic Block	*Push Buttons*	1						5.01E-01
2.2.1.1		Resistors 100k	3	R0805_100K_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R18,R37,R56	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0284735 pi_S=0.710681	2.61E-04
2.2.1.2		Capacitors 100nF Ceramic	3	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C62,C63,C73	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00133 pi_SR=1	3.13E-03
2.2.1.3		Push-Button Switch	1	3ETL9-10.4	Switch	Pushbutton	PB2	l_BASE=0.1 pi_E=1 pi_Q=2 pi_CT=1 pi_LS=1	2.00E-01
2.2.1.4		Push-Button Switch	1	3ETL9-10.4	Switch	Pushbutton	PB3	l_BASE=0.1 pi_E=1 pi_Q=2 pi_CT=1 pi_LS=1.32082	2.64E-01
2.2.1.5		Diode 70V 350mW	1	BAV99 -1	Custom - No Stress		D1		1.61E-03

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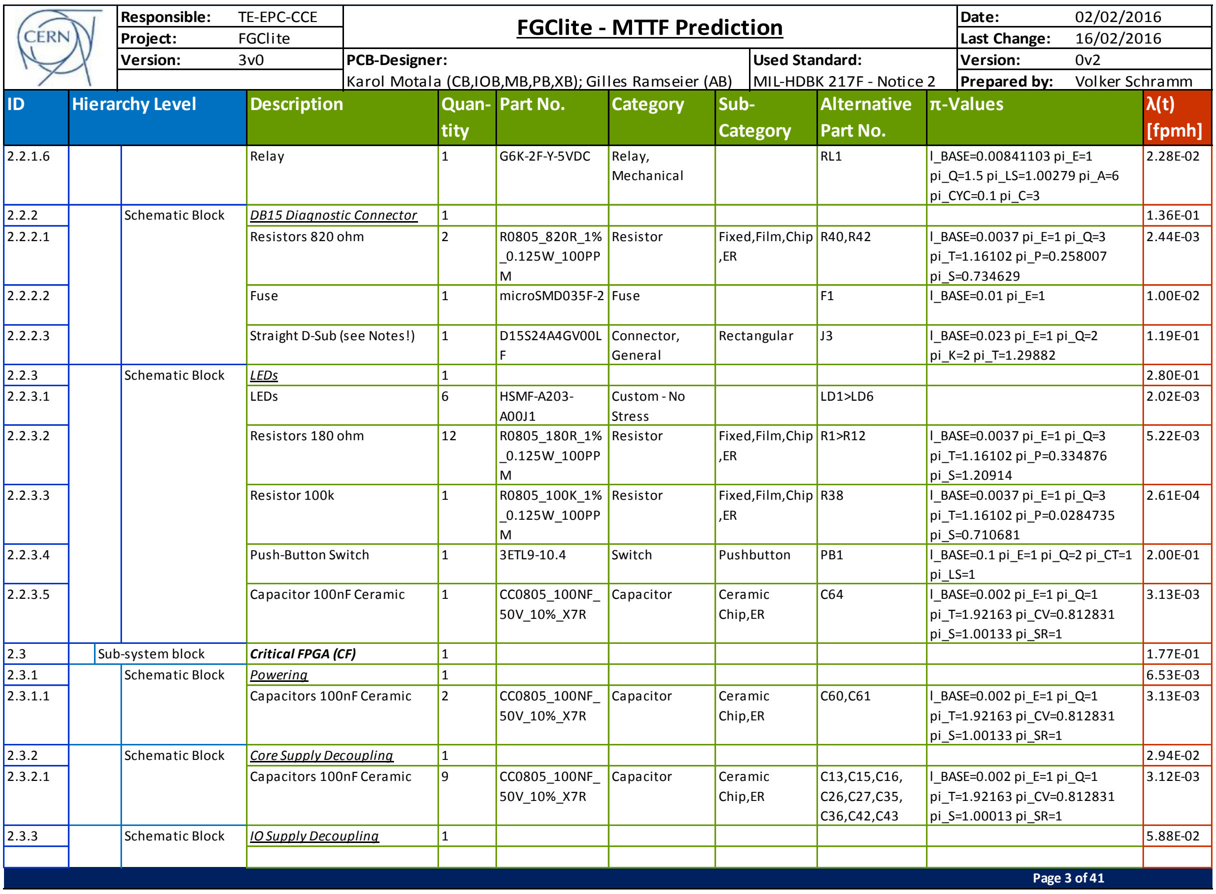

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - MTTF Prediction

PCB-Designer: Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)
Used Standard: MIL-HDBK 217F - Notice 2

Date: 02/02/2016
Last Change: 16/02/2016
Version: 0v2
Prepared by: Volker Schramm

ID	Hierarchy Level	Description	Quantity	Part No.	Category	Sub-Category	Alternative Part No.	π-Values	λ(t) [fpmh]
2.2.1.6		Relay	1	G6K-2F-Y-5VDC	Relay, Mechanical		RL1	l_BASE=0.00841103 pi_E=1 pi_Q=1.5 pi_LS=1.00279 pi_A=6 pi_CYC=0.1 pi_C=3	2.28E-02
2.2.2	Schematic Block	*DB15 Diagnostic Connector*	1						1.36E-01
2.2.2.1		Resistors 820 ohm	2	R0805_820R_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R40,R42	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.258007 pi_S=0.734629	2.44E-03
2.2.2.2		Fuse	1	microSMD035F-2	Fuse		F1	l_BASE=0.01 pi_E=1	1.00E-02
2.2.2.3		Straight D-Sub (see Notes!)	1	D15S24A4GV00LF	Connector, General	Rectangular	J3	l_BASE=0.023 pi_E=1 pi_Q=2 pi_K=2 pi_T=1.29882	1.19E-01
2.2.3	Schematic Block	*LEDs*	1						2.80E-01
2.2.3.1		LEDs	6	HSMF-A203-A00J1	Custom - No Stress		LD1>LD6		2.02E-03
2.2.3.2		Resistors 180 ohm	12	R0805_180R_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R1>R12	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.334876 pi_S=1.20914	5.22E-03
2.2.3.3		Resistor 100k	1	R0805_100K_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R38	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0284735 pi_S=0.710681	2.61E-04
2.2.3.4		Push-Button Switch	1	3ETL9-10.4	Switch	Pushbutton	PB1	l_BASE=0.1 pi_E=1 pi_Q=2 pi_CT=1 pi_LS=1	2.00E-01
2.2.3.5		Capacitor 100nF Ceramic	1	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C64	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00133 pi_SR=1	3.13E-03
2.3	Sub-system block	***Critical FPGA (CF)***	1						1.77E-01
2.3.1	Schematic Block	*Powering*	1						6.53E-03
2.3.1.1		Capacitors 100nF Ceramic	2	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C60,C61	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00133 pi_SR=1	3.13E-03
2.3.2	Schematic Block	*Core Supply Decoupling*	1						2.94E-02
2.3.2.1		Capacitors 100nF Ceramic	9	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C13,C15,C16, C26,C27,C35, C36,C42,C43	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00013 pi_SR=1	3.12E-03
2.3.3	Schematic Block	*IO Supply Decoupling*	1						5.88E-02

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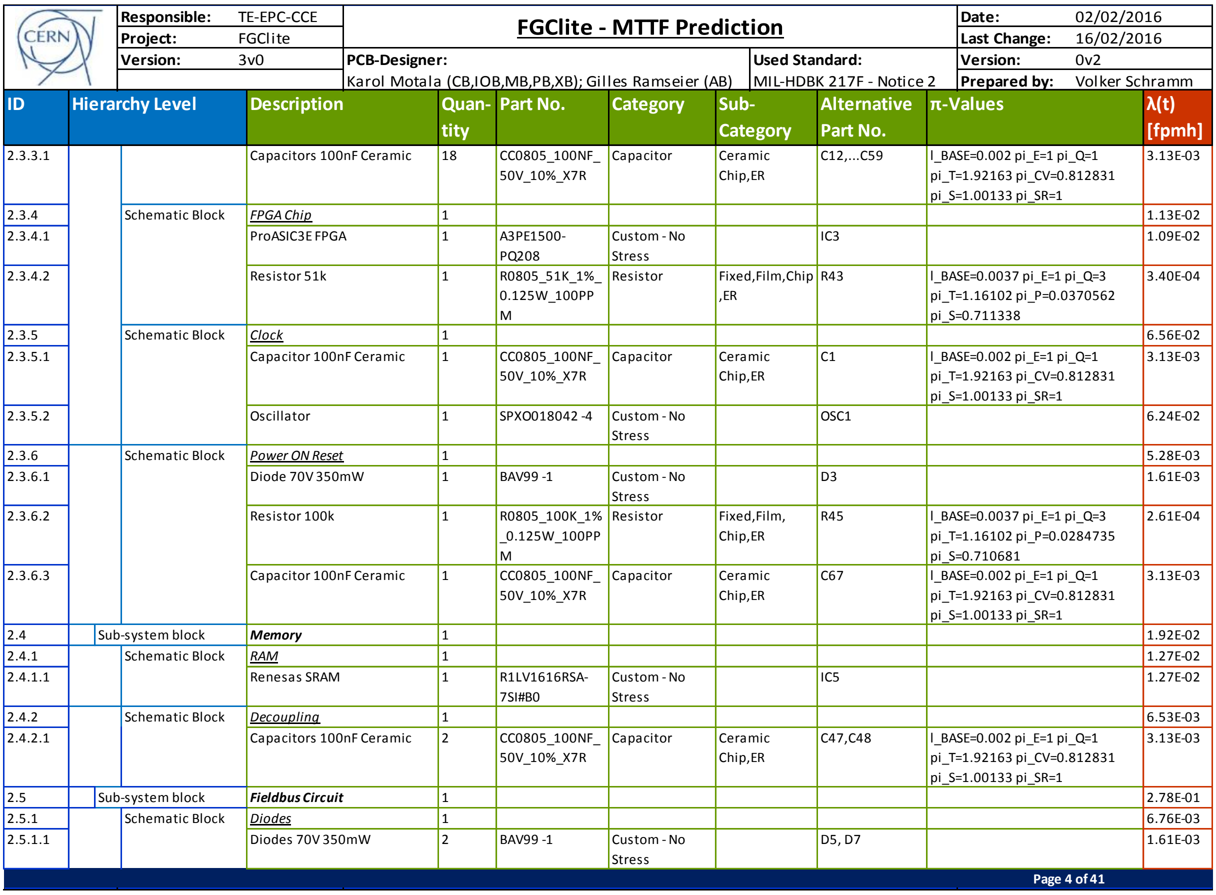

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - MTTF Prediction

PCB-Designer: Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)
Used Standard: MIL-HDBK 217F - Notice 2

Date: 02/02/2016
Last Change: 16/02/2016
Version: 0v2
Prepared by: Volker Schramm

ID	Hierarchy Level	Description	Quan-tity	Part No.	Category	Sub-Category	Alternative Part No.	π-Values	λ(t) [fpmh]
2.3.3.1		Capacitors 100nF Ceramic	18	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C12,...C59	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00133 pi_SR=1	3.13E-03
2.3.4	Schematic Block	*FPGA Chip*	1						1.13E-02
2.3.4.1		ProASIC3E FPGA	1	A3PE1500-PQ208	Custom - No Stress		IC3		1.09E-02
2.3.4.2		Resistor 51k	1	R0805_51K_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R43	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0370562 pi_S=0.711338	3.40E-04
2.3.5	Schematic Block	*Clock*	1						6.56E-02
2.3.5.1		Capacitor 100nF Ceramic	1	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C1	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00133 pi_SR=1	3.13E-03
2.3.5.2		Oscillator	1	SPXO018042 -4	Custom - No Stress		OSC1		6.24E-02
2.3.6	Schematic Block	*Power ON Reset*	1						5.28E-03
2.3.6.1		Diode 70V 350mW	1	BAV99 -1	Custom - No Stress		D3		1.61E-03
2.3.6.2		Resistor 100k	1	R0805_100K_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R45	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0284735 pi_S=0.710681	2.61E-04
2.3.6.3		Capacitor 100nF Ceramic	1	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C67	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00133 pi_SR=1	3.13E-03
2.4	Sub-system block	***Memory***	1						1.92E-02
2.4.1	Schematic Block	*RAM*	1						1.27E-02
2.4.1.1		Renesas SRAM	1	R1LV1616RSA-7SI#B0	Custom - No Stress		IC5		1.27E-02
2.4.2	Schematic Block	*Decoupling*	1						6.53E-03
2.4.2.1		Capacitors 100nF Ceramic	2	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C47,C48	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00133 pi_SR=1	3.13E-03
2.5	Sub-system block	***Fieldbus Circuit***	1						2.78E-01
2.5.1	Schematic Block	*Diodes*	1						6.76E-03
2.5.1.1		Diodes 70V 350mW	2	BAV99 -1	Custom - No Stress		D5, D7		1.61E-03

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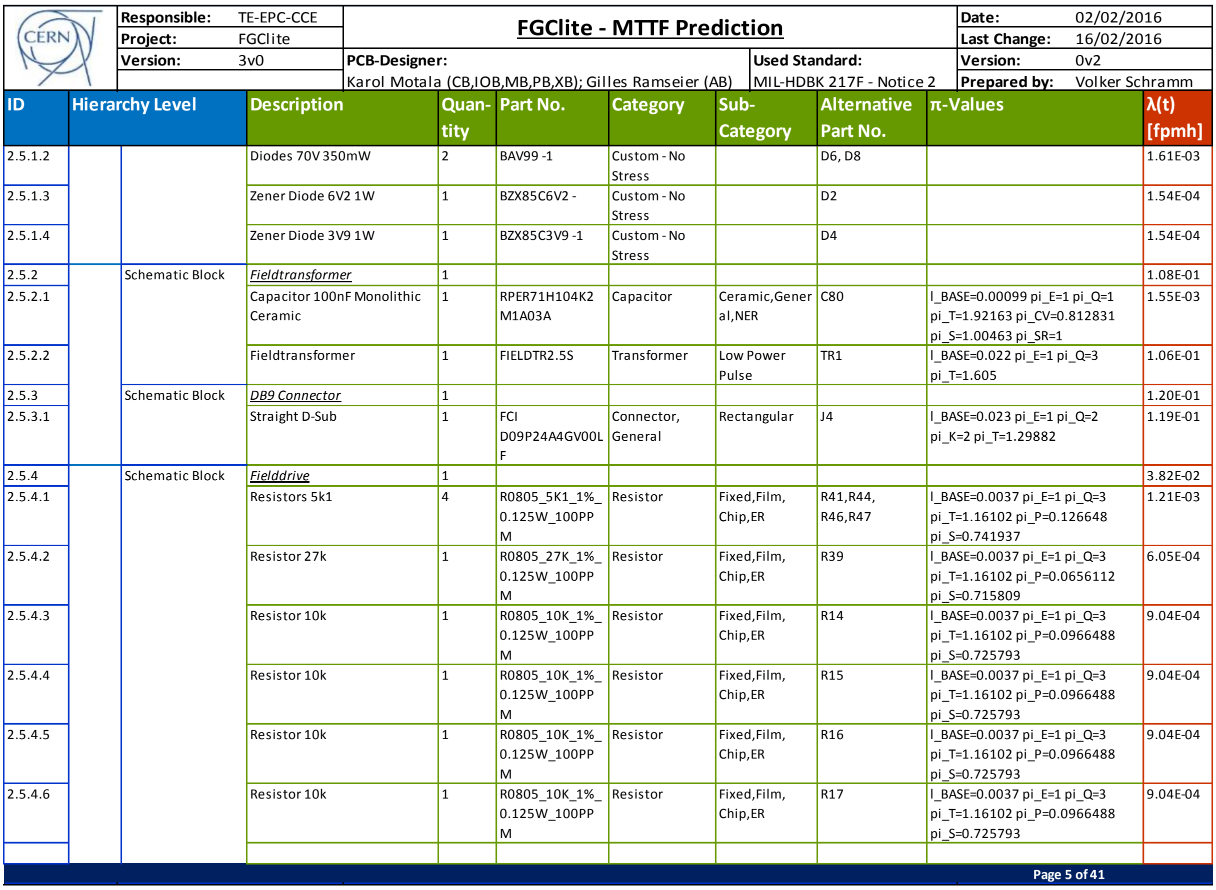

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - MTTF Prediction

PCB-Designer: Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)
Used Standard: MIL-HDBK 217F - Notice 2

Date: 02/02/2016
Last Change: 16/02/2016
Version: 0v2
Prepared by: Volker Schramm

ID	Hierarchy Level	Description	Quan-tity	Part No.	Category	Sub-Category	Alternative Part No.	π-Values	λ(t) [fpmh]
2.5.1.2		Diodes 70V 350mW	2	BAV99 -1	Custom - No Stress		D6, D8		1.61E-03
2.5.1.3		Zener Diode 6V2 1W	1	BZX85C6V2 -	Custom - No Stress		D2		1.54E-04
2.5.1.4		Zener Diode 3V9 1W	1	BZX85C3V9 -1	Custom - No Stress		D4		1.54E-04
2.5.2	Schematic Block	*Fieldtransformer*	1						1.08E-01
2.5.2.1		Capacitor 100nF Monolithic Ceramic	1	RPER71H104K2M1A03A	Capacitor	Ceramic,General,NER	C80	l_BASE=0.00099 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00463 pi_SR=1	1.55E-03
2.5.2.2		Fieldtransformer	1	FIELDTR2.5S	Transformer	Low Power Pulse	TR1	l_BASE=0.022 pi_E=1 pi_Q=3 pi_T=1.605	1.06E-01
2.5.3	Schematic Block	*DB9 Connector*	1						1.20E-01
2.5.3.1		Straight D-Sub	1	FCI D09P24A4GV00LF	Connector, General	Rectangular	J4	l_BASE=0.023 pi_E=1 pi_Q=2 pi_K=2 pi_T=1.29882	1.19E-01
2.5.4	Schematic Block	*Fielddrive*	1						3.82E-02
2.5.4.1		Resistors 5k1	4	R0805_5K1_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R41,R44, R46,R47	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.126648 pi_S=0.741937	1.21E-03
2.5.4.2		Resistor 27k	1	R0805_27K_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R39	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0656112 pi_S=0.715809	6.05E-04
2.5.4.3		Resistor 10k	1	R0805_10K_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R14	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0966488 pi_S=0.725793	9.04E-04
2.5.4.4		Resistor 10k	1	R0805_10K_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R15	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0966488 pi_S=0.725793	9.04E-04
2.5.4.5		Resistor 10k	1	R0805_10K_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R16	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0966488 pi_S=0.725793	9.04E-04
2.5.4.6		Resistor 10k	1	R0805_10K_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R17	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0966488 pi_S=0.725793	9.04E-04

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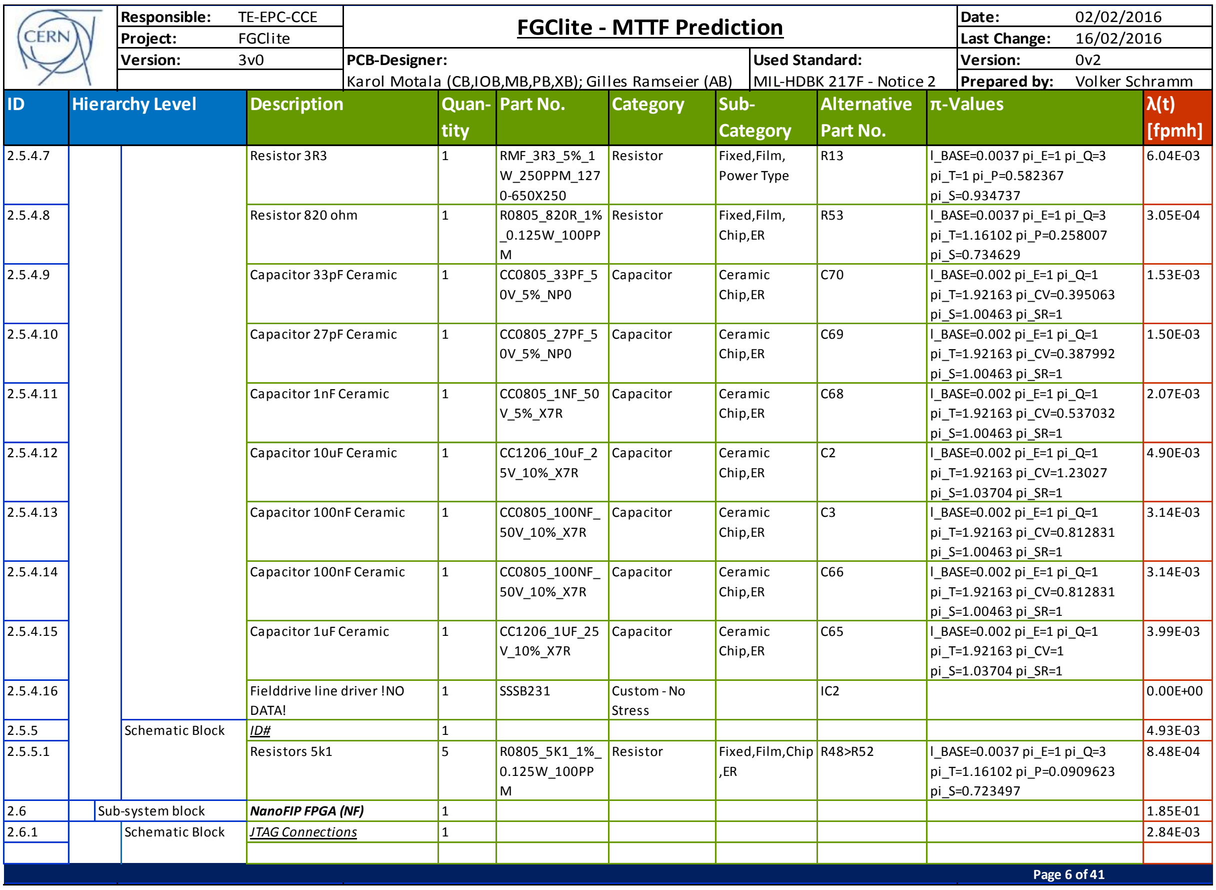

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - MTTF Prediction

PCB-Designer: Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)
Used Standard: MIL-HDBK 217F - Notice 2

Date: 02/02/2016
Last Change: 16/02/2016
Version: 0v2
Prepared by: Volker Schramm

ID	Hierarchy Level	Description	Quantity	Part No.	Category	Sub-Category	Alternative Part No.	π-Values	λ(t) [fpmh]
2.5.4.7		Resistor 3R3	1	RMF_3R3_5%_1W_250PPM_1270-650X250	Resistor	Fixed,Film, Power Type	R13	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1 pi_P=0.582367 pi_S=0.934737	6.04E-03
2.5.4.8		Resistor 820 ohm	1	R0805_820R_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R53	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.258007 pi_S=0.734629	3.05E-04
2.5.4.9		Capacitor 33pF Ceramic	1	CC0805_33PF_50V_5%_NP0	Capacitor	Ceramic Chip,ER	C70	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.395063 pi_S=1.00463 pi_SR=1	1.53E-03
2.5.4.10		Capacitor 27pF Ceramic	1	CC0805_27PF_50V_5%_NP0	Capacitor	Ceramic Chip,ER	C69	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.387992 pi_S=1.00463 pi_SR=1	1.50E-03
2.5.4.11		Capacitor 1nF Ceramic	1	CC0805_1NF_50V_5%_X7R	Capacitor	Ceramic Chip,ER	C68	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.537032 pi_S=1.00463 pi_SR=1	2.07E-03
2.5.4.12		Capacitor 10uF Ceramic	1	CC1206_10uF_25V_10%_X7R	Capacitor	Ceramic Chip,ER	C2	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1.23027 pi_S=1.03704 pi_SR=1	4.90E-03
2.5.4.13		Capacitor 100nF Ceramic	1	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C3	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00463 pi_SR=1	3.14E-03
2.5.4.14		Capacitor 100nF Ceramic	1	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C66	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00463 pi_SR=1	3.14E-03
2.5.4.15		Capacitor 1uF Ceramic	1	CC1206_1UF_25V_10%_X7R	Capacitor	Ceramic Chip,ER	C65	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1 pi_S=1.03704 pi_SR=1	3.99E-03
2.5.4.16		Fielddrive line driver !NO DATA!	1	SSB231	Custom - No Stress		IC2		0.00E+00
2.5.5	Schematic Block	*ID#*	1						4.93E-03
2.5.5.1		Resistors 5k1	5	R0805_5K1_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R48>R52	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0909623 pi_S=0.723497	8.48E-04
2.6	Sub-system block	***NanoFIP FPGA (NF)***	1						1.85E-01
2.6.1	Schematic Block	*JTAG Connections*	1						2.84E-03

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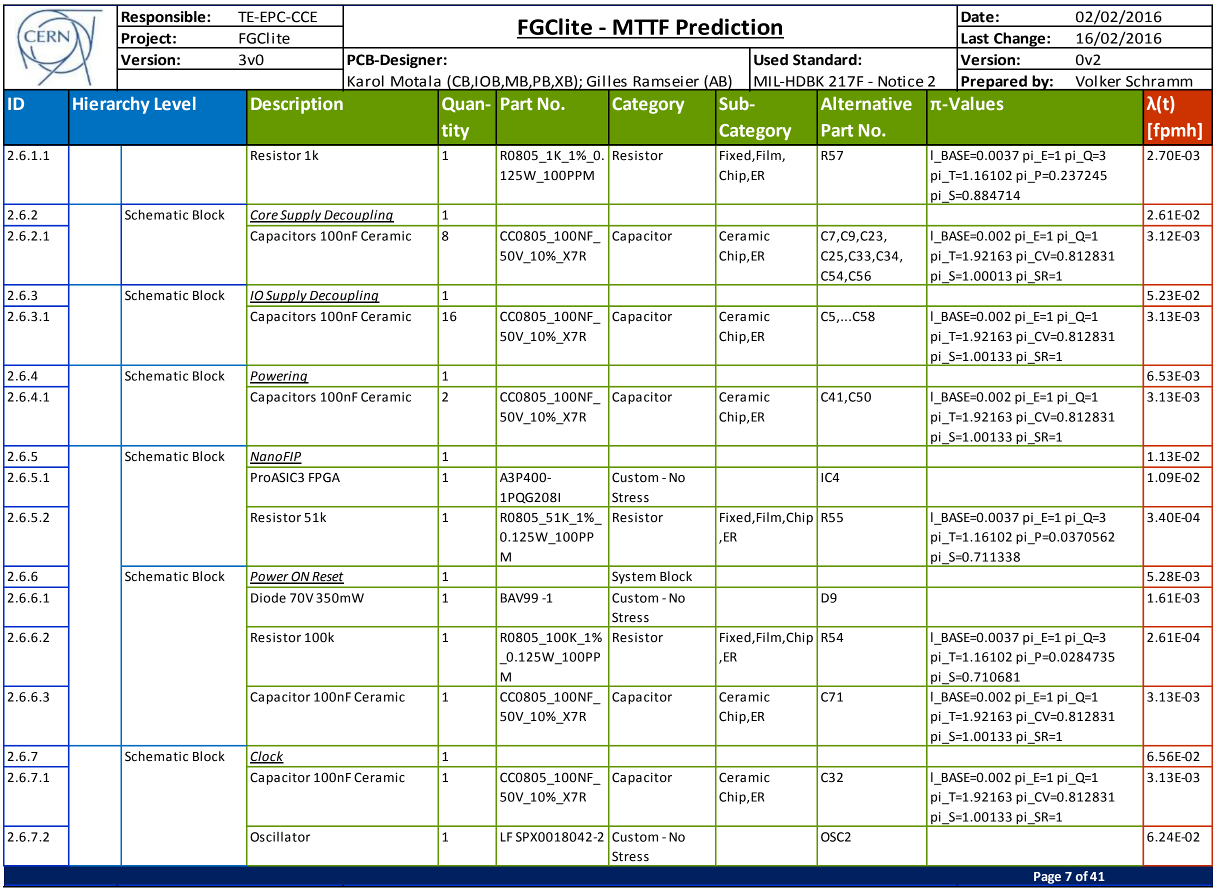

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - MTTF Prediction

PCB-Designer: Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)
Used Standard: MIL-HDBK 217F - Notice 2

Date: 02/02/2016
Last Change: 16/02/2016
Version: 0v2
Prepared by: Volker Schramm

ID	Hierarchy Level	Description	Quantity	Part No.	Category	Sub-Category	Alternative Part No.	π-Values	λ(t) [fpmh]
2.6.1.1		Resistor 1k	1	R0805_1K_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R57	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.237245 pi_S=0.884714	2.70E-03
2.6.2	Schematic Block	*Core Supply Decoupling*	1						2.61E-02
2.6.2.1		Capacitors 100nF Ceramic	8	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C7,C9,C23, C25,C33,C34, C54,C56	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00013 pi_SR=1	3.12E-03
2.6.3	Schematic Block	*IO Supply Decoupling*	1						5.23E-02
2.6.3.1		Capacitors 100nF Ceramic	16	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C5,...C58	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00133 pi_SR=1	3.13E-03
2.6.4	Schematic Block	*Powering*	1						6.53E-03
2.6.4.1		Capacitors 100nF Ceramic	2	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C41,C50	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00133 pi_SR=1	3.13E-03
2.6.5	Schematic Block	*NanoFIP*	1						1.13E-02
2.6.5.1		ProASIC3 FPGA	1	A3P400-1PQG208I	Custom - No Stress		IC4		1.09E-02
2.6.5.2		Resistor 51k	1	R0805_51K_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R55	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0370562 pi_S=0.711338	3.40E-04
2.6.6	Schematic Block	*Power ON Reset*	1		System Block				5.28E-03
2.6.6.1		Diode 70V 350mW	1	BAV99 -1	Custom - No Stress		D9		1.61E-03
2.6.6.2		Resistor 100k	1	R0805_100K_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R54	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0284735 pi_S=0.710681	2.61E-04
2.6.6.3		Capacitor 100nF Ceramic	1	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C71	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00133 pi_SR=1	3.13E-03
2.6.7	Schematic Block	*Clock*	1						6.56E-02
2.6.7.1		Capacitor 100nF Ceramic	1	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C32	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00133 pi_SR=1	3.13E-03
2.6.7.2		Oscillator	1	LF SPX0018042-2	Custom - No Stress		OSC2		6.24E-02

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Responsible: TE-EPC-CCE	**FGClite - MTTF Prediction**		**Date:**	02/02/2016
Project: FGClite			**Last Change:**	16/02/2016
Version: 3v0	**PCB-Designer:**	**Used Standard:**	**Version:**	0v2
	Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)	MIL-HDBK 217F - Notice 2	**Prepared by:**	Volker Schramm

ID	Hierarchy Level	Description	Quantity	Part No.	Category	Sub-Category	Alternative Part No.	π-Values	λ(t) [fpmh]
2.6.8	Schematic Block	*Unique ID*	1						1.48E-02
2.6.8.1		Unique ID	1	DS2401Z+	Custom - No Stress		IC1		1.48E-02
2.7	Sub-system block	***Analogue Board Link***	1						5.85E-02
2.7.1	Schematic Block	*Modulation Stream Filters*	1						2.90E-02
2.7.1.1		Resistors 10 ohm	9	R0805_10R_1%_0.125W_200PPM	Resistor	Fixed,Film,Chip,ER	R19>R27	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0945008 pi_S=0.724899	8.83E-04
2.7.1.2		Capacitors 1nF Ceramic	9	CC0805_1NF_50V_5%_X7R	Capacitor	Ceramic Chip,ER	C74>C82	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.537032 pi_S=1.00001 pi_SR=1	2.06E-03
2.7.2	Schematic Block	*Open Collectors*	1						2.95E-02
2.7.2.1		Resistors 2k2	9	R0805_2K2_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R28>R36	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.17466 pi_S=0.784922	1.77E-03
2.7.2.2		Resistors 27k	9	R0805_27K_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R58>R66	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0657216 pi_S=0.715834	6.06E-04
2.7.2.3		Transistors	9	BC817 -1	Custom - No Stress		T1>T9		6.30E-04
3	System Block	**Analogue Board AB**	1						1.31E+00
3.1	Sub-System Block	***UREF***	1						3.27E-01
3.1.1	Schematic Block	*Reference Voltage*	1						1.36E-01
3.1.1.1		Capacitor 1uF Ceramic	1	CD0805-1UF-25V_±10%-CX7R	Capacitor	Ceramic Chip,ER	C66	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1 pi_S=2 pi_SR=1	7.69E-03
3.1.1.2		Capacitor 100nF Ceramic	1	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C62	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.125 pi_SR=1	3.51E-03
3.1.1.3		LT1236ACS8-10	1	LT1236ACS8-10	Custom - No Stress		IC7		7.70E-05
3.1.1.4		Capacitors 1uF Ceramic	6	CC0805_1UF_25V_10%_X7R	Capacitor	Ceramic Chip,ER	CD4, CD5, CD6, CD59>CD61	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1 pi_S=2 pi_SR=1	7.69E-03

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Responsible: TE-EPC-CCE	**FGClite - MTTF Prediction**		**Date:**	02/02/2016
Project: FGClite			**Last Change:**	16/02/2016
Version: 3v0	**PCB-Designer:**	**Used Standard:**	**Version:**	0v2
	Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)	MIL-HDBK 217F - Notice 2	**Prepared by:**	Volker Schramm

ID	Hierarchy Level	Description	Quantity	Part No.	Category	Sub-Category	Alternative Part No.	π-Values	λ(t) [fpmh]
3.1.1.5		Resistors 0 ohm	4	R0805_0R_JUMPER	Resistor	Fixed,Film,Chip,ER	R31>R34	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0 pi_S=1.71174	0.00E+00
3.1.1.6		Resistor 10k	1	R0805_10K_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R22	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.227694 pi_S=0.865463	2.54E-03
3.1.1.7		Capacitor 1uF Ceramic	1	CC0805_1UF_25V_10%_X7R	Capacitor	Ceramic Chip,ER	CD2	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1 pi_S=2 pi_SR=1	7.69E-03
3.1.1.8		OP2177ARZ	1	OP2177ARZ	Custom - No Stress		IC4		9.50E-05
3.1.1.9		OP2177ARZ 2x	2	OP2177ARZ	Custom - No Stress		IC8, IC9		9.50E-05
3.1.1.10		Capacitors 33pF Ceramic	2	CC0805_33PF_50V_5%_NP0	Capacitor	Ceramic Chip,ER	C16, C17	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.395063 pi_S=1.125 pi_SR=1	1.71E-03
3.1.1.11		Capacitors 33pF Ceramic	4	CC0805_33PF_50V_5%_NP0	Capacitor	Ceramic Chip,ER	C16, C17, C25, C26	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.395063 pi_S=1.125 pi_SR=1	1.71E-03
3.1.1.12		Resistors 100 ohm	3	R0805_100R_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R25, R29, R30	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.154326 pi_S=0.763799	1.52E-03
3.1.1.13		Resistors 100 ohm	4	R0805_100R_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R38>R41	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.154326 pi_S=0.763799	1.52E-03
3.1.1.14		Resistor Network 2x10k	2	VISHAY FOIL RESISTOR Y1365V0008QT9	Resistor	Fixed,Film,Networks	RN5 (2-1)	l_BASE=0.0019 pi_E=1 pi_Q=3 pi_T=1.45244 pi_P=0.165959 pi_S=1	1.37E-03
3.1.1.15		Resistor Network 2x10k	2	VISHAY FOIL RESISTOR Y1365V0008QT9	Resistor	Fixed,Film,Networks	RN5 (2-2)	l_BASE=0.0019 pi_E=1 pi_Q=3 pi_T=1.45244 pi_P=0.165959 pi_S=1	1.37E-03
3.1.1.16		Resistor Network 4x10k	4	VISHAY FOIL RESISTOR Y1365V0008QT9	Resistor	Fixed,Film,Networks	RN1	l_BASE=0.0019 pi_E=1 pi_Q=3 pi_T=1.45244 pi_P=0.132601 pi_S=1	1.10E-03

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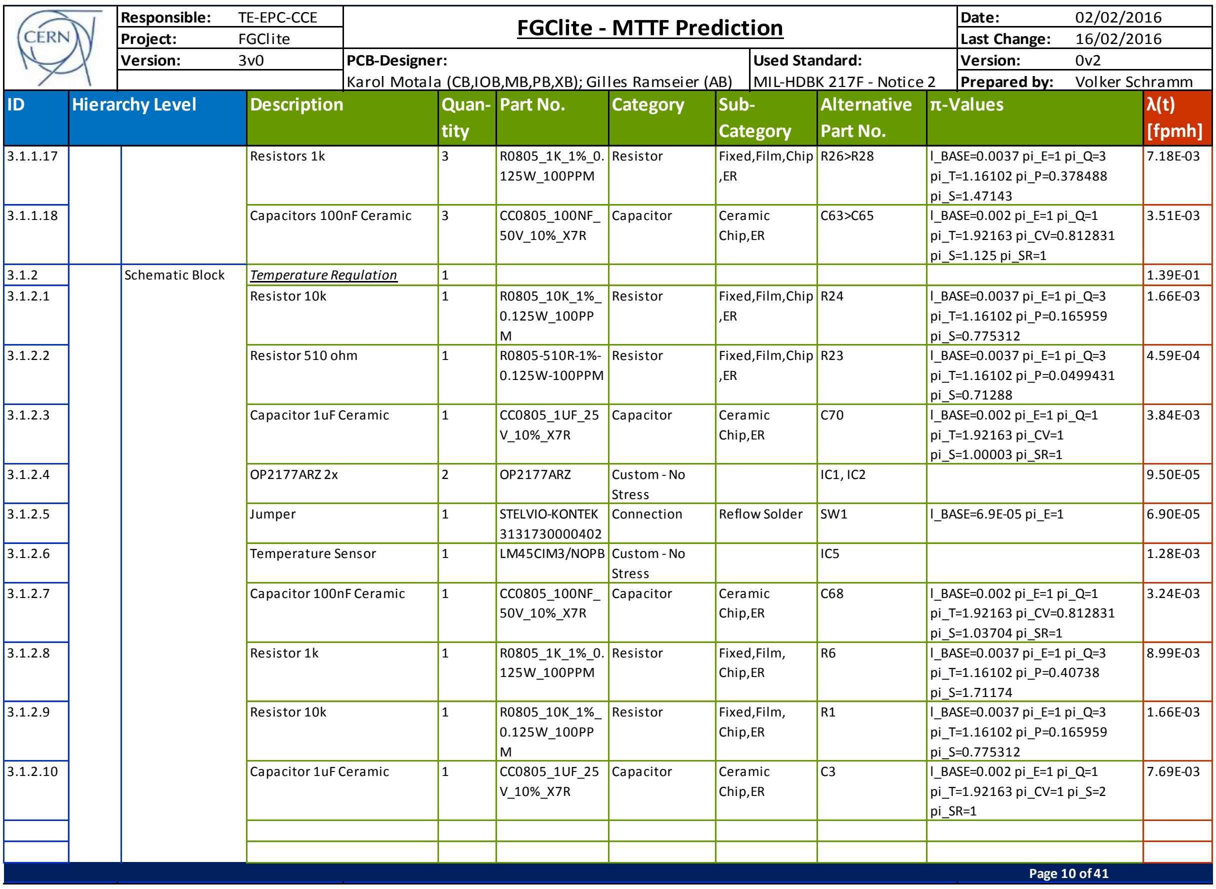

Responsible: TE-EPC-CCE	**FGClite - MTTF Prediction**		**Date:** 02/02/2016
Project: FGClite			**Last Change:** 16/02/2016
Version: 3v0	**PCB-Designer:**	**Used Standard:**	**Version:** 0v2
	Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)	MIL-HDBK 217F - Notice 2	**Prepared by:** Volker Schramm

ID	Hierarchy Level	Description	Quantity	Part No.	Category	Sub-Category	Alternative Part No.	π-Values	λ(t) [fpmh]
3.1.1.17		Resistors 1k	3	R0805_1K_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R26>R28	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.378488 pi_S=1.47143	7.18E-03
3.1.1.18		Capacitors 100nF Ceramic	3	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C63>C65	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.125 pi_SR=1	3.51E-03
3.1.2	Schematic Block	*Temperature Regulation*	1						1.39E-01
3.1.2.1		Resistor 10k	1	R0805_10K_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R24	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.165959 pi_S=0.775312	1.66E-03
3.1.2.2		Resistor 510 ohm	1	R0805-510R-1%-0.125W-100PPM	Resistor	Fixed,Film,Chip,ER	R23	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0499431 pi_S=0.71288	4.59E-04
3.1.2.3		Capacitor 1uF Ceramic	1	CC0805_1UF_25V_10%_X7R	Capacitor	Ceramic Chip,ER	C70	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1 pi_S=1.00003 pi_SR=1	3.84E-03
3.1.2.4		OP2177ARZ 2x	2	OP2177ARZ	Custom - No Stress		IC1, IC2		9.50E-05
3.1.2.5		Jumper	1	STELVIO-KONTEK 3131730000402	Connection	Reflow Solder	SW1	l_BASE=6.9E-05 pi_E=1	6.90E-05
3.1.2.6		Temperature Sensor	1	LM45CIM3/NOPB	Custom - No Stress		IC5		1.28E-03
3.1.2.7		Capacitor 100nF Ceramic	1	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C68	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.03704 pi_SR=1	3.24E-03
3.1.2.8		Resistor 1k	1	R0805_1K_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R6	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.40738 pi_S=1.71174	8.99E-03
3.1.2.9		Resistor 10k	1	R0805_10K_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R1	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.165959 pi_S=0.775312	1.66E-03
3.1.2.10		Capacitor 1uF Ceramic	1	CC0805_1UF_25V_10%_X7R	Capacitor	Ceramic Chip,ER	C3	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1 pi_S=2 pi_SR=1	7.69E-03

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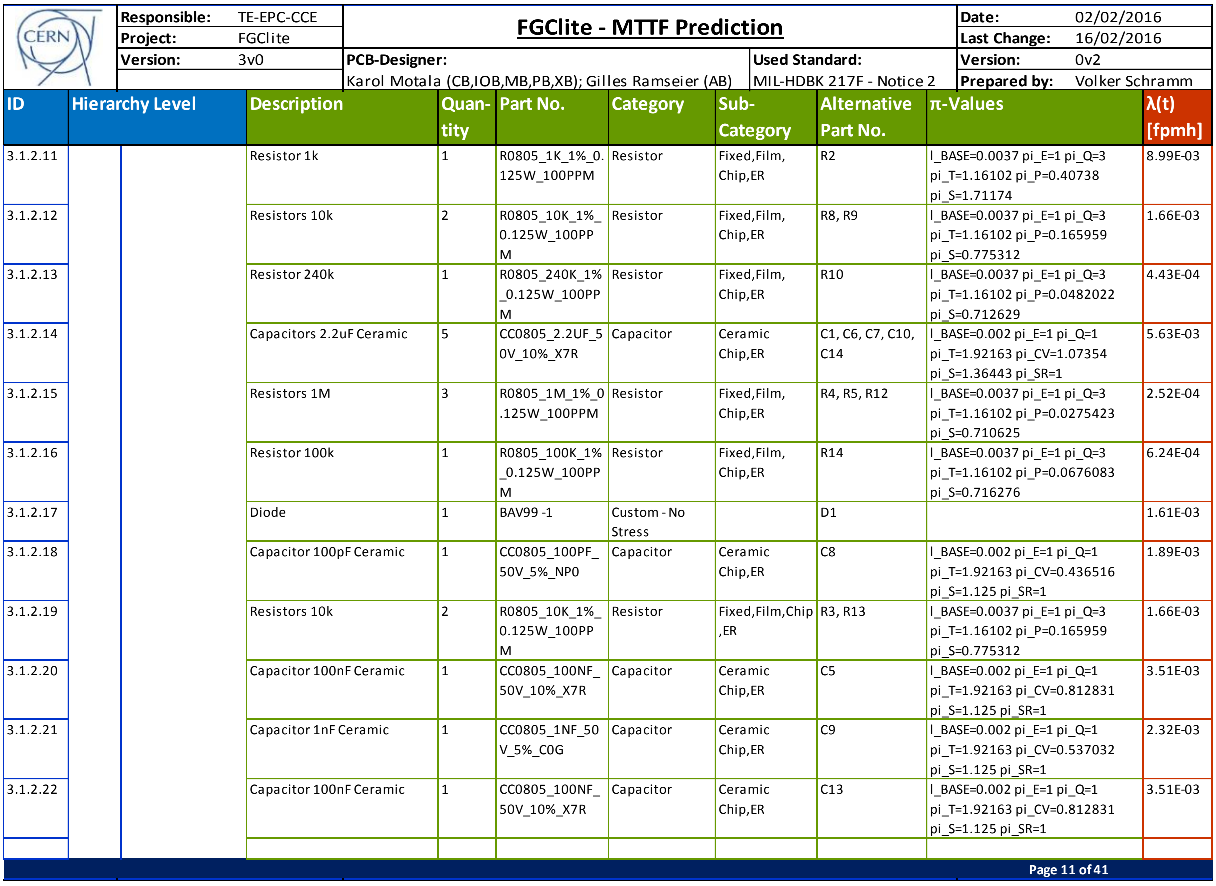

Responsible: TE-EPC-CCE	**FGClite - MTTF Prediction**		**Date:** 02/02/2016
Project: FGClite			**Last Change:** 16/02/2016
Version: 3v0	**PCB-Designer:**	**Used Standard:**	**Version:** 0v2
	Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)	MIL-HDBK 217F - Notice 2	**Prepared by:** Volker Schramm

ID	Hierarchy Level	Description	Quantity	Part No.	Category	Sub-Category	Alternative Part No.	π-Values	λ(t) [fpmh]
3.1.2.11		Resistor 1k	1	R0805_1K_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R2	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.40738 pi_S=1.71174	8.99E-03
3.1.2.12		Resistors 10k	2	R0805_10K_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R8, R9	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.165959 pi_S=0.775312	1.66E-03
3.1.2.13		Resistor 240k	1	R0805_240K_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R10	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0482022 pi_S=0.712629	4.43E-04
3.1.2.14		Capacitors 2.2uF Ceramic	5	CC0805_2.2UF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C1, C6, C7, C10, C14	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1.07354 pi_S=1.36443 pi_SR=1	5.63E-03
3.1.2.15		Resistors 1M	3	R0805_1M_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R4, R5, R12	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0275423 pi_S=0.710625	2.52E-04
3.1.2.16		Resistor 100k	1	R0805_100K_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R14	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0676083 pi_S=0.716276	6.24E-04
3.1.2.17		Diode	1	BAV99 -1	Custom - No Stress		D1		1.61E-03
3.1.2.18		Capacitor 100pF Ceramic	1	CC0805_100PF_50V_5%_NP0	Capacitor	Ceramic Chip,ER	C8	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.436516 pi_S=1.125 pi_SR=1	1.89E-03
3.1.2.19		Resistors 10k	2	R0805_10K_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R3, R13	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.165959 pi_S=0.775312	1.66E-03
3.1.2.20		Capacitor 100nF Ceramic	1	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C5	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.125 pi_SR=1	3.51E-03
3.1.2.21		Capacitor 1nF Ceramic	1	CC0805_1NF_50V_5%_C0G	Capacitor	Ceramic Chip,ER	C9	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.537032 pi_S=1.125 pi_SR=1	2.32E-03
3.1.2.22		Capacitor 100nF Ceramic	1	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C13	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.125 pi_SR=1	3.51E-03

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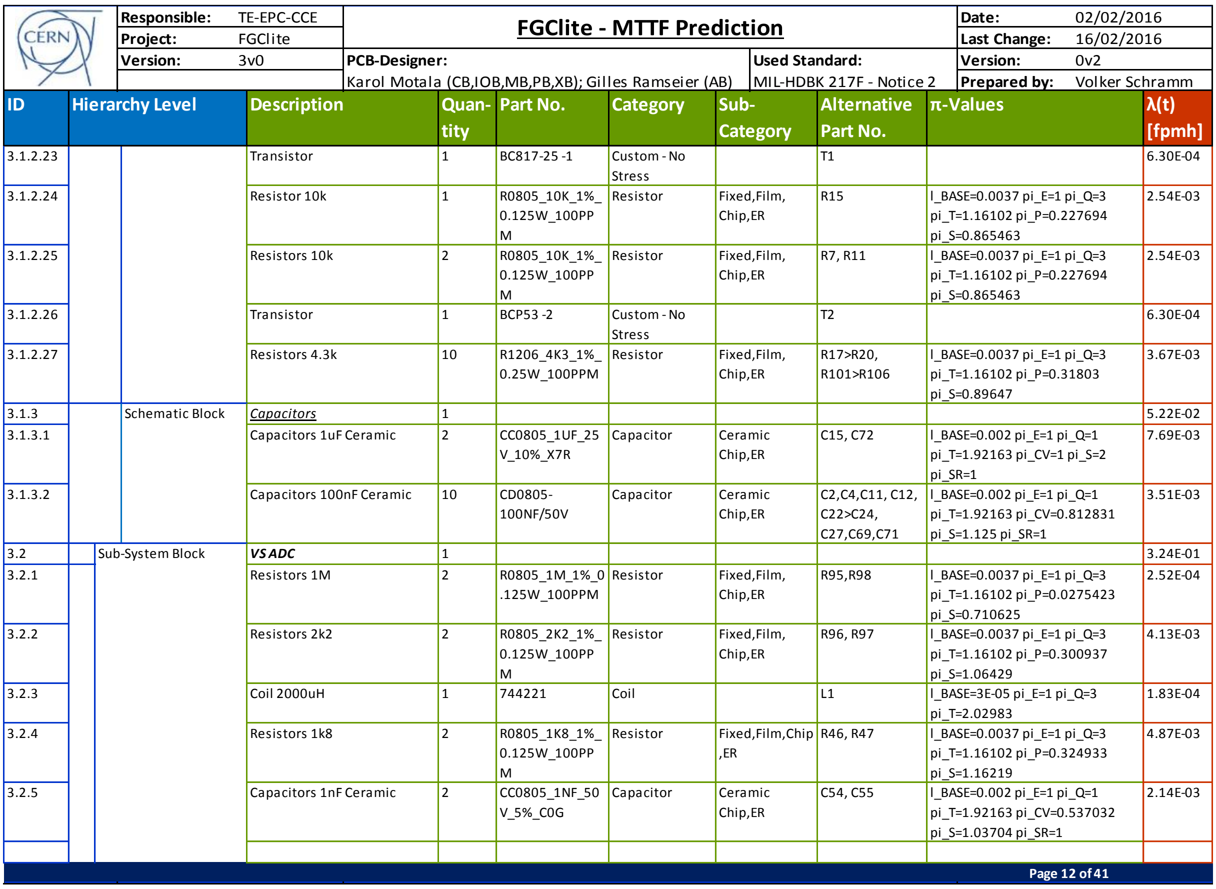

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - MTTF Prediction

PCB-Designer:
Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)

Used Standard:
MIL-HDBK 217F - Notice 2

Date: 02/02/2016
Last Change: 16/02/2016
Version: 0v2
Prepared by: Volker Schramm

ID	Hierarchy Level	Description	Quantity	Part No.	Category	Sub-Category	Alternative Part No.	π-Values	λ(t) [fpmh]
3.1.2.23		Transistor	1	BC817-25 -1	Custom - No Stress		T1		6.30E-04
3.1.2.24		Resistor 10k	1	R0805_10K_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R15	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.227694 pi_S=0.865463	2.54E-03
3.1.2.25		Resistors 10k	2	R0805_10K_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R7, R11	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.227694 pi_S=0.865463	2.54E-03
3.1.2.26		Transistor	1	BCP53 -2	Custom - No Stress		T2		6.30E-04
3.1.2.27		Resistors 4.3k	10	R1206_4K3_1%_0.25W_100PPM	Resistor	Fixed,Film, Chip,ER	R17>R20, R101>R106	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.31803 pi_S=0.89647	3.67E-03
3.1.3	Schematic Block	*Capacitors*	1						5.22E-02
3.1.3.1		Capacitors 1uF Ceramic	2	CC0805_1UF_25V_10%_X7R	Capacitor	Ceramic Chip,ER	C15, C72	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1 pi_S=2 pi_SR=1	7.69E-03
3.1.3.2		Capacitors 100nF Ceramic	10	CD0805-100NF/50V	Capacitor	Ceramic Chip,ER	C2,C4,C11, C12, C22>C24, C27,C69,C71	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.125 pi_SR=1	3.51E-03
3.2	Sub-System Block	***VS ADC***	1						3.24E-01
3.2.1		Resistors 1M	2	R0805_1M_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R95,R98	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0275423 pi_S=0.710625	2.52E-04
3.2.2		Resistors 2k2	2	R0805_2K2_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R96, R97	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.300937 pi_S=1.06429	4.13E-03
3.2.3		Coil 2000uH	1	744221	Coil		L1	l_BASE=3E-05 pi_E=1 pi_Q=3 pi_T=2.02983	1.83E-04
3.2.4		Resistors 1k8	2	R0805_1K8_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R46, R47	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.324933 pi_S=1.16219	4.87E-03
3.2.5		Capacitors 1nF Ceramic	2	CC0805_1NF_50V_5%_C0G	Capacitor	Ceramic Chip,ER	C54, C55	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.537032 pi_S=1.03704 pi_SR=1	2.14E-03

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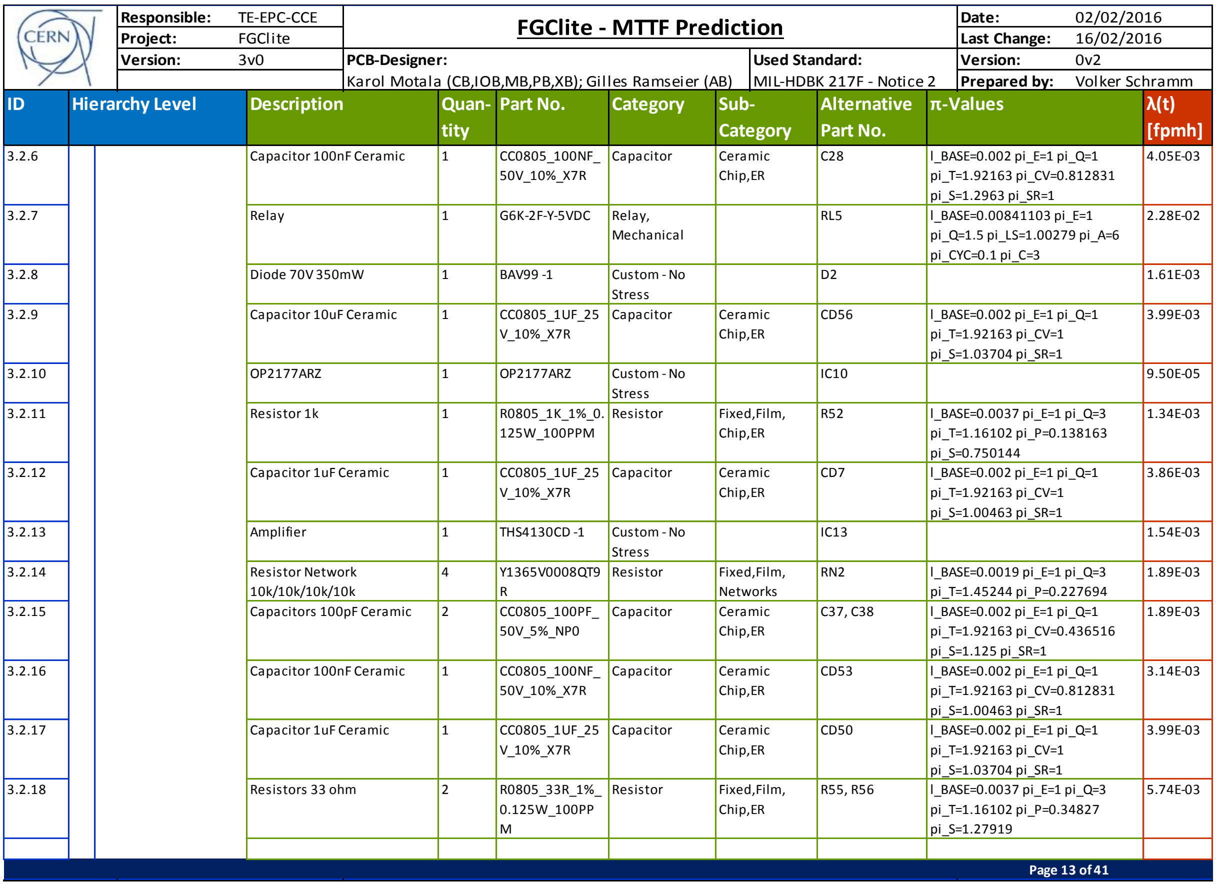

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - MTTF Prediction

PCB-Designer:
Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)

Used Standard:
MIL-HDBK 217F - Notice 2

Date: 02/02/2016
Last Change: 16/02/2016
Version: 0v2
Prepared by: Volker Schramm

ID	Hierarchy Level	Description	Quantity	Part No.	Category	Sub-Category	Alternative Part No.	π-Values	λ(t) [fpmh]
3.2.6		Capacitor 100nF Ceramic	1	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C28	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.2963 pi_SR=1	4.05E-03
3.2.7		Relay	1	G6K-2F-Y-5VDC	Relay, Mechanical		RL5	l_BASE=0.00841103 pi_E=1 pi_Q=1.5 pi_LS=1.00279 pi_A=6 pi_CYC=0.1 pi_C=3	2.28E-02
3.2.8		Diode 70V 350mW	1	BAV99 -1	Custom - No Stress		D2		1.61E-03
3.2.9		Capacitor 10uF Ceramic	1	CC0805_1UF_25V_10%_X7R	Capacitor	Ceramic Chip,ER	CD56	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1 pi_S=1.03704 pi_SR=1	3.99E-03
3.2.10		OP2177ARZ	1	OP2177ARZ	Custom - No Stress		IC10		9.50E-05
3.2.11		Resistor 1k	1	R0805_1K_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R52	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.138163 pi_S=0.750144	1.34E-03
3.2.12		Capacitor 1uF Ceramic	1	CC0805_1UF_25V_10%_X7R	Capacitor	Ceramic Chip,ER	CD7	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1 pi_S=1.00463 pi_SR=1	3.86E-03
3.2.13		Amplifier	1	THS4130CD -1	Custom - No Stress		IC13		1.54E-03
3.2.14		Resistor Network 10k/10k/10k/10k	4	Y1365V0008QT9R	Resistor	Fixed,Film, Networks	RN2	l_BASE=0.0019 pi_E=1 pi_Q=3 pi_T=1.45244 pi_P=0.227694	1.89E-03
3.2.15		Capacitors 100pF Ceramic	2	CC0805_100PF_50V_5%_NP0	Capacitor	Ceramic Chip,ER	C37, C38	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.436516 pi_S=1.125 pi_SR=1	1.89E-03
3.2.16		Capacitor 100nF Ceramic	1	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	CD53	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00463 pi_SR=1	3.14E-03
3.2.17		Capacitor 1uF Ceramic	1	CC0805_1UF_25V_10%_X7R	Capacitor	Ceramic Chip,ER	CD50	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1 pi_S=1.03704 pi_SR=1	3.99E-03
3.2.18		Resistors 33 ohm	2	R0805_33R_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R55, R56	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.34827 pi_S=1.27919	5.74E-03

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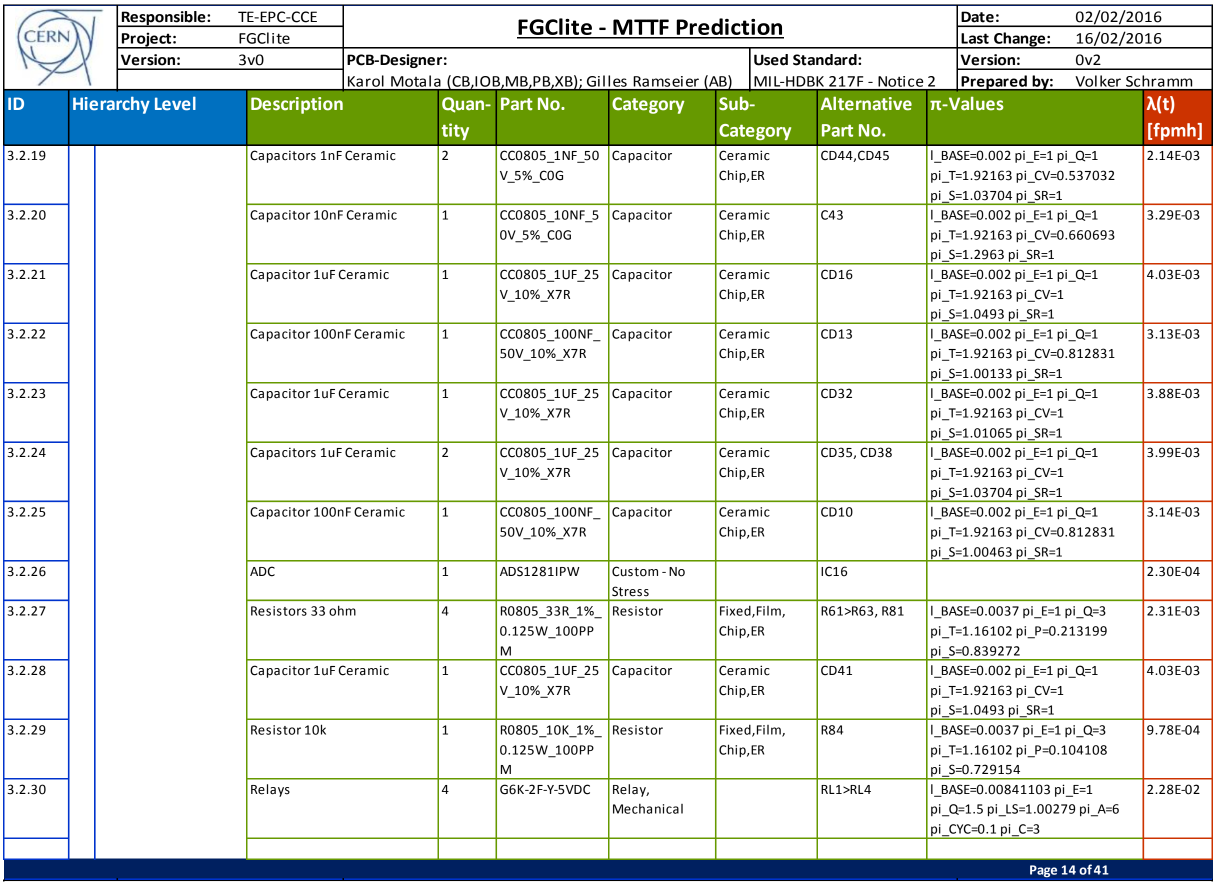

FGClite - MTTF Prediction

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0
PCB-Designer: Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)
Used Standard: MIL-HDBK 217F - Notice 2
Date: 02/02/2016
Last Change: 16/02/2016
Version: 0v2
Prepared by: Volker Schramm

ID	Hierarchy Level	Description	Quantity	Part No.	Category	Sub-Category	Alternative Part No.	π-Values	λ(t) [fpmh]
3.2.19		Capacitors 1nF Ceramic	2	CC0805_1NF_50V_5%_C0G	Capacitor	Ceramic Chip,ER	CD44,CD45	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.537032 pi_S=1.03704 pi_SR=1	2.14E-03
3.2.20		Capacitor 10nF Ceramic	1	CC0805_10NF_50V_5%_C0G	Capacitor	Ceramic Chip,ER	C43	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.660693 pi_S=1.2963 pi_SR=1	3.29E-03
3.2.21		Capacitor 1uF Ceramic	1	CC0805_1UF_25V_10%_X7R	Capacitor	Ceramic Chip,ER	CD16	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1 pi_S=1.0493 pi_SR=1	4.03E-03
3.2.22		Capacitor 100nF Ceramic	1	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	CD13	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00133 pi_SR=1	3.13E-03
3.2.23		Capacitor 1uF Ceramic	1	CC0805_1UF_25V_10%_X7R	Capacitor	Ceramic Chip,ER	CD32	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1 pi_S=1.01065 pi_SR=1	3.88E-03
3.2.24		Capacitors 1uF Ceramic	2	CC0805_1UF_25V_10%_X7R	Capacitor	Ceramic Chip,ER	CD35, CD38	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1 pi_S=1.03704 pi_SR=1	3.99E-03
3.2.25		Capacitor 100nF Ceramic	1	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	CD10	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00463 pi_SR=1	3.14E-03
3.2.26		ADC	1	ADS1281IPW	Custom - No Stress		IC16		2.30E-04
3.2.27		Resistors 33 ohm	4	R0805_33R_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R61>R63, R81	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.213199 pi_S=0.839272	2.31E-03
3.2.28		Capacitor 1uF Ceramic	1	CC0805_1UF_25V_10%_X7R	Capacitor	Ceramic Chip,ER	CD41	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1 pi_S=1.0493 pi_SR=1	4.03E-03
3.2.29		Resistor 10k	1	R0805_10K_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R84	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.104108 pi_S=0.729154	9.78E-04
3.2.30		Relays	4	G6K-2F-Y-5VDC	Relay, Mechanical		RL1>RL4	l_BASE=0.00841103 pi_E=1 pi_Q=1.5 pi_LS=1.00279 pi_A=6 pi_CYC=0.1 pi_C=3	2.28E-02

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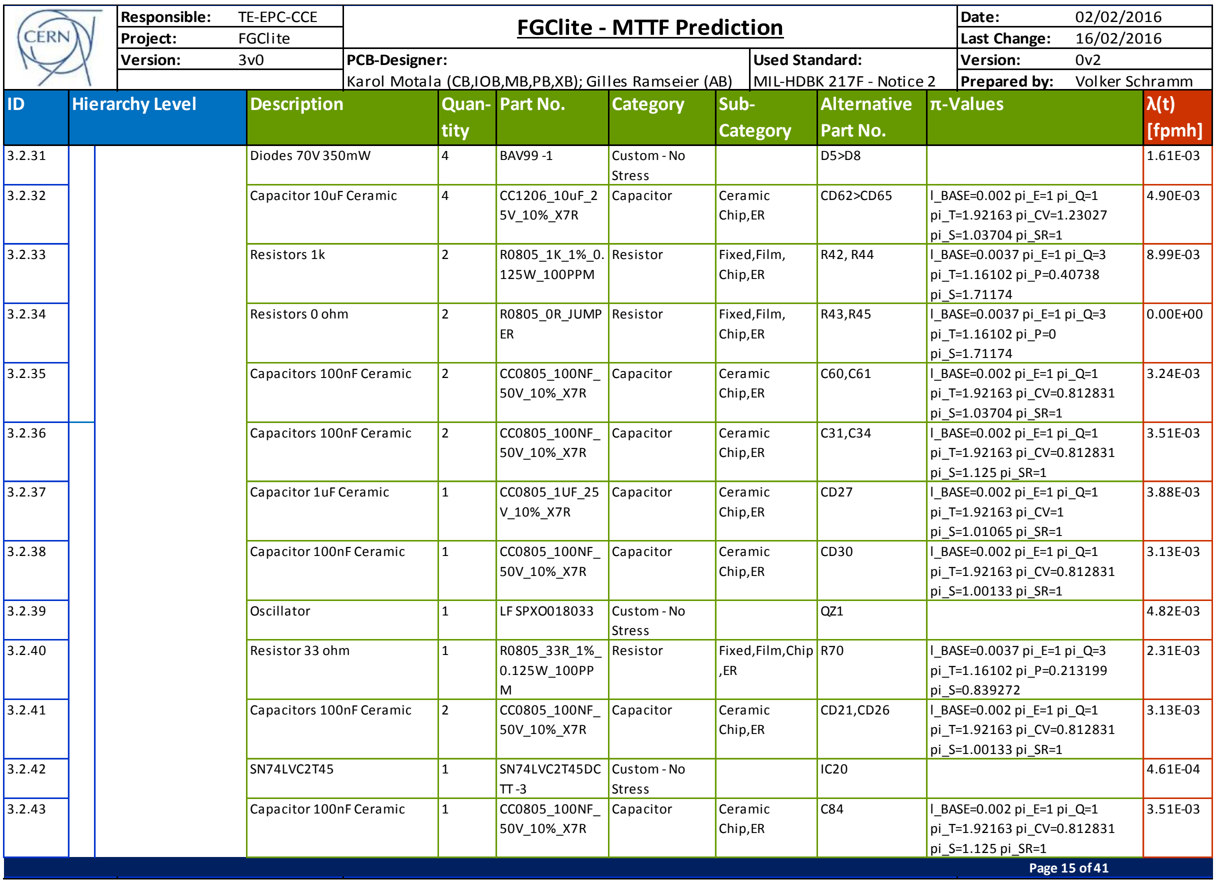

FGClite - MTTF Prediction

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0
PCB-Designer: Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)
Used Standard: MIL-HDBK 217F - Notice 2
Date: 02/02/2016
Last Change: 16/02/2016
Version: 0v2
Prepared by: Volker Schramm

ID	Hierarchy Level	Description	Quantity	Part No.	Category	Sub-Category	Alternative Part No.	π-Values	λ(t) [fpmh]
3.2.31		Diodes 70V 350mW	4	BAV99 -1	Custom - No Stress		D5>D8		1.61E-03
3.2.32		Capacitor 10uF Ceramic	4	CC1206_10uF_25V_10%_X7R	Capacitor	Ceramic Chip,ER	CD62>CD65	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1.23027 pi_S=1.03704 pi_SR=1	4.90E-03
3.2.33		Resistors 1k	2	R0805_1K_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R42, R44	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.40738 pi_S=1.71174	8.99E-03
3.2.34		Resistors 0 ohm	2	R0805_0R_JUMPER	Resistor	Fixed,Film, Chip,ER	R43,R45	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0 pi_S=1.71174	0.00E+00
3.2.35		Capacitors 100nF Ceramic	2	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C60,C61	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.03704 pi_SR=1	3.24E-03
3.2.36		Capacitors 100nF Ceramic	2	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C31,C34	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.125 pi_SR=1	3.51E-03
3.2.37		Capacitor 1uF Ceramic	1	CC0805_1UF_25V_10%_X7R	Capacitor	Ceramic Chip,ER	CD27	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1 pi_S=1.01065 pi_SR=1	3.88E-03
3.2.38		Capacitor 100nF Ceramic	1	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	CD30	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00133 pi_SR=1	3.13E-03
3.2.39		Oscillator	1	LF SPXO018033	Custom - No Stress		QZ1		4.82E-03
3.2.40		Resistor 33 ohm	1	R0805_33R_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R70	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.213199 pi_S=0.839272	2.31E-03
3.2.41		Capacitors 100nF Ceramic	2	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	CD21,CD26	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00133 pi_SR=1	3.13E-03
3.2.42		SN74LVC2T45	1	SN74LVC2T45DCTT-3	Custom - No Stress		IC20		4.61E-04
3.2.43		Capacitor 100nF Ceramic	1	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C84	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.125 pi_SR=1	3.51E-03

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Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - MTTF Prediction

PCB-Designer: Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)
Used Standard: MIL-HDBK 217F - Notice 2

Date: 02/02/2016
Last Change: 16/02/2016
Version: 0v2
Prepared by: Volker Schramm

ID	Hierarchy Level	Description	Quantity	Part No.	Category	Sub-Category	Alternative Part No.	π-Values	λ(t) [fpmh]
3.2.44		Capacitor 100nF Ceramic	1	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C81	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.125 pi_SR=1	3.51E-03
3.3	Sub-System Block	***DCCTA ADC***	1						1.42E-01
3.3.1		Resistors 1M	2	R0805_1M_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R91, R94	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0275423 pi_S=0.710625	2.52E-04
3.3.2		Resistors 2k2	2	R0805_2K2_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R92,R93	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.300937 pi_S=1.06429	4.13E-03
3.3.3		Coil 2000uH	1	744221	Coil		L2	l_BASE=3E-05 pi_E=1 pi_Q=3 pi_T=2.02983	1.83E-04
3.3.4		Resistors 1k8	2	R0805_1K8_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R48,R49	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.324933 pi_S=1.16219	4.87E-03
3.3.5		Capacitors 1nF Ceramic	2	CC0805_1NF_50V_5%_C0G	Capacitor	Ceramic Chip,ER	C56,C57	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.537032 pi_S=1.03704 pi_SR=1	2.14E-03
3.3.6		Capacitor 100nF Ceramic	1	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C29	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.2963 pi_SR=1	4.05E-03
3.3.7		Relay	1	G6K-2F-Y-5VDC	Relay, Mechanical		RL6	l_BASE=0.00841103 pi_E=1 pi_Q=1.5 pi_LS=1.00279 pi_A=6 pi_CYC=0.1 pi_C=3	2.28E-02
3.3.8		Diode 70V 350mW	1	BAV99 -1	Custom - No Stress		D3		1.61E-03
3.3.9		Capacitor 10uF Ceramic	1	CC0805_1UF_25V_10%_X7R	Capacitor	Ceramic Chip,ER	CD57	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1 pi_S=1.03704 pi_SR=1	3.99E-03
3.3.10		OP2177ARZ	1	OP2177ARZ	Custom - No Stress		IC11		9.50E-05
3.3.11		Resistor 1k	1	R0805_1K_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R53	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.138163 pi_S=0.750144	1.34E-03

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Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - MTTF Prediction

PCB-Designer: Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)
Used Standard: MIL-HDBK 217F - Notice 2

Date: 02/02/2016
Last Change: 16/02/2016
Version: 0v2
Prepared by: Volker Schramm

ID	Hierarchy Level	Description	Quantity	Part No.	Category	Sub-Category	Alternative Part No.	π-Values	λ(t) [fpmh]
3.3.12		Capacitor 1uF Ceramic	1	CC0805_1UF_25V_10%_X7R	Capacitor	Ceramic Chip,ER	CD8	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1 pi_S=1.00463 pi_SR=1	3.86E-03
3.3.13		Amplifier	1	THS4130CD -1	Custom - No Stress		IC14		1.54E-03
3.3.14		Resistor Network 10k/10k/10k/10k	4	Y1365V0008QT9R	Resistor	Fixed,Film, Networks	RN3	l_BASE=0.0019 pi_E=1 pi_Q=3 pi_T=1.45244 pi_P=0.227694	1.89E-03
3.3.15		Capacitors 100pF Ceramic	2	CC0805_100PF_50V_5%_NP0	Capacitor	Ceramic Chip,ER	C39,C40	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.436516 pi_S=1.125 pi_SR=1	1.89E-03
3.3.16		Capacitor 100nF Ceramic	1	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	CD54	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00463 pi_SR=1	3.14E-03
3.3.17		Capacitor 1uF Ceramic	1	CC0805_1UF_25V_10%_X7R	Capacitor	Ceramic Chip,ER	CD51	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1 pi_S=1.03704 pi_SR=1	3.99E-03
3.3.18		Resistors 33 ohm	2	R0805_33R_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R57,R58	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.34827 pi_S=1.27919	5.74E-03
3.3.19		Capacitors 1nF Ceramic	2	CC0805_1NF_50V_5%_C0G	Capacitor	Ceramic Chip,ER	CD46,CD47	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.537032 pi_S=1.03704 pi_SR=1	2.14E-03
3.3.20		Capacitor 10nF Ceramic	1	CC0805_10NF_50V_5%_C0G	Capacitor	Ceramic Chip,ER	C44	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.660693 pi_S=1.2963 pi_SR=1	3.29E-03
3.3.21		Capacitor 1uF Ceramic	1	CC0805_1UF_25V_10%_X7R	Capacitor	Ceramic Chip,ER	CD17	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1 pi_S=1.0493 pi_SR=1	4.03E-03
3.3.22		Capacitor 100nF Ceramic	1	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	CD14	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00133 pi_SR=1	3.13E-03
3.3.23		Capacitor 1uF Ceramic	1	CC0805_1UF_25V_10%_X7R	Capacitor	Ceramic Chip,ER	CD33	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1 pi_S=1.01065 pi_SR=1	3.88E-03

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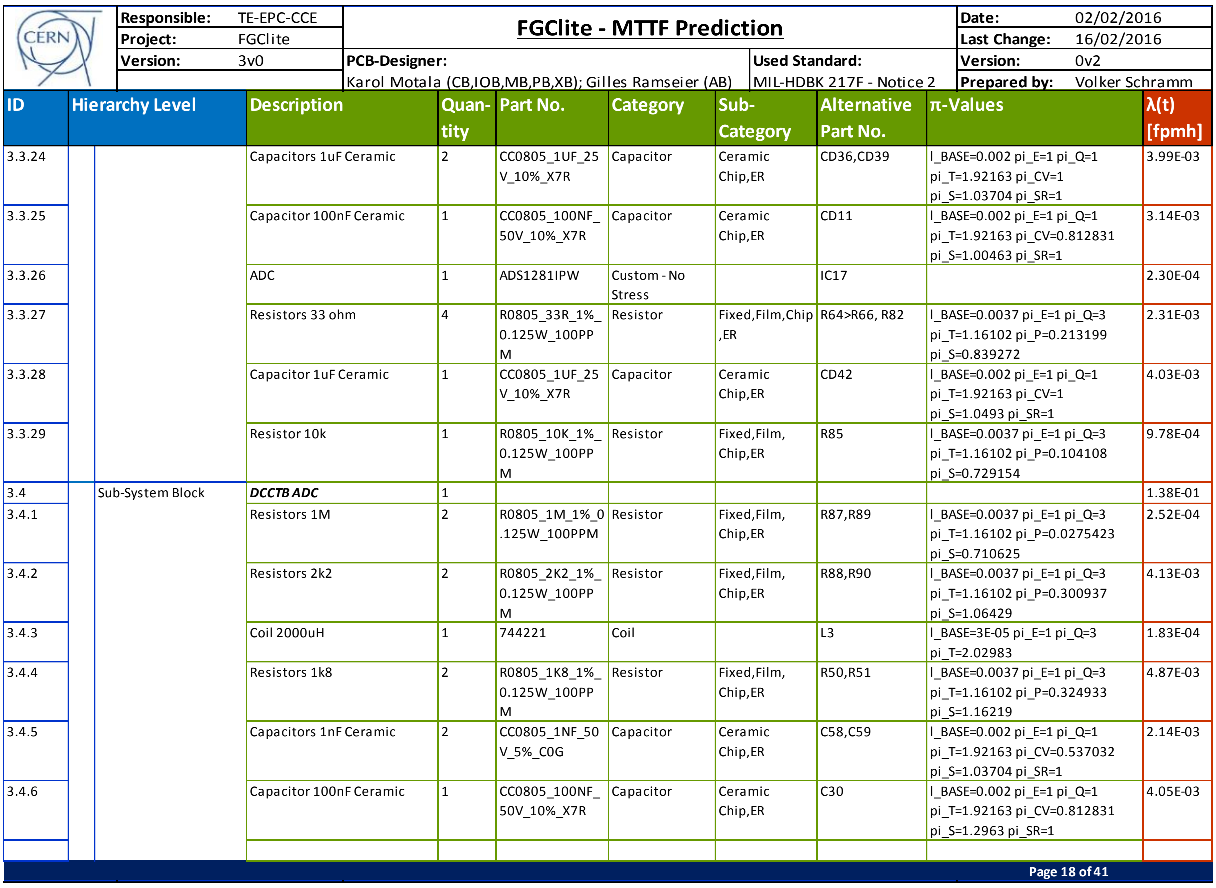

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - MTTF Prediction

PCB-Designer:
Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)

Used Standard:
MIL-HDBK 217F - Notice 2

Date: 02/02/2016
Last Change: 16/02/2016
Version: 0v2
Prepared by: Volker Schramm

ID	Hierarchy Level	Description	Quantity	Part No.	Category	Sub-Category	Alternative Part No.	π-Values	λ(t) [fpmh]
3.3.24		Capacitors 1uF Ceramic	2	CC0805_1UF_25V_10%_X7R	Capacitor	Ceramic Chip,ER	CD36,CD39	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1 pi_S=1.03704 pi_SR=1	3.99E-03
3.3.25		Capacitor 100nF Ceramic	1	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	CD11	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00463 pi_SR=1	3.14E-03
3.3.26		ADC	1	ADS1281IPW	Custom - No Stress		IC17		2.30E-04
3.3.27		Resistors 33 ohm	4	R0805_33R_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R64>R66, R82	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.213199 pi_S=0.839272	2.31E-03
3.3.28		Capacitor 1uF Ceramic	1	CC0805_1UF_25V_10%_X7R	Capacitor	Ceramic Chip,ER	CD42	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1 pi_S=1.0493 pi_SR=1	4.03E-03
3.3.29		Resistor 10k	1	R0805_10K_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R85	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.104108 pi_S=0.729154	9.78E-04
3.4	Sub-System Block	***DCCTB ADC***	1						1.38E-01
3.4.1		Resistors 1M	2	R0805_1M_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R87,R89	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0275423 pi_S=0.710625	2.52E-04
3.4.2		Resistors 2k2	2	R0805_2K2_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R88,R90	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.300937 pi_S=1.06429	4.13E-03
3.4.3		Coil 2000uH	1	744221	Coil		L3	l_BASE=3E-05 pi_E=1 pi_Q=3 pi_T=2.02983	1.83E-04
3.4.4		Resistors 1k8	2	R0805_1K8_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R50,R51	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.324933 pi_S=1.16219	4.87E-03
3.4.5		Capacitors 1nF Ceramic	2	CC0805_1NF_50V_5%_C0G	Capacitor	Ceramic Chip,ER	C58,C59	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.537032 pi_S=1.03704 pi_SR=1	2.14E-03
3.4.6		Capacitor 100nF Ceramic	1	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C30	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.2963 pi_SR=1	4.05E-03

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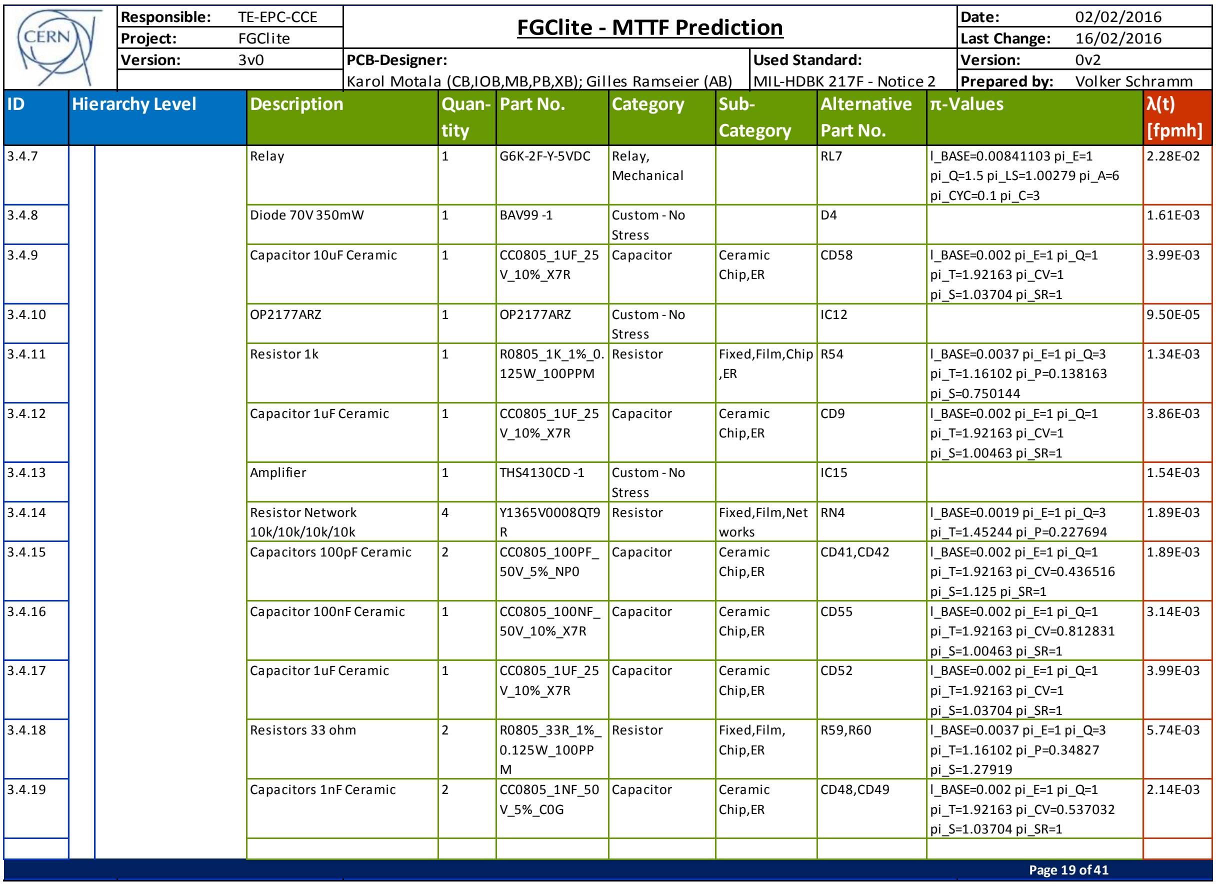

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - MTTF Prediction

PCB-Designer:
Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)

Used Standard:
MIL-HDBK 217F - Notice 2

Date: 02/02/2016
Last Change: 16/02/2016
Version: 0v2
Prepared by: Volker Schramm

ID	Hierarchy Level	Description	Quantity	Part No.	Category	Sub-Category	Alternative Part No.	π-Values	λ(t) [fpmh]
3.4.7		Relay	1	G6K-2F-Y-5VDC	Relay, Mechanical		RL7	l_BASE=0.00841103 pi_E=1 pi_Q=1.5 pi_LS=1.00279 pi_A=6 pi_CYC=0.1 pi_C=3	2.28E-02
3.4.8		Diode 70V 350mW	1	BAV99 -1	Custom - No Stress		D4		1.61E-03
3.4.9		Capacitor 10uF Ceramic	1	CC0805_1UF_25V_10%_X7R	Capacitor	Ceramic Chip,ER	CD58	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1 pi_S=1.03704 pi_SR=1	3.99E-03
3.4.10		OP2177ARZ	1	OP2177ARZ	Custom - No Stress		IC12		9.50E-05
3.4.11		Resistor 1k	1	R0805_1K_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R54	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.138163 pi_S=0.750144	1.34E-03
3.4.12		Capacitor 1uF Ceramic	1	CC0805_1UF_25V_10%_X7R	Capacitor	Ceramic Chip,ER	CD9	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1 pi_S=1.00463 pi_SR=1	3.86E-03
3.4.13		Amplifier	1	THS4130CD -1	Custom - No Stress		IC15		1.54E-03
3.4.14		Resistor Network 10k/10k/10k/10k	4	Y1365V0008QT9R	Resistor	Fixed,Film,Networks	RN4	l_BASE=0.0019 pi_E=1 pi_Q=3 pi_T=1.45244 pi_P=0.227694	1.89E-03
3.4.15		Capacitors 100pF Ceramic	2	CC0805_100PF_50V_5%_NP0	Capacitor	Ceramic Chip,ER	CD41,CD42	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.436516 pi_S=1.125 pi_SR=1	1.89E-03
3.4.16		Capacitor 100nF Ceramic	1	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	CD55	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00463 pi_SR=1	3.14E-03
3.4.17		Capacitor 1uF Ceramic	1	CC0805_1UF_25V_10%_X7R	Capacitor	Ceramic Chip,ER	CD52	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1 pi_S=1.03704 pi_SR=1	3.99E-03
3.4.18		Resistors 33 ohm	2	R0805_33R_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R59,R60	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.34827 pi_S=1.27919	5.74E-03
3.4.19		Capacitors 1nF Ceramic	2	CC0805_1NF_50V_5%_C0G	Capacitor	Ceramic Chip,ER	CD48,CD49	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.537032 pi_S=1.03704 pi_SR=1	2.14E-03

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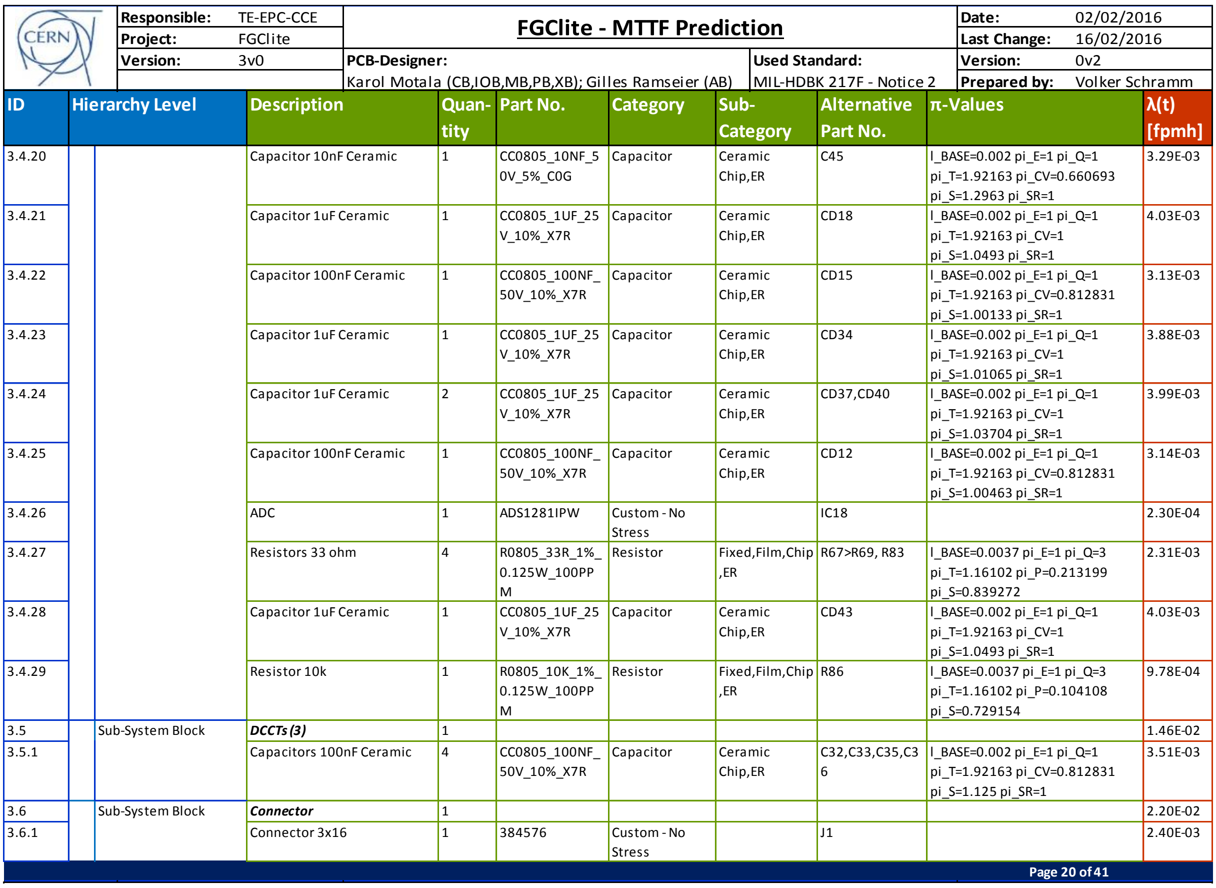

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - MTTF Prediction

PCB-Designer: Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)
Used Standard: MIL-HDBK 217F - Notice 2

Date: 02/02/2016
Last Change: 16/02/2016
Version: 0v2
Prepared by: Volker Schramm

ID	Hierarchy Level	Description	Quan-tity	Part No.	Category	Sub-Category	Alternative Part No.	π-Values	λ(t) [fpmh]
3.4.20		Capacitor 10nF Ceramic	1	CC0805_10NF_50V_5%_C0G	Capacitor	Ceramic Chip,ER	C45	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.660693 pi_S=1.2963 pi_SR=1	3.29E-03
3.4.21		Capacitor 1uF Ceramic	1	CC0805_1UF_25V_10%_X7R	Capacitor	Ceramic Chip,ER	CD18	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1 pi_S=1.0493 pi_SR=1	4.03E-03
3.4.22		Capacitor 100nF Ceramic	1	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	CD15	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00133 pi_SR=1	3.13E-03
3.4.23		Capacitor 1uF Ceramic	1	CC0805_1UF_25V_10%_X7R	Capacitor	Ceramic Chip,ER	CD34	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1 pi_S=1.01065 pi_SR=1	3.88E-03
3.4.24		Capacitor 1uF Ceramic	2	CC0805_1UF_25V_10%_X7R	Capacitor	Ceramic Chip,ER	CD37,CD40	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1 pi_S=1.03704 pi_SR=1	3.99E-03
3.4.25		Capacitor 100nF Ceramic	1	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	CD12	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00463 pi_SR=1	3.14E-03
3.4.26		ADC	1	ADS1281IPW	Custom - No Stress		IC18		2.30E-04
3.4.27		Resistors 33 ohm	4	R0805_33R_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R67>R69, R83	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.213199 pi_S=0.839272	2.31E-03
3.4.28		Capacitor 1uF Ceramic	1	CC0805_1UF_25V_10%_X7R	Capacitor	Ceramic Chip,ER	CD43	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1 pi_S=1.0493 pi_SR=1	4.03E-03
3.4.29		Resistor 10k	1	R0805_10K_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R86	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.104108 pi_S=0.729154	9.78E-04
3.5	Sub-System Block	***DCCTs (3)***	1						1.46E-02
3.5.1		Capacitors 100nF Ceramic	4	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C32,C33,C35,C36	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.125 pi_SR=1	3.51E-03
3.6	Sub-System Block	***Connector***	1						2.20E-02
3.6.1		Connector 3x16	1	384576	Custom - No Stress		J1		2.40E-03

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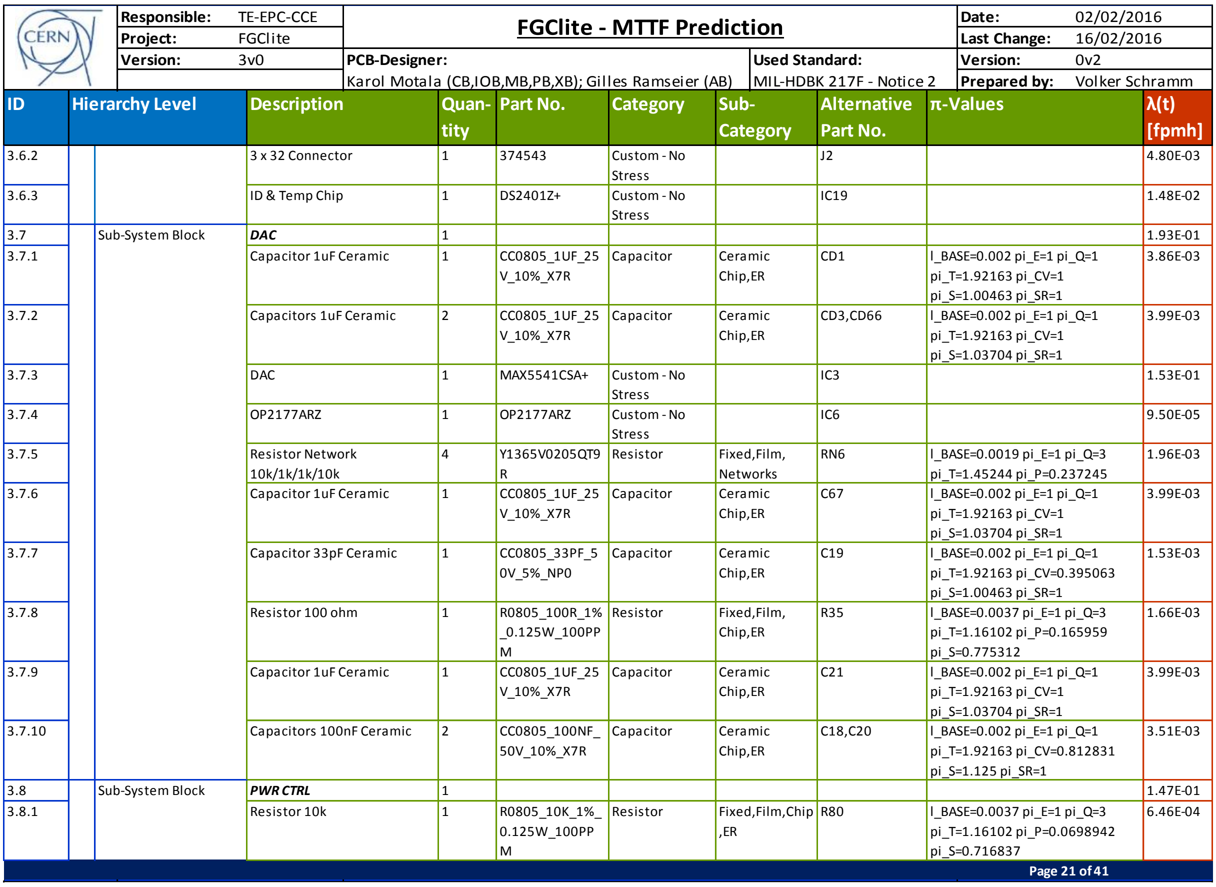

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - MTTF Prediction

PCB-Designer: Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)
Used Standard: MIL-HDBK 217F - Notice 2

Date: 02/02/2016
Last Change: 16/02/2016
Version: 0v2
Prepared by: Volker Schramm

ID	Hierarchy Level	Description	Quan-tity	Part No.	Category	Sub-Category	Alternative Part No.	π-Values	λ(t) [fpmh]
3.6.2		3 x 32 Connector	1	374543	Custom - No Stress		J2		4.80E-03
3.6.3		ID & Temp Chip	1	DS2401Z+	Custom - No Stress		IC19		1.48E-02
3.7	Sub-System Block	***DAC***	1						1.93E-01
3.7.1		Capacitor 1uF Ceramic	1	CC0805_1UF_25V_10%_X7R	Capacitor	Ceramic Chip,ER	CD1	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1 pi_S=1.00463 pi_SR=1	3.86E-03
3.7.2		Capacitors 1uF Ceramic	2	CC0805_1UF_25V_10%_X7R	Capacitor	Ceramic Chip,ER	CD3,CD66	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1 pi_S=1.03704 pi_SR=1	3.99E-03
3.7.3		DAC	1	MAX5541CSA+	Custom - No Stress		IC3		1.53E-01
3.7.4		OP2177ARZ	1	OP2177ARZ	Custom - No Stress		IC6		9.50E-05
3.7.5		Resistor Network 10k/1k/1k/10k	4	Y1365V0205QT9R	Resistor	Fixed,Film, Networks	RN6	l_BASE=0.0019 pi_E=1 pi_Q=3 pi_T=1.45244 pi_P=0.237245	1.96E-03
3.7.6		Capacitor 1uF Ceramic	1	CC0805_1UF_25V_10%_X7R	Capacitor	Ceramic Chip,ER	C67	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1 pi_S=1.03704 pi_SR=1	3.99E-03
3.7.7		Capacitor 33pF Ceramic	1	CC0805_33PF_50V_5%_NP0	Capacitor	Ceramic Chip,ER	C19	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.395063 pi_S=1.00463 pi_SR=1	1.53E-03
3.7.8		Resistor 100 ohm	1	R0805_100R_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R35	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.165959 pi_S=0.775312	1.66E-03
3.7.9		Capacitor 1uF Ceramic	1	CC0805_1UF_25V_10%_X7R	Capacitor	Ceramic Chip,ER	C21	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1 pi_S=1.03704 pi_SR=1	3.99E-03
3.7.10		Capacitors 100nF Ceramic	2	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C18,C20	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.125 pi_SR=1	3.51E-03
3.8	Sub-System Block	***PWR CTRL***	1						1.47E-01
3.8.1		Resistor 10k	1	R0805_10K_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R80	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0698942 pi_S=0.716837	6.46E-04

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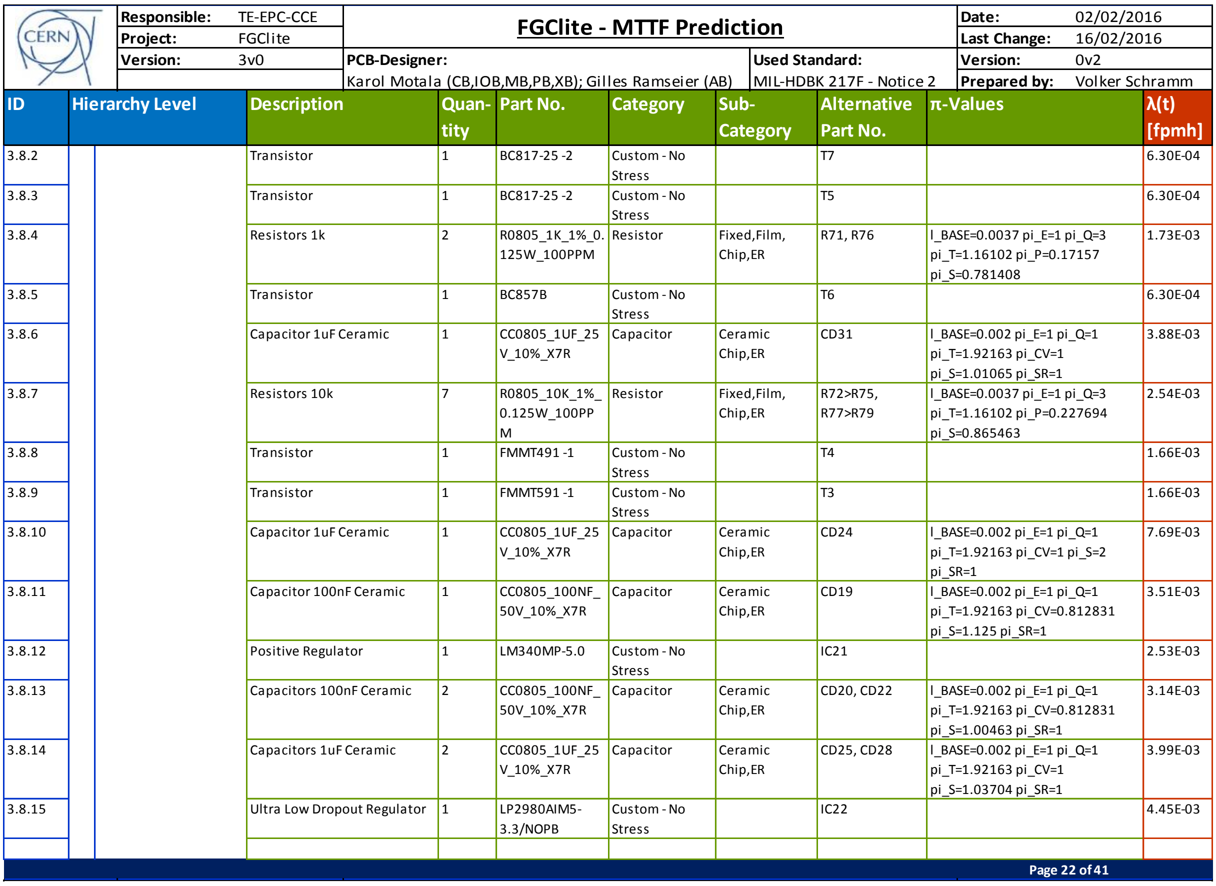

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - MTTF Prediction

PCB-Designer: Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)
Used Standard: MIL-HDBK 217F - Notice 2

Date: 02/02/2016
Last Change: 16/02/2016
Version: 0v2
Prepared by: Volker Schramm

ID	Hierarchy Level	Description	Quantity	Part No.	Category	Sub-Category	Alternative Part No.	π-Values	λ(t) [fpmh]
3.8.2		Transistor	1	BC817-25 -2	Custom - No Stress		T7		6.30E-04
3.8.3		Transistor	1	BC817-25 -2	Custom - No Stress		T5		6.30E-04
3.8.4		Resistors 1k	2	R0805_1K_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R71, R76	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.17157 pi_S=0.781408	1.73E-03
3.8.5		Transistor	1	BC857B	Custom - No Stress		T6		6.30E-04
3.8.6		Capacitor 1uF Ceramic	1	CC0805_1UF_25V_10%_X7R	Capacitor	Ceramic Chip,ER	CD31	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1 pi_S=1.01065 pi_SR=1	3.88E-03
3.8.7		Resistors 10k	7	R0805_10K_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R72>R75, R77>R79	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.227694 pi_S=0.865463	2.54E-03
3.8.8		Transistor	1	FMMT491 -1	Custom - No Stress		T4		1.66E-03
3.8.9		Transistor	1	FMMT591 -1	Custom - No Stress		T3		1.66E-03
3.8.10		Capacitor 1uF Ceramic	1	CC0805_1UF_25V_10%_X7R	Capacitor	Ceramic Chip,ER	CD24	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1 pi_S=2 pi_SR=1	7.69E-03
3.8.11		Capacitor 100nF Ceramic	1	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	CD19	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.125 pi_SR=1	3.51E-03
3.8.12		Positive Regulator	1	LM340MP-5.0	Custom - No Stress		IC21		2.53E-03
3.8.13		Capacitors 100nF Ceramic	2	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	CD20, CD22	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00463 pi_SR=1	3.14E-03
3.8.14		Capacitors 1uF Ceramic	2	CC0805_1UF_25V_10%_X7R	Capacitor	Ceramic Chip,ER	CD25, CD28	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1 pi_S=1.03704 pi_SR=1	3.99E-03
3.8.15		Ultra Low Dropout Regulator	1	LP2980AIM5-3.3/NOPB	Custom - No Stress		IC22		4.45E-03

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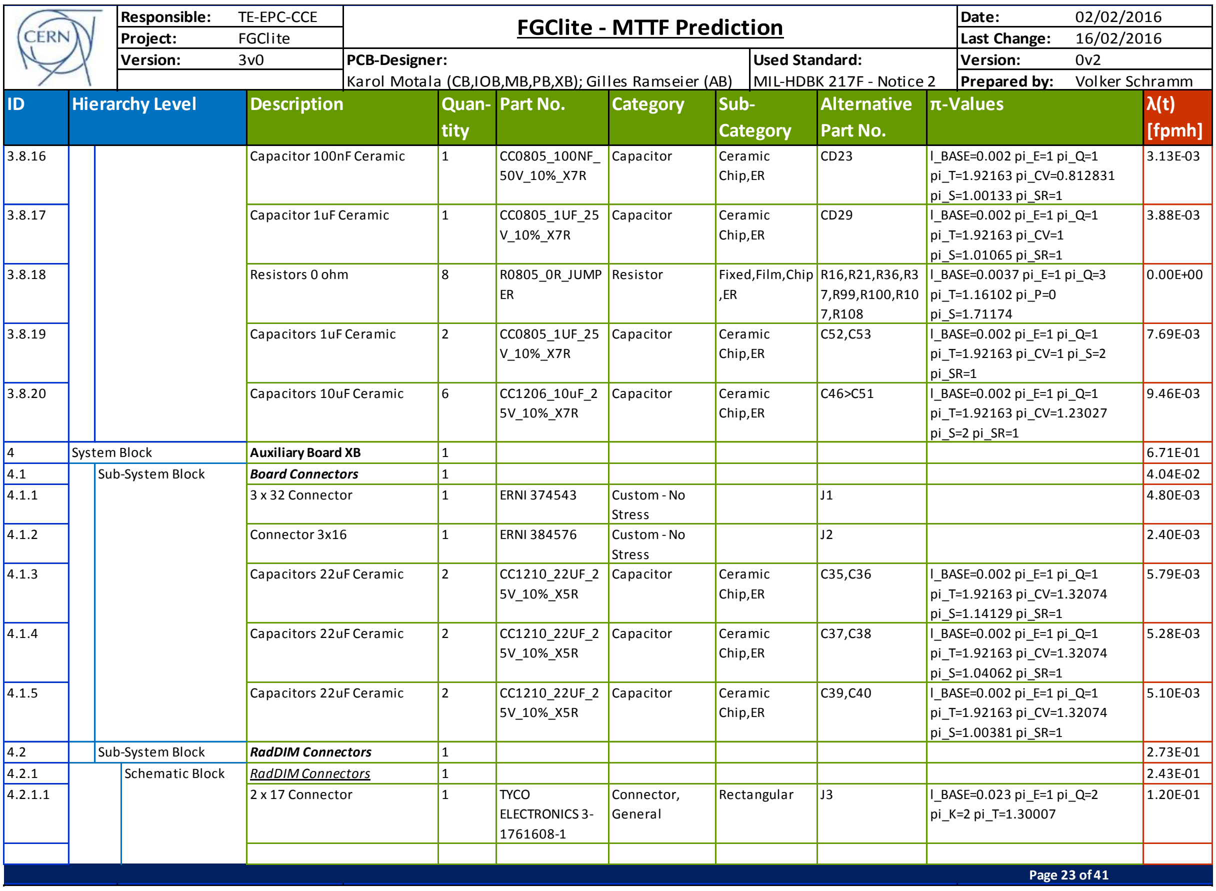

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - MTTF Prediction

PCB-Designer: Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)
Used Standard: MIL-HDBK 217F - Notice 2

Date: 02/02/2016
Last Change: 16/02/2016
Version: 0v2
Prepared by: Volker Schramm

ID	Hierarchy Level	Description	Quantity	Part No.	Category	Sub-Category	Alternative Part No.	π-Values	λ(t) [fpmh]
3.8.16		Capacitor 100nF Ceramic	1	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	CD23	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00133 pi_SR=1	3.13E-03
3.8.17		Capacitor 1uF Ceramic	1	CC0805_1UF_25V_10%_X7R	Capacitor	Ceramic Chip,ER	CD29	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1 pi_S=1.01065 pi_SR=1	3.88E-03
3.8.18		Resistors 0 ohm	8	R0805_0R_JUMPER	Resistor	Fixed,Film,Chip,ER	R16,R21,R36,R37,R99,R100,R107,R108	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0 pi_S=1.71174	0.00E+00
3.8.19		Capacitors 1uF Ceramic	2	CC0805_1UF_25V_10%_X7R	Capacitor	Ceramic Chip,ER	C52,C53	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1 pi_S=2 pi_SR=1	7.69E-03
3.8.20		Capacitors 10uF Ceramic	6	CC1206_10uF_25V_10%_X7R	Capacitor	Ceramic Chip,ER	C46>C51	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1.23027 pi_S=2 pi_SR=1	9.46E-03
4	System Block	**Auxiliary Board XB**	1						6.71E-01
4.1	Sub-System Block	***Board Connectors***	1						4.04E-02
4.1.1		3 x 32 Connector	1	ERNI 374543	Custom - No Stress		J1		4.80E-03
4.1.2		Connector 3x16	1	ERNI 384576	Custom - No Stress		J2		2.40E-03
4.1.3		Capacitors 22uF Ceramic	2	CC1210_22UF_25V_10%_X5R	Capacitor	Ceramic Chip,ER	C35,C36	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1.32074 pi_S=1.14129 pi_SR=1	5.79E-03
4.1.4		Capacitors 22uF Ceramic	2	CC1210_22UF_25V_10%_X5R	Capacitor	Ceramic Chip,ER	C37,C38	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1.32074 pi_S=1.04062 pi_SR=1	5.28E-03
4.1.5		Capacitors 22uF Ceramic	2	CC1210_22UF_25V_10%_X5R	Capacitor	Ceramic Chip,ER	C39,C40	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1.32074 pi_S=1.00381 pi_SR=1	5.10E-03
4.2	Sub-System Block	***RadDIM Connectors***	1						2.73E-01
4.2.1	Schematic Block	*RadDIM Connectors*	1						2.43E-01
4.2.1.1		2 x 17 Connector	1	TYCO ELECTRONICS 3-1761608-1	Connector, General	Rectangular	J3	l_BASE=0.023 pi_E=1 pi_Q=2 pi_K=2 pi_T=1.30007	1.20E-01

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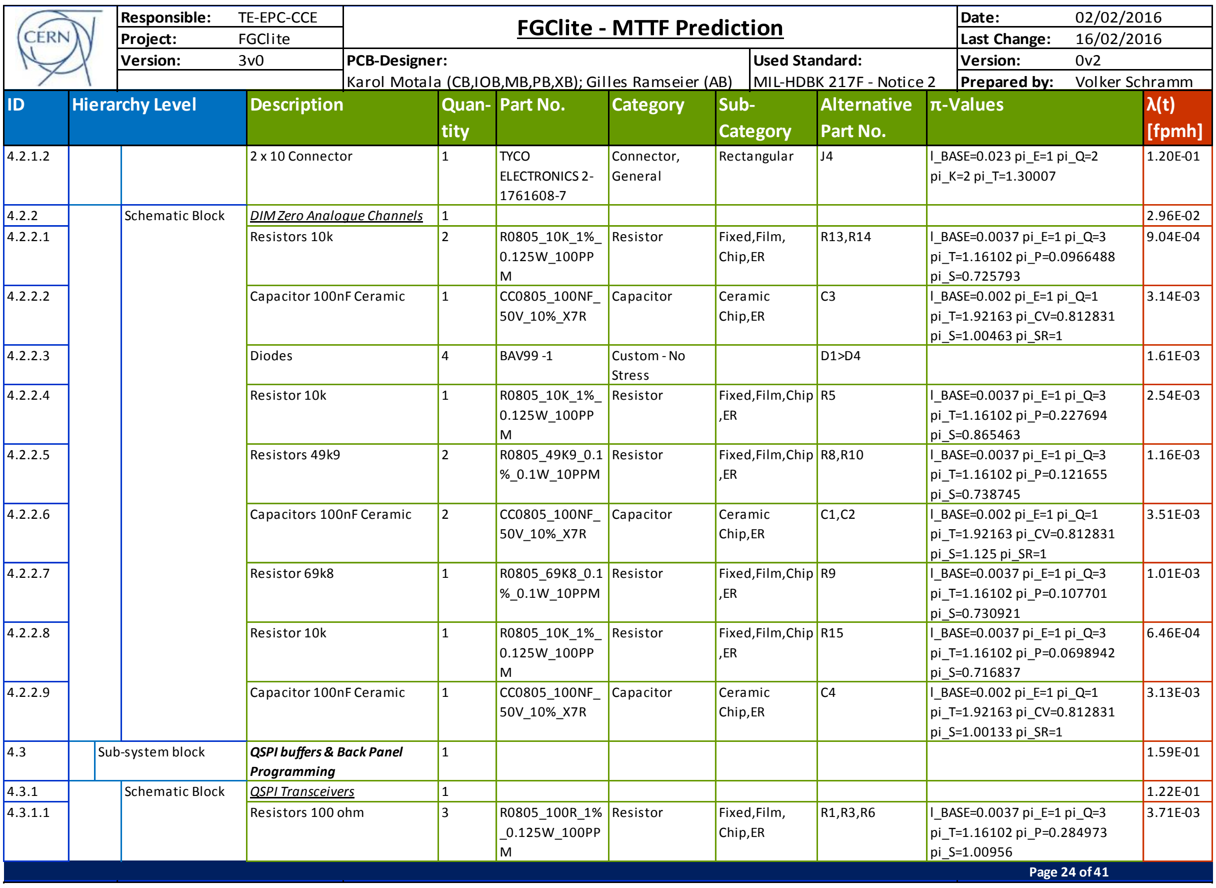

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - MTTF Prediction

PCB-Designer: Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)
Used Standard: MIL-HDBK 217F - Notice 2
Date: 02/02/2016
Last Change: 16/02/2016
Version: 0v2
Prepared by: Volker Schramm

ID	Hierarchy Level	Description	Quan-tity	Part No.	Category	Sub-Category	Alternative Part No.	π-Values	λ(t) [fpmh]
4.2.1.2		2 x 10 Connector	1	TYCO ELECTRONICS 2-1761608-7	Connector, General	Rectangular	J4	l_BASE=0.023 pi_E=1 pi_Q=2 pi_K=2 pi_T=1.30007	1.20E-01
4.2.2	Schematic Block	*DIM Zero Analogue Channels*	1						2.96E-02
4.2.2.1		Resistors 10k	2	R0805_10K_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R13,R14	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0966488 pi_S=0.725793	9.04E-04
4.2.2.2		Capacitor 100nF Ceramic	1	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C3	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00463 pi_SR=1	3.14E-03
4.2.2.3		Diodes	4	BAV99 -1	Custom - No Stress		D1>D4		1.61E-03
4.2.2.4		Resistor 10k	1	R0805_10K_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R5	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.227694 pi_S=0.865463	2.54E-03
4.2.2.5		Resistors 49k9	2	R0805_49K9_0.1%_0.1W_10PPM	Resistor	Fixed,Film,Chip,ER	R8,R10	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.121655 pi_S=0.738745	1.16E-03
4.2.2.6		Capacitors 100nF Ceramic	2	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C1,C2	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.125 pi_SR=1	3.51E-03
4.2.2.7		Resistor 69k8	1	R0805_69K8_0.1%_0.1W_10PPM	Resistor	Fixed,Film,Chip,ER	R9	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.107701 pi_S=0.730921	1.01E-03
4.2.2.8		Resistor 10k	1	R0805_10K_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R15	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0698942 pi_S=0.716837	6.46E-04
4.2.2.9		Capacitor 100nF Ceramic	1	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C4	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00133 pi_SR=1	3.13E-03
4.3	Sub-system block	***QSPI buffers & Back Panel Programming***	1						1.59E-01
4.3.1	Schematic Block	*QSPI Transceivers*	1						1.22E-01
4.3.1.1		Resistors 100 ohm	3	R0805_100R_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R1,R3,R6	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.284973 pi_S=1.00956	3.71E-03

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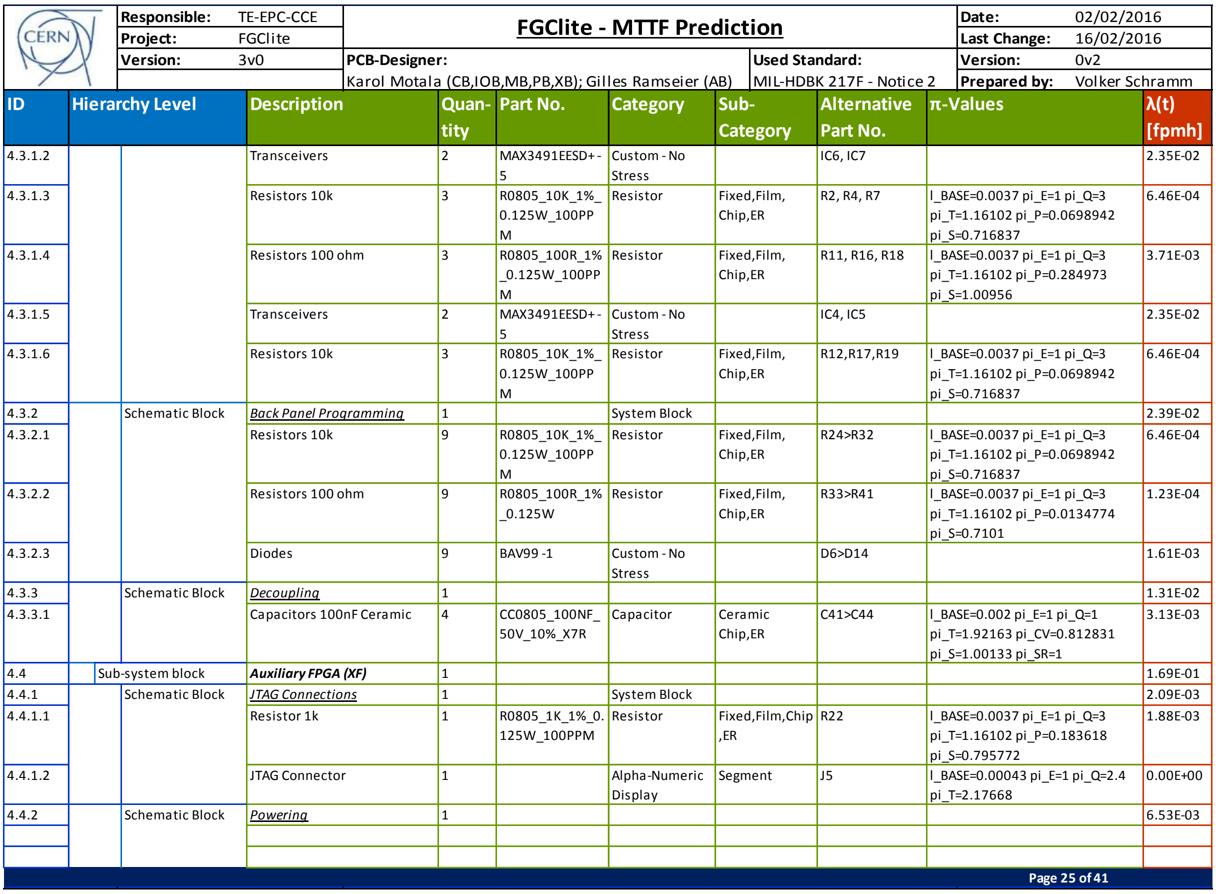

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - MTTF Prediction

PCB-Designer: Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)
Used Standard: MIL-HDBK 217F - Notice 2
Date: 02/02/2016
Last Change: 16/02/2016
Version: 0v2
Prepared by: Volker Schramm

ID	Hierarchy Level	Description	Quan-tity	Part No.	Category	Sub-Category	Alternative Part No.	π-Values	λ(t) [fpmh]
4.3.1.2		Transceivers	2	MAX3491EESD+-5	Custom - No Stress		IC6, IC7		2.35E-02
4.3.1.3		Resistors 10k	3	R0805_10K_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R2, R4, R7	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0698942 pi_S=0.716837	6.46E-04
4.3.1.4		Resistors 100 ohm	3	R0805_100R_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R11, R16, R18	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.284973 pi_S=1.00956	3.71E-03
4.3.1.5		Transceivers	2	MAX3491EESD+-5	Custom - No Stress		IC4, IC5		2.35E-02
4.3.1.6		Resistors 10k	3	R0805_10K_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R12,R17,R19	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0698942 pi_S=0.716837	6.46E-04
4.3.2	Schematic Block	*Back Panel Programming*	1		System Block				2.39E-02
4.3.2.1		Resistors 10k	9	R0805_10K_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R24>R32	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0698942 pi_S=0.716837	6.46E-04
4.3.2.2		Resistors 100 ohm	9	R0805_100R_1%_0.125W	Resistor	Fixed,Film,Chip,ER	R33>R41	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0134774 pi_S=0.7101	1.23E-04
4.3.2.3		Diodes	9	BAV99 -1	Custom - No Stress		D6>D14		1.61E-03
4.3.3	Schematic Block	*Decoupling*	1						1.31E-02
4.3.3.1		Capacitors 100nF Ceramic	4	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C41>C44	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00133 pi_SR=1	3.13E-03
4.4	Sub-system block	***Auxiliary FPGA (XF)***	1						1.69E-01
4.4.1	Schematic Block	*JTAG Connections*	1		System Block				2.09E-03
4.4.1.1		Resistor 1k	1	R0805_1K_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R22	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.183618 pi_S=0.795772	1.88E-03
4.4.1.2		JTAG Connector	1		Alpha-Numeric Display	Segment	J5	l_BASE=0.00043 pi_E=1 pi_Q=2.4 pi_T=2.17668	0.00E+00
4.4.2	Schematic Block	*Powering*	1						6.53E-03

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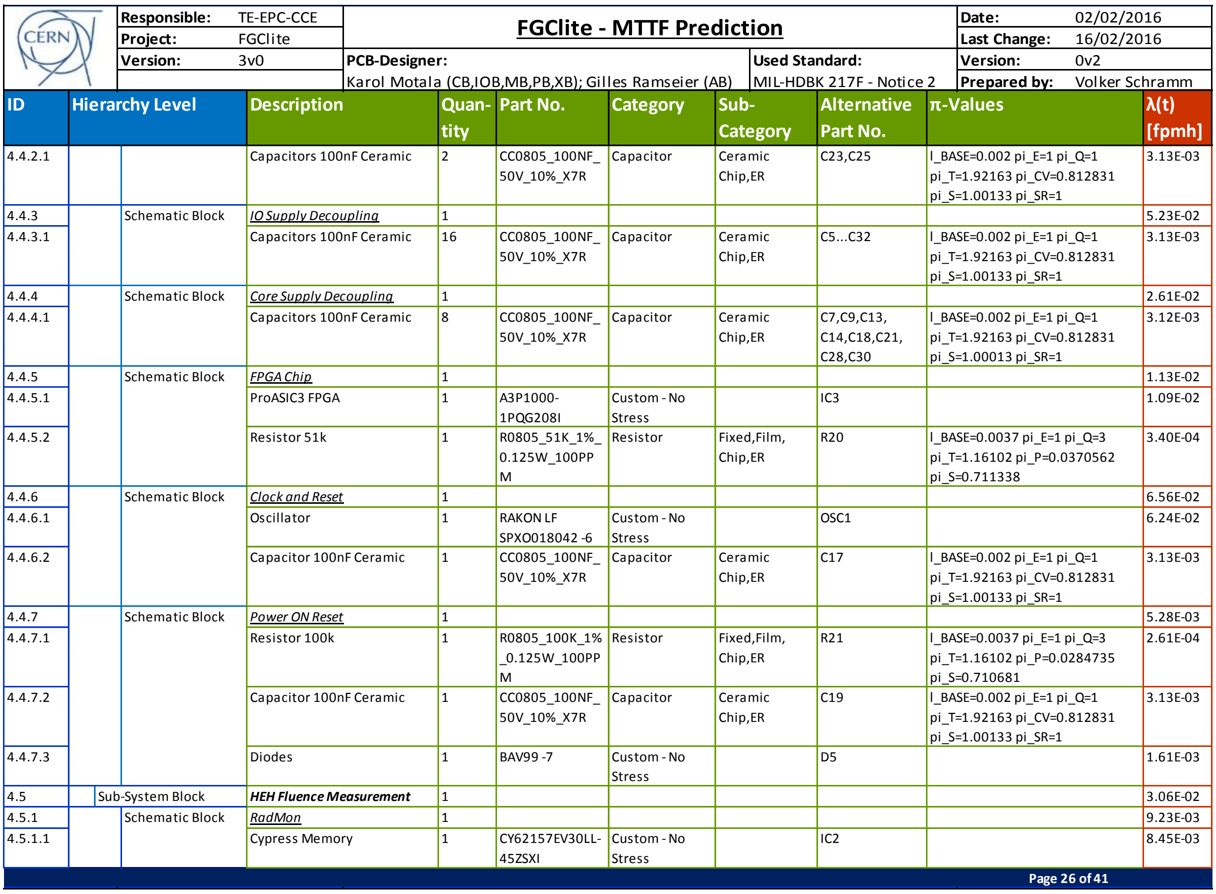

Responsible:	TE-EPC-CCE	**FGClite - MTTF Prediction**		**Date:**	02/02/2016
Project:	FGClite			**Last Change:**	16/02/2016
Version:	3v0	**PCB-Designer:**	**Used Standard:**	**Version:**	0v2
		Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)	MIL-HDBK 217F - Notice 2	**Prepared by:**	Volker Schramm

ID	Hierarchy Level	Description	Quantity	Part No.	Category	Sub-Category	Alternative Part No.	π-Values	λ(t) [fpmh]
4.4.2.1		Capacitors 100nF Ceramic	2	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C23,C25	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00133 pi_SR=1	3.13E-03
4.4.3	Schematic Block	*IO Supply Decoupling*	1						5.23E-02
4.4.3.1		Capacitors 100nF Ceramic	16	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C5...C32	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00133 pi_SR=1	3.13E-03
4.4.4	Schematic Block	*Core Supply Decoupling*	1						2.61E-02
4.4.4.1		Capacitors 100nF Ceramic	8	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C7,C9,C13, C14,C18,C21, C28,C30	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00013 pi_SR=1	3.12E-03
4.4.5	Schematic Block	*FPGA Chip*	1						1.13E-02
4.4.5.1		ProASIC3 FPGA	1	A3P1000-1PQG208I	Custom - No Stress		IC3		1.09E-02
4.4.5.2		Resistor 51k	1	R0805_51K_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R20	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0370562 pi_S=0.711338	3.40E-04
4.4.6	Schematic Block	*Clock and Reset*	1						6.56E-02
4.4.6.1		Oscillator	1	RAKON LF SPXO018042 -6	Custom - No Stress		OSC1		6.24E-02
4.4.6.2		Capacitor 100nF Ceramic	1	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C17	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00133 pi_SR=1	3.13E-03
4.4.7	Schematic Block	*Power ON Reset*	1						5.28E-03
4.4.7.1		Resistor 100k	1	R0805_100K_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R21	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0284735 pi_S=0.710681	2.61E-04
4.4.7.2		Capacitor 100nF Ceramic	1	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C19	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00133 pi_SR=1	3.13E-03
4.4.7.3		Diodes	1	BAV99 -7	Custom - No Stress		D5		1.61E-03
4.5	Sub-System Block	***HEH Fluence Measurement***	1						3.06E-02
4.5.1	Schematic Block	*RadMon*	1						9.23E-03
4.5.1.1		Cypress Memory	1	CY62157EV30LL-45ZSXI	Custom - No Stress		IC2		8.45E-03

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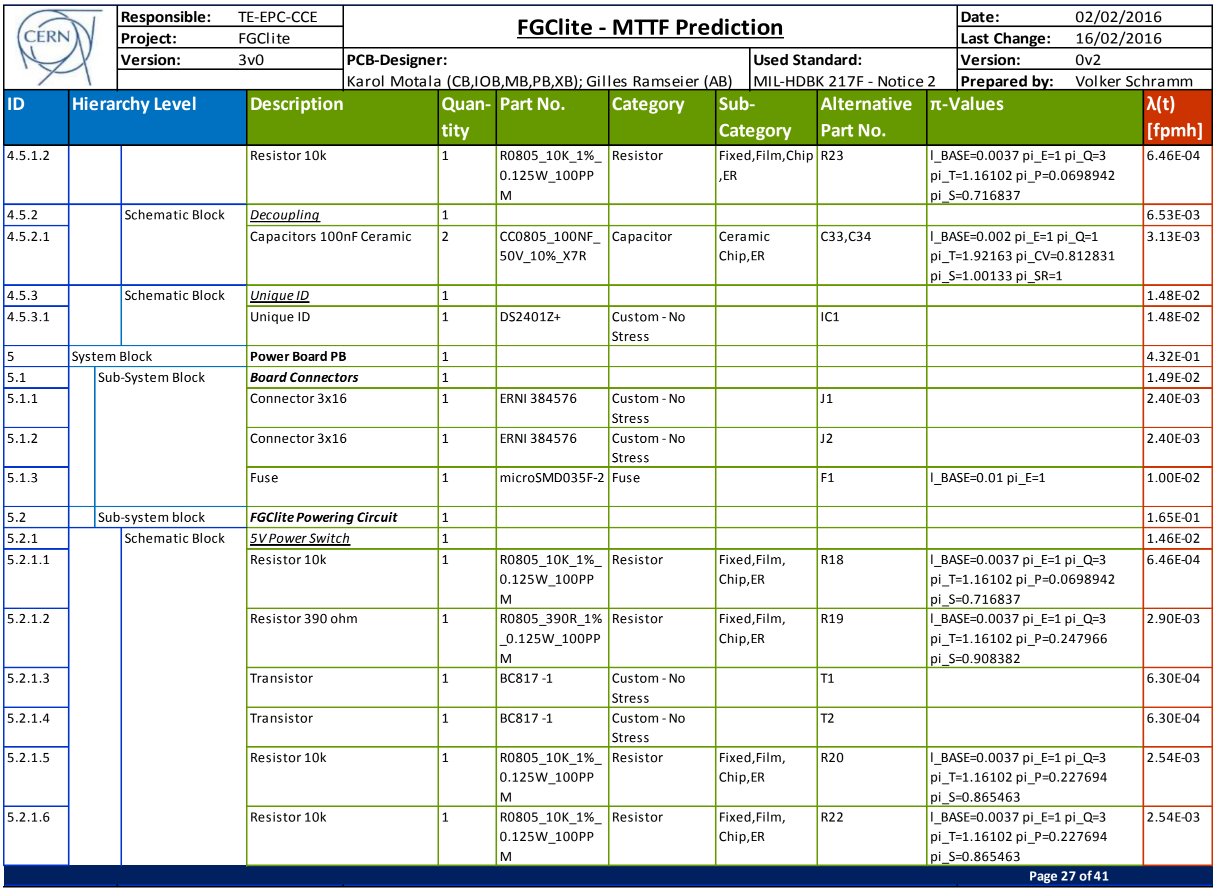

Responsible:	TE-EPC-CCE	**FGClite - MTTF Prediction**		**Date:**	02/02/2016
Project:	FGClite			**Last Change:**	16/02/2016
Version:	3v0	**PCB-Designer:**	**Used Standard:**	**Version:**	0v2
		Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)	MIL-HDBK 217F - Notice 2	**Prepared by:**	Volker Schramm

ID	Hierarchy Level	Description	Quantity	Part No.	Category	Sub-Category	Alternative Part No.	π-Values	λ(t) [fpmh]
4.5.1.2		Resistor 10k	1	R0805_10K_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R23	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0698942 pi_S=0.716837	6.46E-04
4.5.2	Schematic Block	*Decoupling*	1						6.53E-03
4.5.2.1		Capacitors 100nF Ceramic	2	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C33,C34	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00133 pi_SR=1	3.13E-03
4.5.3	Schematic Block	*Unique ID*	1						1.48E-02
4.5.3.1		Unique ID	1	DS2401Z+	Custom - No Stress		IC1		1.48E-02
5	System Block	**Power Board PB**	1						4.32E-01
5.1	Sub-System Block	***Board Connectors***	1						1.49E-02
5.1.1		Connector 3x16	1	ERNI 384576	Custom - No Stress		J1		2.40E-03
5.1.2		Connector 3x16	1	ERNI 384576	Custom - No Stress		J2		2.40E-03
5.1.3		Fuse	1	microSMD035F-2	Fuse		F1	l_BASE=0.01 pi_E=1	1.00E-02
5.2	Sub-system block	***FGClite Powering Circuit***	1						1.65E-01
5.2.1	Schematic Block	*5V Power Switch*	1						1.46E-02
5.2.1.1		Resistor 10k	1	R0805_10K_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R18	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0698942 pi_S=0.716837	6.46E-04
5.2.1.2		Resistor 390 ohm	1	R0805_390R_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R19	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.247966 pi_S=0.908382	2.90E-03
5.2.1.3		Transistor	1	BC817 -1	Custom - No Stress		T1		6.30E-04
5.2.1.4		Transistor	1	BC817 -1	Custom - No Stress		T2		6.30E-04
5.2.1.5		Resistor 10k	1	R0805_10K_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R20	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.227694 pi_S=0.865463	2.54E-03
5.2.1.6		Resistor 10k	1	R0805_10K_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R22	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.227694 pi_S=0.865463	2.54E-03

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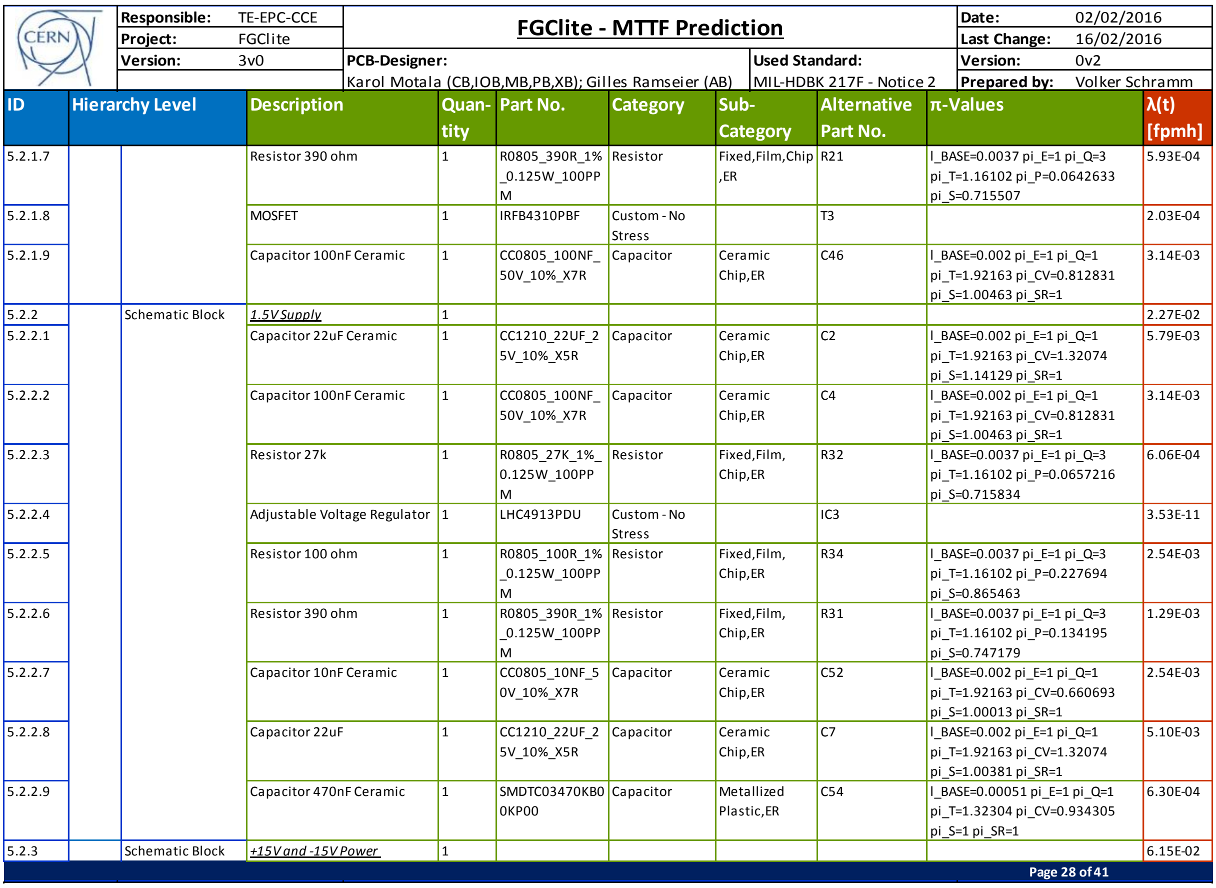

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - MTTF Prediction

PCB-Designer:
Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)

Used Standard:
MIL-HDBK 217F - Notice 2

Date: 02/02/2016
Last Change: 16/02/2016
Version: 0v2
Prepared by: Volker Schramm

ID	Hierarchy Level	Description	Quantity	Part No.	Category	Sub-Category	Alternative Part No.	π-Values	λ(t) [fpmh]
5.2.1.7		Resistor 390 ohm	1	R0805_390R_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R21	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0642633 pi_S=0.715507	5.93E-04
5.2.1.8		MOSFET	1	IRFB4310PBF	Custom - No Stress		T3		2.03E-04
5.2.1.9		Capacitor 100nF Ceramic	1	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C46	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00463 pi_SR=1	3.14E-03
5.2.2	Schematic Block	*1.5V Supply*	1						2.27E-02
5.2.2.1		Capacitor 22uF Ceramic	1	CC1210_22UF_25V_10%_X5R	Capacitor	Ceramic Chip,ER	C2	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1.32074 pi_S=1.14129 pi_SR=1	5.79E-03
5.2.2.2		Capacitor 100nF Ceramic	1	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C4	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00463 pi_SR=1	3.14E-03
5.2.2.3		Resistor 27k	1	R0805_27K_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R32	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0657216 pi_S=0.715834	6.06E-04
5.2.2.4		Adjustable Voltage Regulator	1	LHC4913PDU	Custom - No Stress		IC3		3.53E-11
5.2.2.5		Resistor 100 ohm	1	R0805_100R_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R34	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.227694 pi_S=0.865463	2.54E-03
5.2.2.6		Resistor 390 ohm	1	R0805_390R_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R31	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.134195 pi_S=0.747179	1.29E-03
5.2.2.7		Capacitor 10nF Ceramic	1	CC0805_10NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C52	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.660693 pi_S=1.00013 pi_SR=1	2.54E-03
5.2.2.8		Capacitor 22uF	1	CC1210_22UF_25V_10%_X5R	Capacitor	Ceramic Chip,ER	C7	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1.32074 pi_S=1.00381 pi_SR=1	5.10E-03
5.2.2.9		Capacitor 470nF Ceramic	1	SMDTC03470KB00KP00	Capacitor	Metallized Plastic,ER	C54	l_BASE=0.00051 pi_E=1 pi_Q=1 pi_T=1.32304 pi_CV=0.934305 pi_S=1 pi_SR=1	6.30E-04
5.2.3	Schematic Block	*+15V and -15V Power*	1						6.15E-02

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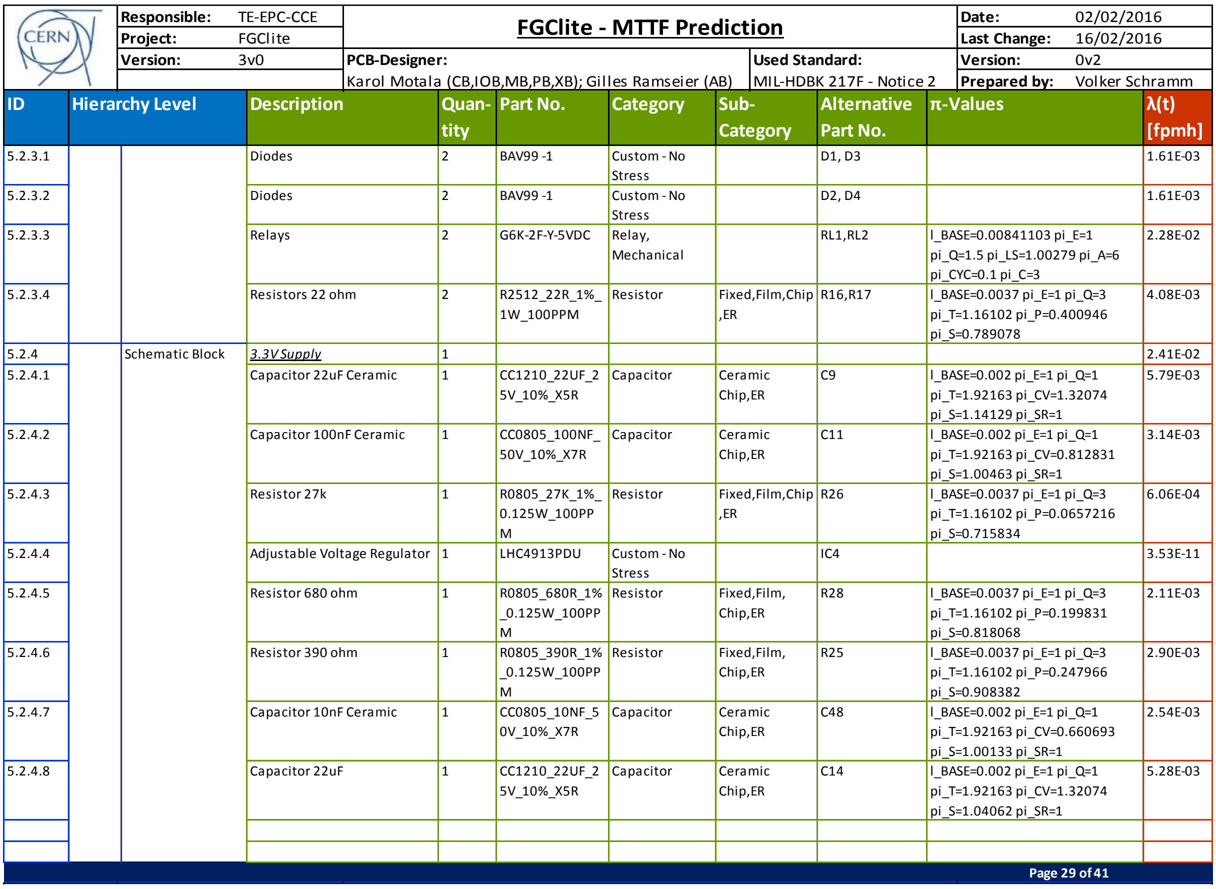

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - MTTF Prediction

PCB-Designer:
Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)

Used Standard:
MIL-HDBK 217F - Notice 2

Date: 02/02/2016
Last Change: 16/02/2016
Version: 0v2
Prepared by: Volker Schramm

ID	Hierarchy Level	Description	Quantity	Part No.	Category	Sub-Category	Alternative Part No.	π-Values	λ(t) [fpmh]
5.2.3.1		Diodes	2	BAV99 -1	Custom - No Stress		D1, D3		1.61E-03
5.2.3.2		Diodes	2	BAV99 -1	Custom - No Stress		D2, D4		1.61E-03
5.2.3.3		Relays	2	G6K-2F-Y-5VDC	Relay, Mechanical		RL1,RL2	l_BASE=0.00841103 pi_E=1 pi_Q=1.5 pi_LS=1.00279 pi_A=6 pi_CYC=0.1 pi_C=3	2.28E-02
5.2.3.4		Resistors 22 ohm	2	R2512_22R_1%_1W_100PPM	Resistor	Fixed,Film,Chip,ER	R16,R17	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.400946 pi_S=0.789078	4.08E-03
5.2.4	Schematic Block	*3.3V Supply*	1						2.41E-02
5.2.4.1		Capacitor 22uF Ceramic	1	CC1210_22UF_25V_10%_X5R	Capacitor	Ceramic Chip,ER	C9	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1.32074 pi_S=1.14129 pi_SR=1	5.79E-03
5.2.4.2		Capacitor 100nF Ceramic	1	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C11	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00463 pi_SR=1	3.14E-03
5.2.4.3		Resistor 27k	1	R0805_27K_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R26	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0657216 pi_S=0.715834	6.06E-04
5.2.4.4		Adjustable Voltage Regulator	1	LHC4913PDU	Custom - No Stress		IC4		3.53E-11
5.2.4.5		Resistor 680 ohm	1	R0805_680R_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R28	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.199831 pi_S=0.818068	2.11E-03
5.2.4.6		Resistor 390 ohm	1	R0805_390R_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R25	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.247966 pi_S=0.908382	2.90E-03
5.2.4.7		Capacitor 10nF Ceramic	1	CC0805_10NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C48	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.660693 pi_S=1.00133 pi_SR=1	2.54E-03
5.2.4.8		Capacitor 22uF	1	CC1210_22UF_25V_10%_X5R	Capacitor	Ceramic Chip,ER	C14	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1.32074 pi_S=1.04062 pi_SR=1	5.28E-03

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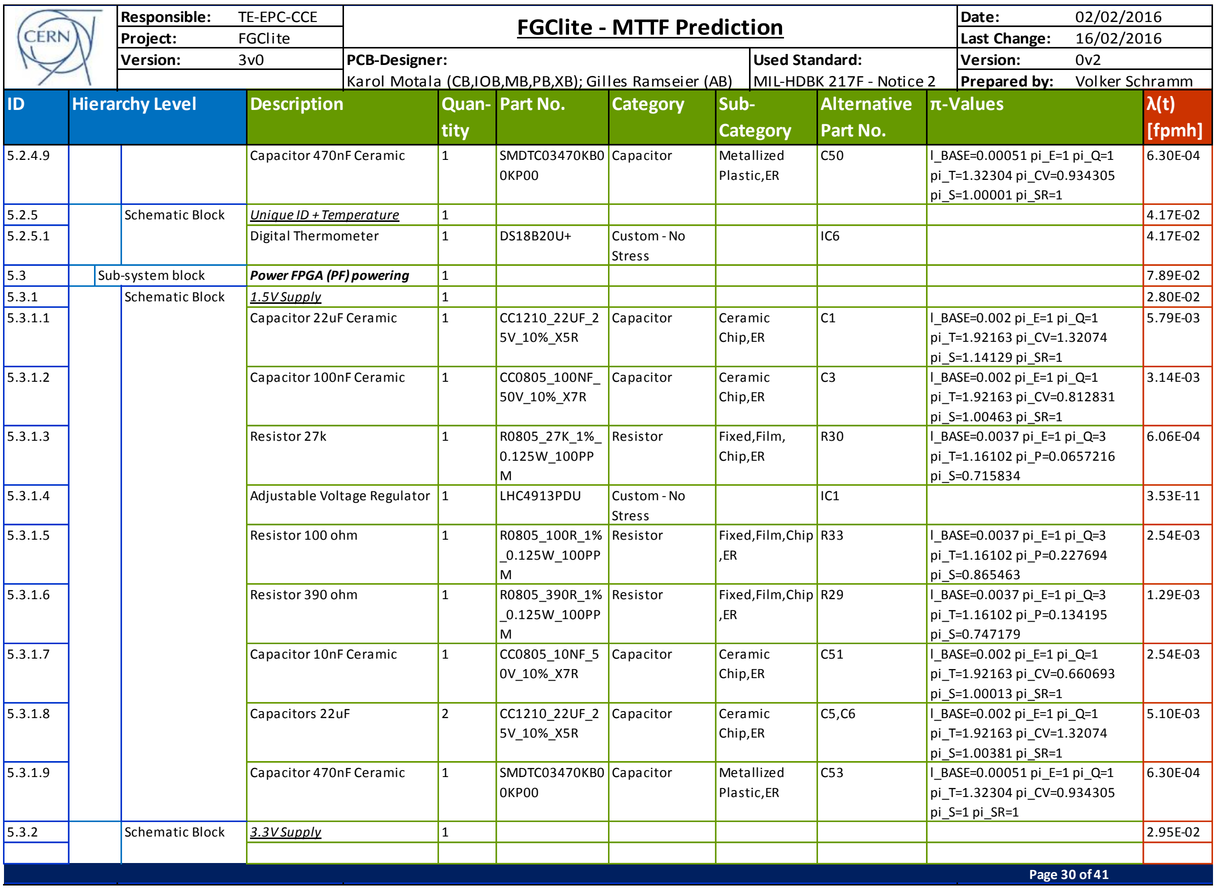

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - MTTF Prediction

PCB-Designer: Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)
Used Standard: MIL-HDBK 217F - Notice 2

Date: 02/02/2016
Last Change: 16/02/2016
Version: 0v2
Prepared by: Volker Schramm

ID	Hierarchy Level	Description	Quantity	Part No.	Category	Sub-Category	Alternative Part No.	π-Values	λ(t) [fpmh]
5.2.4.9		Capacitor 470nF Ceramic	1	SMDTC03470KB00KP00	Capacitor	Metallized Plastic,ER	C50	l_BASE=0.00051 pi_E=1 pi_Q=1 pi_T=1.32304 pi_CV=0.934305 pi_S=1.00001 pi_SR=1	6.30E-04
5.2.5	Schematic Block	*Unique ID + Temperature*	1						4.17E-02
5.2.5.1		Digital Thermometer	1	DS18B20U+	Custom - No Stress		IC6		4.17E-02
5.3	Sub-system block	***Power FPGA (PF) powering***	1						7.89E-02
5.3.1	Schematic Block	*1.5V Supply*	1						2.80E-02
5.3.1.1		Capacitor 22uF Ceramic	1	CC1210_22UF_25V_10%_X5R	Capacitor	Ceramic Chip,ER	C1	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1.32074 pi_S=1.14129 pi_SR=1	5.79E-03
5.3.1.2		Capacitor 100nF Ceramic	1	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C3	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00463 pi_SR=1	3.14E-03
5.3.1.3		Resistor 27k	1	R0805_27K_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R30	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0657216 pi_S=0.715834	6.06E-04
5.3.1.4		Adjustable Voltage Regulator	1	LHC4913PDU	Custom - No Stress		IC1		3.53E-11
5.3.1.5		Resistor 100 ohm	1	R0805_100R_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R33	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.227694 pi_S=0.865463	2.54E-03
5.3.1.6		Resistor 390 ohm	1	R0805_390R_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R29	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.134195 pi_S=0.747179	1.29E-03
5.3.1.7		Capacitor 10nF Ceramic	1	CC0805_10NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C51	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.660693 pi_S=1.00013 pi_SR=1	2.54E-03
5.3.1.8		Capacitors 22uF	2	CC1210_22UF_25V_10%_X5R	Capacitor	Ceramic Chip,ER	C5,C6	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1.32074 pi_S=1.00381 pi_SR=1	5.10E-03
5.3.1.9		Capacitor 470nF Ceramic	1	SMDTC03470KB00KP00	Capacitor	Metallized Plastic,ER	C53	l_BASE=0.00051 pi_E=1 pi_Q=1 pi_T=1.32304 pi_CV=0.934305 pi_S=1 pi_SR=1	6.30E-04
5.3.2	Schematic Block	*3.3V Supply*	1						2.95E-02

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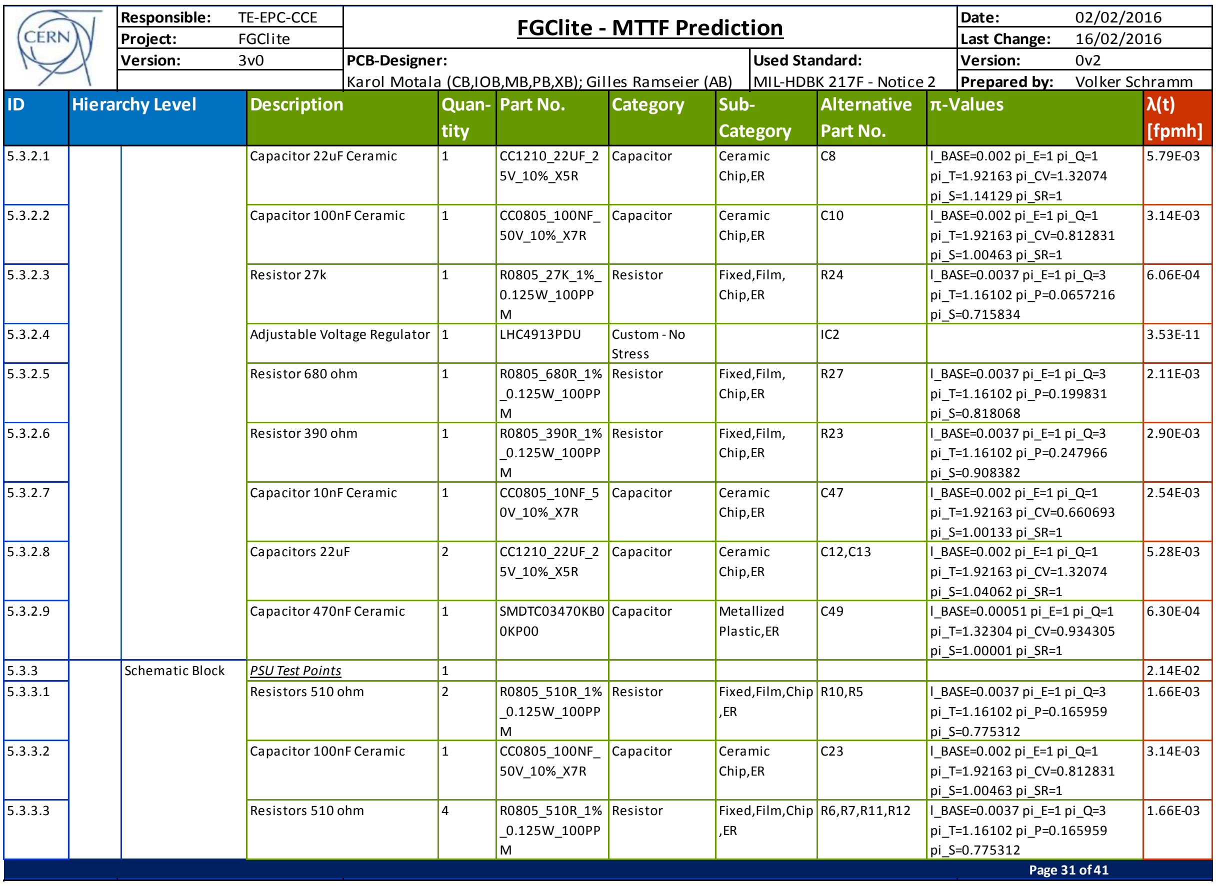

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - MTTF Prediction

PCB-Designer: Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)
Used Standard: MIL-HDBK 217F - Notice 2

Date: 02/02/2016
Last Change: 16/02/2016
Version: 0v2
Prepared by: Volker Schramm

ID	Hierarchy Level	Description	Quantity	Part No.	Category	Sub-Category	Alternative Part No.	π-Values	λ(t) [fpmh]
5.3.2.1		Capacitor 22uF Ceramic	1	CC1210_22UF_25V_10%_X5R	Capacitor	Ceramic Chip,ER	C8	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1.32074 pi_S=1.14129 pi_SR=1	5.79E-03
5.3.2.2		Capacitor 100nF Ceramic	1	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C10	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00463 pi_SR=1	3.14E-03
5.3.2.3		Resistor 27k	1	R0805_27K_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R24	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0657216 pi_S=0.715834	6.06E-04
5.3.2.4		Adjustable Voltage Regulator	1	LHC4913PDU	Custom - No Stress		IC2		3.53E-11
5.3.2.5		Resistor 680 ohm	1	R0805_680R_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R27	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.199831 pi_S=0.818068	2.11E-03
5.3.2.6		Resistor 390 ohm	1	R0805_390R_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R23	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.247966 pi_S=0.908382	2.90E-03
5.3.2.7		Capacitor 10nF Ceramic	1	CC0805_10NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C47	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.660693 pi_S=1.00133 pi_SR=1	2.54E-03
5.3.2.8		Capacitors 22uF	2	CC1210_22UF_25V_10%_X5R	Capacitor	Ceramic Chip,ER	C12,C13	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1.32074 pi_S=1.04062 pi_SR=1	5.28E-03
5.3.2.9		Capacitor 470nF Ceramic	1	SMDTC03470KB00KP00	Capacitor	Metallized Plastic,ER	C49	l_BASE=0.00051 pi_E=1 pi_Q=1 pi_T=1.32304 pi_CV=0.934305 pi_S=1.00001 pi_SR=1	6.30E-04
5.3.3	Schematic Block	*PSU Test Points*	1						2.14E-02
5.3.3.1		Resistors 510 ohm	2	R0805_510R_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R10,R5	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.165959 pi_S=0.775312	1.66E-03
5.3.3.2		Capacitor 100nF Ceramic	1	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C23	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00463 pi_SR=1	3.14E-03
5.3.3.3		Resistors 510 ohm	4	R0805_510R_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R6,R7,R11,R12	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.165959 pi_S=0.775312	1.66E-03

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Responsible: TE-EPC-CCE **Project:** FGClite **Version:** 3v0	**FGClite - MTTF Prediction**		**Date:** 02/02/2016 **Last Change:** 16/02/2016
	PCB-Designer: Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)	**Used Standard:** MIL-HDBK 217F - Notice 2	**Version:** 0v2 **Prepared by:** Volker Schramm

ID	Hierarchy Level	Description	Quan-tity	Part No.	Category	Sub-Category	Alternative Part No.	π-Values	λ(t) [fpmh]
5.3.3.4		Capacitors 100nF Ceramic	2	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C24,C25	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.125 pi_SR=1	3.51E-03
5.4	Sub-system block	***Power Control Circuit Power FPGA (PF)***	1						1.74E-01
5.4.1	Schematic Block	*JTAG Connections*	1						2.10E-03
5.4.1.1		Resistor 1k	1	R0805_1K_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R2	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.189756 pi_S=0.803796	1.97E-03
5.4.2	Schematic Block	*Powering*	1						6.53E-03
5.4.2.1		Capacitors 100nF Ceramic	2	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C35,C37	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00133 pi_SR=1	3.13E-03
5.4.3	Schematic Block	*IO Supply Decoupling*	1						7.84E-02
5.4.3.1		Capacitors 100nF Ceramic	8	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C17,C19,C26, C27,C31,C32, C40,C42	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00013 pi_SR=1	3.12E-03
5.4.3.2		Capacitors 100nF Ceramic	16	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C15...C44	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00133 pi_SR=1	3.13E-03
5.4.4	Schematic Block	*FPGA*	1						1.60E-02
5.4.4.1		ProASIC3 FPGA	1	A3P400-1PQG208I -2	Custom - No Stress		IC5		1.09E-02
5.4.4.2		Resistor 10k	1	R0805_10K_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R1	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0698942 pi_S=0.716837	6.46E-04
5.4.4.3		Resistor 10k	1	R0805_10K_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R3	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0698942 pi_S=0.716837	6.46E-04
5.4.4.4		Resistor 51k	1	R0805_10K_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R8	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0370562 pi_S=0.711338	3.40E-04
5.4.4.5		Resistors 10k	4	R0805_10K_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R9,R13>R15	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0698942 pi_S=0.716837	6.46E-04
5.4.5	Schematic Block	*Clock*	1						6.56E-02

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Responsible: TE-EPC-CCE **Project:** FGClite **Version:** 3v0	**FGClite - MTTF Prediction**		**Date:** 02/02/2016 **Last Change:** 16/02/2016
	PCB-Designer: Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)	**Used Standard:** MIL-HDBK 217F - Notice 2	**Version:** 0v2 **Prepared by:** Volker Schramm

ID	Hierarchy Level	Description	Quan-tity	Part No.	Category	Sub-Category	Alternative Part No.	π-Values	λ(t) [fpmh]
5.4.5.1		Oscillator	1	RAKON LF SPXO018042 -5	Custom - No Stress		OSC1		6.24E-02
5.4.5.2		Capacitor 100nF Ceramic	1	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C28	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00133 pi_SR=1	3.13E-03
5.4.6	Schematic Block	*Power ON Reset*	1						5.28E-03
5.4.6.1		Diode	1	BAV99 -1	Custom - No Stress		D5		1.61E-03
5.4.6.2		Resistor 100k	1	R0805_100K_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R4	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0284735 pi_S=0.710681	2.61E-04
5.4.6.3		Capacitor 100nF Ceramic	1	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C45	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00133 pi_SR=1	3.13E-03
6	System Block	**I/O Board IOB**	1						8.50E-01
6.1	Sub-System Block	***Board Connectors***	1						9.98E-02
6.1.1	Schematic Block	*Unique ID*	1						1.48E-02
6.1.1.1		Unique ID	1	DS2401Z+	Custom - No Stress		IC4		1.48E-02
6.1.2	Schematic Block	*Board Connectors*	1						8.50E-02
6.1.2.1		3 x 32 Connectors	2	ERNI 374543	Custom - No Stress		J1,J2		4.80E-03
6.1.2.2		Capacitors 22uF	2	CC1210_22UF_25V_10%_X5R	Capacitor	Ceramic Chip,ER	C52,C53	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1.32074 pi_S=1.04062 pi_SR=1	5.28E-03
6.1.2.3		Capacitors 22uF	2	CC1210_22UF_25V_10%_X5R	Capacitor	Ceramic Chip,ER	C46,C47	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1.32074 pi_S=1.14129 pi_SR=1	5.79E-03
6.1.2.4		Capacitors 10uF	8	GMJ316BB7106KLHT	Capacitor	Ceramic Chip,ER	C48>C51, XX>XX	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1.23027 pi_S=1.36443 pi_SR=1	6.45E-03
6.2	Sub-System Block	***Voltage Source Interlocks***	1						2.81E-01
6.2.1	Schematic Block	*Power Permit*	1						2.44E-01
6.2.1.1		Resistor 62 ohm	1	R1206_62R_1%_0.25W_100PPM	Resistor	Fixed,Film, Chip,ER	R73	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.236503 pi_S=0.79186	2.41E-03

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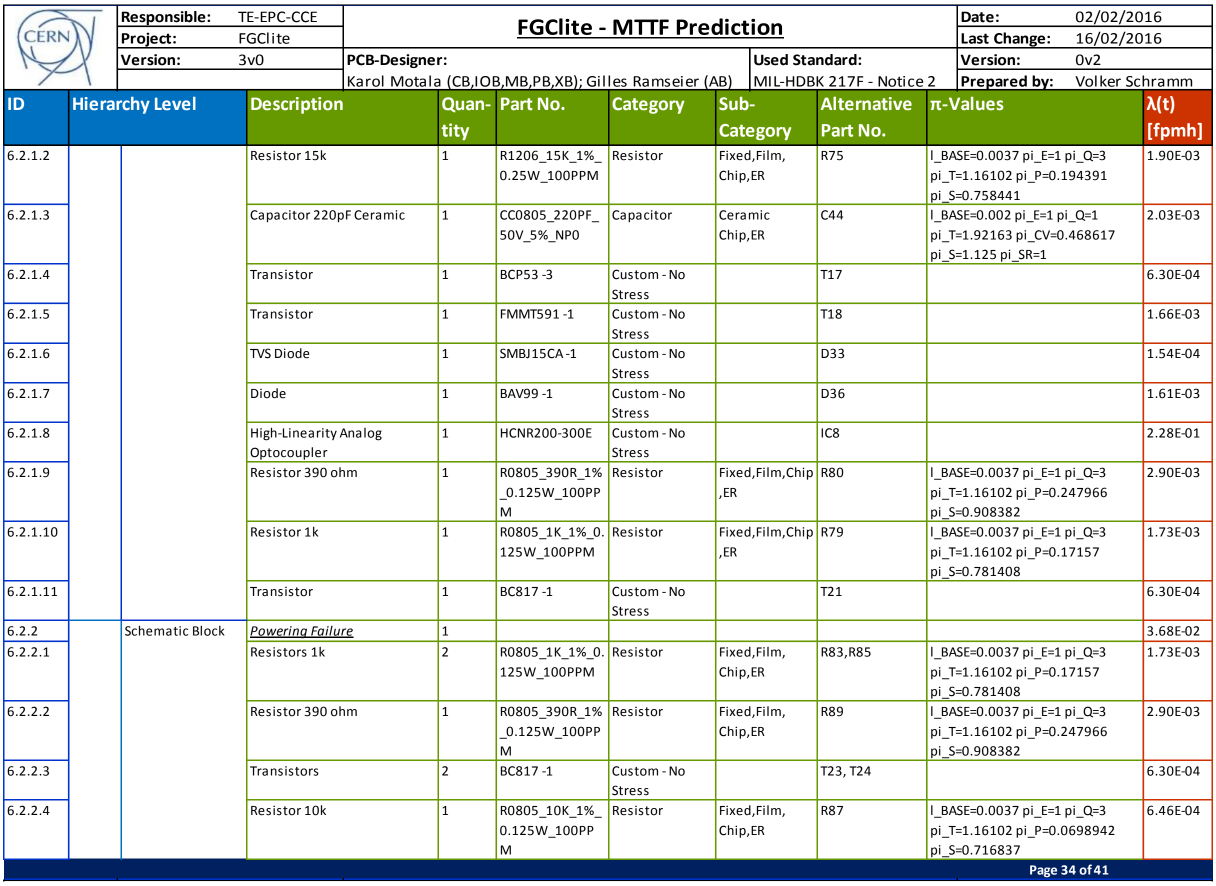

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - MTTF Prediction

PCB-Designer: Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)
Used Standard: MIL-HDBK 217F - Notice 2
Date: 02/02/2016
Last Change: 16/02/2016
Version: 0v2
Prepared by: Volker Schramm

ID	Hierarchy Level	Description	Quantity	Part No.	Category	Sub-Category	Alternative Part No.	π-Values	λ(t) [fpmh]
6.2.1.2		Resistor 15k	1	R1206_15K_1%_0.25W_100PPM	Resistor	Fixed,Film, Chip,ER	R75	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.194391 pi_S=0.758441	1.90E-03
6.2.1.3		Capacitor 220pF Ceramic	1	CC0805_220PF_50V_5%_NP0	Capacitor	Ceramic Chip,ER	C44	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.468617 pi_S=1.125 pi_SR=1	2.03E-03
6.2.1.4		Transistor	1	BCP53 -3	Custom - No Stress		T17		6.30E-04
6.2.1.5		Transistor	1	FMMT591 -1	Custom - No Stress		T18		1.66E-03
6.2.1.6		TVS Diode	1	SMBJ15CA -1	Custom - No Stress		D33		1.54E-04
6.2.1.7		Diode	1	BAV99 -1	Custom - No Stress		D36		1.61E-03
6.2.1.8		High-Linearity Analog Optocoupler	1	HCNR200-300E	Custom - No Stress		IC8		2.28E-01
6.2.1.9		Resistor 390 ohm	1	R0805_390R_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R80	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.247966 pi_S=0.908382	2.90E-03
6.2.1.10		Resistor 1k	1	R0805_1K_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R79	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.17157 pi_S=0.781408	1.73E-03
6.2.1.11		Transistor	1	BC817 -1	Custom - No Stress		T21		6.30E-04
6.2.2	Schematic Block	*Powering Failure*	1						3.68E-02
6.2.2.1		Resistors 1k	2	R0805_1K_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R83,R85	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.17157 pi_S=0.781408	1.73E-03
6.2.2.2		Resistor 390 ohm	1	R0805_390R_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R89	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.247966 pi_S=0.908382	2.90E-03
6.2.2.3		Transistors	2	BC817 -1	Custom - No Stress		T23, T24		6.30E-04
6.2.2.4		Resistor 10k	1	R0805_10K_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R87	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0698942 pi_S=0.716837	6.46E-04

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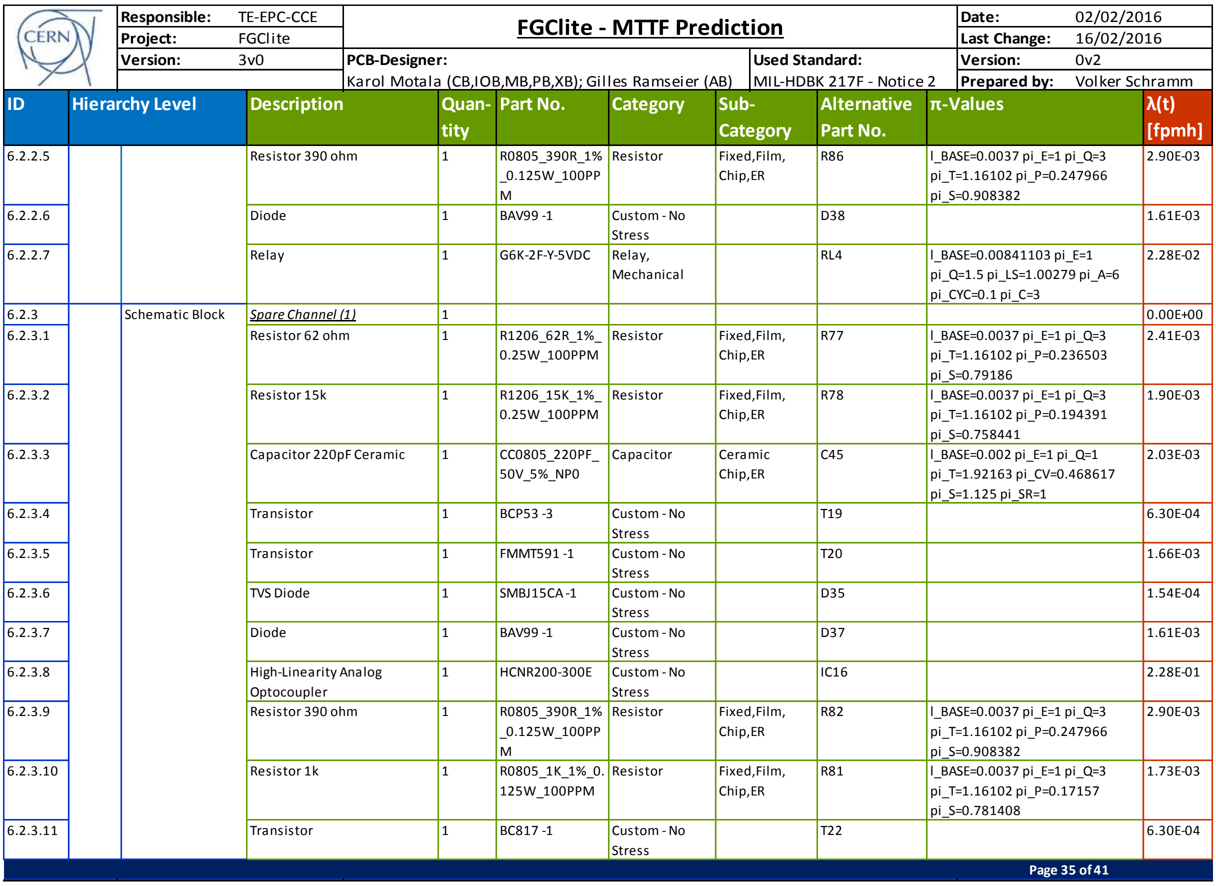

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - MTTF Prediction

PCB-Designer: Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)
Used Standard: MIL-HDBK 217F - Notice 2
Date: 02/02/2016
Last Change: 16/02/2016
Version: 0v2
Prepared by: Volker Schramm

ID	Hierarchy Level	Description	Quantity	Part No.	Category	Sub-Category	Alternative Part No.	π-Values	λ(t) [fpmh]
6.2.2.5		Resistor 390 ohm	1	R0805_390R_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R86	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.247966 pi_S=0.908382	2.90E-03
6.2.2.6		Diode	1	BAV99 -1	Custom - No Stress		D38		1.61E-03
6.2.2.7		Relay	1	G6K-2F-Y-5VDC	Relay, Mechanical		RL4	l_BASE=0.00841103 pi_E=1 pi_Q=1.5 pi_LS=1.00279 pi_A=6 pi_CYC=0.1 pi_C=3	2.28E-02
6.2.3	Schematic Block	*Spare Channel (1)*	1						0.00E+00
6.2.3.1		Resistor 62 ohm	1	R1206_62R_1%_0.25W_100PPM	Resistor	Fixed,Film, Chip,ER	R77	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.236503 pi_S=0.79186	2.41E-03
6.2.3.2		Resistor 15k	1	R1206_15K_1%_0.25W_100PPM	Resistor	Fixed,Film, Chip,ER	R78	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.194391 pi_S=0.758441	1.90E-03
6.2.3.3		Capacitor 220pF Ceramic	1	CC0805_220PF_50V_5%_NP0	Capacitor	Ceramic Chip,ER	C45	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.468617 pi_S=1.125 pi_SR=1	2.03E-03
6.2.3.4		Transistor	1	BCP53 -3	Custom - No Stress		T19		6.30E-04
6.2.3.5		Transistor	1	FMMT591 -1	Custom - No Stress		T20		1.66E-03
6.2.3.6		TVS Diode	1	SMBJ15CA -1	Custom - No Stress		D35		1.54E-04
6.2.3.7		Diode	1	BAV99 -1	Custom - No Stress		D37		1.61E-03
6.2.3.8		High-Linearity Analog Optocoupler	1	HCNR200-300E	Custom - No Stress		IC16		2.28E-01
6.2.3.9		Resistor 390 ohm	1	R0805_390R_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R82	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.247966 pi_S=0.908382	2.90E-03
6.2.3.10		Resistor 1k	1	R0805_1K_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R81	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.17157 pi_S=0.781408	1.73E-03
6.2.3.11		Transistor	1	BC817 -1	Custom - No Stress		T22		6.30E-04

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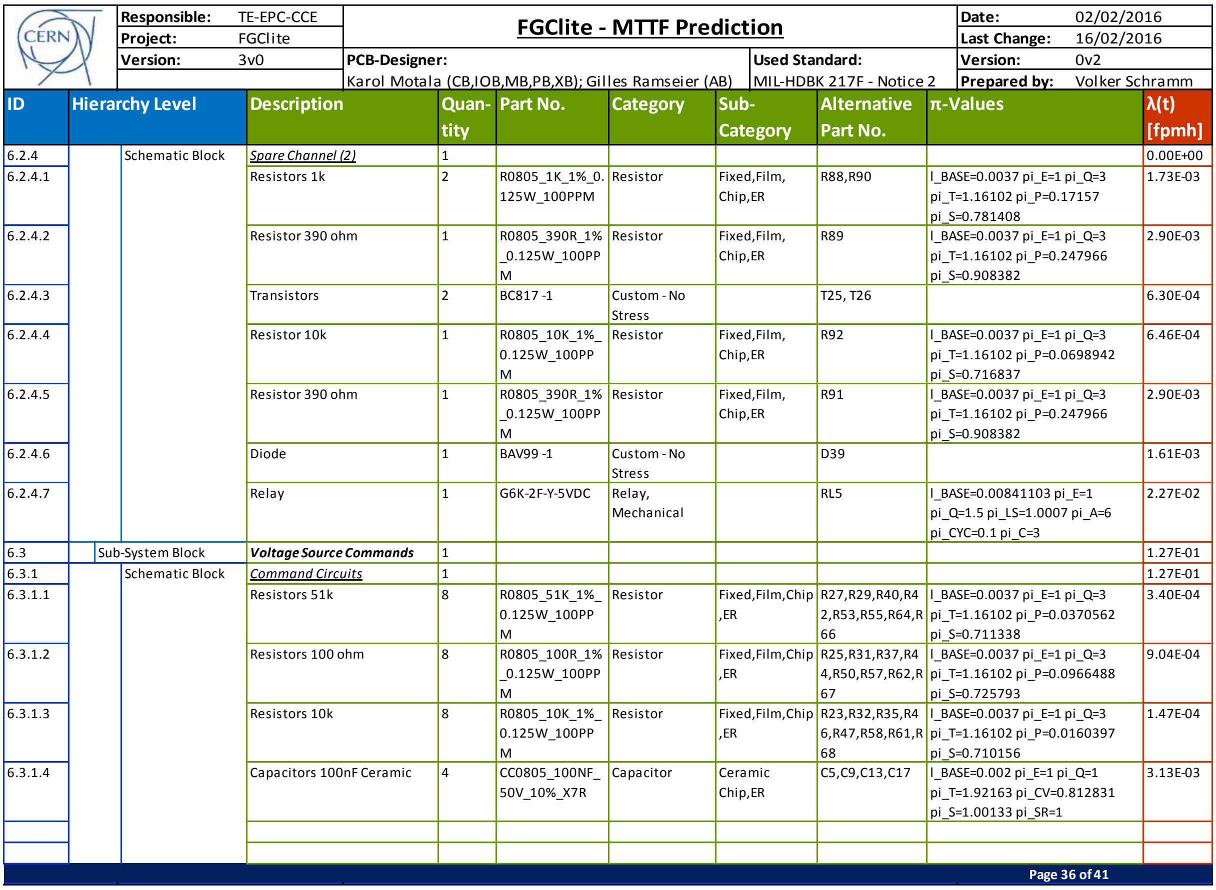

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - MTTF Prediction

PCB-Designer: Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)
Used Standard: MIL-HDBK 217F - Notice 2

Date: 02/02/2016
Last Change: 16/02/2016
Version: 0v2
Prepared by: Volker Schramm

ID	Hierarchy Level	Description	Quantity	Part No.	Category	Sub-Category	Alternative Part No.	π-Values	λ(t) [fpmh]
6.2.4	Schematic Block	*Spare Channel (2)*	1						0.00E+00
6.2.4.1		Resistors 1k	2	R0805_1K_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R88,R90	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.17157 pi_S=0.781408	1.73E-03
6.2.4.2		Resistor 390 ohm	1	R0805_390R_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R89	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.247966 pi_S=0.908382	2.90E-03
6.2.4.3		Transistors	2	BC817 -1	Custom - No Stress		T25, T26		6.30E-04
6.2.4.4		Resistor 10k	1	R0805_10K_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R92	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0698942 pi_S=0.716837	6.46E-04
6.2.4.5		Resistor 390 ohm	1	R0805_390R_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R91	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.247966 pi_S=0.908382	2.90E-03
6.2.4.6		Diode	1	BAV99 -1	Custom - No Stress		D39		1.61E-03
6.2.4.7		Relay	1	G6K-2F-Y-5VDC	Relay, Mechanical		RL5	l_BASE=0.00841103 pi_E=1 pi_Q=1.5 pi_LS=1.0007 pi_A=6 pi_CYC=0.1 pi_C=3	2.27E-02
6.3	Sub-System Block	***Voltage Source Commands***	1						1.27E-01
6.3.1	Schematic Block	*Command Circuits*	1						1.27E-01
6.3.1.1		Resistors 51k	8	R0805_51K_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R27,R29,R40,R42,R53,R55,R64,R66	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0370562 pi_S=0.711338	3.40E-04
6.3.1.2		Resistors 100 ohm	8	R0805_100R_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R25,R31,R37,R44,R50,R57,R62,R67	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0966488 pi_S=0.725793	9.04E-04
6.3.1.3		Resistors 10k	8	R0805_10K_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R23,R32,R35,R46,R47,R58,R61,R68	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0160397 pi_S=0.710156	1.47E-04
6.3.1.4		Capacitors 100nF Ceramic	4	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C5,C9,C13,C17	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00133 pi_SR=1	3.13E-03

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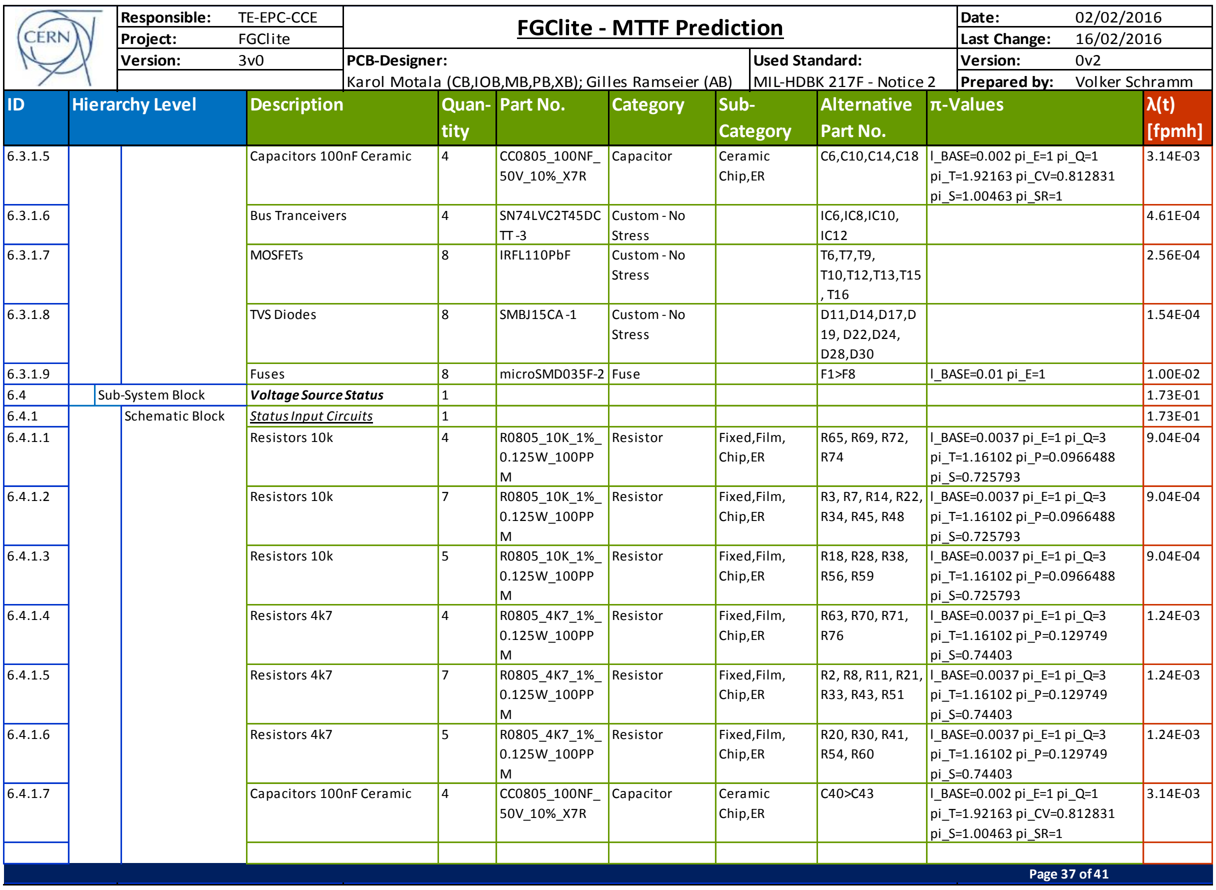

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - MTTF Prediction

PCB-Designer: Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)
Used Standard: MIL-HDBK 217F - Notice 2

Date: 02/02/2016
Last Change: 16/02/2016
Version: 0v2
Prepared by: Volker Schramm

ID	Hierarchy Level	Description	Quantity	Part No.	Category	Sub-Category	Alternative Part No.	π-Values	λ(t) [fpmh]
6.3.1.5		Capacitors 100nF Ceramic	4	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C6,C10,C14,C18	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00463 pi_SR=1	3.14E-03
6.3.1.6		Bus Tranceivers	4	SN74LVC2T45DCTT -3	Custom - No Stress		IC6,IC8,IC10, IC12		4.61E-04
6.3.1.7		MOSFETs	8	IRFL110PbF	Custom - No Stress		T6,T7,T9, T10,T12,T13,T15, T16		2.56E-04
6.3.1.8		TVS Diodes	8	SMBJ15CA -1	Custom - No Stress		D11,D14,D17,D19, D22,D24, D28,D30		1.54E-04
6.3.1.9		Fuses	8	microSMD035F-2	Fuse		F1>F8	l_BASE=0.01 pi_E=1	1.00E-02
6.4	Sub-System Block	***Voltage Source Status***	1						1.73E-01
6.4.1	Schematic Block	*Status Input Circuits*	1						1.73E-01
6.4.1.1		Resistors 10k	4	R0805_10K_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R65, R69, R72, R74	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0966488 pi_S=0.725793	9.04E-04
6.4.1.2		Resistors 10k	7	R0805_10K_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R3, R7, R14, R22, R34, R45, R48	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0966488 pi_S=0.725793	9.04E-04
6.4.1.3		Resistors 10k	5	R0805_10K_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R18, R28, R38, R56, R59	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0966488 pi_S=0.725793	9.04E-04
6.4.1.4		Resistors 4k7	4	R0805_4K7_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R63, R70, R71, R76	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.129749 pi_S=0.74403	1.24E-03
6.4.1.5		Resistors 4k7	7	R0805_4K7_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R2, R8, R11, R21, R33, R43, R51	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.129749 pi_S=0.74403	1.24E-03
6.4.1.6		Resistors 4k7	5	R0805_4K7_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R20, R30, R41, R54, R60	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.129749 pi_S=0.74403	1.24E-03
6.4.1.7		Capacitors 100nF Ceramic	4	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C40>C43	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00463 pi_SR=1	3.14E-03

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Responsible:	TE-EPC-CCE	**FGClite - MTTF Prediction**		**Date:**	02/02/2016
Project:	FGClite			**Last Change:**	16/02/2016
Version:	3v0	**PCB-Designer:**	**Used Standard:**	**Version:**	0v2
		Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)	MIL-HDBK 217F - Notice 2	**Prepared by:**	Volker Schramm

ID	Hierarchy Level	Description	Quan-tity	Part No.	Category	Sub-Category	Alternative Part No.	π-Values	λ(t) [fpmh]
6.4.1.8		Capacitors 100nF Ceramic	7	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C26, C28, C29, C32, C34, C36, C37	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00463 pi_SR=1	3.14E-03
6.4.1.9		Capacitors 100nF Ceramic	5	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C31, C33, C35, C38, C39	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00463 pi_SR=1	3.14E-03
6.4.1.10		Capacitors 100nF Ceramic	8	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C2,C4,C8,C12,C16,C20,C22,C25	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00463 pi_SR=1	3.14E-03
6.4.1.11		Capacitors 100nF Ceramic	8	CC0805_100NF_50V_10%_X7R	Capacitor	Ceramic Chip,ER	C1,C3,C7,C11,C15,C19,C21,C24	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.812831 pi_S=1.00133 pi_SR=1	3.13E-03
6.4.1.12		Diodes	5	BAV99 -1	Custom - No Stress		D10, D13, D18, D25, D27		1.61E-03
6.4.1.13		Diodes	7	BAV99 -1	Custom - No Stress		D5, D6, D8, D12, D16, D20, D23		1.61E-03
6.4.1.14		Diodes	4	BAV99 -1	Custom - No Stress		D29, D31, D32, D34		1.61E-03
6.4.1.15		Bus Transceivers	2	SN74LVC2T45DCTT -4	Custom - No Stress		IC13, IC14		4.61E-04
6.4.1.16		Bus Transceivers	5	SN74LVC2T45DCTT -4	Custom - No Stress		IC1,IC3,IC5, IC7,IC9		4.61E-04
6.4.1.17		Bus Transceiver	1	SN74LVC2T45DCTT -4	Custom - No Stress		IC11		4.61E-04
6.5	Sub-System Block	***Dallasbus Driver & Control***	1						1.69E-01
6.5.1	Schematic Block	*One Wire Transceiver*	1						5.46E-02
6.5.1.1		Diode	1	BAV99 -1	Custom - No Stress		D7		1.61E-03
6.5.1.2		Resistor 390 ohm	1	R0805_390R_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R4	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.288004 pi_S=1.01937	3.78E-03
6.5.1.3		Resistor 390 ohm	1	R0805_390R_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R5	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.288004 pi_S=1.01937	3.78E-03

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Responsible:	TE-EPC-CCE	**FGClite - MTTF Prediction**		**Date:**	02/02/2016
Project:	FGClite			**Last Change:**	16/02/2016
Version:	3v0	**PCB-Designer:**	**Used Standard:**	**Version:**	0v2
		Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)	MIL-HDBK 217F - Notice 2	**Prepared by:**	Volker Schramm

ID	Hierarchy Level	Description	Quan-tity	Part No.	Category	Sub-Category	Alternative Part No.	π-Values	λ(t) [fpmh]
6.5.1.4		Resistor 390 ohm	1	R0805_390R_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R13	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.288004 pi_S=1.01937	3.78E-03
6.5.1.5		Resistor 390 ohm	1	R0805_390R_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R15	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.288004 pi_S=1.01937	3.78E-03
6.5.1.6		Resistor 390 ohm	1	R0805_390R_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R16	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.288004 pi_S=1.01937	3.78E-03
6.5.1.7		Resistor 390 ohm	1	R0805_390R_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R19	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.288004 pi_S=1.01937	3.78E-03
6.5.1.8		Capacitor 220pF Ceramic	1	CC0805_220PF_50V_5%_NP0	Capacitor	Ceramic Chip,ER	C30	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=0.468617 pi_S=1.00237 pi_SR=1	1.81E-03
6.5.1.9		MOSFETs	2	BST82	Custom - No Stress		T3,T4		1.85E-03
6.5.1.10		Resistor 1k	1	R0805_1K_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R17	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.199346 pi_S=0.817348	2.10E-03
6.5.1.11		Resistor 10k	1	R0805_10K_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R6	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0698942 pi_S=0.716837	6.46E-04
6.5.1.12		Transistors	2	BC817 -1	Custom - No Stress		T1,T2		6.30E-04
6.5.1.13		Resistor 10k	1	R0805_10K_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R12	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0698942 pi_S=0.716837	6.46E-04
6.5.1.14		Transistor	1	BC807-25 -1	Custom - No Stress		T5		6.30E-04
6.5.1.15		Resistor 22 ohm	1	R2512_22R_1%_1W_100PPM	Resistor	Fixed,Film, Chip,ER	R1	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.88355 pi_S=1.5814	1.80E-02
6.5.2	Schematic Block	*Local/External Selector*	1						3.20E-02
6.5.2.1		Diode	1	BAV99 -1	Custom - No Stress		D15		1.61E-03

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Responsible: TE-EPC-CCE	**FGClite - MTTF Prediction**		**Date:**	02/02/2016
Project: FGClite			**Last Change:**	16/02/2016
Version: 3v0	**PCB-Designer:**	**Used Standard:**	**Version:**	0v2
	Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)	MIL-HDBK 217F - Notice 2	**Prepared by:**	Volker Schramm

ID	Hierarchy Level		Description	Quantity	Part No.	Category	Sub-Category	Alternative Part No.	π-Values	λ(t) [fpmh]
6.5.2.2			Relay	1	G6K-2F-Y-5VDC	Relay, Mechanical		RL1	l_BASE=0.00841103 pi_E=1 pi_Q=1.5 pi_LS=1.00279 pi_A=6 pi_CYC=0.1 pi_C=3	2.28E-02
6.5.2.3			Transistor	1	BC817 -1	Custom - No Stress		T8		6.30E-04
6.5.2.4			Resistor 390 ohm	1	R0805_390R_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R26	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.342303 pi_S=1.24696	5.50E-03
6.5.2.5			Resistor 27k	1	R0805_27K_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R24	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0657216 pi_S=0.715834	6.06E-04
6.5.3		Schematic Block	*Main/Auxiliary Selector*	1						2.78E-02
6.5.3.1			Diode	1	BAV99 -1	Custom - No Stress		D21		1.61E-03
6.5.3.2			Relay	1	G6K-2F-Y-5VDC	Relay, Mechanical		RL2	l_BASE=0.00841103 pi_E=1 pi_Q=1.5 pi_LS=1.00279 pi_A=6 pi_CYC=0.1 pi_C=3	2.28E-02
6.5.3.3			Transistor	1	BC817 -1	Custom - No Stress		T11		6.30E-04
6.5.3.4			Resistor 390 ohm	1	R0805_390R_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R39	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.139617 pi_S=0.751267	1.35E-03
6.5.3.5			Resistor 27k	1	R0805_27K_1%_0.125W_100PPM	Resistor	Fixed,Film,Chip,ER	R36	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0657216 pi_S=0.715834	6.06E-04
6.5.4		Schematic Block	*A/B Selector*	1						3.20E-02
6.5.4.1			Diode	1	BAV99 -1	Custom - No Stress		D26		1.61E-03
6.5.4.2			Relay	1	G6K-2F-Y-5VDC	Relay, Mechanical		RL3	l_BASE=0.00841103 pi_E=1 pi_Q=1.5 pi_LS=1.00279 pi_A=6 pi_CYC=0.1 pi_C=3	2.28E-02
6.5.4.3			Transistor	1	BC817 -1	Custom - No Stress		T14		6.30E-04
6.5.4.4			Resistor 390 ohm	1	R0805_390R_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R52	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.342719 pi_S=1.24916	5.52E-03

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Responsible: TE-EPC-CCE	**FGClite - MTTF Prediction**		**Date:**	02/02/2016
Project: FGClite			**Last Change:**	16/02/2016
Version: 3v0	**PCB-Designer:**	**Used Standard:**	**Version:**	0v2
	Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)	MIL-HDBK 217F - Notice 2	**Prepared by:**	Volker Schramm

ID	Hierarchy Level		Description	Quantity	Part No.	Category	Sub-Category	Alternative Part No.	π-Values	λ(t) [fpmh]
6.5.4.5			Resistor 27k	1	R0805_27K_1%_0.125W_100PPM	Resistor	Fixed,Film, Chip,ER	R49	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.0657216 pi_S=0.715834	6.06E-04
6.5.5		Schematic Block	*Independent Supply for One Wire*	1						2.26E-02
6.5.5.1			Capacitor 22uF Ceramic	1	CC1210_22UF_25V_10%_X5R	Capacitor	Ceramic Chip,ER	C23	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1.32074 pi_S=1.14129 pi_SR=1	5.79E-03
6.5.5.2			Low Voltage Regulator	1	MCP1826T-ADJE/DC	Custom - No Stress		IC2		6.14E-03
6.5.5.3			Resistor 3k3	1	R1206_3K3_1%_0.25W_100PPM	Resistor	Fixed,Film, Chip,ER	R9	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.126648 pi_S=0.741937	1.21E-03
6.5.5.4			Resistor 330 ohm	1	R1206_330R_1%_0.25W_100PPM	Resistor	Fixed,Film, Chip,ER	R10	l_BASE=0.0037 pi_E=1 pi_Q=3 pi_T=1.16102 pi_P=0.308444 pi_S=0.88083	3.50E-03
6.5.5.5			Capacitor 22uF Ceramic	1	CC1210_22UF_25V_10%_X5R	Capacitor	Ceramic Chip,ER	C27	l_BASE=0.002 pi_E=1 pi_Q=1 pi_T=1.92163 pi_CV=1.32074 pi_S=1.07234 pi_SR=1	5.44E-03

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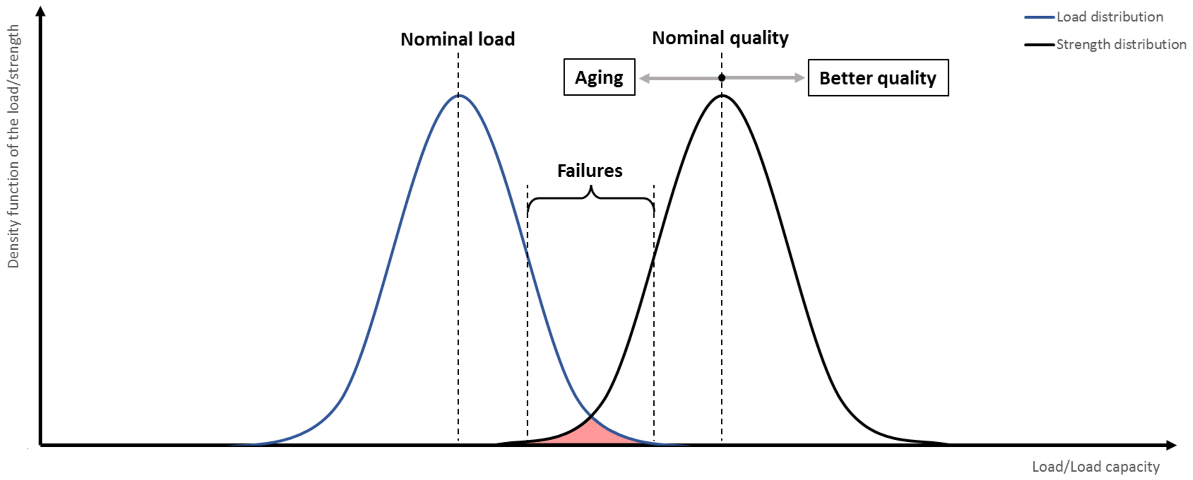
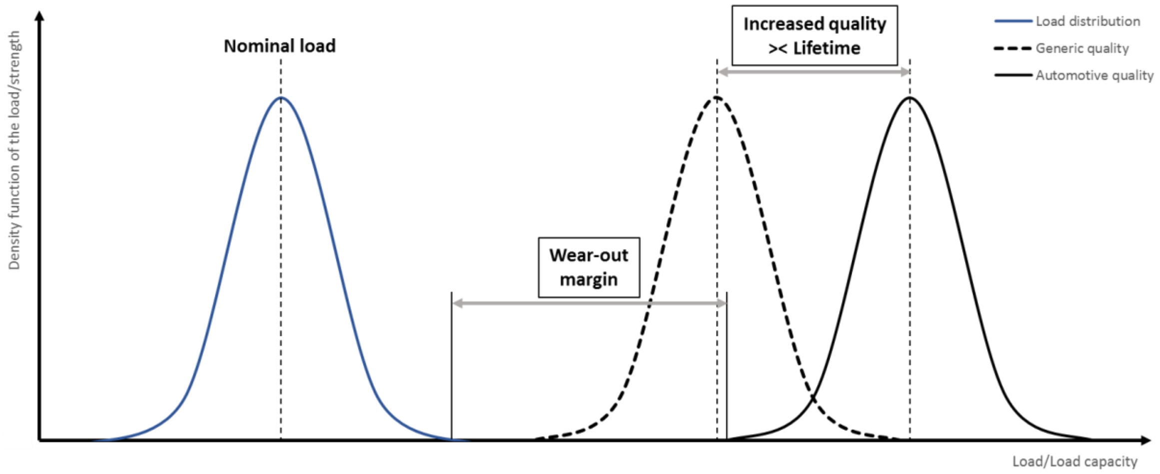
Integrated Reliability Improvements

In general a manufacturing process can never guarantee that all products are of same quality and meet exactly all specifications. There is always a spread with some parts being of better and some of worse quality than the average. To illustrate this spread an individual distribution can be used. For a normal distribution, the Load-Strength Interference diagram [36] exists. It uses this distribution for the quality of the product and adds another distribution which is individual for the operating conditions because in general these conditions also spread. In the following figure this operating condition is represented by a load.



As it can be seen, it is possible that these distributions overlap. This means that those low quality components in this region, which suffer from a high load, fail. To avoid such failures there are two simple ways. On the one hand the load in operation can be reduced and on the other hand the product quality and its resisting parameters can be improved thus moving the right distribution up the abscissa. For the improved components of table 3-3 this was done, e.g. with the automotive upgrade of all ceramic chip capacitors. This can lead to a diagram like the following, where it is possible that the quality distribution is not overlapping with the load distribution anymore. If this is the case, a non-scaled wear-out margin can be imagined which is representative to the time until the first failures start occurring as a consequence of the load. During this time the quality distribution moves down the abscissa as an effect of aging. In fact when the graphs start overlapping it represents the exponential failure rate increase in the third part of the bathtub curve (Figure 3-3). The exponential progression can easily be seen when imagining the exponential growing increase of the overlapping area.

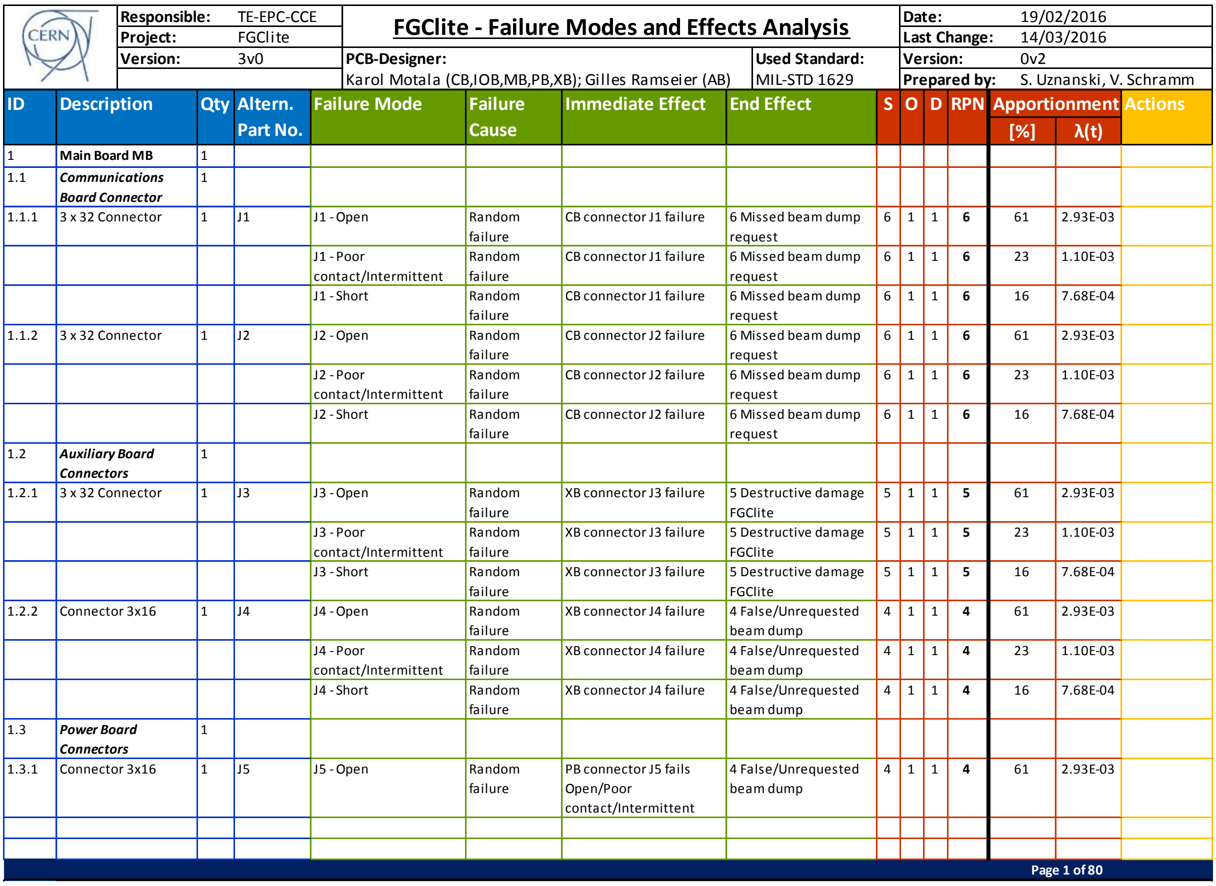

Density function of the load/strength
Nominal load
Increased quality
>< Lifetime
Wear-out
margin
Load distribution
Generic quality
Automotive quality
Load/Load capacity

3.4.2 Results of the FMEA

- **FMEA Report:**

Table annotations: - The failure rate λ(t) is given in fpmh

- The apportionment failure rates are given for a single component, not for the indicated quantity



Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - Failure Modes and Effects Analysis

PCB-Designer: Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)
Used Standard: MIL-STD 1629

Date: 19/02/2016
Last Change: 14/03/2016
Version: 0v2
Prepared by: S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment [%]	Apportionment λ(t)	Actions
1	**Main Board MB**	1												
1.1	***Communications Board Connector***	1												
1.1.1	3 x 32 Connector	1	J1	J1 - Open	Random failure	CB connector J1 failure	6 Missed beam dump request	6	1	1	**6**	61	2.93E-03	
				J1 - Poor contact/Intermittent	Random failure	CB connector J1 failure	6 Missed beam dump request	6	1	1	**6**	23	1.10E-03	
				J1 - Short	Random failure	CB connector J1 failure	6 Missed beam dump request	6	1	1	**6**	16	7.68E-04	
1.1.2	3 x 32 Connector	1	J2	J2 - Open	Random failure	CB connector J2 failure	6 Missed beam dump request	6	1	1	**6**	61	2.93E-03	
				J2 - Poor contact/Intermittent	Random failure	CB connector J2 failure	6 Missed beam dump request	6	1	1	**6**	23	1.10E-03	
				J2 - Short	Random failure	CB connector J2 failure	6 Missed beam dump request	6	1	1	**6**	16	7.68E-04	
1.2	***Auxiliary Board Connectors***	1												
1.2.1	3 x 32 Connector	1	J3	J3 - Open	Random failure	XB connector J3 failure	5 Destructive damage FGClite	5	1	1	**5**	61	2.93E-03	
				J3 - Poor contact/Intermittent	Random failure	XB connector J3 failure	5 Destructive damage FGClite	5	1	1	**5**	23	1.10E-03	
				J3 - Short	Random failure	XB connector J3 failure	5 Destructive damage FGClite	5	1	1	**5**	16	7.68E-04	
1.2.2	Connector 3x16	1	J4	J4 - Open	Random failure	XB connector J4 failure	4 False/Unrequested beam dump	4	1	1	**4**	61	2.93E-03	
				J4 - Poor contact/Intermittent	Random failure	XB connector J4 failure	4 False/Unrequested beam dump	4	1	1	**4**	23	1.10E-03	
				J4 - Short	Random failure	XB connector J4 failure	4 False/Unrequested beam dump	4	1	1	**4**	16	7.68E-04	
1.3	***Power Board Connectors***	1												
1.3.1	Connector 3x16	1	J5	J5 - Open	Random failure	PB connector J5 fails Open/Poor contact/Intermittent	4 False/Unrequested beam dump	4	1	1	**4**	61	2.93E-03	

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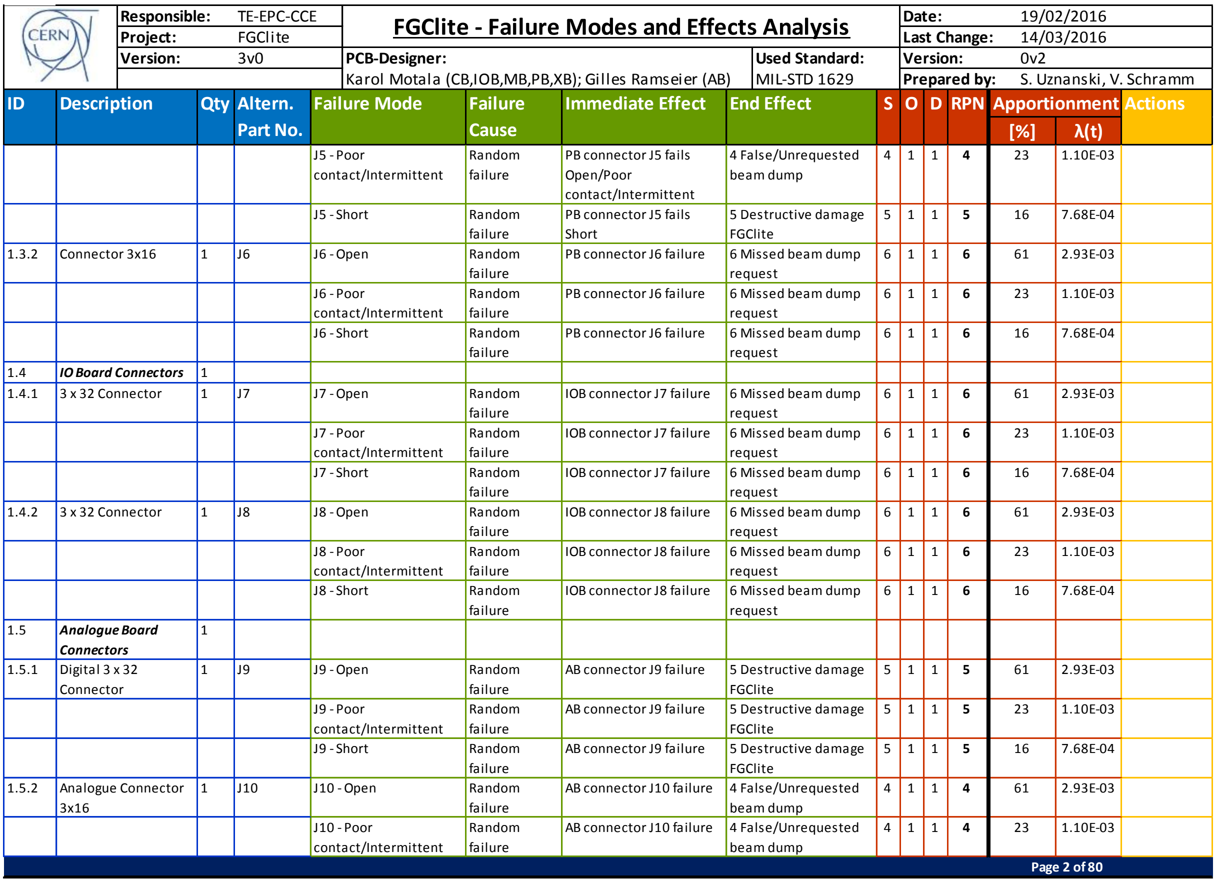

Responsible: TE-EPC-CCE
Project: FGClite
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ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment [%]	λ(t)	Actions
				J5 - Poor contact/Intermittent	Random failure	PB connector J5 fails Open/Poor contact/Intermittent	4 False/Unrequested beam dump	4	1	1	**4**	23	1.10E-03	
				J5 - Short	Random failure	PB connector J5 fails Short	5 Destructive damage FGClite	5	1	1	**5**	16	7.68E-04	
1.3.2	Connector 3x16	1	J6	J6 - Open	Random failure	PB connector J6 failure	6 Missed beam dump request	6	1	1	**6**	61	2.93E-03	
				J6 - Poor contact/Intermittent	Random failure	PB connector J6 failure	6 Missed beam dump request	6	1	1	**6**	23	1.10E-03	
				J6 - Short	Random failure	PB connector J6 failure	6 Missed beam dump request	6	1	1	**6**	16	7.68E-04	
1.4	***IO Board Connectors***	1												
1.4.1	3 x 32 Connector	1	J7	J7 - Open	Random failure	IOB connector J7 failure	6 Missed beam dump request	6	1	1	**6**	61	2.93E-03	
				J7 - Poor contact/Intermittent	Random failure	IOB connector J7 failure	6 Missed beam dump request	6	1	1	**6**	23	1.10E-03	
				J7 - Short	Random failure	IOB connector J7 failure	6 Missed beam dump request	6	1	1	**6**	16	7.68E-04	
1.4.2	3 x 32 Connector	1	J8	J8 - Open	Random failure	IOB connector J8 failure	6 Missed beam dump request	6	1	1	**6**	61	2.93E-03	
				J8 - Poor contact/Intermittent	Random failure	IOB connector J8 failure	6 Missed beam dump request	6	1	1	**6**	23	1.10E-03	
				J8 - Short	Random failure	IOB connector J8 failure	6 Missed beam dump request	6	1	1	**6**	16	7.68E-04	
1.5	***Analogue Board Connectors***	1												
1.5.1	Digital 3 x 32 Connector	1	J9	J9 - Open	Random failure	AB connector J9 failure	5 Destructive damage FGClite	5	1	1	**5**	61	2.93E-03	
				J9 - Poor contact/Intermittent	Random failure	AB connector J9 failure	5 Destructive damage FGClite	5	1	1	**5**	23	1.10E-03	
				J9 - Short	Random failure	AB connector J9 failure	5 Destructive damage FGClite	5	1	1	**5**	16	7.68E-04	
1.5.2	Analogue Connector 3x16	1	J10	J10 - Open	Random failure	AB connector J10 failure	4 False/Unrequested beam dump	4	1	1	**4**	61	2.93E-03	
				J10 - Poor contact/Intermittent	Random failure	AB connector J10 failure	4 False/Unrequested beam dump	4	1	1	**4**	23	1.10E-03	

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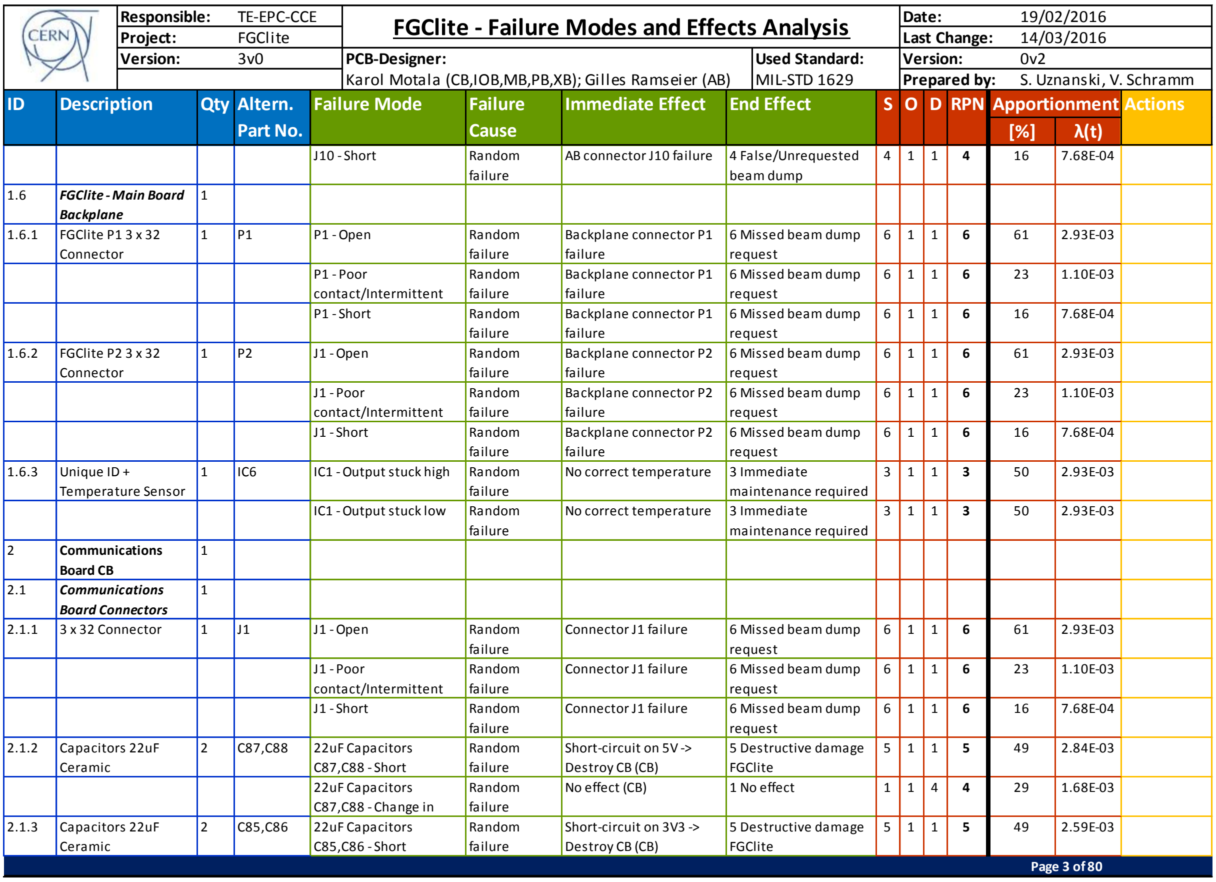

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				J10 - Short	Random failure	AB connector J10 failure	4 False/Unrequested beam dump	4	1	1	**4**	16	7.68E-04	
1.6	***FGClite - Main Board Backplane***	1												
1.6.1	FGClite P1 3 x 32 Connector	1	P1	P1 - Open	Random failure	Backplane connector P1 failure	6 Missed beam dump request	6	1	1	**6**	61	2.93E-03	
				P1 - Poor contact/Intermittent	Random failure	Backplane connector P1 failure	6 Missed beam dump request	6	1	1	**6**	23	1.10E-03	
				P1 - Short	Random failure	Backplane connector P1 failure	6 Missed beam dump request	6	1	1	**6**	16	7.68E-04	
1.6.2	FGClite P2 3 x 32 Connector	1	P2	J1 - Open	Random failure	Backplane connector P2 failure	6 Missed beam dump request	6	1	1	**6**	61	2.93E-03	
				J1 - Poor contact/Intermittent	Random failure	Backplane connector P2 failure	6 Missed beam dump request	6	1	1	**6**	23	1.10E-03	
				J1 - Short	Random failure	Backplane connector P2 failure	6 Missed beam dump request	6	1	1	**6**	16	7.68E-04	
1.6.3	Unique ID + Temperature Sensor	1	IC6	IC1 - Output stuck high	Random failure	No correct temperature	3 Immediate maintenance required	3	1	1	**3**	50	2.93E-03	
				IC1 - Output stuck low	Random failure	No correct temperature	3 Immediate maintenance required	3	1	1	**3**	50	2.93E-03	
2	**Communications Board CB**	1												
2.1	***Communications Board Connectors***	1												
2.1.1	3 x 32 Connector	1	J1	J1 - Open	Random failure	Connector J1 failure	6 Missed beam dump request	6	1	1	**6**	61	2.93E-03	
				J1 - Poor contact/Intermittent	Random failure	Connector J1 failure	6 Missed beam dump request	6	1	1	**6**	23	1.10E-03	
				J1 - Short	Random failure	Connector J1 failure	6 Missed beam dump request	6	1	1	**6**	16	7.68E-04	
2.1.2	Capacitors 22uF Ceramic	2	C87,C88	22uF Capacitors C87,C88 - Short	Random failure	Short-circuit on 5V -> Destroy CB (CB)	5 Destructive damage FGClite	5	1	1	**5**	49	2.84E-03	
				22uF Capacitors C87,C88 - Change in	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	29	1.68E-03	
2.1.3	Capacitors 22uF Ceramic	2	C85,C86	22uF Capacitors C85,C86 - Short	Random failure	Short-circuit on 3V3 -> Destroy CB (CB)	5 Destructive damage FGClite	5	1	1	**5**	49	2.59E-03	

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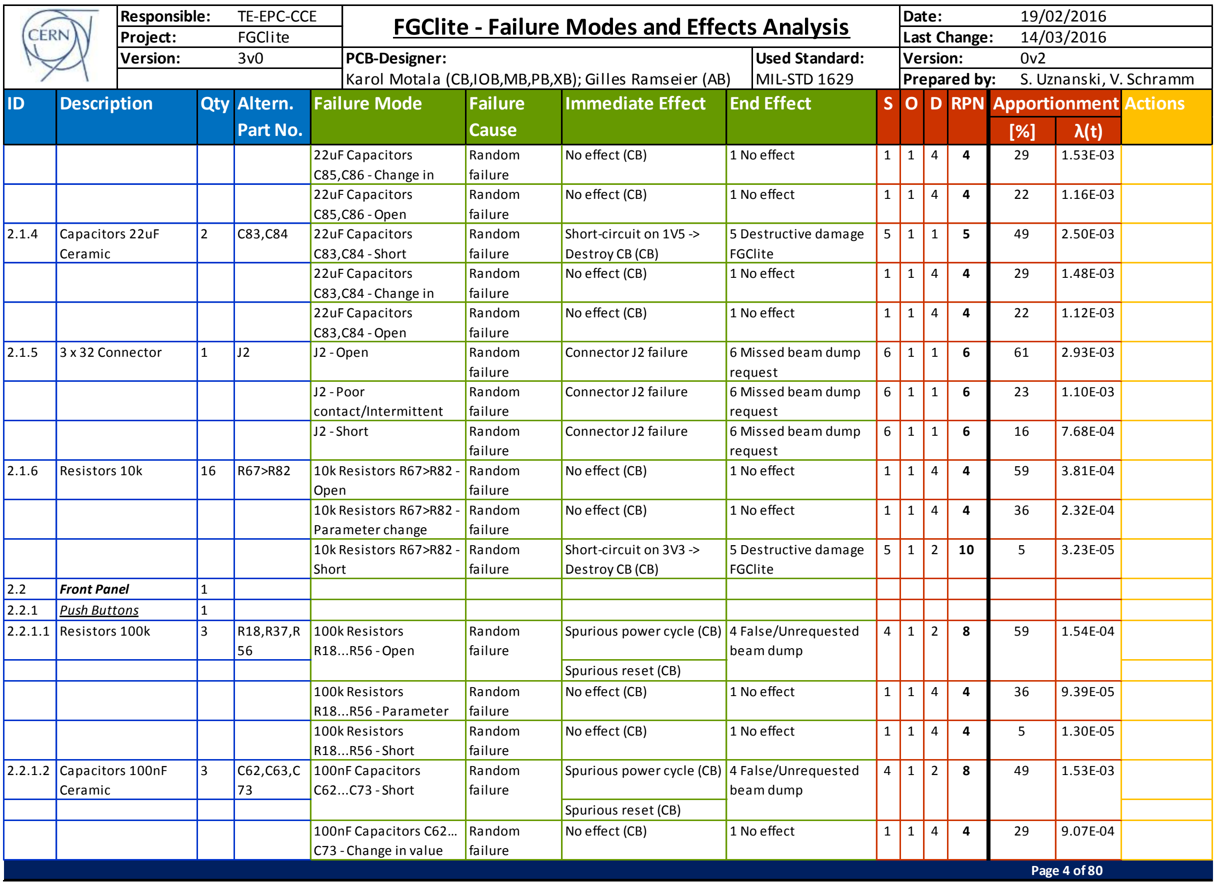

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ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment		Actions
												[%]	λ(t)	
				22uF Capacitors C85,C86 - Change in	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	29	1.53E-03	
				22uF Capacitors C85,C86 - Open	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	22	1.16E-03	
2.1.4	Capacitors 22uF Ceramic	2	C83,C84	22uF Capacitors C83,C84 - Short	Random failure	Short-circuit on 1V5 -> Destroy CB (CB)	5 Destructive damage FGClite	5	1	1	**5**	49	2.50E-03	
				22uF Capacitors C83,C84 - Change in	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	29	1.48E-03	
				22uF Capacitors C83,C84 - Open	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	22	1.12E-03	
2.1.5	3 x 32 Connector	1	J2	J2 - Open	Random failure	Connector J2 failure	6 Missed beam dump request	6	1	1	**6**	61	2.93E-03	
				J2 - Poor contact/Intermittent	Random failure	Connector J2 failure	6 Missed beam dump request	6	1	1	**6**	23	1.10E-03	
				J2 - Short	Random failure	Connector J2 failure	6 Missed beam dump request	6	1	1	**6**	16	7.68E-04	
2.1.6	Resistors 10k	16	R67>R82	10k Resistors R67>R82 - Open	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	59	3.81E-04	
				10k Resistors R67>R82 - Parameter change	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	36	2.32E-04	
				10k Resistors R67>R82 - Short	Random failure	Short-circuit on 3V3 -> Destroy CB (CB)	5 Destructive damage FGClite	5	1	2	**10**	5	3.23E-05	
2.2	***Front Panel***	1												
2.2.1	*Push Buttons*	1												
2.2.1.1	Resistors 100k	3	R18,R37,R56	100k Resistors R18...R56 - Open	Random failure	Spurious power cycle (CB)	4 False/Unrequested beam dump	4	1	2	**8**	59	1.54E-04	
						Spurious reset (CB)								
				100k Resistors R18...R56 - Parameter	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	36	9.39E-05	
				100k Resistors R18...R56 - Short	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	5	1.30E-05	
2.2.1.2	Capacitors 100nF Ceramic	3	C62,C63,C73	100nF Capacitors C62...C73 - Short	Random failure	Spurious power cycle (CB)	4 False/Unrequested beam dump	4	1	2	**8**	49	1.53E-03	
						Spurious reset (CB)								
				100nF Capacitors C62... C73 - Change in value	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	29	9.07E-04	

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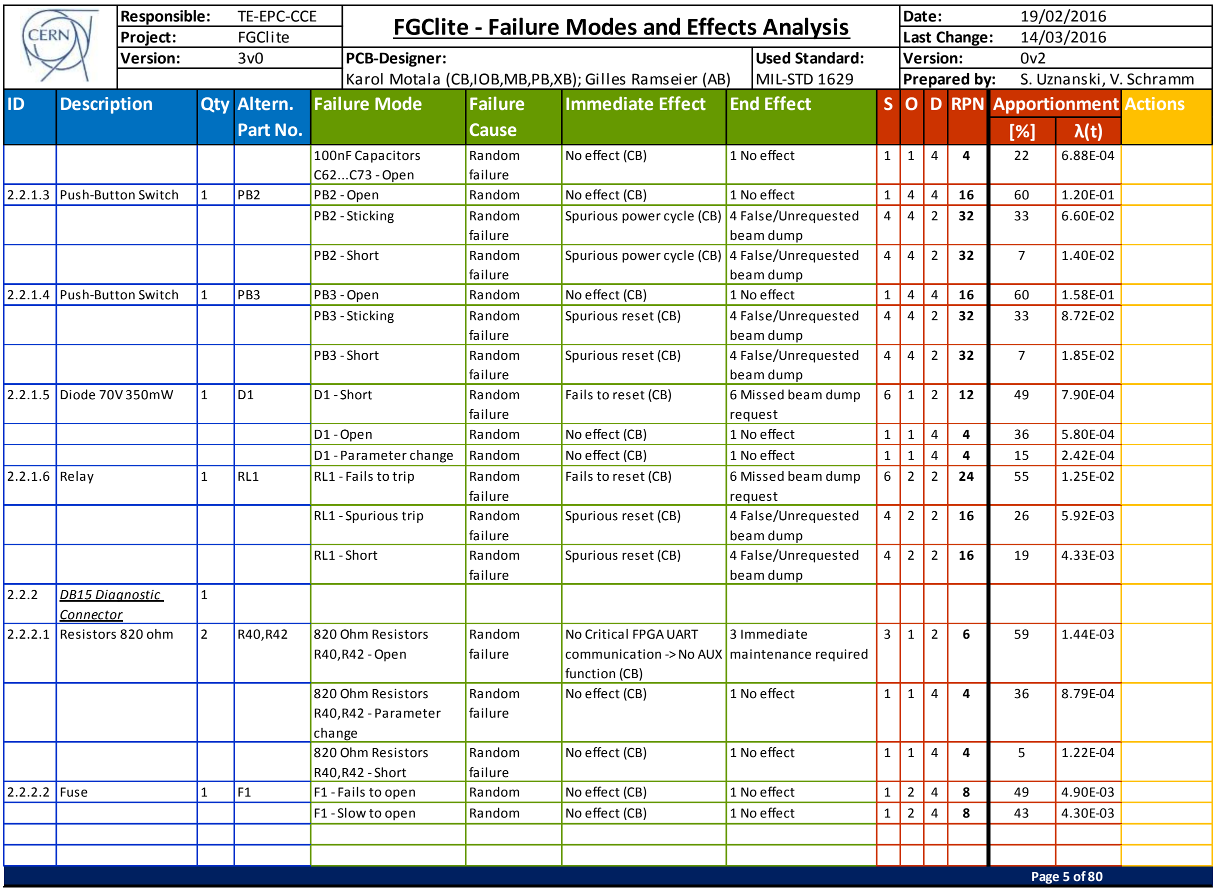

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												[%]	λ(t)	
				100nF Capacitors C62...C73 - Open	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	22	6.88E-04	
2.2.1.3	Push-Button Switch	1	PB2	PB2 - Open	Random	No effect (CB)	1 No effect	1	4	4	**16**	60	1.20E-01	
				PB2 - Sticking	Random failure	Spurious power cycle (CB)	4 False/Unrequested beam dump	4	4	2	**32**	33	6.60E-02	
				PB2 - Short	Random failure	Spurious power cycle (CB)	4 False/Unrequested beam dump	4	4	2	**32**	7	1.40E-02	
2.2.1.4	Push-Button Switch	1	PB3	PB3 - Open	Random	No effect (CB)	1 No effect	1	4	4	**16**	60	1.58E-01	
				PB3 - Sticking	Random failure	Spurious reset (CB)	4 False/Unrequested beam dump	4	4	2	**32**	33	8.72E-02	
				PB3 - Short	Random failure	Spurious reset (CB)	4 False/Unrequested beam dump	4	4	2	**32**	7	1.85E-02	
2.2.1.5	Diode 70V 350mW	1	D1	D1 - Short	Random failure	Fails to reset (CB)	6 Missed beam dump request	6	1	2	**12**	49	7.90E-04	
				D1 - Open	Random	No effect (CB)	1 No effect	1	1	4	**4**	36	5.80E-04	
				D1 - Parameter change	Random	No effect (CB)	1 No effect	1	1	4	**4**	15	2.42E-04	
2.2.1.6	Relay	1	RL1	RL1 - Fails to trip	Random failure	Fails to reset (CB)	6 Missed beam dump request	6	2	2	**24**	55	1.25E-02	
				RL1 - Spurious trip	Random failure	Spurious reset (CB)	4 False/Unrequested beam dump	4	2	2	**16**	26	5.92E-03	
				RL1 - Short	Random failure	Spurious reset (CB)	4 False/Unrequested beam dump	4	2	2	**16**	19	4.33E-03	
2.2.2	*DB15 Diagnostic Connector*	1												
2.2.2.1	Resistors 820 ohm	2	R40,R42	820 Ohm Resistors R40,R42 - Open	Random failure	No Critical FPGA UART communication -> No AUX function (CB)	3 Immediate maintenance required	3	1	2	**6**	59	1.44E-03	
				820 Ohm Resistors R40,R42 - Parameter change	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	36	8.79E-04	
				820 Ohm Resistors R40,R42 - Short	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	5	1.22E-04	
2.2.2.2	Fuse	1	F1	F1 - Fails to open	Random	No effect (CB)	1 No effect	1	2	4	**8**	49	4.90E-03	
				F1 - Slow to open	Random	No effect (CB)	1 No effect	1	2	4	**8**	43	4.30E-03	

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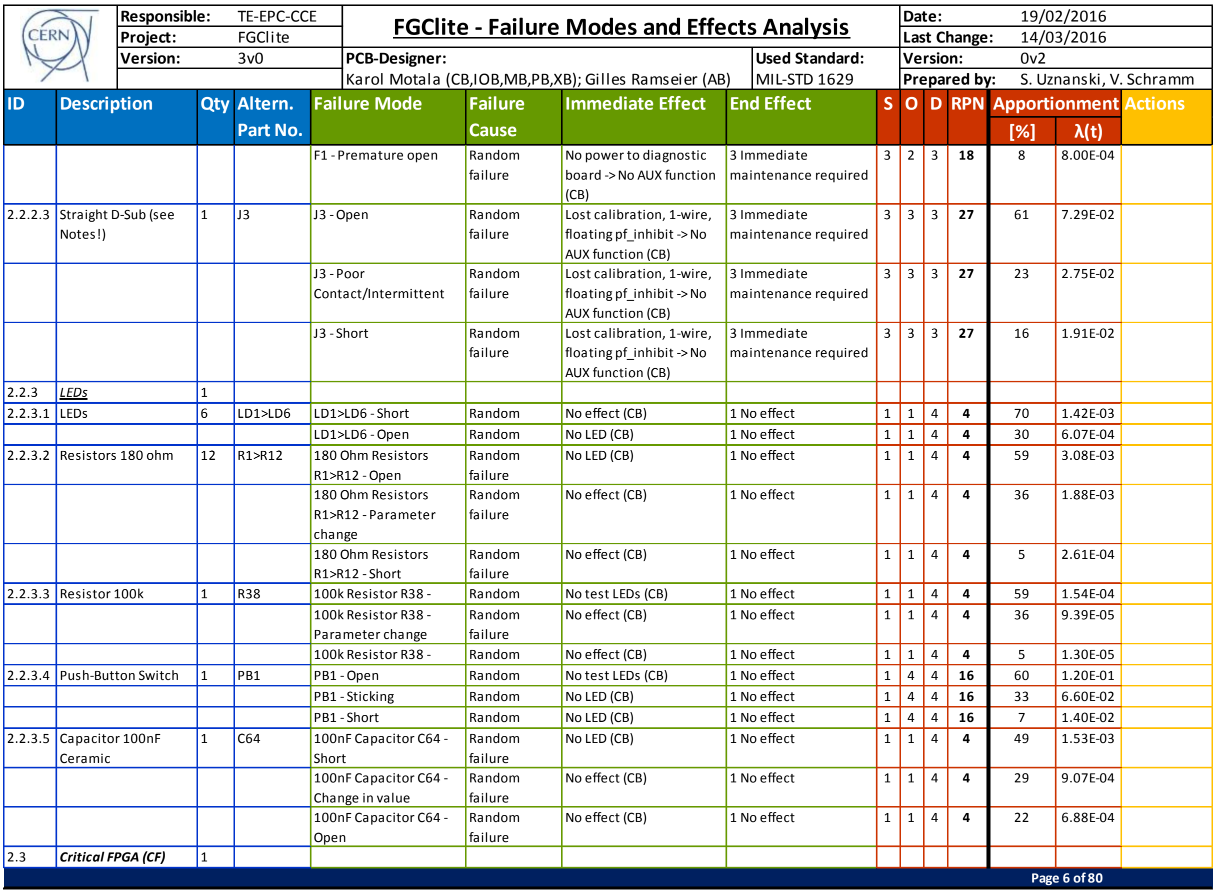

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				F1 - Premature open	Random failure	No power to diagnostic board -> No AUX function (CB)	3 Immediate maintenance required	3	2	3	**18**	8	8.00E-04	
2.2.2.3	Straight D-Sub (see Notes!)	1	J3	J3 - Open	Random failure	Lost calibration, 1-wire, floating pf_inhibit -> No AUX function (CB)	3 Immediate maintenance required	3	3	3	**27**	61	7.29E-02	
				J3 - Poor Contact/Intermittent	Random failure	Lost calibration, 1-wire, floating pf_inhibit -> No AUX function (CB)	3 Immediate maintenance required	3	3	3	**27**	23	2.75E-02	
				J3 - Short	Random failure	Lost calibration, 1-wire, floating pf_inhibit -> No AUX function (CB)	3 Immediate maintenance required	3	3	3	**27**	16	1.91E-02	
2.2.3	*LEDs*	1												
2.2.3.1	LEDs	6	LD1>LD6	LD1>LD6 - Short	Random	No effect (CB)	1 No effect	1	1	4	**4**	70	1.42E-03	
				LD1>LD6 - Open	Random	No LED (CB)	1 No effect	1	1	4	**4**	30	6.07E-04	
2.2.3.2	Resistors 180 ohm	12	R1>R12	180 Ohm Resistors R1>R12 - Open	Random failure	No LED (CB)	1 No effect	1	1	4	**4**	59	3.08E-03	
				180 Ohm Resistors R1>R12 - Parameter change	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	36	1.88E-03	
				180 Ohm Resistors R1>R12 - Short	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	5	2.61E-04	
2.2.3.3	Resistor 100k	1	R38	100k Resistor R38 -	Random	No test LEDs (CB)	1 No effect	1	1	4	**4**	59	1.54E-04	
				100k Resistor R38 - Parameter change	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	36	9.39E-05	
				100k Resistor R38 -	Random	No effect (CB)	1 No effect	1	1	4	**4**	5	1.30E-05	
2.2.3.4	Push-Button Switch	1	PB1	PB1 - Open	Random	No test LEDs (CB)	1 No effect	1	4	4	**16**	60	1.20E-01	
				PB1 - Sticking	Random	No LED (CB)	1 No effect	1	4	4	**16**	33	6.60E-02	
				PB1 - Short	Random	No LED (CB)	1 No effect	1	4	4	**16**	7	1.40E-02	
2.2.3.5	Capacitor 100nF Ceramic	1	C64	100nF Capacitor C64 - Short	Random failure	No LED (CB)	1 No effect	1	1	4	**4**	49	1.53E-03	
				100nF Capacitor C64 - Change in value	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	29	9.07E-04	
				100nF Capacitor C64 - Open	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	22	6.88E-04	
2.3	***Critical FPGA (CF)***	1												

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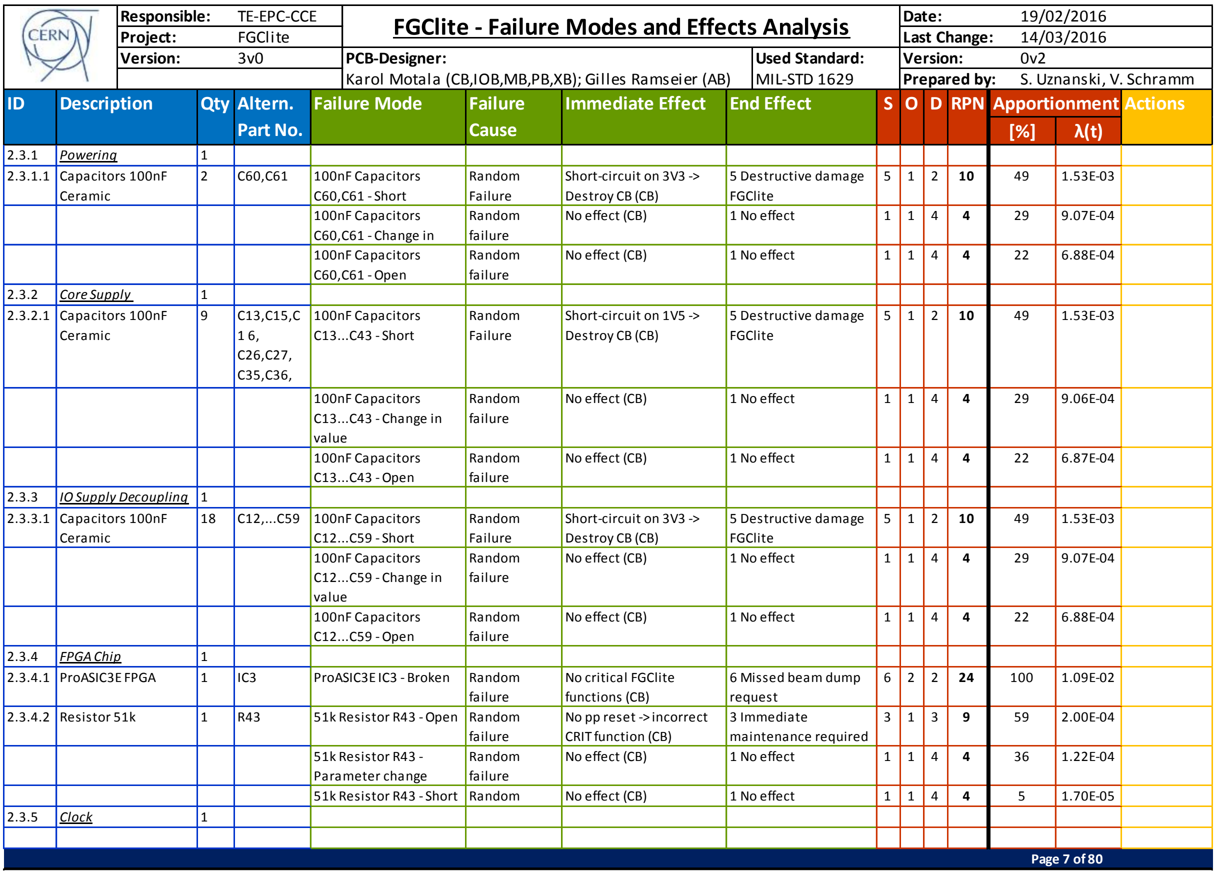

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2.3.1	*Powering*	1												
2.3.1.1	Capacitors 100nF Ceramic	2	C60,C61	100nF Capacitors C60,C61 - Short	Random Failure	Short-circuit on 3V3 -> Destroy CB (CB)	5 Destructive damage FGClite	5	1	2	**10**	49	1.53E-03	
				100nF Capacitors C60,C61 - Change in	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	29	9.07E-04	
				100nF Capacitors C60,C61 - Open	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	22	6.88E-04	
2.3.2	*Core Supply*	1												
2.3.2.1	Capacitors 100nF Ceramic	9	C13,C15,C 1 6, C26,C27, C35,C36,	100nF Capacitors C13...C43 - Short	Random Failure	Short-circuit on 1V5 -> Destroy CB (CB)	5 Destructive damage FGClite	5	1	2	**10**	49	1.53E-03	
				100nF Capacitors C13...C43 - Change in value	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	29	9.06E-04	
				100nF Capacitors C13...C43 - Open	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	22	6.87E-04	
2.3.3	*IO Supply Decoupling*	1												
2.3.3.1	Capacitors 100nF Ceramic	18	C12,...C59	100nF Capacitors C12...C59 - Short	Random Failure	Short-circuit on 3V3 -> Destroy CB (CB)	5 Destructive damage FGClite	5	1	2	**10**	49	1.53E-03	
				100nF Capacitors C12...C59 - Change in value	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	29	9.07E-04	
				100nF Capacitors C12...C59 - Open	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	22	6.88E-04	
2.3.4	*FPGA Chip*	1												
2.3.4.1	ProASIC3E FPGA	1	IC3	ProASIC3E IC3 - Broken	Random failure	No critical FGClite functions (CB)	6 Missed beam dump request	6	2	2	**24**	100	1.09E-02	
2.3.4.2	Resistor 51k	1	R43	51k Resistor R43 - Open	Random failure	No pp reset -> incorrect CRIT function (CB)	3 Immediate maintenance required	3	1	3	**9**	59	2.00E-04	
				51k Resistor R43 - Parameter change	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	36	1.22E-04	
				51k Resistor R43 - Short	Random	No effect (CB)	1 No effect	1	1	4	**4**	5	1.70E-05	
2.3.5	*Clock*	1												

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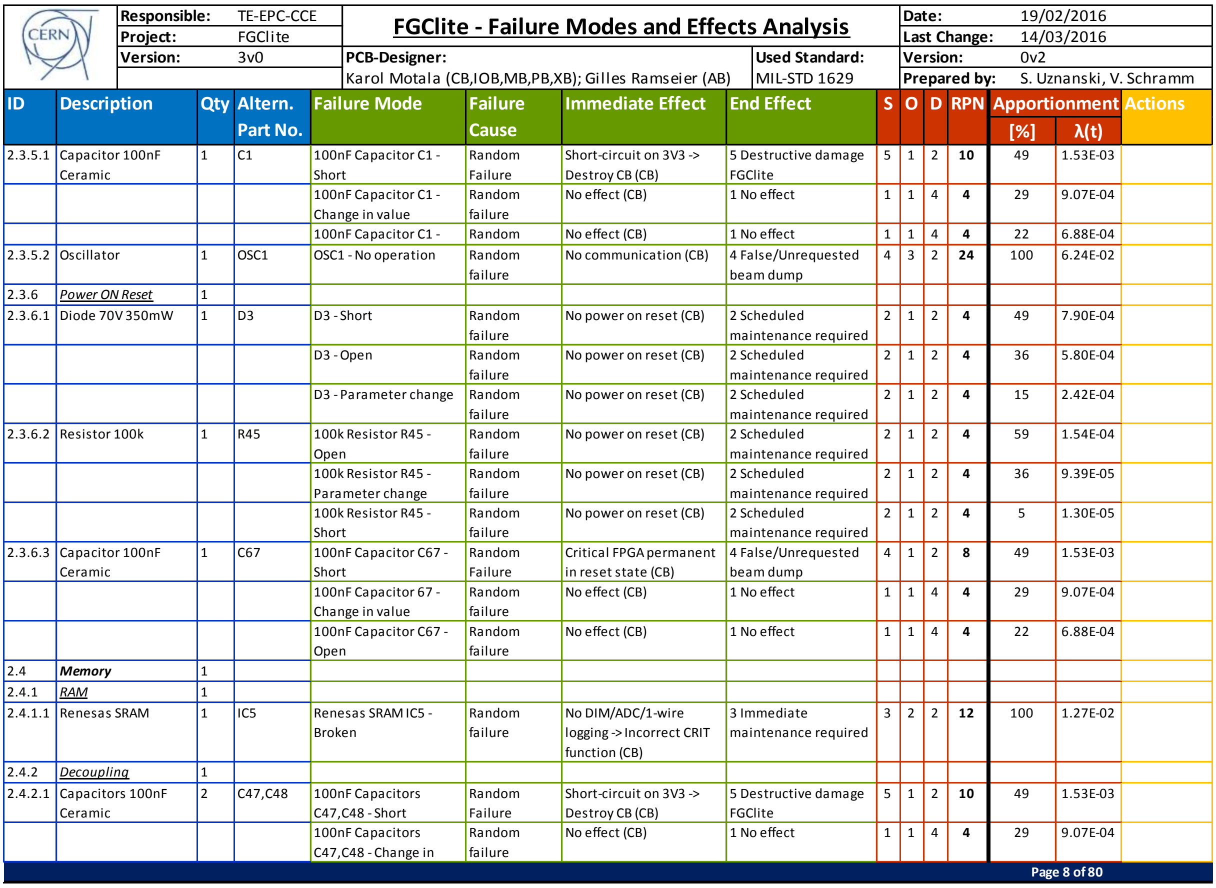

Responsible: TE-EPC-CCE	**FGClite - Failure Modes and Effects Analysis**		**Date:** 19/02/2016
Project: FGClite			**Last Change:** 14/03/2016
Version: 3v0	**PCB-Designer:**	**Used Standard:**	**Version:** 0v2
	Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)	MIL-STD 1629	**Prepared by:** S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment [%]	λ(t)	Actions
2.3.5.1	Capacitor 100nF Ceramic	1	C1	100nF Capacitor C1 - Short	Random Failure	Short-circuit on 3V3 -> Destroy CB (CB)	5 Destructive damage FGClite	5	1	2	**10**	49	1.53E-03	
				100nF Capacitor C1 - Change in value	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	29	9.07E-04	
				100nF Capacitor C1 -	Random	No effect (CB)	1 No effect	1	1	4	**4**	22	6.88E-04	
2.3.5.2	Oscillator	1	OSC1	OSC1 - No operation	Random failure	No communication (CB)	4 False/Unrequested beam dump	4	3	2	**24**	100	6.24E-02	
2.3.6	*Power ON Reset*	1												
2.3.6.1	Diode 70V 350mW	1	D3	D3 - Short	Random failure	No power on reset (CB)	2 Scheduled maintenance required	2	1	2	**4**	49	7.90E-04	
				D3 - Open	Random failure	No power on reset (CB)	2 Scheduled maintenance required	2	1	2	**4**	36	5.80E-04	
				D3 - Parameter change	Random failure	No power on reset (CB)	2 Scheduled maintenance required	2	1	2	**4**	15	2.42E-04	
2.3.6.2	Resistor 100k	1	R45	100k Resistor R45 - Open	Random failure	No power on reset (CB)	2 Scheduled maintenance required	2	1	2	**4**	59	1.54E-04	
				100k Resistor R45 - Parameter change	Random failure	No power on reset (CB)	2 Scheduled maintenance required	2	1	2	**4**	36	9.39E-05	
				100k Resistor R45 - Short	Random failure	No power on reset (CB)	2 Scheduled maintenance required	2	1	2	**4**	5	1.30E-05	
2.3.6.3	Capacitor 100nF Ceramic	1	C67	100nF Capacitor C67 - Short	Random Failure	Critical FPGA permanent in reset state (CB)	4 False/Unrequested beam dump	4	1	2	**8**	49	1.53E-03	
				100nF Capacitor 67 - Change in value	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	29	9.07E-04	
				100nF Capacitor C67 - Open	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	22	6.88E-04	
2.4	***Memory***	1												
2.4.1	*RAM*	1												
2.4.1.1	Renesas SRAM	1	IC5	Renesas SRAM IC5 - Broken	Random failure	No DIM/ADC/1-wire logging -> Incorrect CRIT function (CB)	3 Immediate maintenance required	3	2	2	**12**	100	1.27E-02	
2.4.2	*Decoupling*	1												
2.4.2.1	Capacitors 100nF Ceramic	2	C47,C48	100nF Capacitors C47,C48 - Short	Random Failure	Short-circuit on 3V3 -> Destroy CB (CB)	5 Destructive damage FGClite	5	1	2	**10**	49	1.53E-03	
				100nF Capacitors C47,C48 - Change in	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	29	9.07E-04	

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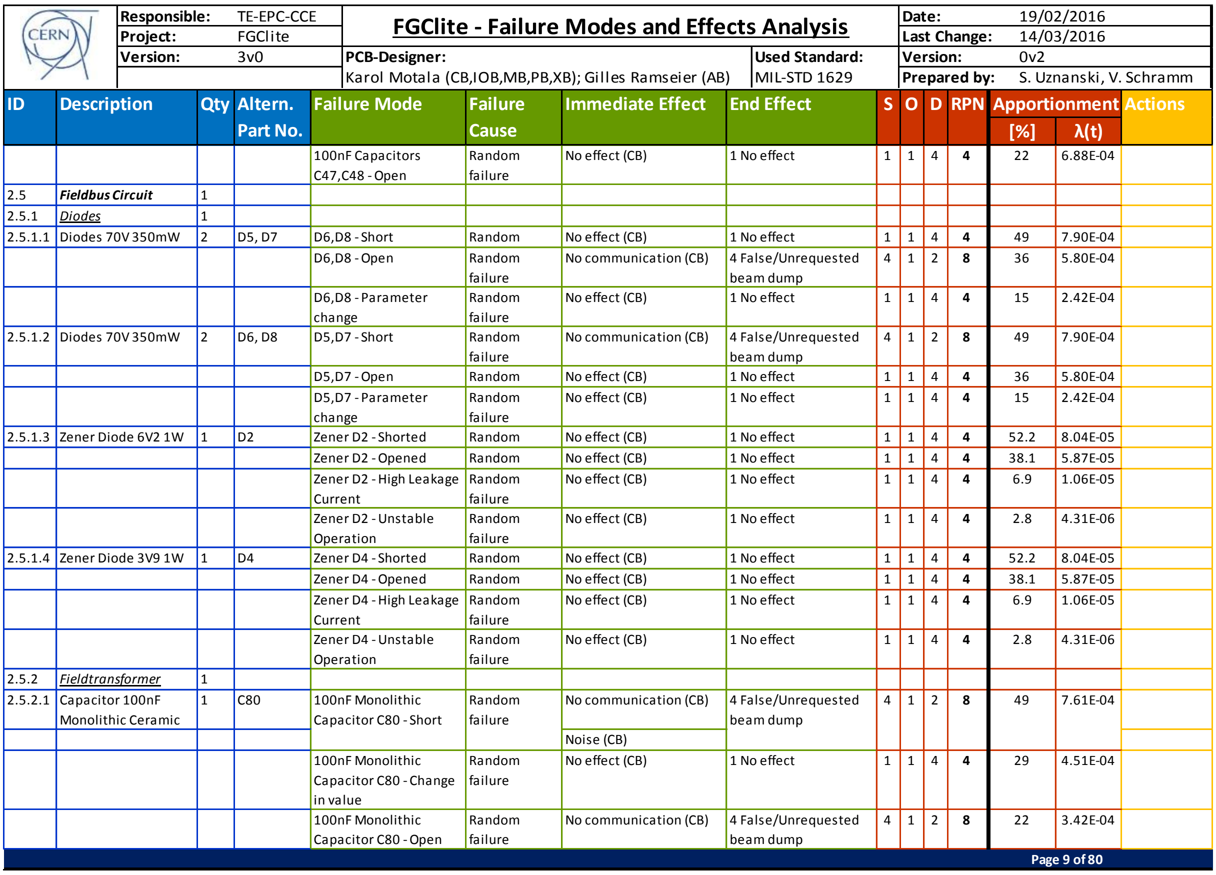

Responsible: TE-EPC-CCE	**FGClite - Failure Modes and Effects Analysis**		**Date:** 19/02/2016
Project: FGClite			**Last Change:** 14/03/2016
Version: 3v0	**PCB-Designer:**	**Used Standard:**	**Version:** 0v2
	Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)	MIL-STD 1629	**Prepared by:** S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment [%]	λ(t)	Actions
				100nF Capacitors C47,C48 - Open	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	22	6.88E-04	
2.5	***Fieldbus Circuit***	1												
2.5.1	*Diodes*	1												
2.5.1.1	Diodes 70V 350mW	2	D5, D7	D6,D8 - Short	Random	No effect (CB)	1 No effect	1	1	4	**4**	49	7.90E-04	
				D6,D8 - Open	Random failure	No communication (CB)	4 False/Unrequested beam dump	4	1	2	**8**	36	5.80E-04	
				D6,D8 - Parameter change	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	15	2.42E-04	
2.5.1.2	Diodes 70V 350mW	2	D6, D8	D5,D7 - Short	Random failure	No communication (CB)	4 False/Unrequested beam dump	4	1	2	**8**	49	7.90E-04	
				D5,D7 - Open	Random	No effect (CB)	1 No effect	1	1	4	**4**	36	5.80E-04	
				D5,D7 - Parameter change	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	15	2.42E-04	
2.5.1.3	Zener Diode 6V2 1W	1	D2	Zener D2 - Shorted	Random	No effect (CB)	1 No effect	1	1	4	**4**	52.2	8.04E-05	
				Zener D2 - Opened	Random	No effect (CB)	1 No effect	1	1	4	**4**	38.1	5.87E-05	
				Zener D2 - High Leakage Current	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	6.9	1.06E-05	
				Zener D2 - Unstable Operation	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	2.8	4.31E-06	
2.5.1.4	Zener Diode 3V9 1W	1	D4	Zener D4 - Shorted	Random	No effect (CB)	1 No effect	1	1	4	**4**	52.2	8.04E-05	
				Zener D4 - Opened	Random	No effect (CB)	1 No effect	1	1	4	**4**	38.1	5.87E-05	
				Zener D4 - High Leakage Current	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	6.9	1.06E-05	
				Zener D4 - Unstable Operation	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	2.8	4.31E-06	
2.5.2	*Fieldtransformer*	1												
2.5.2.1	Capacitor 100nF Monolithic Ceramic	1	C80	100nF Monolithic Capacitor C80 - Short	Random failure	No communication (CB)	4 False/Unrequested beam dump	4	1	2	**8**	49	7.61E-04	
						Noise (CB)								
				100nF Monolithic Capacitor C80 - Change in value	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	29	4.51E-04	
				100nF Monolithic Capacitor C80 - Open	Random failure	No communication (CB)	4 False/Unrequested beam dump	4	1	2	**8**	22	3.42E-04	

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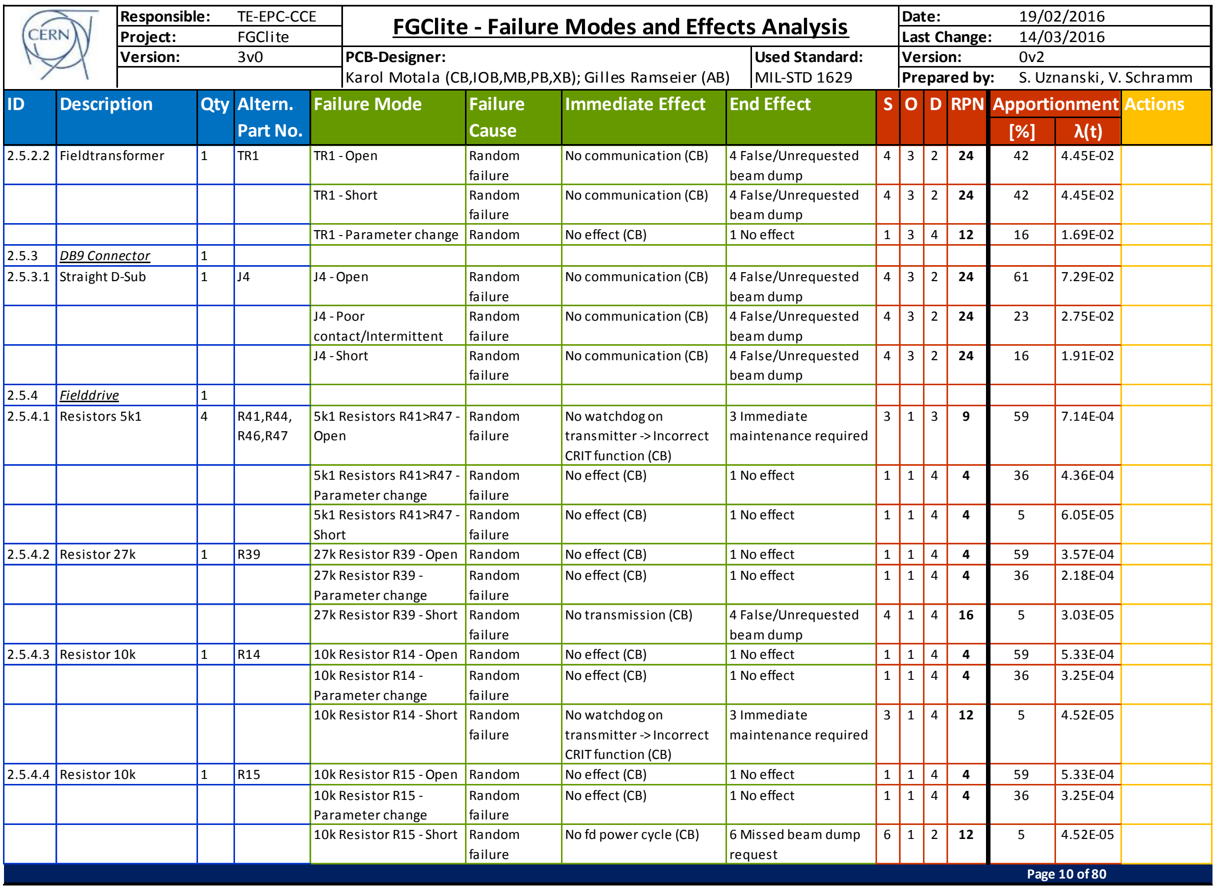

Responsible:	TE-EPC-CCE	**Date:**	19/02/2016
Project:	FGClite	**Last Change:**	14/03/2016
Version:	3v0	**Version:**	0v2
PCB-Designer:	Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)	**Prepared by:**	S. Uznanski, V. Schramm
Used Standard:	MIL-STD 1629		

FGClite - Failure Modes and Effects Analysis

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment [%]	λ(t)	Actions
2.5.2.2	Fieldtransformer	1	TR1	TR1 - Open	Random failure	No communication (CB)	4 False/Unrequested beam dump	4	3	2	**24**	42	4.45E-02	
				TR1 - Short	Random failure	No communication (CB)	4 False/Unrequested beam dump	4	3	2	**24**	42	4.45E-02	
				TR1 - Parameter change	Random	No effect (CB)	1 No effect	1	3	4	**12**	16	1.69E-02	
2.5.3	*DB9 Connector*	1												
2.5.3.1	Straight D-Sub	1	J4	J4 - Open	Random failure	No communication (CB)	4 False/Unrequested beam dump	4	3	2	**24**	61	7.29E-02	
				J4 - Poor contact/Intermittent	Random failure	No communication (CB)	4 False/Unrequested beam dump	4	3	2	**24**	23	2.75E-02	
				J4 - Short	Random failure	No communication (CB)	4 False/Unrequested beam dump	4	3	2	**24**	16	1.91E-02	
2.5.4	*Fielddrive*	1												
2.5.4.1	Resistors 5k1	4	R41,R44, R46,R47	5k1 Resistors R41>R47 - Open	Random failure	No watchdog on transmitter -> Incorrect CRIT function (CB)	3 Immediate maintenance required	3	1	3	**9**	59	7.14E-04	
				5k1 Resistors R41>R47 - Parameter change	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	36	4.36E-04	
				5k1 Resistors R41>R47 - Short	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	5	6.05E-05	
2.5.4.2	Resistor 27k	1	R39	27k Resistor R39 - Open	Random	No effect (CB)	1 No effect	1	1	4	**4**	59	3.57E-04	
				27k Resistor R39 - Parameter change	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	36	2.18E-04	
				27k Resistor R39 - Short	Random failure	No transmission (CB)	4 False/Unrequested beam dump	4	1	4	**16**	5	3.03E-05	
2.5.4.3	Resistor 10k	1	R14	10k Resistor R14 - Open	Random	No effect (CB)	1 No effect	1	1	4	**4**	59	5.33E-04	
				10k Resistor R14 - Parameter change	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	36	3.25E-04	
				10k Resistor R14 - Short	Random failure	No watchdog on transmitter -> Incorrect CRIT function (CB)	3 Immediate maintenance required	3	1	4	**12**	5	4.52E-05	
2.5.4.4	Resistor 10k	1	R15	10k Resistor R15 - Open	Random	No effect (CB)	1 No effect	1	1	4	**4**	59	5.33E-04	
				10k Resistor R15 - Parameter change	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	36	3.25E-04	
				10k Resistor R15 - Short	Random failure	No fd power cycle (CB)	6 Missed beam dump request	6	1	2	**12**	5	4.52E-05	

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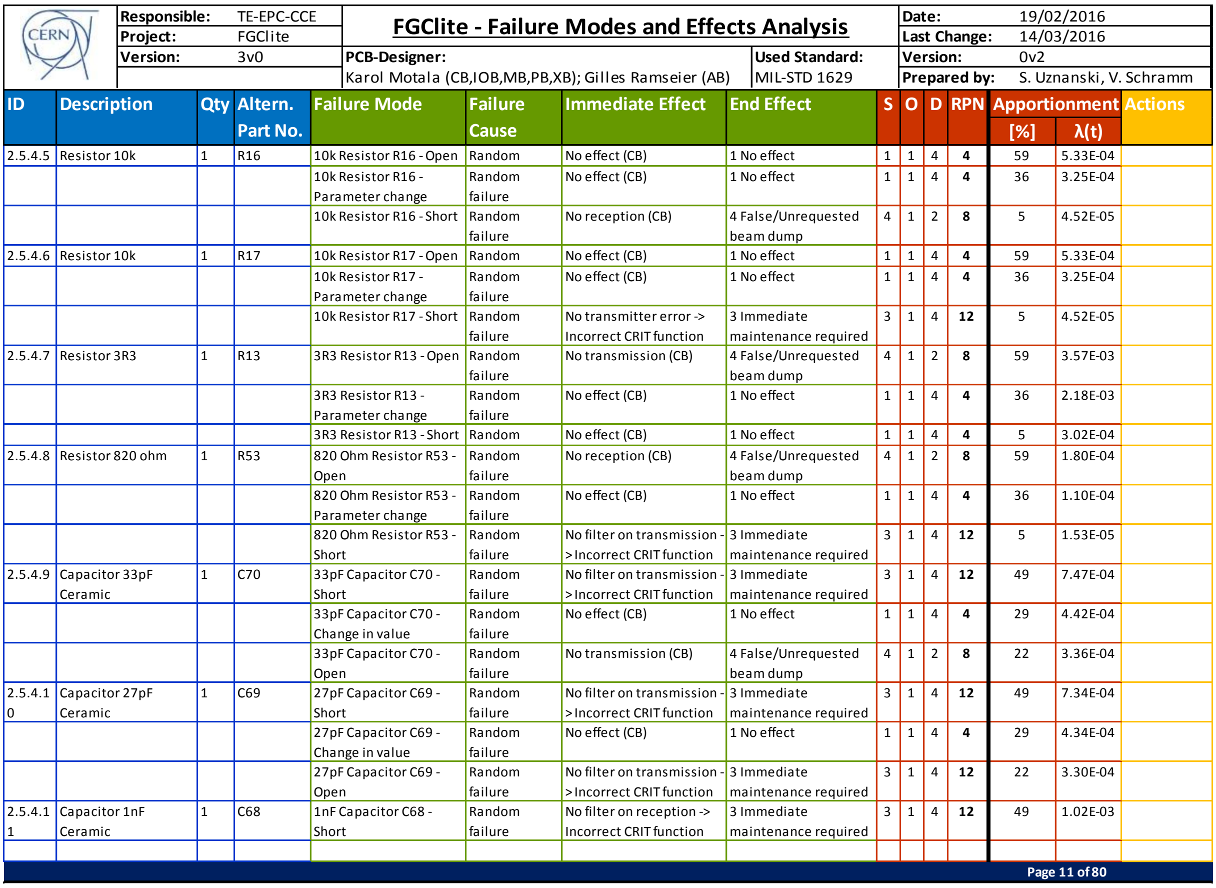

Responsible:	TE-EPC-CCE	**Date:**	19/02/2016
Project:	FGClite	**Last Change:**	14/03/2016
Version:	3v0	**Version:**	0v2
PCB-Designer:	Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)	**Prepared by:**	S. Uznanski, V. Schramm
Used Standard:	MIL-STD 1629		

FGClite - Failure Modes and Effects Analysis

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment [%]	λ(t)	Actions
2.5.4.5	Resistor 10k	1	R16	10k Resistor R16 - Open	Random	No effect (CB)	1 No effect	1	1	4	**4**	59	5.33E-04	
				10k Resistor R16 - Parameter change	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	36	3.25E-04	
				10k Resistor R16 - Short	Random failure	No reception (CB)	4 False/Unrequested beam dump	4	1	2	**8**	5	4.52E-05	
2.5.4.6	Resistor 10k	1	R17	10k Resistor R17 - Open	Random	No effect (CB)	1 No effect	1	1	4	**4**	59	5.33E-04	
				10k Resistor R17 - Parameter change	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	36	3.25E-04	
				10k Resistor R17 - Short	Random failure	No transmitter error -> Incorrect CRIT function	3 Immediate maintenance required	3	1	4	**12**	5	4.52E-05	
2.5.4.7	Resistor 3R3	1	R13	3R3 Resistor R13 - Open	Random failure	No transmission (CB)	4 False/Unrequested beam dump	4	1	2	**8**	59	3.57E-03	
				3R3 Resistor R13 - Parameter change	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	36	2.18E-03	
				3R3 Resistor R13 - Short	Random	No effect (CB)	1 No effect	1	1	4	**4**	5	3.02E-04	
2.5.4.8	Resistor 820 ohm	1	R53	820 Ohm Resistor R53 - Open	Random failure	No reception (CB)	4 False/Unrequested beam dump	4	1	2	**8**	59	1.80E-04	
				820 Ohm Resistor R53 - Parameter change	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	36	1.10E-04	
				820 Ohm Resistor R53 - Short	Random failure	No filter on transmission -> Incorrect CRIT function	3 Immediate maintenance required	3	1	4	**12**	5	1.53E-05	
2.5.4.9	Capacitor 33pF Ceramic	1	C70	33pF Capacitor C70 - Short	Random failure	No filter on transmission -> Incorrect CRIT function	3 Immediate maintenance required	3	1	4	**12**	49	7.47E-04	
				33pF Capacitor C70 - Change in value	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	29	4.42E-04	
				33pF Capacitor C70 - Open	Random failure	No transmission (CB)	4 False/Unrequested beam dump	4	1	2	**8**	22	3.36E-04	
2.5.4.10	Capacitor 27pF Ceramic	1	C69	27pF Capacitor C69 - Short	Random failure	No filter on transmission -> Incorrect CRIT function	3 Immediate maintenance required	3	1	4	**12**	49	7.34E-04	
				27pF Capacitor C69 - Change in value	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	29	4.34E-04	
				27pF Capacitor C69 - Open	Random failure	No filter on transmission -> Incorrect CRIT function	3 Immediate maintenance required	3	1	4	**12**	22	3.30E-04	
2.5.4.11	Capacitor 1nF Ceramic	1	C68	1nF Capacitor C68 - Short	Random failure	No filter on reception -> Incorrect CRIT function	3 Immediate maintenance required	3	1	4	**12**	49	1.02E-03	

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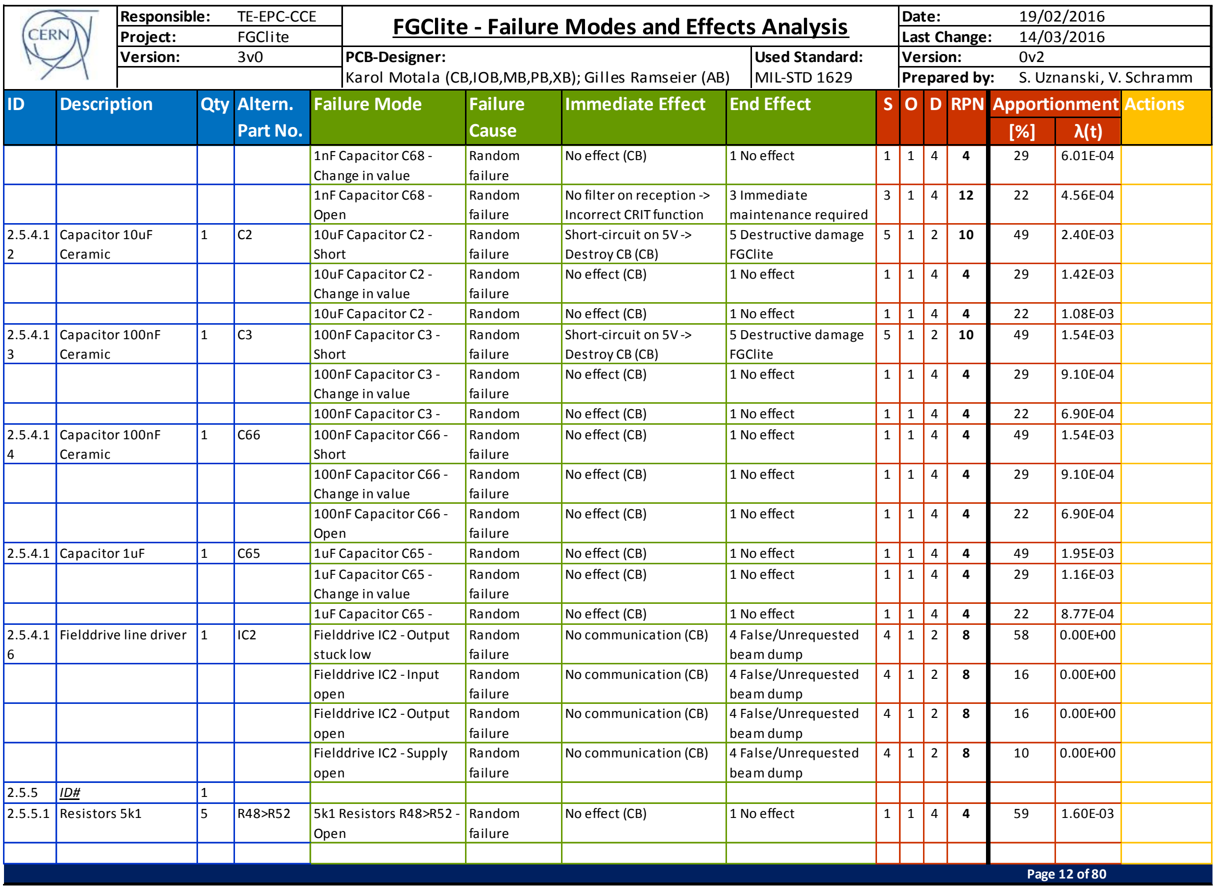

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - Failure Modes and Effects Analysis

PCB-Designer: Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)
Used Standard: MIL-STD 1629

Date: 19/02/2016
Last Change: 14/03/2016
Version: 0v2
Prepared by: S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment [%]	λ(t)	Actions
				1nF Capacitor C68 - Change in value	Random failure	No effect (CB)	1 No effect	1	1	4	4	29	6.01E-04	
				1nF Capacitor C68 - Open	Random failure	No filter on reception -> Incorrect CRIT function	3 Immediate maintenance required	3	1	4	12	22	4.56E-04	
2.5.4.1 2	Capacitor 10uF Ceramic	1	C2	10uF Capacitor C2 - Short	Random failure	Short-circuit on 5V -> Destroy CB (CB)	5 Destructive damage FGClite	5	1	2	10	49	2.40E-03	
				10uF Capacitor C2 - Change in value	Random failure	No effect (CB)	1 No effect	1	1	4	4	29	1.42E-03	
				10uF Capacitor C2 -	Random	No effect (CB)	1 No effect	1	1	4	4	22	1.08E-03	
2.5.4.1 3	Capacitor 100nF Ceramic	1	C3	100nF Capacitor C3 - Short	Random failure	Short-circuit on 5V -> Destroy CB (CB)	5 Destructive damage FGClite	5	1	2	10	49	1.54E-03	
				100nF Capacitor C3 - Change in value	Random failure	No effect (CB)	1 No effect	1	1	4	4	29	9.10E-04	
				100nF Capacitor C3 -	Random	No effect (CB)	1 No effect	1	1	4	4	22	6.90E-04	
2.5.4.1 4	Capacitor 100nF Ceramic	1	C66	100nF Capacitor C66 - Short	Random failure	No effect (CB)	1 No effect	1	1	4	4	49	1.54E-03	
				100nF Capacitor C66 - Change in value	Random failure	No effect (CB)	1 No effect	1	1	4	4	29	9.10E-04	
				100nF Capacitor C66 - Open	Random failure	No effect (CB)	1 No effect	1	1	4	4	22	6.90E-04	
2.5.4.1	Capacitor 1uF	1	C65	1uF Capacitor C65 -	Random	No effect (CB)	1 No effect	1	1	4	4	49	1.95E-03	
				1uF Capacitor C65 - Change in value	Random failure	No effect (CB)	1 No effect	1	1	4	4	29	1.16E-03	
				1uF Capacitor C65 -	Random	No effect (CB)	1 No effect	1	1	4	4	22	8.77E-04	
2.5.4.1 6	Fielddrive line driver	1	IC2	Fielddrive IC2 - Output stuck low	Random failure	No communication (CB)	4 False/Unrequested beam dump	4	1	2	8	58	0.00E+00	
				Fielddrive IC2 - Input open	Random failure	No communication (CB)	4 False/Unrequested beam dump	4	1	2	8	16	0.00E+00	
				Fielddrive IC2 - Output open	Random failure	No communication (CB)	4 False/Unrequested beam dump	4	1	2	8	16	0.00E+00	
				Fielddrive IC2 - Supply open	Random failure	No communication (CB)	4 False/Unrequested beam dump	4	1	2	8	10	0.00E+00	
2.5.5	*ID#*	1												
2.5.5.1	Resistors 5k1	5	R48>R52	5k1 Resistors R48>R52 - Open	Random failure	No effect (CB)	1 No effect	1	1	4	4	59	1.60E-03	

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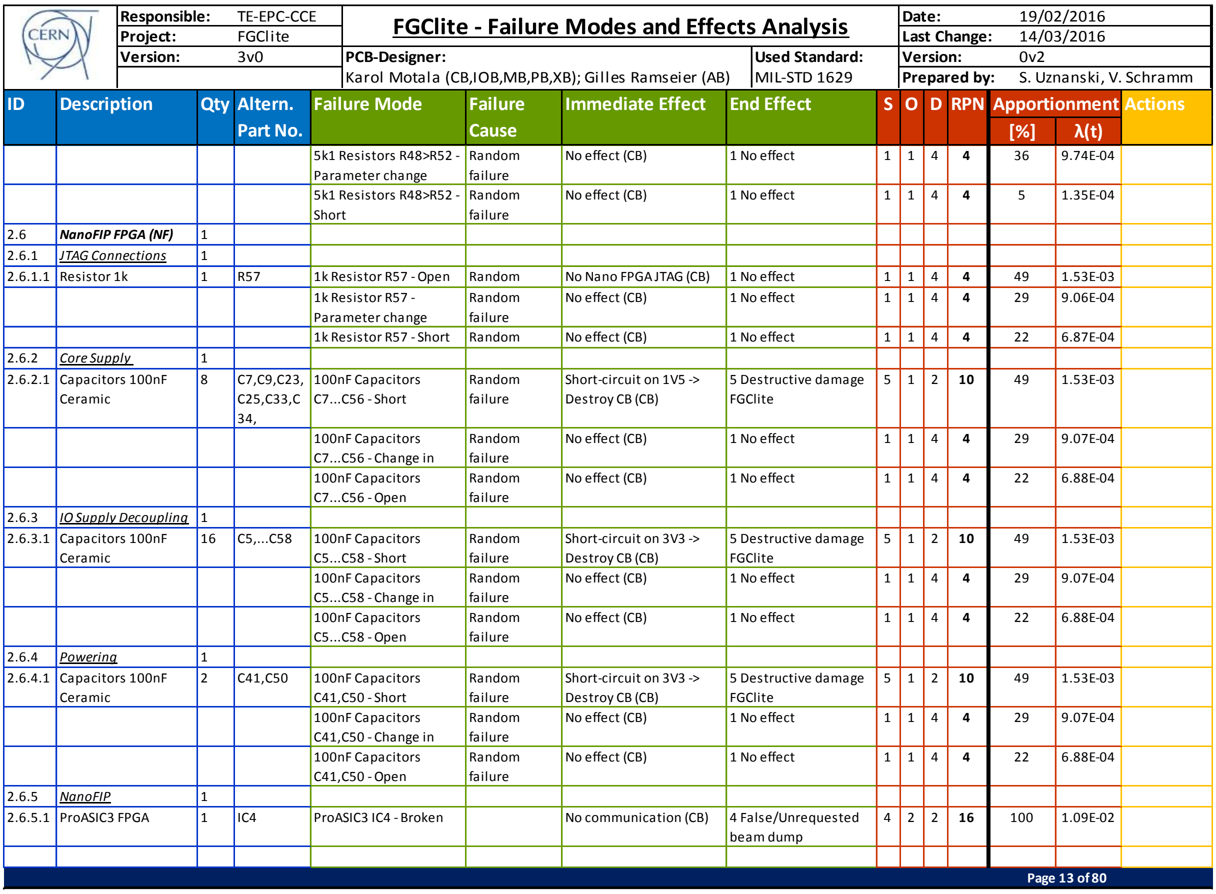

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - Failure Modes and Effects Analysis

PCB-Designer: Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)
Used Standard: MIL-STD 1629

Date: 19/02/2016
Last Change: 14/03/2016
Version: 0v2
Prepared by: S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment [%]	λ(t)	Actions
				5k1 Resistors R48>R52 - Parameter change	Random failure	No effect (CB)	1 No effect	1	1	4	4	36	9.74E-04	
				5k1 Resistors R48>R52 - Short	Random failure	No effect (CB)	1 No effect	1	1	4	4	5	1.35E-04	
2.6	***NanoFIP FPGA (NF)***	1												
2.6.1	*JTAG Connections*	1												
2.6.1.1	Resistor 1k	1	R57	1k Resistor R57 - Open	Random	No Nano FPGA JTAG (CB)	1 No effect	1	1	4	4	49	1.53E-03	
				1k Resistor R57 - Parameter change	Random failure	No effect (CB)	1 No effect	1	1	4	4	29	9.06E-04	
				1k Resistor R57 - Short	Random	No effect (CB)	1 No effect	1	1	4	4	22	6.87E-04	
2.6.2	*Core Supply*	1												
2.6.2.1	Capacitors 100nF Ceramic	8	C7,C9,C23, C25,C33,C 34,	100nF Capacitors C7...C56 - Short	Random failure	Short-circuit on 1V5 -> Destroy CB (CB)	5 Destructive damage FGClite	5	1	2	10	49	1.53E-03	
				100nF Capacitors C7...C56 - Change in	Random failure	No effect (CB)	1 No effect	1	1	4	4	29	9.07E-04	
				100nF Capacitors C7...C56 - Open	Random failure	No effect (CB)	1 No effect	1	1	4	4	22	6.88E-04	
2.6.3	*IO Supply Decoupling*	1												
2.6.3.1	Capacitors 100nF Ceramic	16	C5,...C58	100nF Capacitors C5...C58 - Short	Random failure	Short-circuit on 3V3 -> Destroy CB (CB)	5 Destructive damage FGClite	5	1	2	10	49	1.53E-03	
				100nF Capacitors C5...C58 - Change in	Random failure	No effect (CB)	1 No effect	1	1	4	4	29	9.07E-04	
				100nF Capacitors C5...C58 - Open	Random failure	No effect (CB)	1 No effect	1	1	4	4	22	6.88E-04	
2.6.4	*Powering*	1												
2.6.4.1	Capacitors 100nF Ceramic	2	C41,C50	100nF Capacitors C41,C50 - Short	Random failure	Short-circuit on 3V3 -> Destroy CB (CB)	5 Destructive damage FGClite	5	1	2	10	49	1.53E-03	
				100nF Capacitors C41,C50 - Change in	Random failure	No effect (CB)	1 No effect	1	1	4	4	29	9.07E-04	
				100nF Capacitors C41,C50 - Open	Random failure	No effect (CB)	1 No effect	1	1	4	4	22	6.88E-04	
2.6.5	*NanoFIP*	1												
2.6.5.1	ProASIC3 FPGA	1	IC4	ProASIC3 IC4 - Broken		No communication (CB)	4 False/Unrequested beam dump	4	2	2	16	100	1.09E-02	

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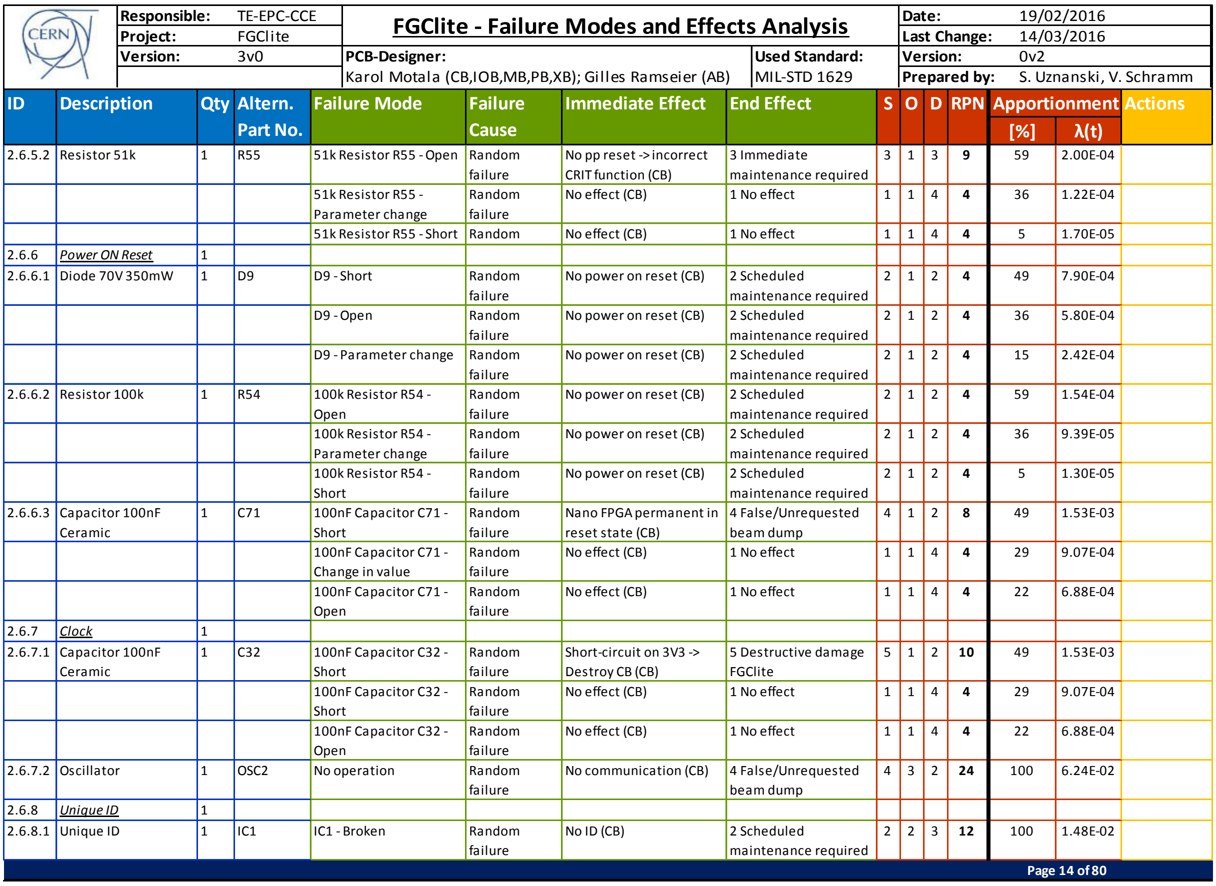

Responsible: TE-EPC-CCE	**FGClite - Failure Modes and Effects Analysis**		**Date:**	19/02/2016
Project: FGClite			**Last Change:**	14/03/2016
Version: 3v0	**PCB-Designer:**	**Used Standard:**	**Version:**	0v2
	Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)	MIL-STD 1629	**Prepared by:**	S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment [%]	λ(t)	Actions
2.6.5.2	Resistor 51k	1	R55	51k Resistor R55 - Open	Random failure	No pp reset -> incorrect CRIT function (CB)	3 Immediate maintenance required	3	1	3	**9**	59	2.00E-04	
				51k Resistor R55 - Parameter change	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	36	1.22E-04	
				51k Resistor R55 - Short	Random	No effect (CB)	1 No effect	1	1	4	**4**	5	1.70E-05	
2.6.6	*Power ON Reset*	1												
2.6.6.1	Diode 70V 350mW	1	D9	D9 - Short	Random failure	No power on reset (CB)	2 Scheduled maintenance required	2	1	2	**4**	49	7.90E-04	
				D9 - Open	Random failure	No power on reset (CB)	2 Scheduled maintenance required	2	1	2	**4**	36	5.80E-04	
				D9 - Parameter change	Random failure	No power on reset (CB)	2 Scheduled maintenance required	2	1	2	**4**	15	2.42E-04	
2.6.6.2	Resistor 100k	1	R54	100k Resistor R54 - Open	Random failure	No power on reset (CB)	2 Scheduled maintenance required	2	1	2	**4**	59	1.54E-04	
				100k Resistor R54 - Parameter change	Random failure	No power on reset (CB)	2 Scheduled maintenance required	2	1	2	**4**	36	9.39E-05	
				100k Resistor R54 - Short	Random failure	No power on reset (CB)	2 Scheduled maintenance required	2	1	2	**4**	5	1.30E-05	
2.6.6.3	Capacitor 100nF Ceramic	1	C71	100nF Capacitor C71 - Short	Random failure	Nano FPGA permanent in reset state (CB)	4 False/Unrequested beam dump	4	1	2	**8**	49	1.53E-03	
				100nF Capacitor C71 - Change in value	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	29	9.07E-04	
				100nF Capacitor C71 - Open	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	22	6.88E-04	
2.6.7	*Clock*	1												
2.6.7.1	Capacitor 100nF Ceramic	1	C32	100nF Capacitor C32 - Short	Random failure	Short-circuit on 3V3 -> Destroy CB (CB)	5 Destructive damage FGClite	5	1	2	**10**	49	1.53E-03	
				100nF Capacitor C32 - Short	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	29	9.07E-04	
				100nF Capacitor C32 - Open	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	22	6.88E-04	
2.6.7.2	Oscillator	1	OSC2	No operation	Random failure	No communication (CB)	4 False/Unrequested beam dump	4	3	2	**24**	100	6.24E-02	
2.6.8	*Unique ID*	1												
2.6.8.1	Unique ID	1	IC1	IC1 - Broken	Random failure	No ID (CB)	2 Scheduled maintenance required	2	2	3	**12**	100	1.48E-02	

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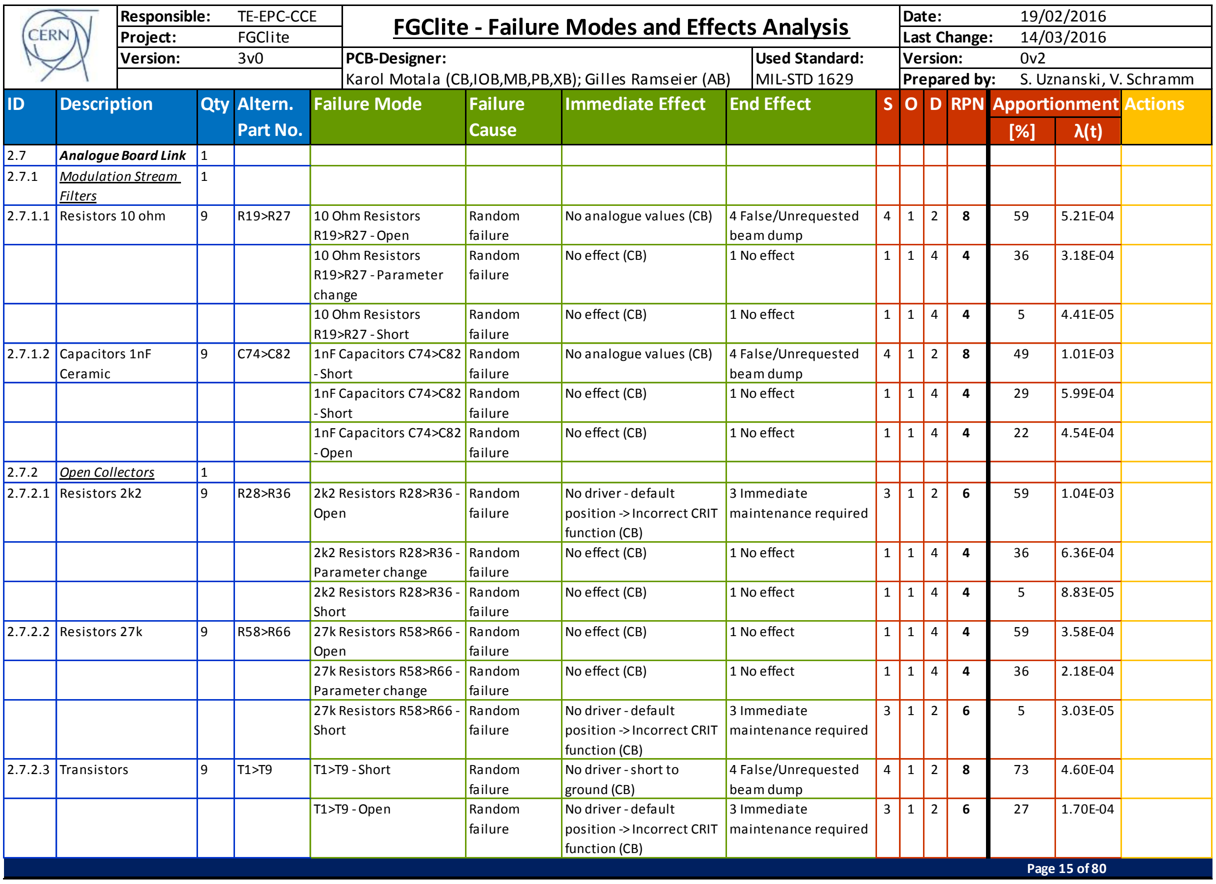

Responsible: TE-EPC-CCE	**FGClite - Failure Modes and Effects Analysis**		**Date:**	19/02/2016
Project: FGClite			**Last Change:**	14/03/2016
Version: 3v0	**PCB-Designer:**	**Used Standard:**	**Version:**	0v2
	Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)	MIL-STD 1629	**Prepared by:**	S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment [%]	λ(t)	Actions
2.7	***Analogue Board Link***	1												
2.7.1	*Modulation Stream Filters*	1												
2.7.1.1	Resistors 10 ohm	9	R19>R27	10 Ohm Resistors R19>R27 - Open	Random failure	No analogue values (CB)	4 False/Unrequested beam dump	4	1	2	**8**	59	5.21E-04	
				10 Ohm Resistors R19>R27 - Parameter change	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	36	3.18E-04	
				10 Ohm Resistors R19>R27 - Short	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	5	4.41E-05	
2.7.1.2	Capacitors 1nF Ceramic	9	C74>C82	1nF Capacitors C74>C82 - Short	Random failure	No analogue values (CB)	4 False/Unrequested beam dump	4	1	2	**8**	49	1.01E-03	
				1nF Capacitors C74>C82 - Short	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	29	5.99E-04	
				1nF Capacitors C74>C82 - Open	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	22	4.54E-04	
2.7.2	*Open Collectors*	1												
2.7.2.1	Resistors 2k2	9	R28>R36	2k2 Resistors R28>R36 - Open	Random failure	No driver - default position -> Incorrect CRIT function (CB)	3 Immediate maintenance required	3	1	2	**6**	59	1.04E-03	
				2k2 Resistors R28>R36 - Parameter change	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	36	6.36E-04	
				2k2 Resistors R28>R36 - Short	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	5	8.83E-05	
2.7.2.2	Resistors 27k	9	R58>R66	27k Resistors R58>R66 - Open	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	59	3.58E-04	
				27k Resistors R58>R66 - Parameter change	Random failure	No effect (CB)	1 No effect	1	1	4	**4**	36	2.18E-04	
				27k Resistors R58>R66 - Short	Random failure	No driver - default position -> Incorrect CRIT function (CB)	3 Immediate maintenance required	3	1	2	**6**	5	3.03E-05	
2.7.2.3	Transistors	9	T1>T9	T1>T9 - Short	Random failure	No driver - short to ground (CB)	4 False/Unrequested beam dump	4	1	2	**8**	73	4.60E-04	
				T1>T9 - Open	Random failure	No driver - default position -> Incorrect CRIT function (CB)	3 Immediate maintenance required	3	1	2	**6**	27	1.70E-04	

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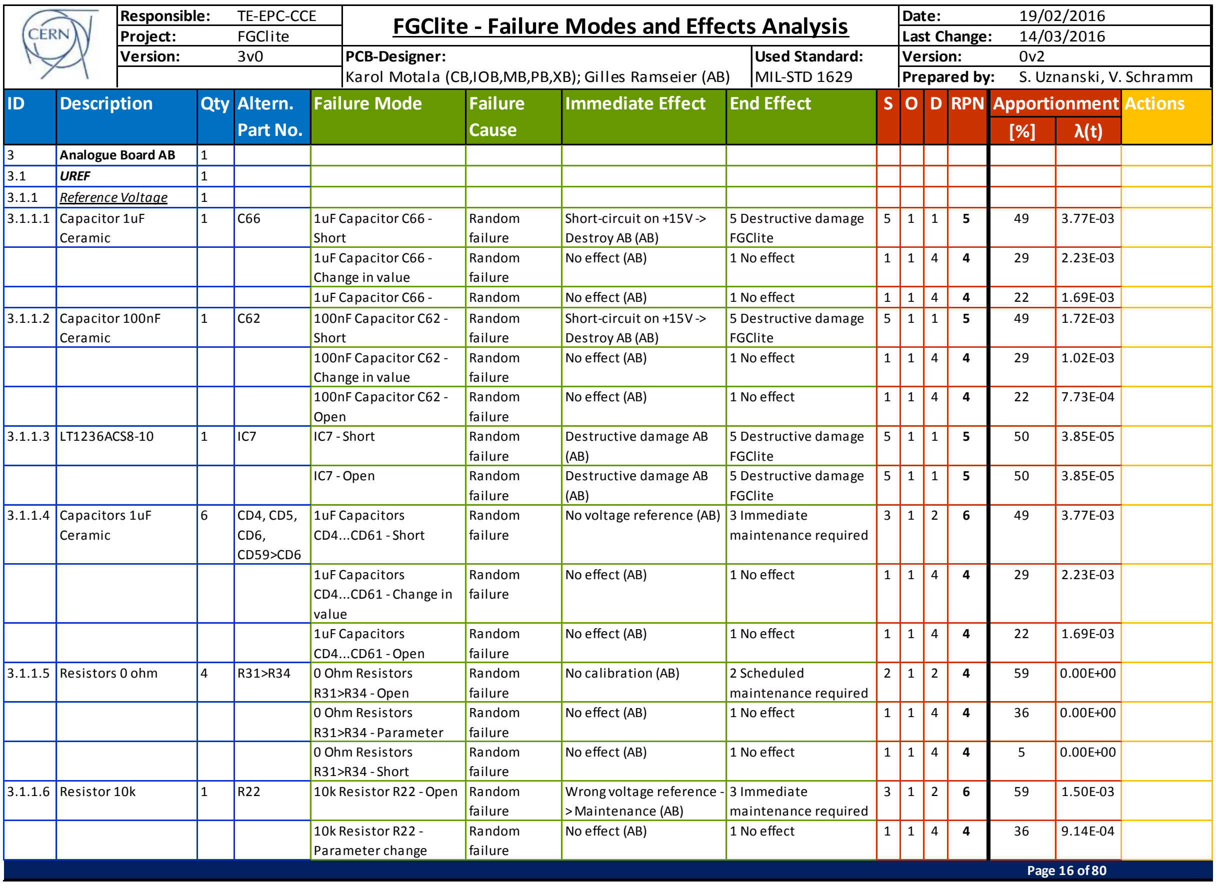

Responsible:	TE-EPC-CCE	**FGClite - Failure Modes and Effects Analysis**		**Date:**	19/02/2016
Project:	FGClite			**Last Change:**	14/03/2016
Version:	3v0	**PCB-Designer:**	**Used Standard:**	**Version:**	0v2
		Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)	MIL-STD 1629	**Prepared by:**	S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment		Actions
												[%]	λ(t)	
3	**Analogue Board AB**	1												
3.1	***UREF***	1												
3.1.1	*Reference Voltage*	1												
3.1.1.1	Capacitor 1uF Ceramic	1	C66	1uF Capacitor C66 - Short	Random failure	Short-circuit on +15V -> Destroy AB (AB)	5 Destructive damage FGClite	5	1	1	5	49	3.77E-03	
				1uF Capacitor C66 - Change in value	Random failure	No effect (AB)	1 No effect	1	1	4	4	29	2.23E-03	
				1uF Capacitor C66 -	Random	No effect (AB)	1 No effect	1	1	4	4	22	1.69E-03	
3.1.1.2	Capacitor 100nF Ceramic	1	C62	100nF Capacitor C62 - Short	Random failure	Short-circuit on +15V -> Destroy AB (AB)	5 Destructive damage FGClite	5	1	1	5	49	1.72E-03	
				100nF Capacitor C62 - Change in value	Random failure	No effect (AB)	1 No effect	1	1	4	4	29	1.02E-03	
				100nF Capacitor C62 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	4	22	7.73E-04	
3.1.1.3	LT1236ACS8-10	1	IC7	IC7 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	5	50	3.85E-05	
				IC7 - Open	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	5	50	3.85E-05	
3.1.1.4	Capacitors 1uF Ceramic	6	CD4, CD5, CD6, CD59>CD6	1uF Capacitors CD4...CD61 - Short	Random failure	No voltage reference (AB)	3 Immediate maintenance required	3	1	2	6	49	3.77E-03	
				1uF Capacitors CD4...CD61 - Change in value	Random failure	No effect (AB)	1 No effect	1	1	4	4	29	2.23E-03	
				1uF Capacitors CD4...CD61 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	4	22	1.69E-03	
3.1.1.5	Resistors 0 ohm	4	R31>R34	0 Ohm Resistors R31>R34 - Open	Random failure	No calibration (AB)	2 Scheduled maintenance required	2	1	2	4	59	0.00E+00	
				0 Ohm Resistors R31>R34 - Parameter	Random failure	No effect (AB)	1 No effect	1	1	4	4	36	0.00E+00	
				0 Ohm Resistors R31>R34 - Short	Random failure	No effect (AB)	1 No effect	1	1	4	4	5	0.00E+00	
3.1.1.6	Resistor 10k	1	R22	10k Resistor R22 - Open	Random failure	Wrong voltage reference - > Maintenance (AB)	3 Immediate maintenance required	3	1	2	6	59	1.50E-03	
				10k Resistor R22 - Parameter change	Random failure	No effect (AB)	1 No effect	1	1	4	4	36	9.14E-04	

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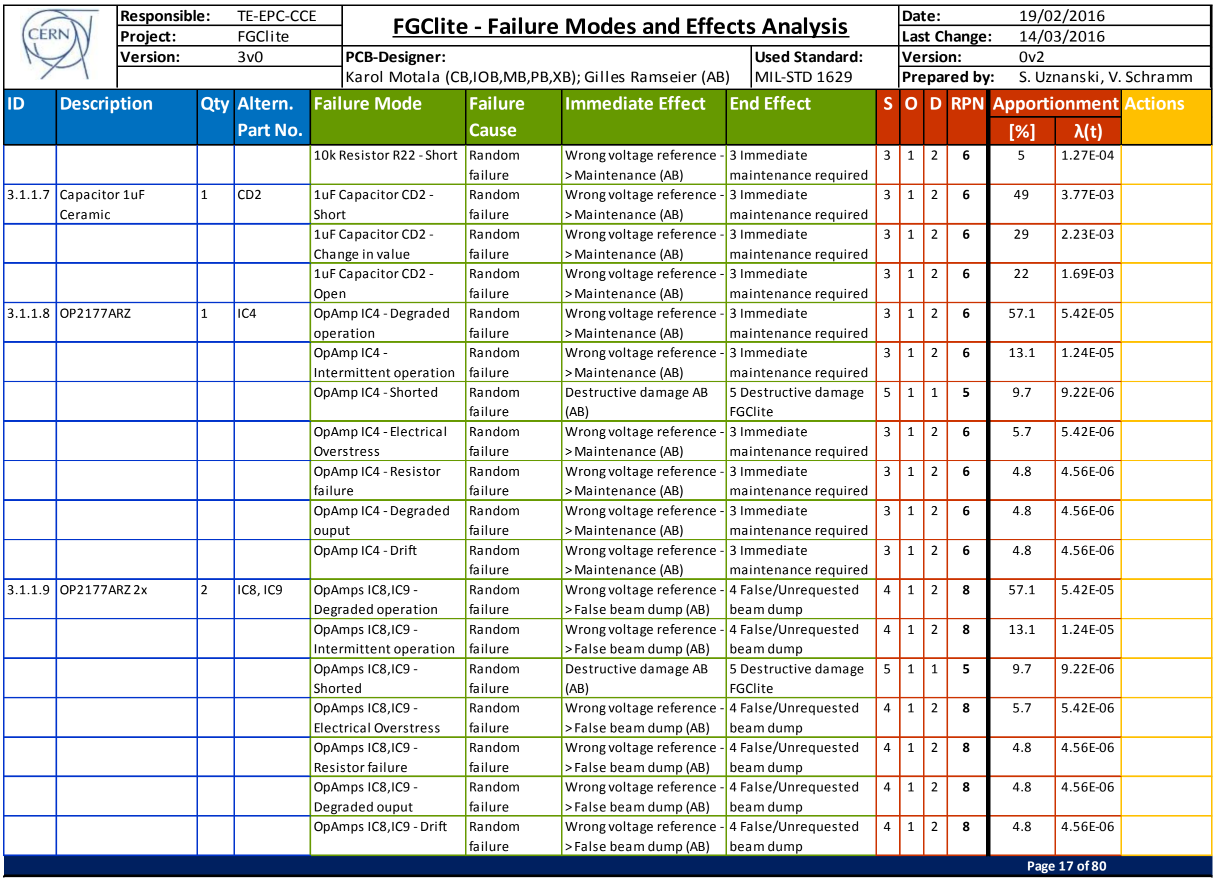

Responsible:	TE-EPC-CCE	**FGClite - Failure Modes and Effects Analysis**		**Date:**	19/02/2016
Project:	FGClite			**Last Change:**	14/03/2016
Version:	3v0	**PCB-Designer:**	**Used Standard:**	**Version:**	0v2
		Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)	MIL-STD 1629	**Prepared by:**	S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment		Actions
												[%]	λ(t)	
				10k Resistor R22 - Short	Random failure	Wrong voltage reference - > Maintenance (AB)	3 Immediate maintenance required	3	1	2	6	5	1.27E-04	
3.1.1.7	Capacitor 1uF Ceramic	1	CD2	1uF Capacitor CD2 - Short	Random failure	Wrong voltage reference - > Maintenance (AB)	3 Immediate maintenance required	3	1	2	6	49	3.77E-03	
				1uF Capacitor CD2 - Change in value	Random failure	Wrong voltage reference - > Maintenance (AB)	3 Immediate maintenance required	3	1	2	6	29	2.23E-03	
				1uF Capacitor CD2 - Open	Random failure	Wrong voltage reference - > Maintenance (AB)	3 Immediate maintenance required	3	1	2	6	22	1.69E-03	
3.1.1.8	OP2177ARZ	1	IC4	OpAmp IC4 - Degraded operation	Random failure	Wrong voltage reference - > Maintenance (AB)	3 Immediate maintenance required	3	1	2	6	57.1	5.42E-05	
				OpAmp IC4 - Intermittent operation	Random failure	Wrong voltage reference - > Maintenance (AB)	3 Immediate maintenance required	3	1	2	6	13.1	1.24E-05	
				OpAmp IC4 - Shorted	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	5	9.7	9.22E-06	
				OpAmp IC4 - Electrical Overstress	Random failure	Wrong voltage reference - > Maintenance (AB)	3 Immediate maintenance required	3	1	2	6	5.7	5.42E-06	
				OpAmp IC4 - Resistor failure	Random failure	Wrong voltage reference - > Maintenance (AB)	3 Immediate maintenance required	3	1	2	6	4.8	4.56E-06	
				OpAmp IC4 - Degraded ouput	Random failure	Wrong voltage reference - > Maintenance (AB)	3 Immediate maintenance required	3	1	2	6	4.8	4.56E-06	
				OpAmp IC4 - Drift	Random failure	Wrong voltage reference - > Maintenance (AB)	3 Immediate maintenance required	3	1	2	6	4.8	4.56E-06	
3.1.1.9	OP2177ARZ 2x	2	IC8, IC9	OpAmps IC8,IC9 - Degraded operation	Random failure	Wrong voltage reference - > False beam dump (AB)	4 False/Unrequested beam dump	4	1	2	8	57.1	5.42E-05	
				OpAmps IC8,IC9 - Intermittent operation	Random failure	Wrong voltage reference - > False beam dump (AB)	4 False/Unrequested beam dump	4	1	2	8	13.1	1.24E-05	
				OpAmps IC8,IC9 - Shorted	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	5	9.7	9.22E-06	
				OpAmps IC8,IC9 - Electrical Overstress	Random failure	Wrong voltage reference - > False beam dump (AB)	4 False/Unrequested beam dump	4	1	2	8	5.7	5.42E-06	
				OpAmps IC8,IC9 - Resistor failure	Random failure	Wrong voltage reference - > False beam dump (AB)	4 False/Unrequested beam dump	4	1	2	8	4.8	4.56E-06	
				OpAmps IC8,IC9 - Degraded ouput	Random failure	Wrong voltage reference - > False beam dump (AB)	4 False/Unrequested beam dump	4	1	2	8	4.8	4.56E-06	
				OpAmps IC8,IC9 - Drift	Random failure	Wrong voltage reference - > False beam dump (AB)	4 False/Unrequested beam dump	4	1	2	8	4.8	4.56E-06	

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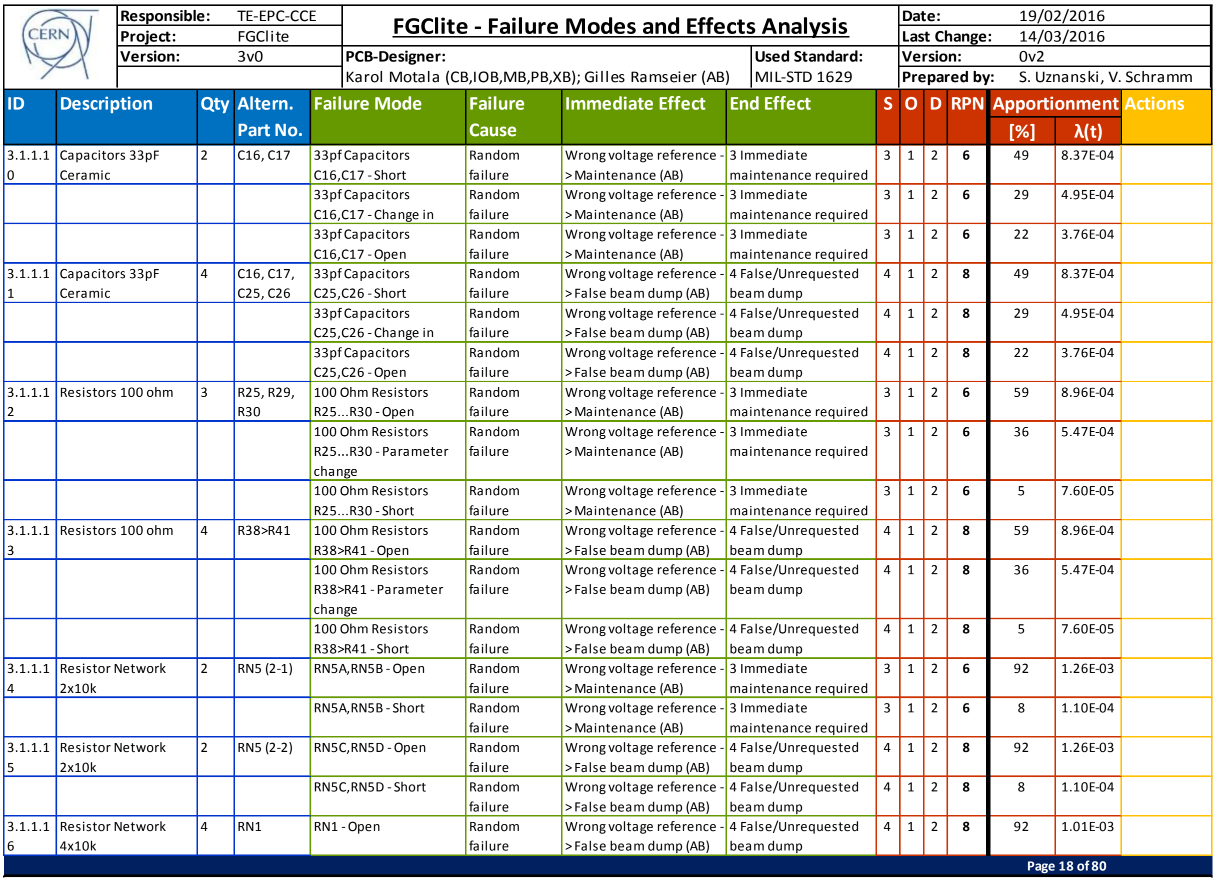

Responsible: TE-EPC-CCE	**FGClite - Failure Modes and Effects Analysis**		**Date:** 19/02/2016
Project: FGClite			**Last Change:** 14/03/2016
Version: 3v0	**PCB-Designer:**	**Used Standard:**	**Version:** 0v2
	Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)	MIL-STD 1629	**Prepared by:** S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment		Actions
												[%]	λ(t)	
3.1.1.10	Capacitors 33pF Ceramic	2	C16, C17	33pf Capacitors C16,C17 - Short	Random failure	Wrong voltage reference ->Maintenance (AB)	3 Immediate maintenance required	3	1	2	**6**	49	8.37E-04	
				33pf Capacitors C16,C17 - Change in	Random failure	Wrong voltage reference ->Maintenance (AB)	3 Immediate maintenance required	3	1	2	**6**	29	4.95E-04	
				33pf Capacitors C16,C17 - Open	Random failure	Wrong voltage reference ->Maintenance (AB)	3 Immediate maintenance required	3	1	2	**6**	22	3.76E-04	
3.1.1.11	Capacitors 33pF Ceramic	4	C16, C17, C25, C26	33pf Capacitors C25,C26 - Short	Random failure	Wrong voltage reference ->False beam dump (AB)	4 False/Unrequested beam dump	4	1	2	**8**	49	8.37E-04	
				33pf Capacitors C25,C26 - Change in	Random failure	Wrong voltage reference ->False beam dump (AB)	4 False/Unrequested beam dump	4	1	2	**8**	29	4.95E-04	
				33pf Capacitors C25,C26 - Open	Random failure	Wrong voltage reference ->False beam dump (AB)	4 False/Unrequested beam dump	4	1	2	**8**	22	3.76E-04	
3.1.1.12	Resistors 100 ohm	3	R25, R29, R30	100 Ohm Resistors R25...R30 - Open	Random failure	Wrong voltage reference ->Maintenance (AB)	3 Immediate maintenance required	3	1	2	**6**	59	8.96E-04	
				100 Ohm Resistors R25...R30 - Parameter change	Random failure	Wrong voltage reference ->Maintenance (AB)	3 Immediate maintenance required	3	1	2	**6**	36	5.47E-04	
				100 Ohm Resistors R25...R30 - Short	Random failure	Wrong voltage reference ->Maintenance (AB)	3 Immediate maintenance required	3	1	2	**6**	5	7.60E-05	
3.1.1.13	Resistors 100 ohm	4	R38>R41	100 Ohm Resistors R38>R41 - Open	Random failure	Wrong voltage reference ->False beam dump (AB)	4 False/Unrequested beam dump	4	1	2	**8**	59	8.96E-04	
				100 Ohm Resistors R38>R41 - Parameter change	Random failure	Wrong voltage reference ->False beam dump (AB)	4 False/Unrequested beam dump	4	1	2	**8**	36	5.47E-04	
				100 Ohm Resistors R38>R41 - Short	Random failure	Wrong voltage reference ->False beam dump (AB)	4 False/Unrequested beam dump	4	1	2	**8**	5	7.60E-05	
3.1.1.14	Resistor Network 2x10k	2	RN5 (2-1)	RN5A,RN5B - Open	Random failure	Wrong voltage reference ->Maintenance (AB)	3 Immediate maintenance required	3	1	2	**6**	92	1.26E-03	
				RN5A,RN5B - Short	Random failure	Wrong voltage reference ->Maintenance (AB)	3 Immediate maintenance required	3	1	2	**6**	8	1.10E-04	
3.1.1.15	Resistor Network 2x10k	2	RN5 (2-2)	RN5C,RN5D - Open	Random failure	Wrong voltage reference ->False beam dump (AB)	4 False/Unrequested beam dump	4	1	2	**8**	92	1.26E-03	
				RN5C,RN5D - Short	Random failure	Wrong voltage reference ->False beam dump (AB)	4 False/Unrequested beam dump	4	1	2	**8**	8	1.10E-04	
3.1.1.16	Resistor Network 4x10k	4	RN1	RN1 - Open	Random failure	Wrong voltage reference ->False beam dump (AB)	4 False/Unrequested beam dump	4	1	2	**8**	92	1.01E-03	

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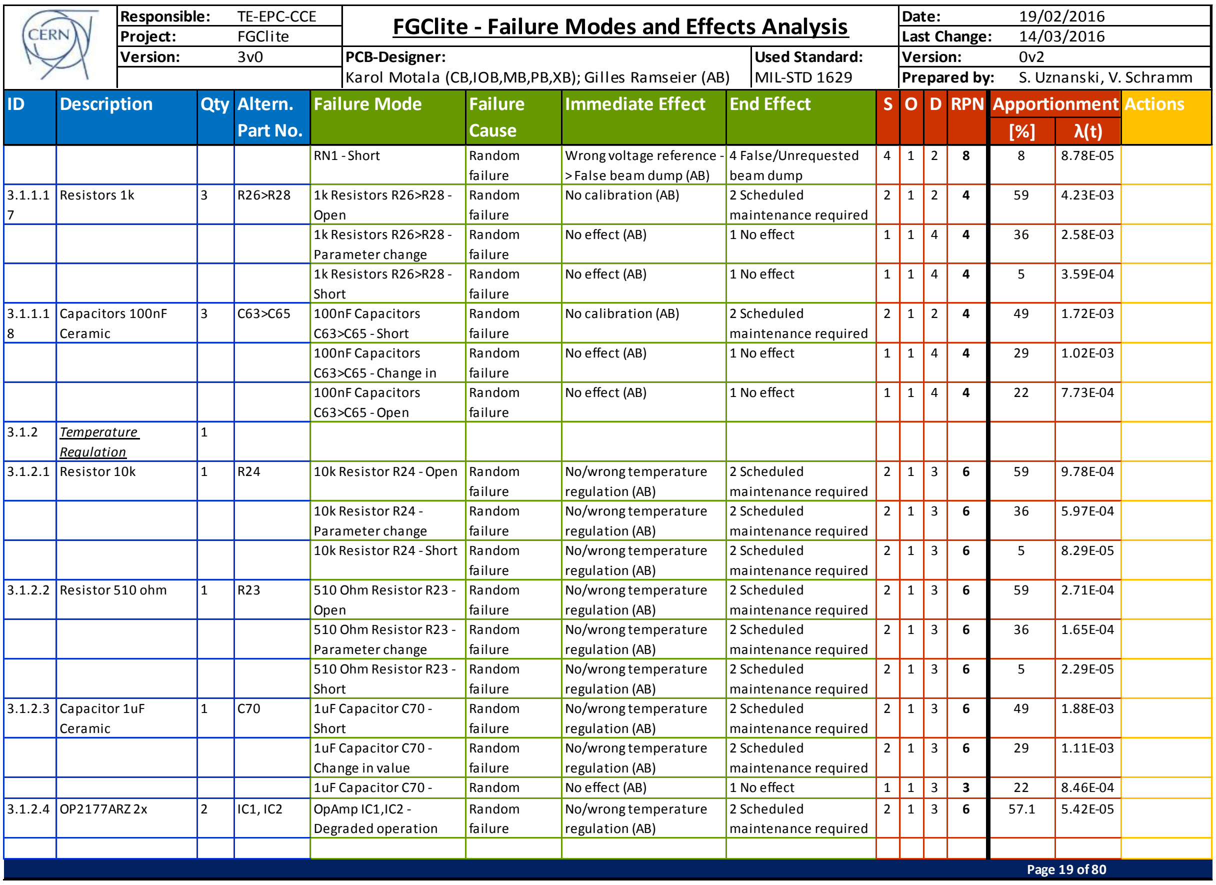

Responsible: TE-EPC-CCE	**FGClite - Failure Modes and Effects Analysis**		**Date:** 19/02/2016
Project: FGClite			**Last Change:** 14/03/2016
Version: 3v0	**PCB-Designer:**	**Used Standard:**	**Version:** 0v2
	Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)	MIL-STD 1629	**Prepared by:** S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment		Actions
												[%]	λ(t)	
				RN1 - Short	Random failure	Wrong voltage reference ->False beam dump (AB)	4 False/Unrequested beam dump	4	1	2	**8**	8	8.78E-05	
3.1.1.17	Resistors 1k	3	R26>R28	1k Resistors R26>R28 - Open	Random failure	No calibration (AB)	2 Scheduled maintenance required	2	1	2	**4**	59	4.23E-03	
				1k Resistors R26>R28 - Parameter change	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	36	2.58E-03	
				1k Resistors R26>R28 - Short	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	5	3.59E-04	
3.1.1.18	Capacitors 100nF Ceramic	3	C63>C65	100nF Capacitors C63>C65 - Short	Random failure	No calibration (AB)	2 Scheduled maintenance required	2	1	2	**4**	49	1.72E-03	
				100nF Capacitors C63>C65 - Change in	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	29	1.02E-03	
				100nF Capacitors C63>C65 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	22	7.73E-04	
3.1.2	*Temperature Regulation*	1												
3.1.2.1	Resistor 10k	1	R24	10k Resistor R24 - Open	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	59	9.78E-04	
				10k Resistor R24 - Parameter change	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	36	5.97E-04	
				10k Resistor R24 - Short	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	5	8.29E-05	
3.1.2.2	Resistor 510 ohm	1	R23	510 Ohm Resistor R23 - Open	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	59	2.71E-04	
				510 Ohm Resistor R23 - Parameter change	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	36	1.65E-04	
				510 Ohm Resistor R23 - Short	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	5	2.29E-05	
3.1.2.3	Capacitor 1uF Ceramic	1	C70	1uF Capacitor C70 - Short	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	49	1.88E-03	
				1uF Capacitor C70 - Change in value	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	29	1.11E-03	
				1uF Capacitor C70 -	Random	No effect (AB)	1 No effect	1	1	3	**3**	22	8.46E-04	
3.1.2.4	OP2177ARZ 2x	2	IC1, IC2	OpAmp IC1,IC2 - Degraded operation	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	57.1	5.42E-05	

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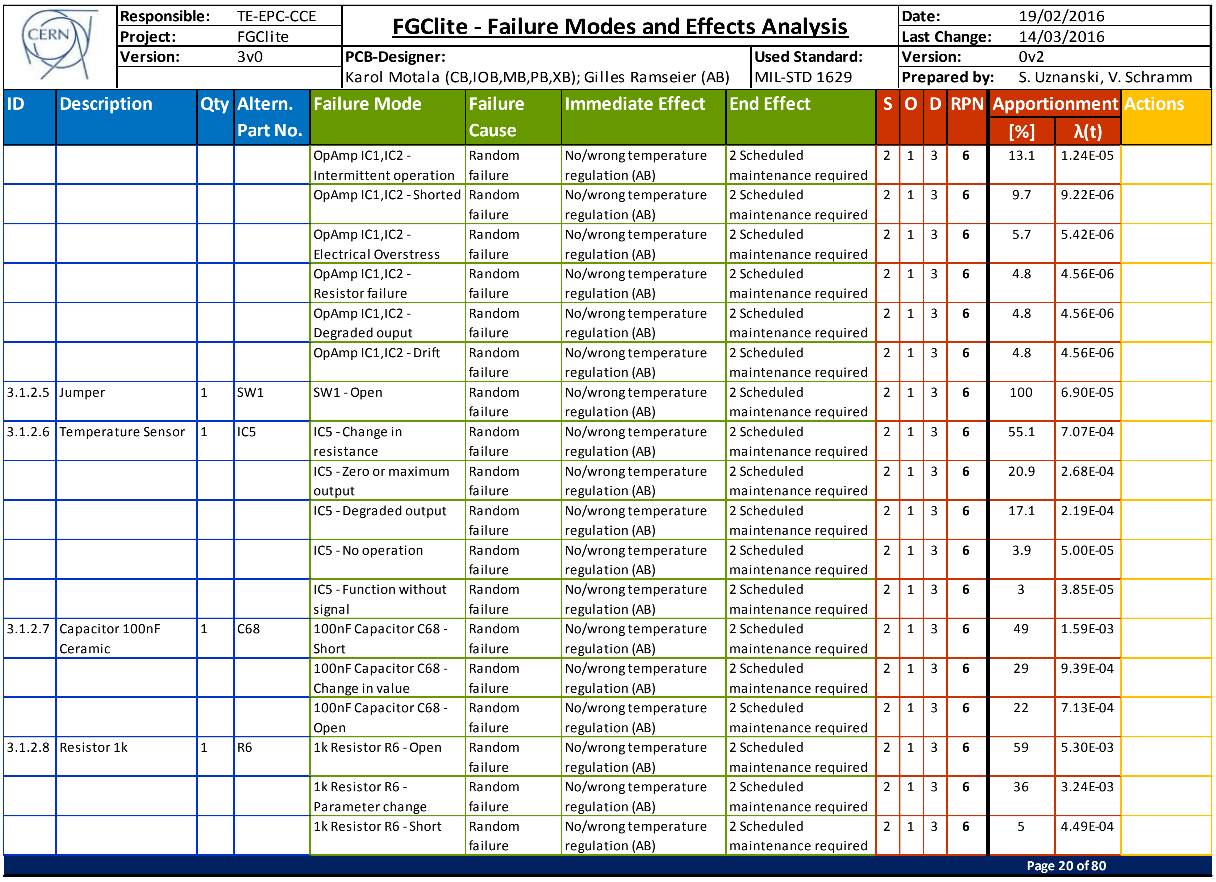

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - Failure Modes and Effects Analysis

PCB-Designer: Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)
Used Standard: MIL-STD 1629

Date: 19/02/2016
Last Change: 14/03/2016
Version: 0v2
Prepared by: S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment		Actions
												[%]	λ(t)	
				OpAmp IC1,IC2 - Intermittent operation	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	13.1	1.24E-05	
				OpAmp IC1,IC2 - Shorted	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	9.7	9.22E-06	
				OpAmp IC1,IC2 - Electrical Overstress	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	5.7	5.42E-06	
				OpAmp IC1,IC2 - Resistor failure	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	4.8	4.56E-06	
				OpAmp IC1,IC2 - Degraded ouput	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	4.8	4.56E-06	
				OpAmp IC1,IC2 - Drift	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	4.8	4.56E-06	
3.1.2.5	Jumper	1	SW1	SW1 - Open	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	100	6.90E-05	
3.1.2.6	Temperature Sensor	1	IC5	IC5 - Change in resistance	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	55.1	7.07E-04	
				IC5 - Zero or maximum output	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	20.9	2.68E-04	
				IC5 - Degraded output	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	17.1	2.19E-04	
				IC5 - No operation	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	3.9	5.00E-05	
				IC5 - Function without signal	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	3	3.85E-05	
3.1.2.7	Capacitor 100nF Ceramic	1	C68	100nF Capacitor C68 - Short	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	49	1.59E-03	
				100nF Capacitor C68 - Change in value	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	29	9.39E-04	
				100nF Capacitor C68 - Open	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	22	7.13E-04	
3.1.2.8	Resistor 1k	1	R6	1k Resistor R6 - Open	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	59	5.30E-03	
				1k Resistor R6 - Parameter change	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	36	3.24E-03	
				1k Resistor R6 - Short	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	5	4.49E-04	

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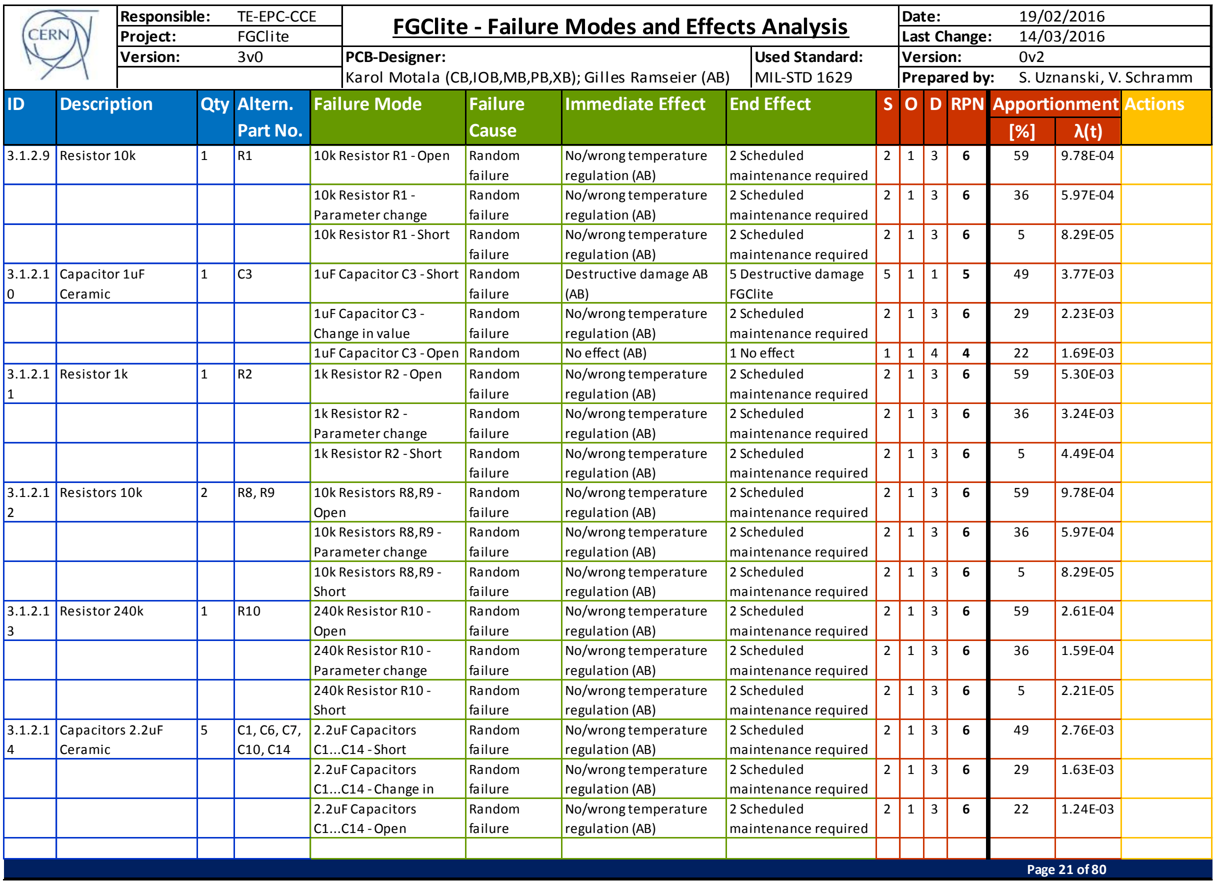

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - Failure Modes and Effects Analysis

PCB-Designer: Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)
Used Standard: MIL-STD 1629

Date: 19/02/2016
Last Change: 14/03/2016
Version: 0v2
Prepared by: S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment		Actions
												[%]	λ(t)	
3.1.2.9	Resistor 10k	1	R1	10k Resistor R1 - Open	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	59	9.78E-04	
				10k Resistor R1 - Parameter change	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	36	5.97E-04	
				10k Resistor R1 - Short	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	5	8.29E-05	
3.1.2.10	Capacitor 1uF Ceramic	1	C3	1uF Capacitor C3 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	49	3.77E-03	
				1uF Capacitor C3 - Change in value	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	29	2.23E-03	
				1uF Capacitor C3 - Open	Random	No effect (AB)	1 No effect	1	1	4	**4**	22	1.69E-03	
3.1.2.11	Resistor 1k	1	R2	1k Resistor R2 - Open	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	59	5.30E-03	
				1k Resistor R2 - Parameter change	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	36	3.24E-03	
				1k Resistor R2 - Short	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	5	4.49E-04	
3.1.2.12	Resistors 10k	2	R8, R9	10k Resistors R8,R9 - Open	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	59	9.78E-04	
				10k Resistors R8,R9 - Parameter change	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	36	5.97E-04	
				10k Resistors R8,R9 - Short	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	5	8.29E-05	
3.1.2.13	Resistor 240k	1	R10	240k Resistor R10 - Open	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	59	2.61E-04	
				240k Resistor R10 - Parameter change	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	36	1.59E-04	
				240k Resistor R10 - Short	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	5	2.21E-05	
3.1.2.14	Capacitors 2.2uF Ceramic	5	C1, C6, C7, C10, C14	2.2uF Capacitors C1...C14 - Short	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	49	2.76E-03	
				2.2uF Capacitors C1...C14 - Change in	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	29	1.63E-03	
				2.2uF Capacitors C1...C14 - Open	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	22	1.24E-03	

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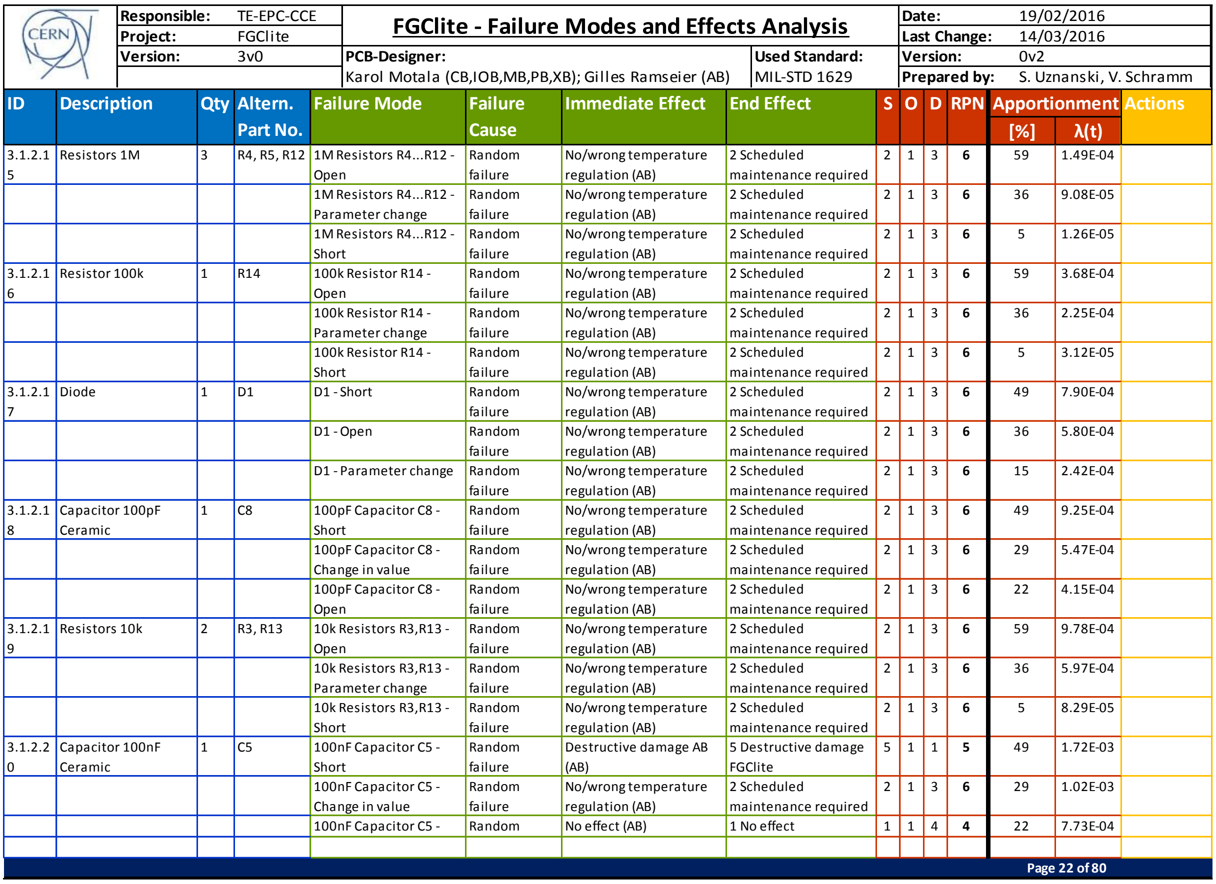

Responsible: TE-EPC-CCE	**FGClite - Failure Modes and Effects Analysis**		**Date:**	19/02/2016
Project: FGClite			**Last Change:**	14/03/2016
Version: 3v0	**PCB-Designer:**	**Used Standard:**	**Version:**	0v2
	Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)	MIL-STD 1629	**Prepared by:**	S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment		Actions
												[%]	λ(t)	
3.1.2.15	Resistors 1M	3	R4, R5, R12	1M Resistors R4...R12 - Open	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	59	1.49E-04	
				1M Resistors R4...R12 - Parameter change	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	36	9.08E-05	
				1M Resistors R4...R12 - Short	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	5	1.26E-05	
3.1.2.16	Resistor 100k	1	R14	100k Resistor R14 - Open	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	59	3.68E-04	
				100k Resistor R14 - Parameter change	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	36	2.25E-04	
				100k Resistor R14 - Short	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	5	3.12E-05	
3.1.2.17	Diode	1	D1	D1 - Short	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	49	7.90E-04	
				D1 - Open	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	36	5.80E-04	
				D1 - Parameter change	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	15	2.42E-04	
3.1.2.18	Capacitor 100pF Ceramic	1	C8	100pF Capacitor C8 - Short	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	49	9.25E-04	
				100pF Capacitor C8 - Change in value	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	29	5.47E-04	
				100pF Capacitor C8 - Open	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	22	4.15E-04	
3.1.2.19	Resistors 10k	2	R3, R13	10k Resistors R3,R13 - Open	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	59	9.78E-04	
				10k Resistors R3,R13 - Parameter change	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	36	5.97E-04	
				10k Resistors R3,R13 - Short	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	5	8.29E-05	
3.1.2.20	Capacitor 100nF Ceramic	1	C5	100nF Capacitor C5 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	49	1.72E-03	
				100nF Capacitor C5 - Change in value	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	29	1.02E-03	
				100nF Capacitor C5 -	Random	No effect (AB)	1 No effect	1	1	4	**4**	22	7.73E-04	

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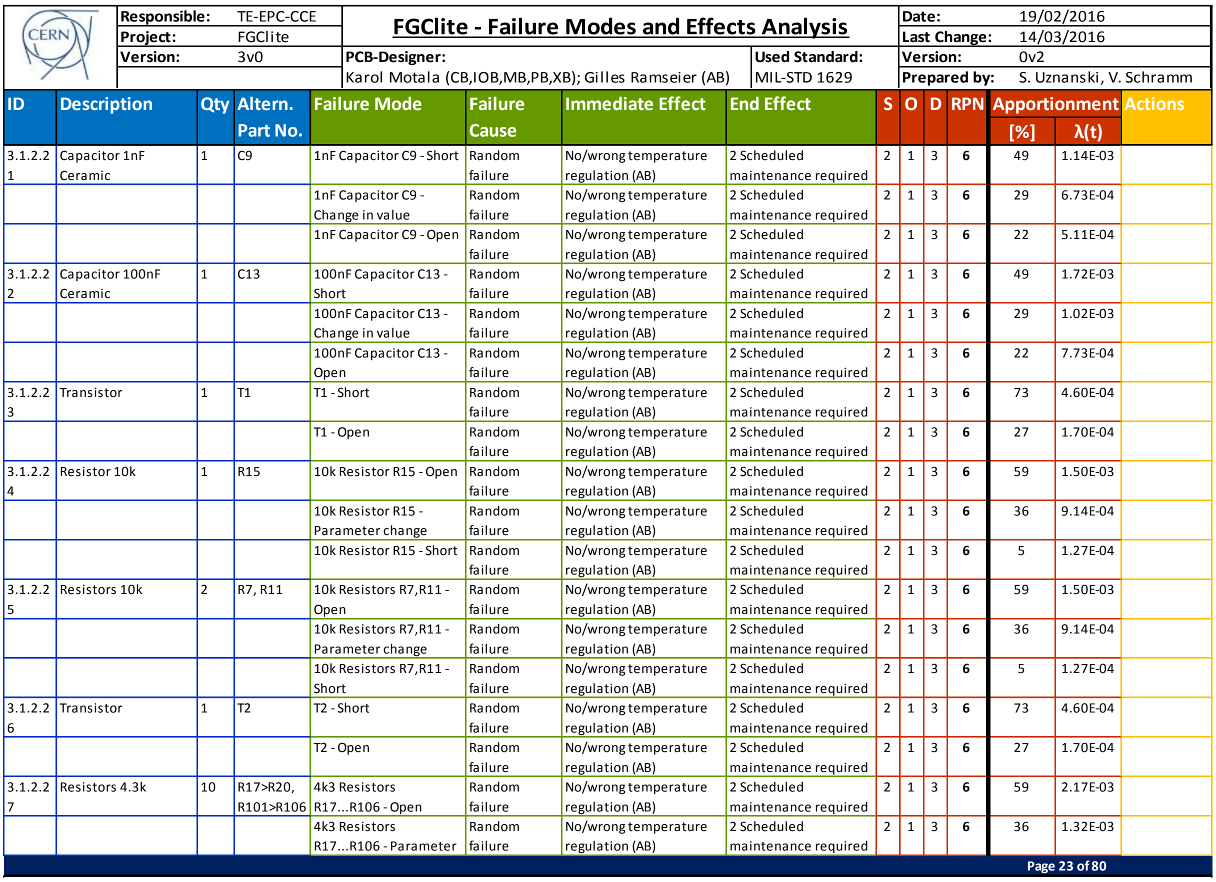

Responsible: TE-EPC-CCE	**FGClite - Failure Modes and Effects Analysis**		**Date:**	19/02/2016
Project: FGClite			**Last Change:**	14/03/2016
Version: 3v0	**PCB-Designer:**	**Used Standard:**	**Version:**	0v2
	Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)	MIL-STD 1629	**Prepared by:**	S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment		Actions
												[%]	λ(t)	
3.1.2.21	Capacitor 1nF Ceramic	1	C9	1nF Capacitor C9 - Short	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	49	1.14E-03	
				1nF Capacitor C9 - Change in value	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	29	6.73E-04	
				1nF Capacitor C9 - Open	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	22	5.11E-04	
3.1.2.22	Capacitor 100nF Ceramic	1	C13	100nF Capacitor C13 - Short	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	49	1.72E-03	
				100nF Capacitor C13 - Change in value	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	29	1.02E-03	
				100nF Capacitor C13 - Open	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	22	7.73E-04	
3.1.2.23	Transistor	1	T1	T1 - Short	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	73	4.60E-04	
				T1 - Open	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	27	1.70E-04	
3.1.2.24	Resistor 10k	1	R15	10k Resistor R15 - Open	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	59	1.50E-03	
				10k Resistor R15 - Parameter change	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	36	9.14E-04	
				10k Resistor R15 - Short	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	5	1.27E-04	
3.1.2.25	Resistors 10k	2	R7, R11	10k Resistors R7,R11 - Open	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	59	1.50E-03	
				10k Resistors R7,R11 - Parameter change	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	36	9.14E-04	
				10k Resistors R7,R11 - Short	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	5	1.27E-04	
3.1.2.26	Transistor	1	T2	T2 - Short	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	73	4.60E-04	
				T2 - Open	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	27	1.70E-04	
3.1.2.27	Resistors 4.3k	10	R17>R20, R101>R106	4k3 Resistors R17...R106 - Open	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	59	2.17E-03	
				4k3 Resistors R17...R106 - Parameter	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	**6**	36	1.32E-03	

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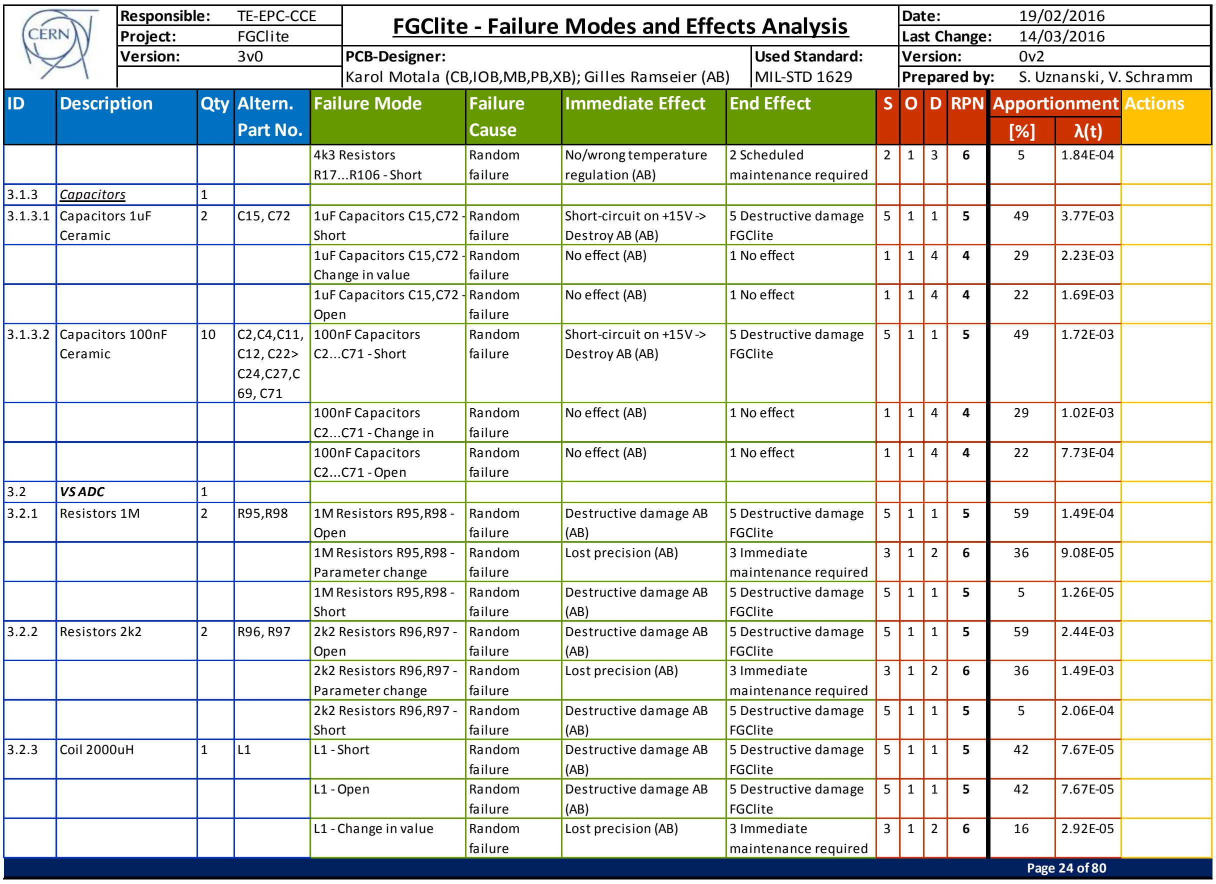

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - Failure Modes and Effects Analysis

PCB-Designer:
Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)

Used Standard:
MIL-STD 1629

Date: 19/02/2016
Last Change: 14/03/2016
Version: 0v2
Prepared by: S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment		Actions
												[%]	λ(t)	
				4k3 Resistors R17...R106 - Short	Random failure	No/wrong temperature regulation (AB)	2 Scheduled maintenance required	2	1	3	6	5	1.84E-04	
3.1.3	*Capacitors*	1												
3.1.3.1	Capacitors 1uF Ceramic	2	C15, C72	1uF Capacitors C15,C72 - Short	Random failure	Short-circuit on +15V -> Destroy AB (AB)	5 Destructive damage FGClite	5	1	1	5	49	3.77E-03	
				1uF Capacitors C15,C72 - Change in value	Random failure	No effect (AB)	1 No effect	1	1	4	4	29	2.23E-03	
				1uF Capacitors C15,C72 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	4	22	1.69E-03	
3.1.3.2	Capacitors 100nF Ceramic	10	C2,C4,C11, C12, C22> C24,C27,C 69, C71	100nF Capacitors C2...C71 - Short	Random failure	Short-circuit on +15V -> Destroy AB (AB)	5 Destructive damage FGClite	5	1	1	5	49	1.72E-03	
				100nF Capacitors C2...C71 - Change in	Random failure	No effect (AB)	1 No effect	1	1	4	4	29	1.02E-03	
				100nF Capacitors C2...C71 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	4	22	7.73E-04	
3.2	***VS ADC***	1												
3.2.1	Resistors 1M	2	R95,R98	1M Resistors R95,R98 - Open	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	5	59	1.49E-04	
				1M Resistors R95,R98 - Parameter change	Random failure	Lost precision (AB)	3 Immediate maintenance required	3	1	2	6	36	9.08E-05	
				1M Resistors R95,R98 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	5	5	1.26E-05	
3.2.2	Resistors 2k2	2	R96, R97	2k2 Resistors R96,R97 - Open	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	5	59	2.44E-03	
				2k2 Resistors R96,R97 - Parameter change	Random failure	Lost precision (AB)	3 Immediate maintenance required	3	1	2	6	36	1.49E-03	
				2k2 Resistors R96,R97 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	5	5	2.06E-04	
3.2.3	Coil 2000uH	1	L1	L1 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	5	42	7.67E-05	
				L1 - Open	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	5	42	7.67E-05	
				L1 - Change in value	Random failure	Lost precision (AB)	3 Immediate maintenance required	3	1	2	6	16	2.92E-05	

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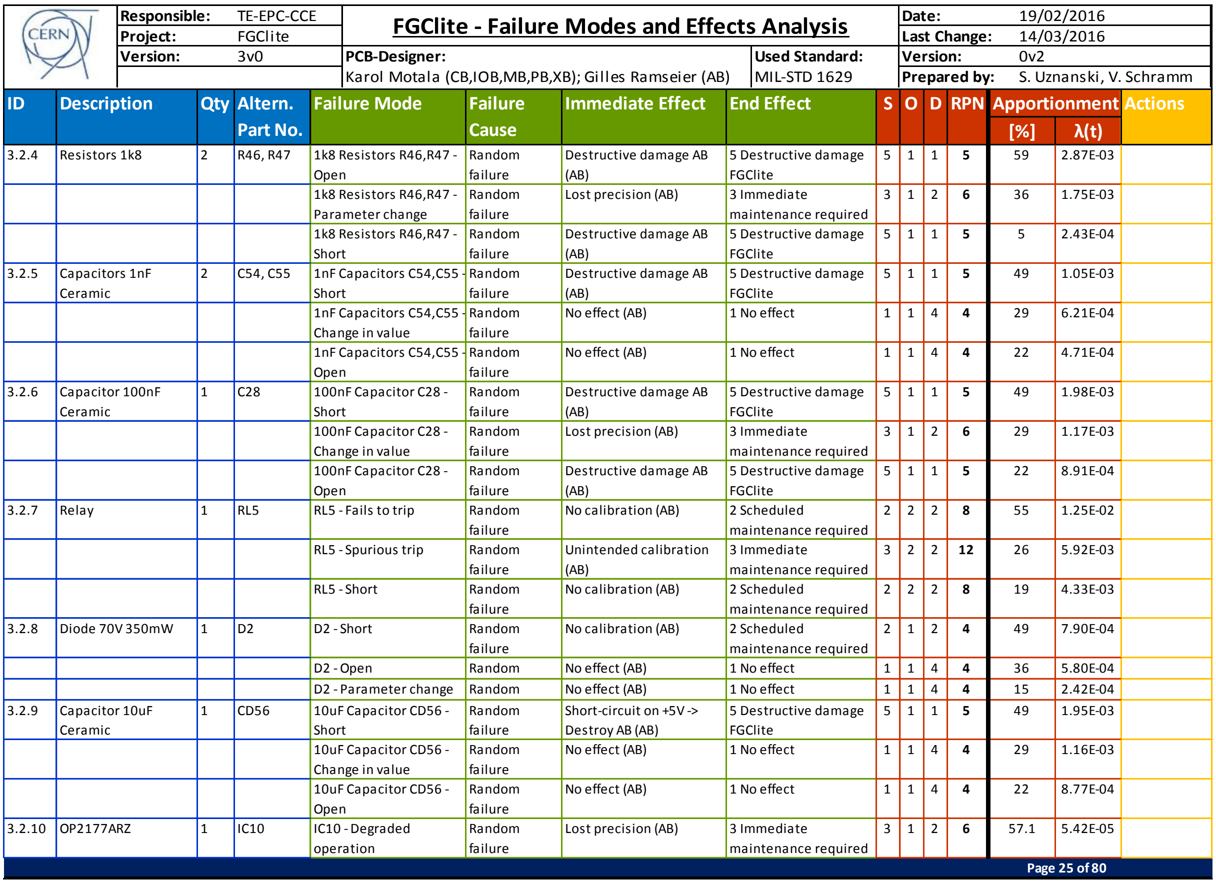

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - Failure Modes and Effects Analysis

PCB-Designer:
Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)

Used Standard:
MIL-STD 1629

Date: 19/02/2016
Last Change: 14/03/2016
Version: 0v2
Prepared by: S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment		Actions
												[%]	λ(t)	
3.2.4	Resistors 1k8	2	R46, R47	1k8 Resistors R46,R47 - Open	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	5	59	2.87E-03	
				1k8 Resistors R46,R47 - Parameter change	Random failure	Lost precision (AB)	3 Immediate maintenance required	3	1	2	6	36	1.75E-03	
				1k8 Resistors R46,R47 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	5	5	2.43E-04	
3.2.5	Capacitors 1nF Ceramic	2	C54, C55	1nF Capacitors C54,C55 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	5	49	1.05E-03	
				1nF Capacitors C54,C55 - Change in value	Random failure	No effect (AB)	1 No effect	1	1	4	4	29	6.21E-04	
				1nF Capacitors C54,C55 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	4	22	4.71E-04	
3.2.6	Capacitor 100nF Ceramic	1	C28	100nF Capacitor C28 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	5	49	1.98E-03	
				100nF Capacitor C28 - Change in value	Random failure	Lost precision (AB)	3 Immediate maintenance required	3	1	2	6	29	1.17E-03	
				100nF Capacitor C28 - Open	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	5	22	8.91E-04	
3.2.7	Relay	1	RL5	RL5 - Fails to trip	Random failure	No calibration (AB)	2 Scheduled maintenance required	2	2	2	8	55	1.25E-02	
				RL5 - Spurious trip	Random failure	Unintended calibration (AB)	3 Immediate maintenance required	3	2	2	12	26	5.92E-03	
				RL5 - Short	Random failure	No calibration (AB)	2 Scheduled maintenance required	2	2	2	8	19	4.33E-03	
3.2.8	Diode 70V 350mW	1	D2	D2 - Short	Random failure	No calibration (AB)	2 Scheduled maintenance required	2	1	2	4	49	7.90E-04	
				D2 - Open	Random	No effect (AB)	1 No effect	1	1	4	4	36	5.80E-04	
				D2 - Parameter change	Random	No effect (AB)	1 No effect	1	1	4	4	15	2.42E-04	
3.2.9	Capacitor 10uF Ceramic	1	CD56	10uF Capacitor CD56 - Short	Random failure	Short-circuit on +5V -> Destroy AB (AB)	5 Destructive damage FGClite	5	1	1	5	49	1.95E-03	
				10uF Capacitor CD56 - Change in value	Random failure	No effect (AB)	1 No effect	1	1	4	4	29	1.16E-03	
				10uF Capacitor CD56 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	4	22	8.77E-04	
3.2.10	OP2177ARZ	1	IC10	IC10 - Degraded operation	Random failure	Lost precision (AB)	3 Immediate maintenance required	3	1	2	6	57.1	5.42E-05	

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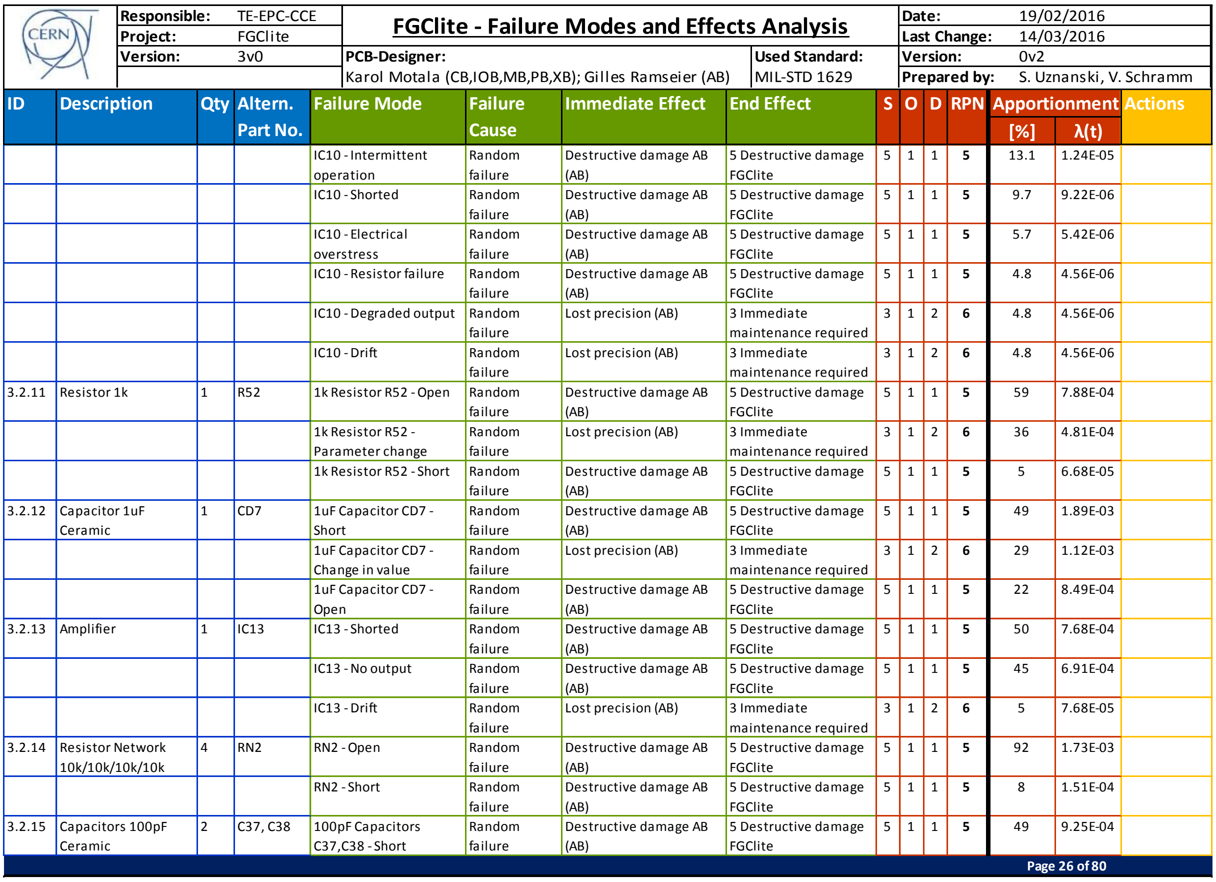

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - Failure Modes and Effects Analysis

PCB-Designer: Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)
Used Standard: MIL-STD 1629

Date: 19/02/2016
Last Change: 14/03/2016
Version: 0v2
Prepared by: S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment		Actions
												[%]	λ(t)	
				IC10 - Intermittent operation	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	13.1	1.24E-05	
				IC10 - Shorted	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	9.7	9.22E-06	
				IC10 - Electrical overstress	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	5.7	5.42E-06	
				IC10 - Resistor failure	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	4.8	4.56E-06	
				IC10 - Degraded output	Random failure	Lost precision (AB)	3 Immediate maintenance required	3	1	2	**6**	4.8	4.56E-06	
				IC10 - Drift	Random failure	Lost precision (AB)	3 Immediate maintenance required	3	1	2	**6**	4.8	4.56E-06	
3.2.11	Resistor 1k	1	R52	1k Resistor R52 - Open	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	59	7.88E-04	
				1k Resistor R52 - Parameter change	Random failure	Lost precision (AB)	3 Immediate maintenance required	3	1	2	**6**	36	4.81E-04	
				1k Resistor R52 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	5	6.68E-05	
3.2.12	Capacitor 1uF Ceramic	1	CD7	1uF Capacitor CD7 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	49	1.89E-03	
				1uF Capacitor CD7 - Change in value	Random failure	Lost precision (AB)	3 Immediate maintenance required	3	1	2	**6**	29	1.12E-03	
				1uF Capacitor CD7 - Open	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	22	8.49E-04	
3.2.13	Amplifier	1	IC13	IC13 - Shorted	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	50	7.68E-04	
				IC13 - No output	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	45	6.91E-04	
				IC13 - Drift	Random failure	Lost precision (AB)	3 Immediate maintenance required	3	1	2	**6**	5	7.68E-05	
3.2.14	Resistor Network 10k/10k/10k/10k	4	RN2	RN2 - Open	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	92	1.73E-03	
				RN2 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	8	1.51E-04	
3.2.15	Capacitors 100pF Ceramic	2	C37, C38	100pF Capacitors C37,C38 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	49	9.25E-04	

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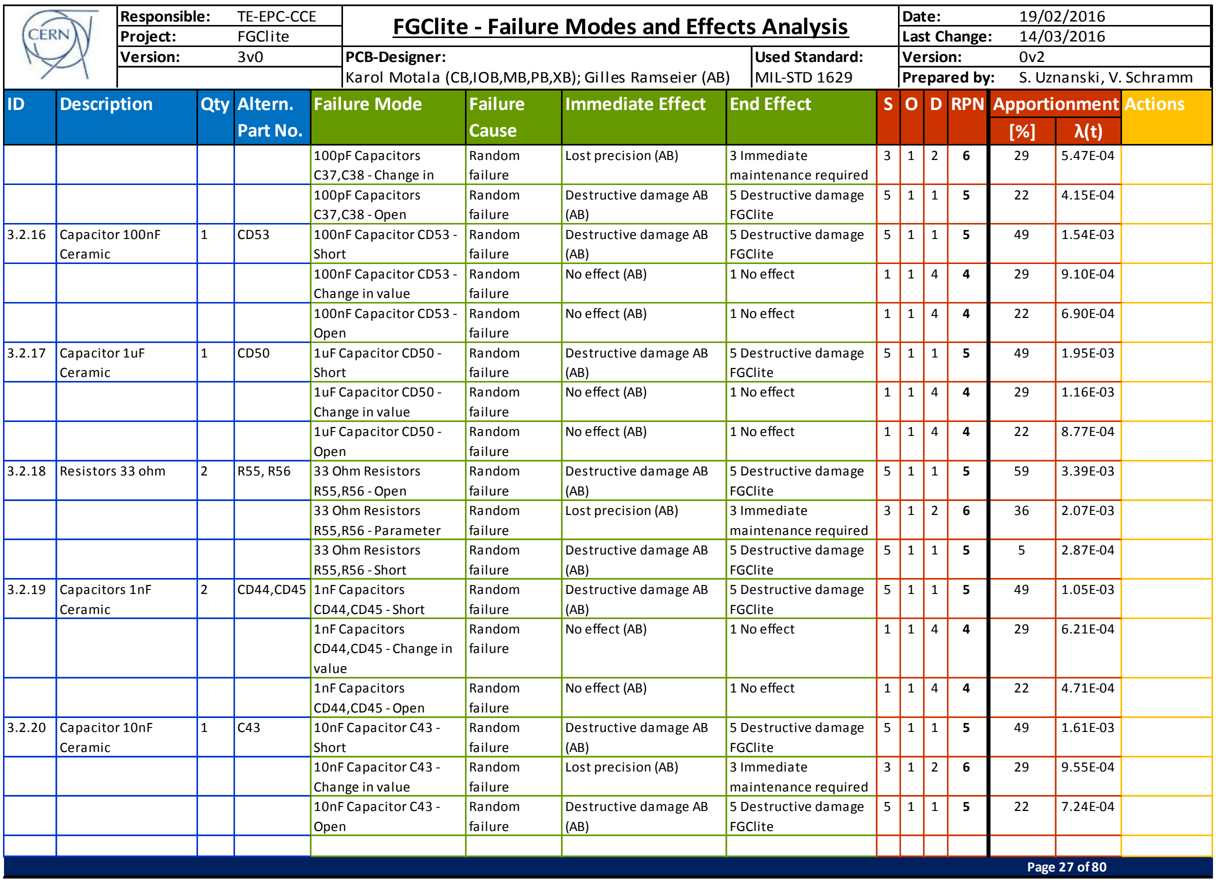

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - Failure Modes and Effects Analysis

PCB-Designer: Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)
Used Standard: MIL-STD 1629

Date: 19/02/2016
Last Change: 14/03/2016
Version: 0v2
Prepared by: S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment		Actions
												[%]	λ(t)	
				100pF Capacitors C37,C38 - Change in	Random failure	Lost precision (AB)	3 Immediate maintenance required	3	1	2	**6**	29	5.47E-04	
				100pF Capacitors C37,C38 - Open	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	22	4.15E-04	
3.2.16	Capacitor 100nF Ceramic	1	CD53	100nF Capacitor CD53 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	49	1.54E-03	
				100nF Capacitor CD53 - Change in value	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	29	9.10E-04	
				100nF Capacitor CD53 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	22	6.90E-04	
3.2.17	Capacitor 1uF Ceramic	1	CD50	1uF Capacitor CD50 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	49	1.95E-03	
				1uF Capacitor CD50 - Change in value	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	29	1.16E-03	
				1uF Capacitor CD50 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	22	8.77E-04	
3.2.18	Resistors 33 ohm	2	R55, R56	33 Ohm Resistors R55,R56 - Open	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	59	3.39E-03	
				33 Ohm Resistors R55,R56 - Parameter	Random failure	Lost precision (AB)	3 Immediate maintenance required	3	1	2	**6**	36	2.07E-03	
				33 Ohm Resistors R55,R56 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	5	2.87E-04	
3.2.19	Capacitors 1nF Ceramic	2	CD44,CD45	1nF Capacitors CD44,CD45 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	49	1.05E-03	
				1nF Capacitors CD44,CD45 - Change in value	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	29	6.21E-04	
				1nF Capacitors CD44,CD45 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	22	4.71E-04	
3.2.20	Capacitor 10nF Ceramic	1	C43	10nF Capacitor C43 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	49	1.61E-03	
				10nF Capacitor C43 - Change in value	Random failure	Lost precision (AB)	3 Immediate maintenance required	3	1	2	**6**	29	9.55E-04	
				10nF Capacitor C43 - Open	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	22	7.24E-04	

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Responsible:	TE-EPC-CCE	**FGClite - Failure Modes and Effects Analysis**		**Date:**	19/02/2016
Project:	FGClite			**Last Change:**	14/03/2016
Version:	3v0	**PCB-Designer:**	**Used Standard:**	**Version:**	0v2
		Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)	MIL-STD 1629	**Prepared by:**	S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment		Actions
												[%]	λ(t)	
3.2.21	Capacitor 1uF Ceramic	1	CD16	1uF Capacitor CD16 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	49	1.98E-03	
				1uF Capacitor CD16 - Change in value	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	29	1.17E-03	
				1uF Capacitor CD16 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	22	8.87E-04	
3.2.22	Capacitor 100nF Ceramic	1	CD13	100nF Capacitor CD13 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	49	1.53E-03	
				100nF Capacitor CD13 - Change in value	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	29	9.07E-04	
				100nF Capacitor CD13 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	22	6.88E-04	
3.2.23	Capacitor 1uF Ceramic	1	CD32	1uF Capacitor CD32 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	49	1.90E-03	
				1uF Capacitor CD32 - Change in value	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	29	1.13E-03	
				1uF Capacitor CD32 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	22	8.55E-04	
3.2.24	Capacitors 1uF Ceramic	2	CD35, CD38	1uF Capacitors CD35,CD38 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	49	1.95E-03	
				1uF Capacitors CD35,CD38 - Change in value	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	29	1.16E-03	
				1uF Capacitors CD35,CD38 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	22	8.77E-04	
3.2.25	Capacitor 100nF Ceramic	1	CD10	100nF Capacitor CD10 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	49	1.54E-03	
				100nF Capacitor CD10 - Change in value	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	29	9.10E-04	
				100nF Capacitor CD10 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	22	6.90E-04	
3.2.26	ADC	1	IC16	IC16 - Shorted	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	50	1.15E-04	
				IC16 - Out of spec	Random failure	Lost precision (AB)	3 Immediate maintenance required	3	1	2	**6**	50	1.15E-04	

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Responsible:	TE-EPC-CCE	**FGClite - Failure Modes and Effects Analysis**		**Date:**	19/02/2016
Project:	FGClite			**Last Change:**	14/03/2016
Version:	3v0	**PCB-Designer:**	**Used Standard:**	**Version:**	0v2
		Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)	MIL-STD 1629	**Prepared by:**	S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment		Actions
												[%]	λ(t)	
3.2.27	Resistors 33 ohm	4	R61>R63, R81	33 Ohm Resistors R61...R81 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	59	1.36E-03	
				33 Ohm Resistors R61...R81 - Parameter change	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	36	8.30E-04	
				33 Ohm Resistors R61...R81 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	5	1.15E-04	
3.2.28	Capacitor 1uF Ceramic	1	CD41	1uF Capacitor CD41 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	49	1.98E-03	
				1uF Capacitor CD41 - Change in value	Random failure	Lost precision (AB)	3 Immediate maintenance required	3	1	2	**6**	29	1.17E-03	
				1uF Capacitor CD41 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	22	8.87E-04	
3.2.29	Resistor 10k	1	R84	10k Resistor R84 - Open	Random	No effect (AB)	1 No effect	1	1	4	**4**	59	5.77E-04	
				10k Resistor R84 -	Random	No effect (AB)	1 No effect	1	1	4	**4**	36	3.52E-04	
				10k Resistor R84 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	5	4.89E-05	
3.2.30	Relays	4	RL1>RL4	RL1>RL4 - Fails to trip	Random failure	No calibration (AB)	2 Scheduled maintenance required	2	2	2	**8**	55	1.25E-02	
				RL1>RL4 - Spurious trip	Random failure	Unintended calibration (AB)	3 Immediate maintenance required	3	2	2	**12**	26	5.92E-03	
				RL1>RL4 - Short	Random failure	No calibration (AB)	2 Scheduled maintenance required	2	2	2	**8**	19	4.33E-03	
3.2.31	Diodes 70V 350mW	4	D5>D8	D5>D8 - Short	Random failure	No calibration (AB)	2 Scheduled maintenance required	2	1	2	**4**	49	7.90E-04	
				D5>D8 - Open	Random	No effect (AB)	1 No effect	1	1	4	**4**	36	5.80E-04	
				D5>D8 - Parameter change	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	15	2.42E-04	
3.2.32	Capacitor 10uF Ceramic	4	CD62>CD65	10uF Capacitors CD62>CD65 - Short	Random failure	Short-circuit on +5V -> Destroy AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	49	2.40E-03	
				10uF Capacitors CD62>CD65 - Change in value	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	29	1.42E-03	
				10uF Capacitors CD62>CD65 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	22	1.08E-03	

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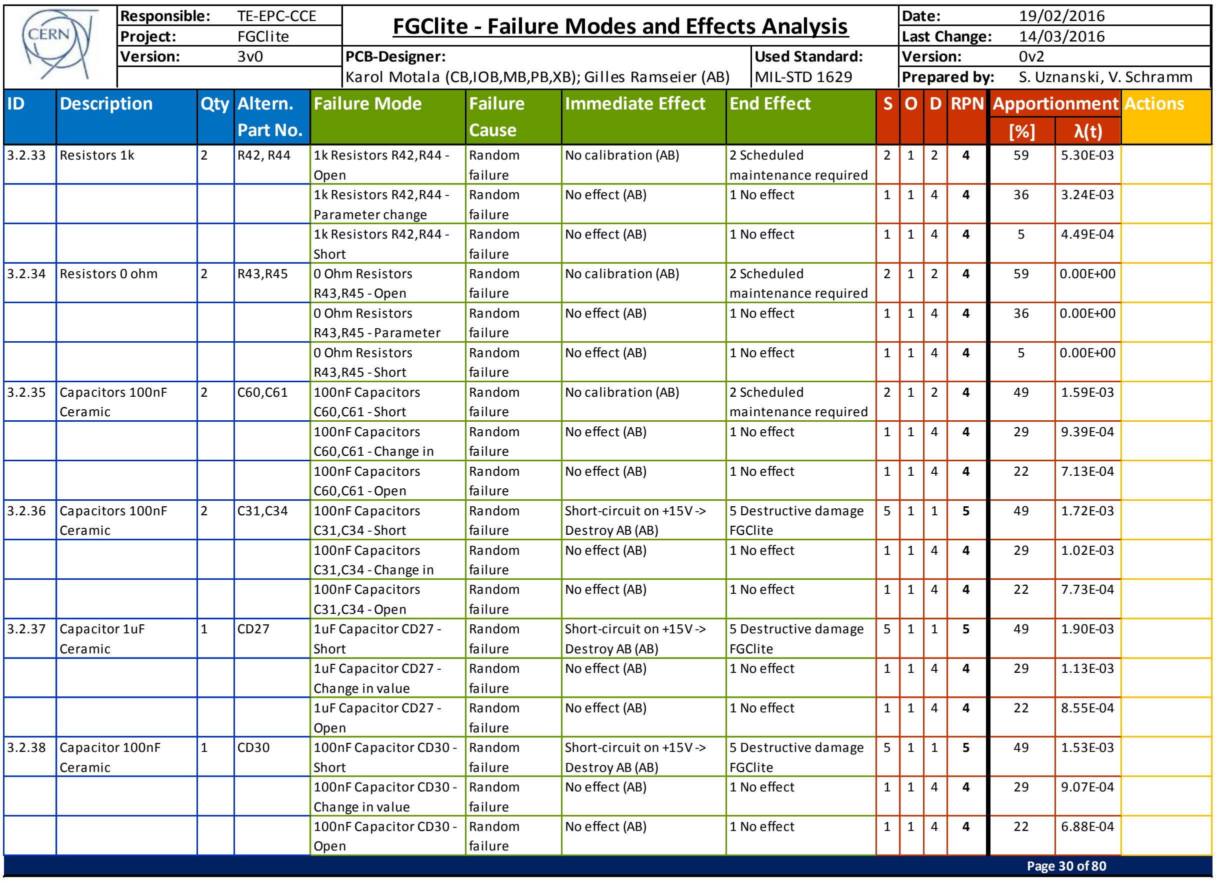

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - Failure Modes and Effects Analysis

PCB-Designer: Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)
Used Standard: MIL-STD 1629

Date: 19/02/2016
Last Change: 14/03/2016
Version: 0v2
Prepared by: S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment [%]	λ(t)	Actions
3.2.33	Resistors 1k	2	R42, R44	1k Resistors R42,R44 - Open	Random failure	No calibration (AB)	2 Scheduled maintenance required	2	1	2	4	59	5.30E-03	
				1k Resistors R42,R44 - Parameter change	Random failure	No effect (AB)	1 No effect	1	1	4	4	36	3.24E-03	
				1k Resistors R42,R44 - Short	Random failure	No effect (AB)	1 No effect	1	1	4	4	5	4.49E-04	
3.2.34	Resistors 0 ohm	2	R43,R45	0 Ohm Resistors R43,R45 - Open	Random failure	No calibration (AB)	2 Scheduled maintenance required	2	1	2	4	59	0.00E+00	
				0 Ohm Resistors R43,R45 - Parameter	Random failure	No effect (AB)	1 No effect	1	1	4	4	36	0.00E+00	
				0 Ohm Resistors R43,R45 - Short	Random failure	No effect (AB)	1 No effect	1	1	4	4	5	0.00E+00	
3.2.35	Capacitors 100nF Ceramic	2	C60,C61	100nF Capacitors C60,C61 - Short	Random failure	No calibration (AB)	2 Scheduled maintenance required	2	1	2	4	49	1.59E-03	
				100nF Capacitors C60,C61 - Change in	Random failure	No effect (AB)	1 No effect	1	1	4	4	29	9.39E-04	
				100nF Capacitors C60,C61 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	4	22	7.13E-04	
3.2.36	Capacitors 100nF Ceramic	2	C31,C34	100nF Capacitors C31,C34 - Short	Random failure	Short-circuit on +15V -> Destroy AB (AB)	5 Destructive damage FGClite	5	1	1	5	49	1.72E-03	
				100nF Capacitors C31,C34 - Change in	Random failure	No effect (AB)	1 No effect	1	1	4	4	29	1.02E-03	
				100nF Capacitors C31,C34 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	4	22	7.73E-04	
3.2.37	Capacitor 1uF Ceramic	1	CD27	1uF Capacitor CD27 - Short	Random failure	Short-circuit on +15V -> Destroy AB (AB)	5 Destructive damage FGClite	5	1	1	5	49	1.90E-03	
				1uF Capacitor CD27 - Change in value	Random failure	No effect (AB)	1 No effect	1	1	4	4	29	1.13E-03	
				1uF Capacitor CD27 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	4	22	8.55E-04	
3.2.38	Capacitor 100nF Ceramic	1	CD30	100nF Capacitor CD30 - Short	Random failure	Short-circuit on +15V -> Destroy AB (AB)	5 Destructive damage FGClite	5	1	1	5	49	1.53E-03	
				100nF Capacitor CD30 - Change in value	Random failure	No effect (AB)	1 No effect	1	1	4	4	29	9.07E-04	
				100nF Capacitor CD30 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	4	22	6.88E-04	

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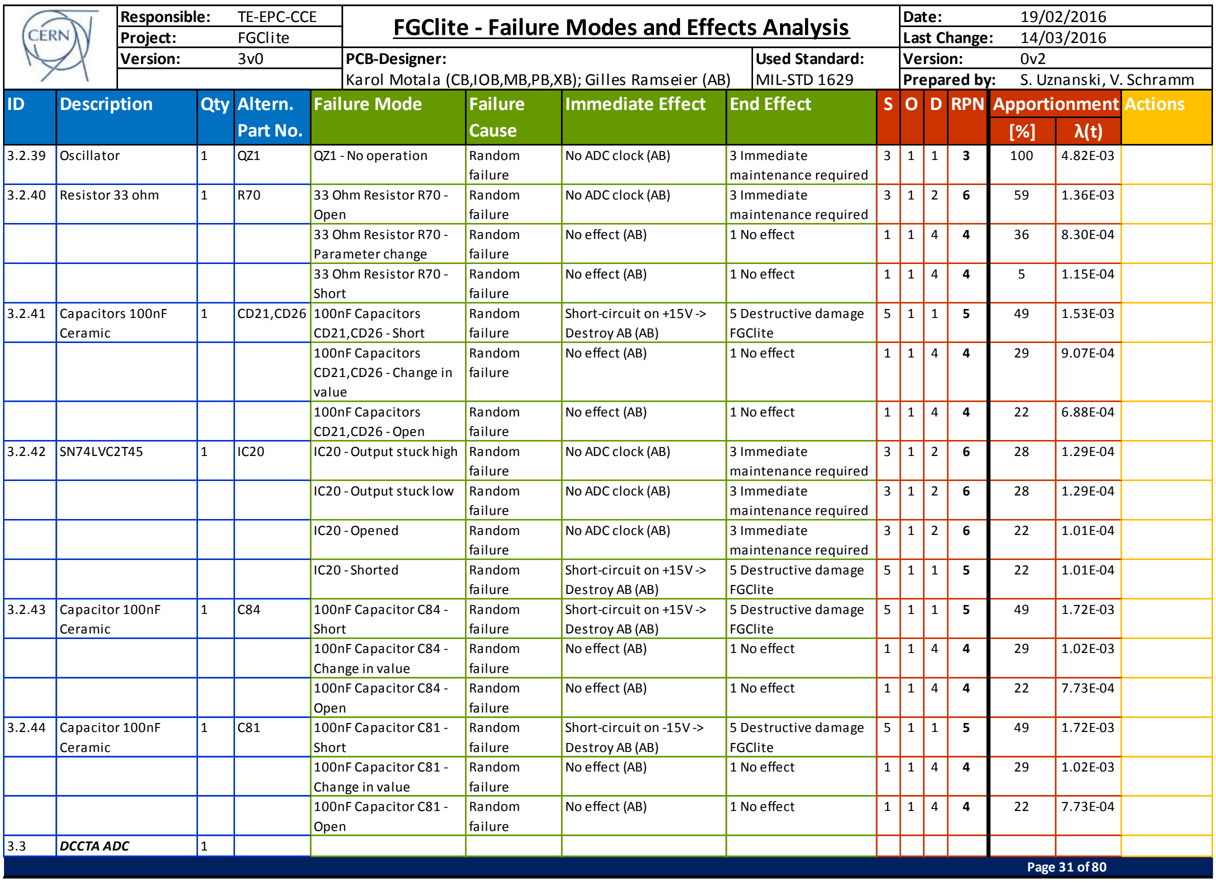

Responsible: TE-EPC-CCE
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Date: 19/02/2016
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Version: 0v2
Prepared by: S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment [%]	λ(t)	Actions
3.2.39	Oscillator	1	QZ1	QZ1 - No operation	Random failure	No ADC clock (AB)	3 Immediate maintenance required	3	1	1	3	100	4.82E-03	
3.2.40	Resistor 33 ohm	1	R70	33 Ohm Resistor R70 - Open	Random failure	No ADC clock (AB)	3 Immediate maintenance required	3	1	2	6	59	1.36E-03	
				33 Ohm Resistor R70 - Parameter change	Random failure	No effect (AB)	1 No effect	1	1	4	4	36	8.30E-04	
				33 Ohm Resistor R70 - Short	Random failure	No effect (AB)	1 No effect	1	1	4	4	5	1.15E-04	
3.2.41	Capacitors 100nF Ceramic	1	CD21,CD26	100nF Capacitors CD21,CD26 - Short	Random failure	Short-circuit on +15V -> Destroy AB (AB)	5 Destructive damage FGClite	5	1	1	5	49	1.53E-03	
				100nF Capacitors CD21,CD26 - Change in value	Random failure	No effect (AB)	1 No effect	1	1	4	4	29	9.07E-04	
				100nF Capacitors CD21,CD26 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	4	22	6.88E-04	
3.2.42	SN74LVC2T45	1	IC20	IC20 - Output stuck high	Random failure	No ADC clock (AB)	3 Immediate maintenance required	3	1	2	6	28	1.29E-04	
				IC20 - Output stuck low	Random failure	No ADC clock (AB)	3 Immediate maintenance required	3	1	2	6	28	1.29E-04	
				IC20 - Opened	Random failure	No ADC clock (AB)	3 Immediate maintenance required	3	1	2	6	22	1.01E-04	
				IC20 - Shorted	Random failure	Short-circuit on +15V -> Destroy AB (AB)	5 Destructive damage FGClite	5	1	1	5	22	1.01E-04	
3.2.43	Capacitor 100nF Ceramic	1	C84	100nF Capacitor C84 - Short	Random failure	Short-circuit on +15V -> Destroy AB (AB)	5 Destructive damage FGClite	5	1	1	5	49	1.72E-03	
				100nF Capacitor C84 - Change in value	Random failure	No effect (AB)	1 No effect	1	1	4	4	29	1.02E-03	
				100nF Capacitor C84 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	4	22	7.73E-04	
3.2.44	Capacitor 100nF Ceramic	1	C81	100nF Capacitor C81 - Short	Random failure	Short-circuit on -15V -> Destroy AB (AB)	5 Destructive damage FGClite	5	1	1	5	49	1.72E-03	
				100nF Capacitor C81 - Change in value	Random failure	No effect (AB)	1 No effect	1	1	4	4	29	1.02E-03	
				100nF Capacitor C81 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	4	22	7.73E-04	
3.3	***DCCTA ADC***	1												

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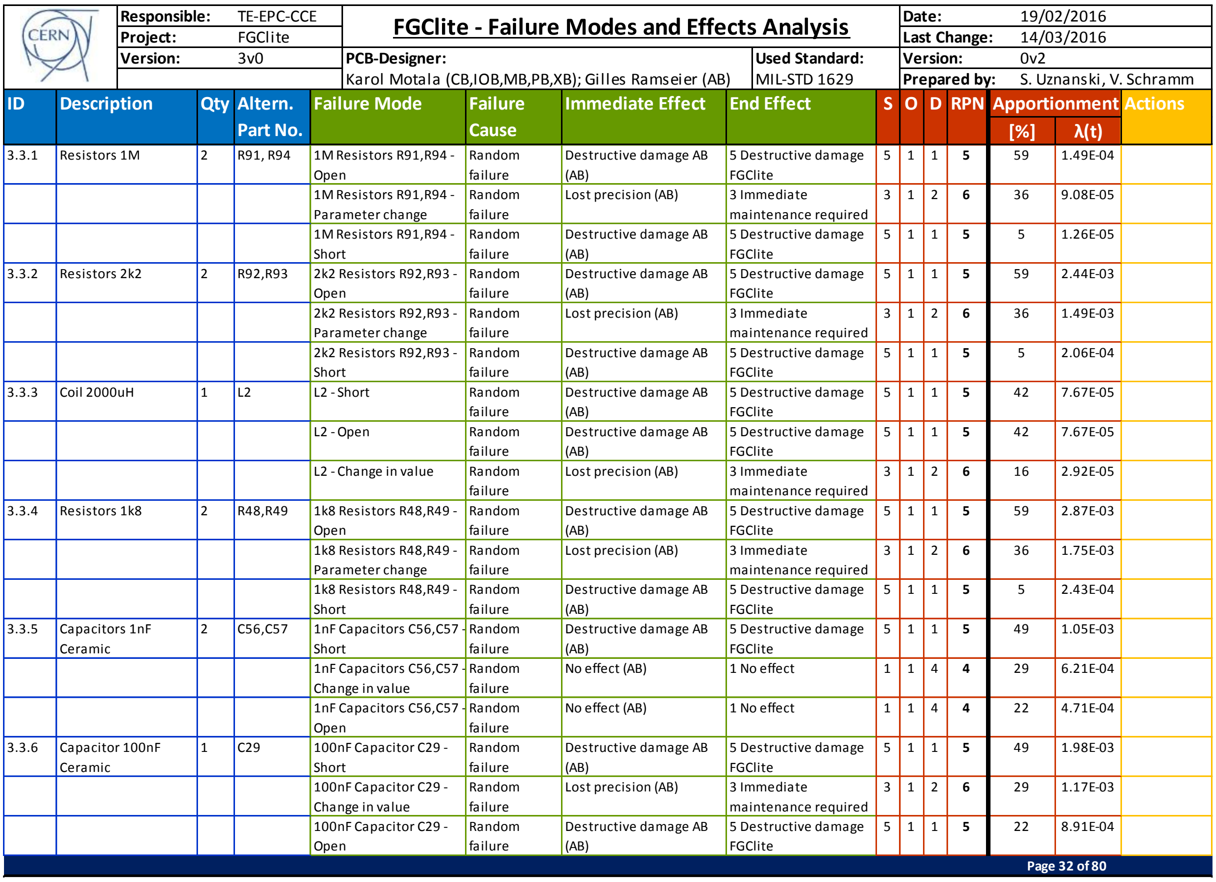

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ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment		Actions
												[%]	λ(t)	
3.3.1	Resistors 1M	2	R91, R94	1M Resistors R91,R94 - Open	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	5	59	1.49E-04	
				1M Resistors R91,R94 - Parameter change	Random failure	Lost precision (AB)	3 Immediate maintenance required	3	1	2	6	36	9.08E-05	
				1M Resistors R91,R94 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	5	5	1.26E-05	
3.3.2	Resistors 2k2	2	R92,R93	2k2 Resistors R92,R93 - Open	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	5	59	2.44E-03	
				2k2 Resistors R92,R93 - Parameter change	Random failure	Lost precision (AB)	3 Immediate maintenance required	3	1	2	6	36	1.49E-03	
				2k2 Resistors R92,R93 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	5	5	2.06E-04	
3.3.3	Coil 2000uH	1	L2	L2 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	5	42	7.67E-05	
				L2 - Open	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	5	42	7.67E-05	
				L2 - Change in value	Random failure	Lost precision (AB)	3 Immediate maintenance required	3	1	2	6	16	2.92E-05	
3.3.4	Resistors 1k8	2	R48,R49	1k8 Resistors R48,R49 - Open	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	5	59	2.87E-03	
				1k8 Resistors R48,R49 - Parameter change	Random failure	Lost precision (AB)	3 Immediate maintenance required	3	1	2	6	36	1.75E-03	
				1k8 Resistors R48,R49 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	5	5	2.43E-04	
3.3.5	Capacitors 1nF Ceramic	2	C56,C57	1nF Capacitors C56,C57 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	5	49	1.05E-03	
				1nF Capacitors C56,C57 - Change in value	Random failure	No effect (AB)	1 No effect	1	1	4	4	29	6.21E-04	
				1nF Capacitors C56,C57 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	4	22	4.71E-04	
3.3.6	Capacitor 100nF Ceramic	1	C29	100nF Capacitor C29 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	5	49	1.98E-03	
				100nF Capacitor C29 - Change in value	Random failure	Lost precision (AB)	3 Immediate maintenance required	3	1	2	6	29	1.17E-03	
				100nF Capacitor C29 - Open	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	5	22	8.91E-04	

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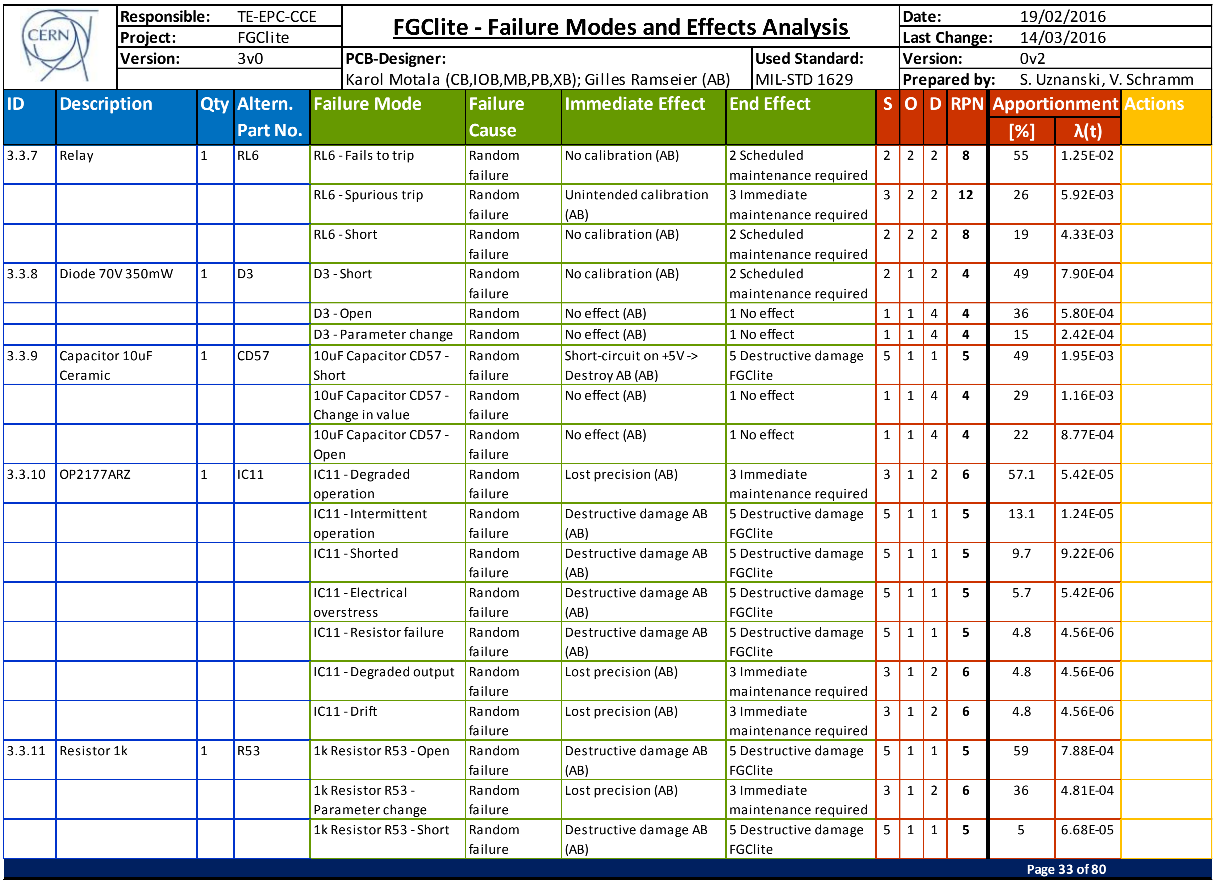

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - Failure Modes and Effects Analysis

PCB-Designer:
Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)

Used Standard:
MIL-STD 1629

Date: 19/02/2016
Last Change: 14/03/2016
Version: 0v2
Prepared by: S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment		Actions
												[%]	λ(t)	
3.3.7	Relay	1	RL6	RL6 - Fails to trip	Random failure	No calibration (AB)	2 Scheduled maintenance required	2	2	2	8	55	1.25E-02	
				RL6 - Spurious trip	Random failure	Unintended calibration (AB)	3 Immediate maintenance required	3	2	2	12	26	5.92E-03	
				RL6 - Short	Random failure	No calibration (AB)	2 Scheduled maintenance required	2	2	2	8	19	4.33E-03	
3.3.8	Diode 70V 350mW	1	D3	D3 - Short	Random failure	No calibration (AB)	2 Scheduled maintenance required	2	1	2	4	49	7.90E-04	
				D3 - Open	Random	No effect (AB)	1 No effect	1	1	4	4	36	5.80E-04	
				D3 - Parameter change	Random	No effect (AB)	1 No effect	1	1	4	4	15	2.42E-04	
3.3.9	Capacitor 10uF Ceramic	1	CD57	10uF Capacitor CD57 - Short	Random failure	Short-circuit on +5V -> Destroy AB (AB)	5 Destructive damage FGClite	5	1	1	5	49	1.95E-03	
				10uF Capacitor CD57 - Change in value	Random failure	No effect (AB)	1 No effect	1	1	4	4	29	1.16E-03	
				10uF Capacitor CD57 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	4	22	8.77E-04	
3.3.10	OP2177ARZ	1	IC11	IC11 - Degraded operation	Random failure	Lost precision (AB)	3 Immediate maintenance required	3	1	2	6	57.1	5.42E-05	
				IC11 - Intermittent operation	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	5	13.1	1.24E-05	
				IC11 - Shorted	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	5	9.7	9.22E-06	
				IC11 - Electrical overstress	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	5	5.7	5.42E-06	
				IC11 - Resistor failure	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	5	4.8	4.56E-06	
				IC11 - Degraded output	Random failure	Lost precision (AB)	3 Immediate maintenance required	3	1	2	6	4.8	4.56E-06	
				IC11 - Drift	Random failure	Lost precision (AB)	3 Immediate maintenance required	3	1	2	6	4.8	4.56E-06	
3.3.11	Resistor 1k	1	R53	1k Resistor R53 - Open	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	5	59	7.88E-04	
				1k Resistor R53 - Parameter change	Random failure	Lost precision (AB)	3 Immediate maintenance required	3	1	2	6	36	4.81E-04	
				1k Resistor R53 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	5	5	6.68E-05	

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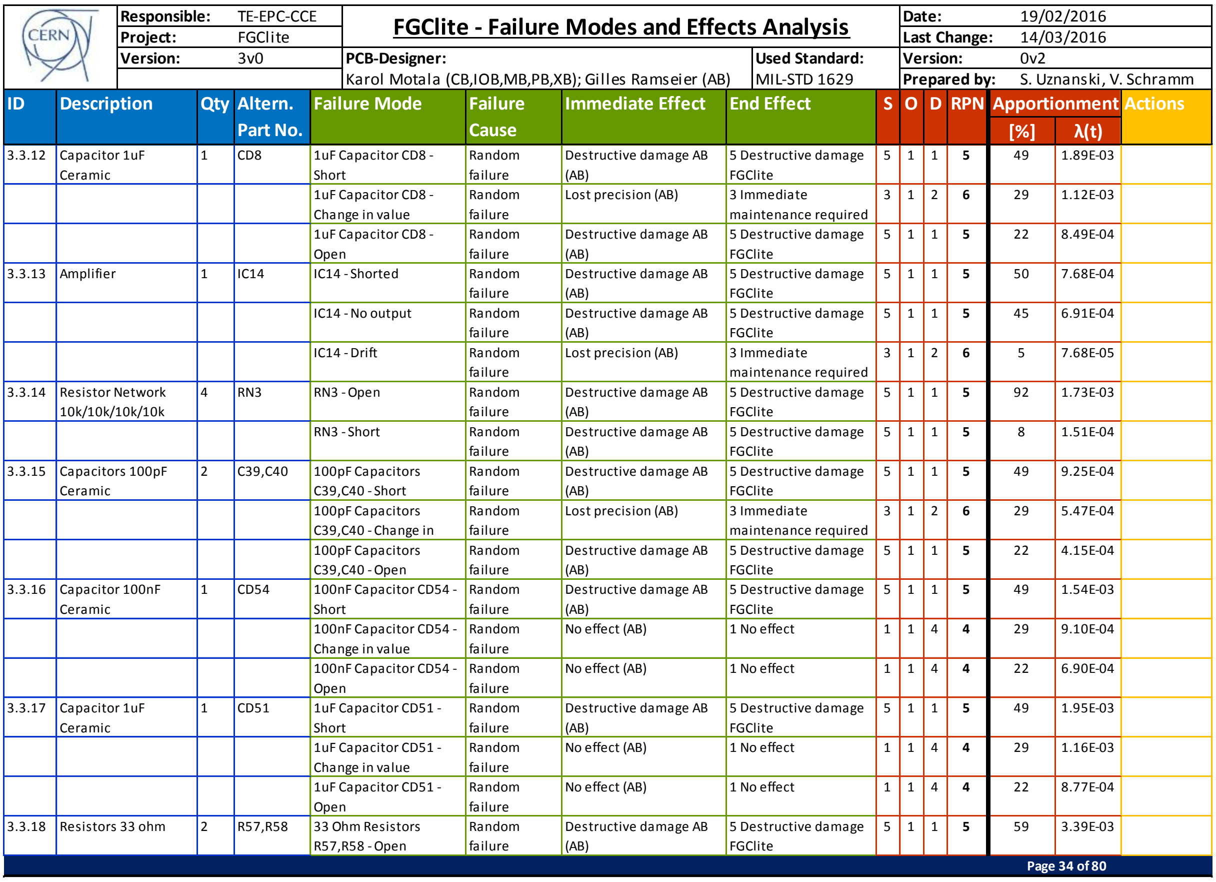

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ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment [%]	λ(t)	Actions
3.3.12	Capacitor 1uF Ceramic	1	CD8	1uF Capacitor CD8 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	5	49	1.89E-03	
				1uF Capacitor CD8 - Change in value	Random failure	Lost precision (AB)	3 Immediate maintenance required	3	1	2	6	29	1.12E-03	
				1uF Capacitor CD8 - Open	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	5	22	8.49E-04	
3.3.13	Amplifier	1	IC14	IC14 - Shorted	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	5	50	7.68E-04	
				IC14 - No output	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	5	45	6.91E-04	
				IC14 - Drift	Random failure	Lost precision (AB)	3 Immediate maintenance required	3	1	2	6	5	7.68E-05	
3.3.14	Resistor Network 10k/10k/10k/10k	4	RN3	RN3 - Open	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	5	92	1.73E-03	
				RN3 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	5	8	1.51E-04	
3.3.15	Capacitors 100pF Ceramic	2	C39,C40	100pF Capacitors C39,C40 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	5	49	9.25E-04	
				100pF Capacitors C39,C40 - Change in	Random failure	Lost precision (AB)	3 Immediate maintenance required	3	1	2	6	29	5.47E-04	
				100pF Capacitors C39,C40 - Open	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	5	22	4.15E-04	
3.3.16	Capacitor 100nF Ceramic	1	CD54	100nF Capacitor CD54 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	5	49	1.54E-03	
				100nF Capacitor CD54 - Change in value	Random failure	No effect (AB)	1 No effect	1	1	4	4	29	9.10E-04	
				100nF Capacitor CD54 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	4	22	6.90E-04	
3.3.17	Capacitor 1uF Ceramic	1	CD51	1uF Capacitor CD51 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	5	49	1.95E-03	
				1uF Capacitor CD51 - Change in value	Random failure	No effect (AB)	1 No effect	1	1	4	4	29	1.16E-03	
				1uF Capacitor CD51 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	4	22	8.77E-04	
3.3.18	Resistors 33 ohm	2	R57,R58	33 Ohm Resistors R57,R58 - Open	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	5	59	3.39E-03	

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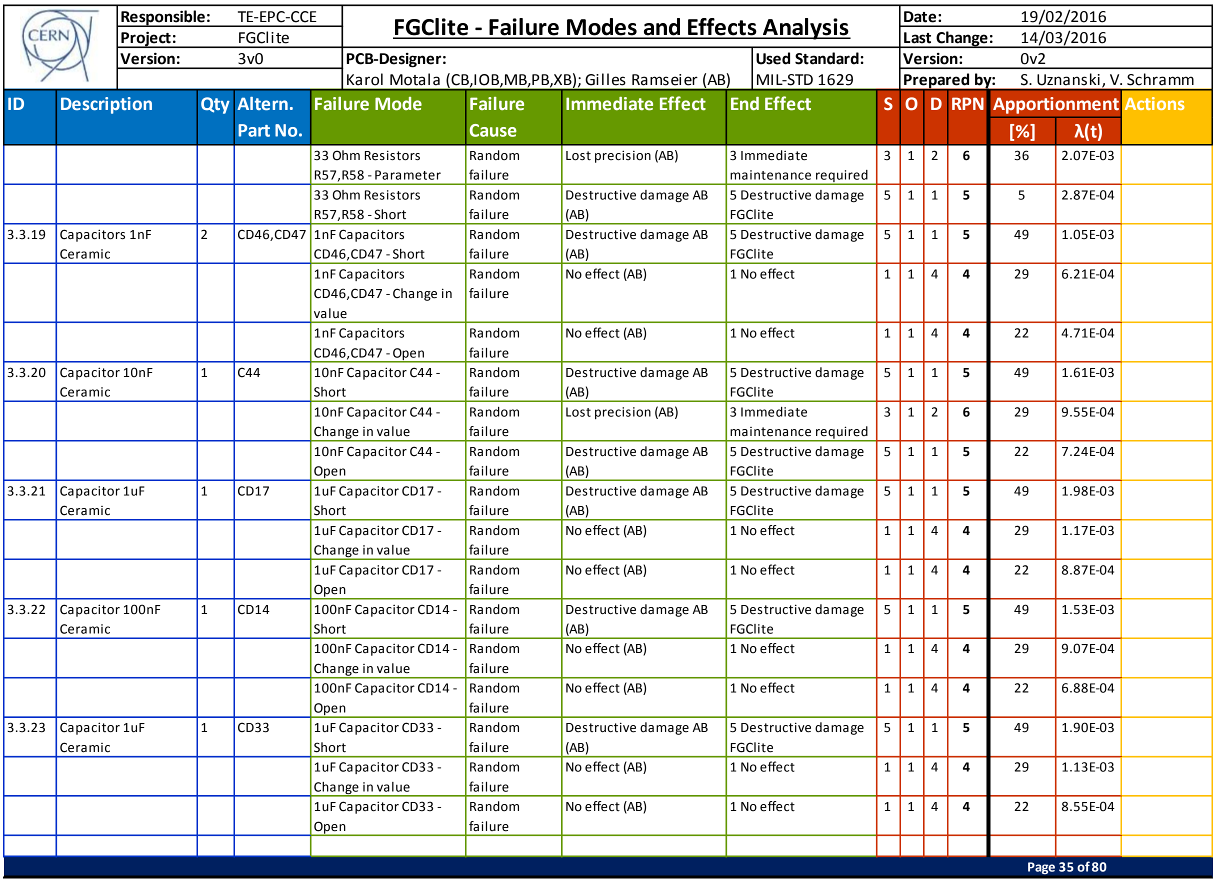

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FGClite - Failure Modes and Effects Analysis

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Date: 19/02/2016
Last Change: 14/03/2016
Version: 0v2
Prepared by: S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment [%]	λ(t)	Actions
				33 Ohm Resistors R57,R58 - Parameter	Random failure	Lost precision (AB)	3 Immediate maintenance required	3	1	2	6	36	2.07E-03	
				33 Ohm Resistors R57,R58 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	5	5	2.87E-04	
3.3.19	Capacitors 1nF Ceramic	2	CD46,CD47	1nF Capacitors CD46,CD47 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	5	49	1.05E-03	
				1nF Capacitors CD46,CD47 - Change in value	Random failure	No effect (AB)	1 No effect	1	1	4	4	29	6.21E-04	
				1nF Capacitors CD46,CD47 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	4	22	4.71E-04	
3.3.20	Capacitor 10nF Ceramic	1	C44	10nF Capacitor C44 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	5	49	1.61E-03	
				10nF Capacitor C44 - Change in value	Random failure	Lost precision (AB)	3 Immediate maintenance required	3	1	2	6	29	9.55E-04	
				10nF Capacitor C44 - Open	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	5	22	7.24E-04	
3.3.21	Capacitor 1uF Ceramic	1	CD17	1uF Capacitor CD17 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	5	49	1.98E-03	
				1uF Capacitor CD17 - Change in value	Random failure	No effect (AB)	1 No effect	1	1	4	4	29	1.17E-03	
				1uF Capacitor CD17 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	4	22	8.87E-04	
3.3.22	Capacitor 100nF Ceramic	1	CD14	100nF Capacitor CD14 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	5	49	1.53E-03	
				100nF Capacitor CD14 - Change in value	Random failure	No effect (AB)	1 No effect	1	1	4	4	29	9.07E-04	
				100nF Capacitor CD14 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	4	22	6.88E-04	
3.3.23	Capacitor 1uF Ceramic	1	CD33	1uF Capacitor CD33 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	5	49	1.90E-03	
				1uF Capacitor CD33 - Change in value	Random failure	No effect (AB)	1 No effect	1	1	4	4	29	1.13E-03	
				1uF Capacitor CD33 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	4	22	8.55E-04	

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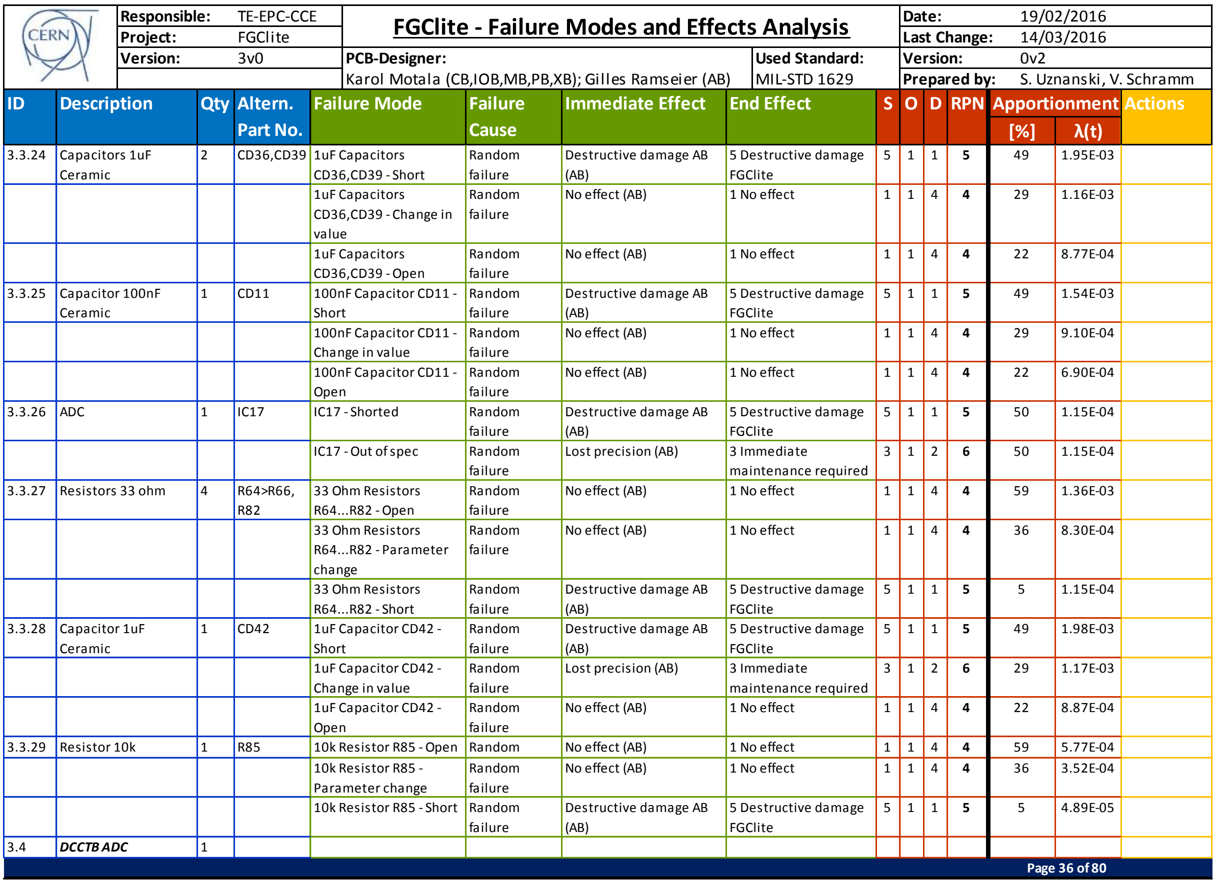

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FGClite - Failure Modes and Effects Analysis

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Used Standard:
MIL-STD 1629
Date: 19/02/2016
Last Change: 14/03/2016
Version: 0v2
Prepared by: S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment		Actions
												[%]	λ(t)	
3.3.24	Capacitors 1uF Ceramic	2	CD36,CD39	1uF Capacitors CD36,CD39 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	49	1.95E-03	
				1uF Capacitors CD36,CD39 - Change in value	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	29	1.16E-03	
				1uF Capacitors CD36,CD39 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	22	8.77E-04	
3.3.25	Capacitor 100nF Ceramic	1	CD11	100nF Capacitor CD11 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	49	1.54E-03	
				100nF Capacitor CD11 - Change in value	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	29	9.10E-04	
				100nF Capacitor CD11 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	22	6.90E-04	
3.3.26	ADC	1	IC17	IC17 - Shorted	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	50	1.15E-04	
				IC17 - Out of spec	Random failure	Lost precision (AB)	3 Immediate maintenance required	3	1	2	**6**	50	1.15E-04	
3.3.27	Resistors 33 ohm	4	R64>R66, R82	33 Ohm Resistors R64...R82 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	59	1.36E-03	
				33 Ohm Resistors R64...R82 - Parameter change	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	36	8.30E-04	
				33 Ohm Resistors R64...R82 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	5	1.15E-04	
3.3.28	Capacitor 1uF Ceramic	1	CD42	1uF Capacitor CD42 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	49	1.98E-03	
				1uF Capacitor CD42 - Change in value	Random failure	Lost precision (AB)	3 Immediate maintenance required	3	1	2	**6**	29	1.17E-03	
				1uF Capacitor CD42 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	22	8.87E-04	
3.3.29	Resistor 10k	1	R85	10k Resistor R85 - Open	Random	No effect (AB)	1 No effect	1	1	4	**4**	59	5.77E-04	
				10k Resistor R85 - Parameter change	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	36	3.52E-04	
				10k Resistor R85 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	5	4.89E-05	
3.4	***DCCTB ADC***	1												

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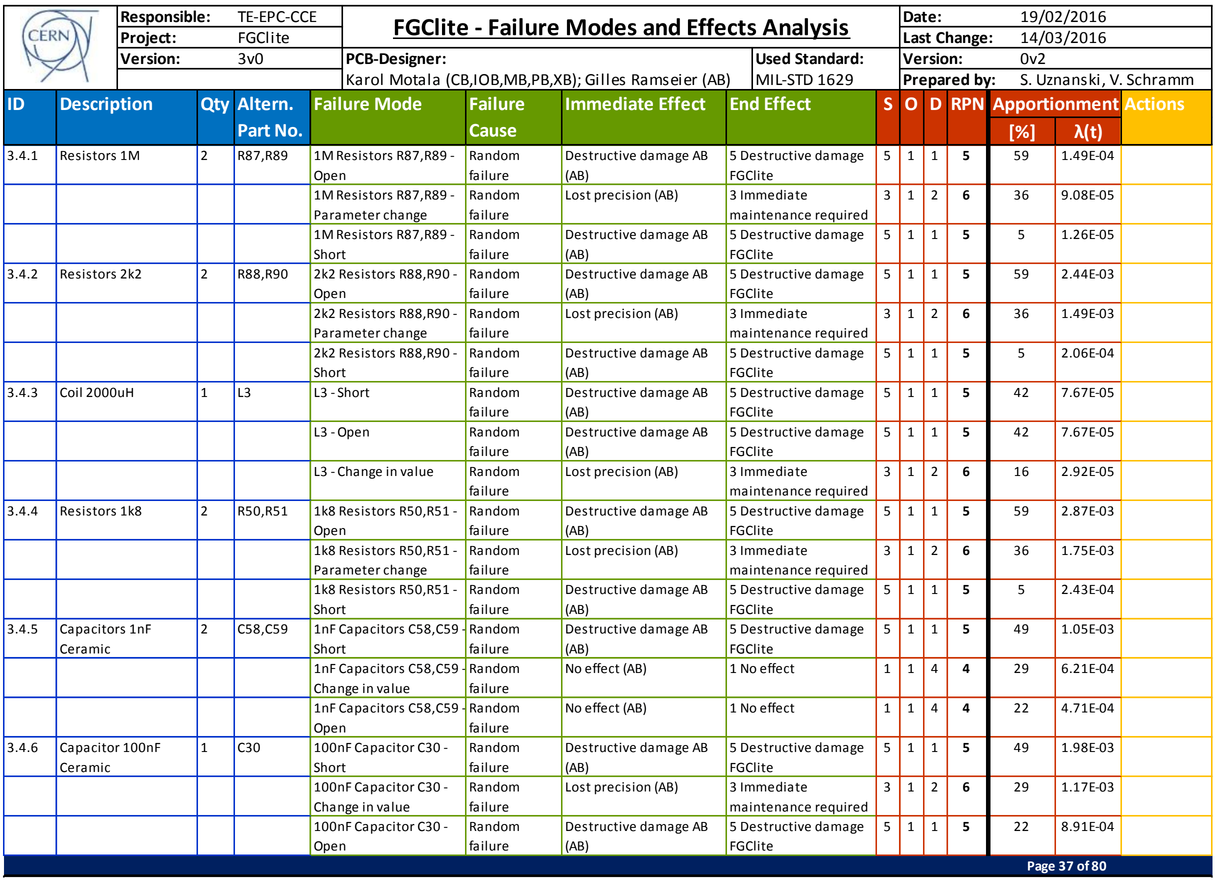

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Date: 19/02/2016
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Prepared by: S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment		Actions
												[%]	λ(t)	
3.4.1	Resistors 1M	2	R87,R89	1M Resistors R87,R89 - Open	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	59	1.49E-04	
				1M Resistors R87,R89 - Parameter change	Random failure	Lost precision (AB)	3 Immediate maintenance required	3	1	2	**6**	36	9.08E-05	
				1M Resistors R87,R89 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	5	1.26E-05	
3.4.2	Resistors 2k2	2	R88,R90	2k2 Resistors R88,R90 - Open	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	59	2.44E-03	
				2k2 Resistors R88,R90 - Parameter change	Random failure	Lost precision (AB)	3 Immediate maintenance required	3	1	2	**6**	36	1.49E-03	
				2k2 Resistors R88,R90 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	5	2.06E-04	
3.4.3	Coil 2000uH	1	L3	L3 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	42	7.67E-05	
				L3 - Open	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	42	7.67E-05	
				L3 - Change in value	Random failure	Lost precision (AB)	3 Immediate maintenance required	3	1	2	**6**	16	2.92E-05	
3.4.4	Resistors 1k8	2	R50,R51	1k8 Resistors R50,R51 - Open	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	59	2.87E-03	
				1k8 Resistors R50,R51 - Parameter change	Random failure	Lost precision (AB)	3 Immediate maintenance required	3	1	2	**6**	36	1.75E-03	
				1k8 Resistors R50,R51 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	5	2.43E-04	
3.4.5	Capacitors 1nF Ceramic	2	C58,C59	1nF Capacitors C58,C59 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	49	1.05E-03	
				1nF Capacitors C58,C59 - Change in value	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	29	6.21E-04	
				1nF Capacitors C58,C59 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	22	4.71E-04	
3.4.6	Capacitor 100nF Ceramic	1	C30	100nF Capacitor C30 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	49	1.98E-03	
				100nF Capacitor C30 - Change in value	Random failure	Lost precision (AB)	3 Immediate maintenance required	3	1	2	**6**	29	1.17E-03	
				100nF Capacitor C30 - Open	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	22	8.91E-04	

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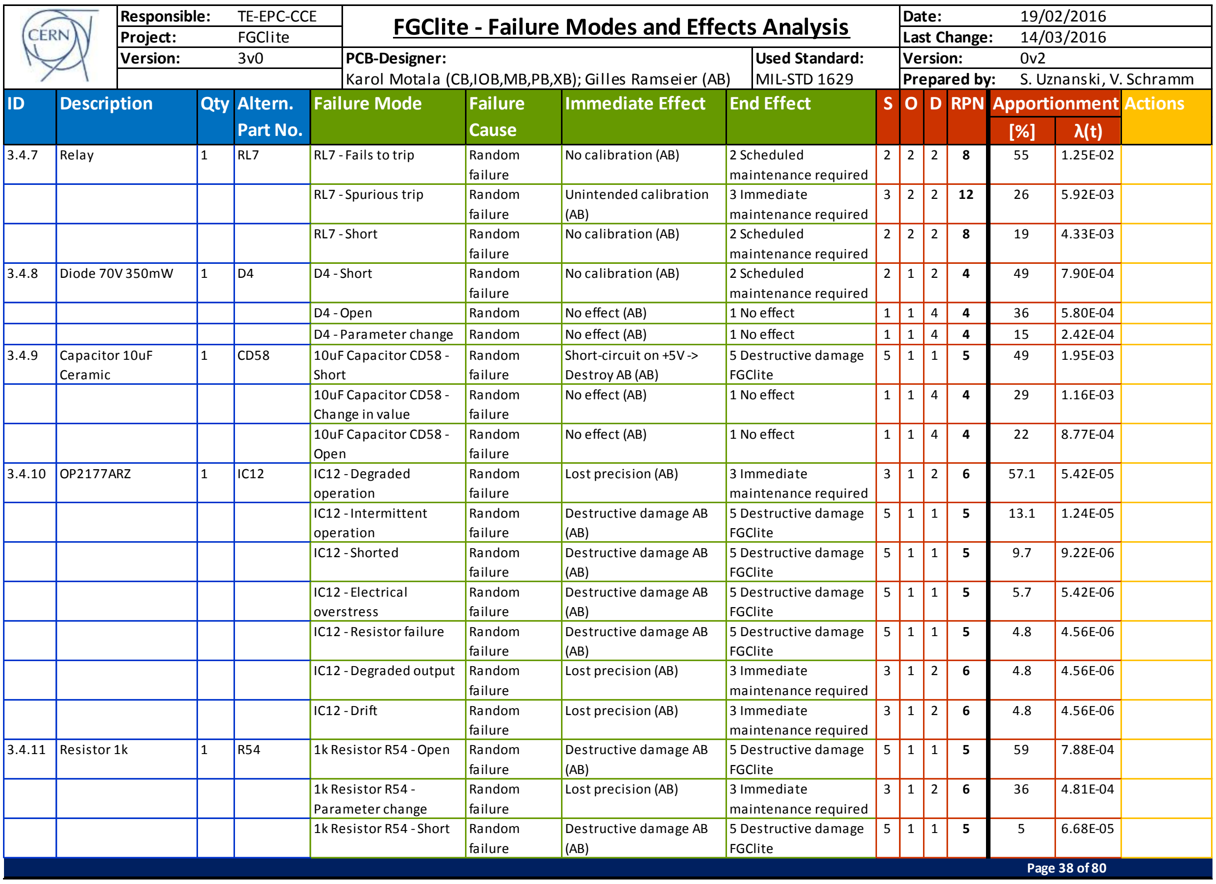

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ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment [%]	λ(t)	Actions
3.4.7	Relay	1	RL7	RL7 - Fails to trip	Random failure	No calibration (AB)	2 Scheduled maintenance required	2	2	2	**8**	55	1.25E-02	
				RL7 - Spurious trip	Random failure	Unintended calibration (AB)	3 Immediate maintenance required	3	2	2	**12**	26	5.92E-03	
				RL7 - Short	Random failure	No calibration (AB)	2 Scheduled maintenance required	2	2	2	**8**	19	4.33E-03	
3.4.8	Diode 70V 350mW	1	D4	D4 - Short	Random failure	No calibration (AB)	2 Scheduled maintenance required	2	1	2	**4**	49	7.90E-04	
				D4 - Open	Random	No effect (AB)	1 No effect	1	1	4	**4**	36	5.80E-04	
				D4 - Parameter change	Random	No effect (AB)	1 No effect	1	1	4	**4**	15	2.42E-04	
3.4.9	Capacitor 10uF Ceramic	1	CD58	10uF Capacitor CD58 - Short	Random failure	Short-circuit on +5V -> Destroy AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	49	1.95E-03	
				10uF Capacitor CD58 - Change in value	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	29	1.16E-03	
				10uF Capacitor CD58 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	22	8.77E-04	
3.4.10	OP2177ARZ	1	IC12	IC12 - Degraded operation	Random failure	Lost precision (AB)	3 Immediate maintenance required	3	1	2	**6**	57.1	5.42E-05	
				IC12 - Intermittent operation	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	13.1	1.24E-05	
				IC12 - Shorted	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	9.7	9.22E-06	
				IC12 - Electrical overstress	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	5.7	5.42E-06	
				IC12 - Resistor failure	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	4.8	4.56E-06	
				IC12 - Degraded output	Random failure	Lost precision (AB)	3 Immediate maintenance required	3	1	2	**6**	4.8	4.56E-06	
				IC12 - Drift	Random failure	Lost precision (AB)	3 Immediate maintenance required	3	1	2	**6**	4.8	4.56E-06	
3.4.11	Resistor 1k	1	R54	1k Resistor R54 - Open	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	59	7.88E-04	
				1k Resistor R54 - Parameter change	Random failure	Lost precision (AB)	3 Immediate maintenance required	3	1	2	**6**	36	4.81E-04	
				1k Resistor R54 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	5	6.68E-05	

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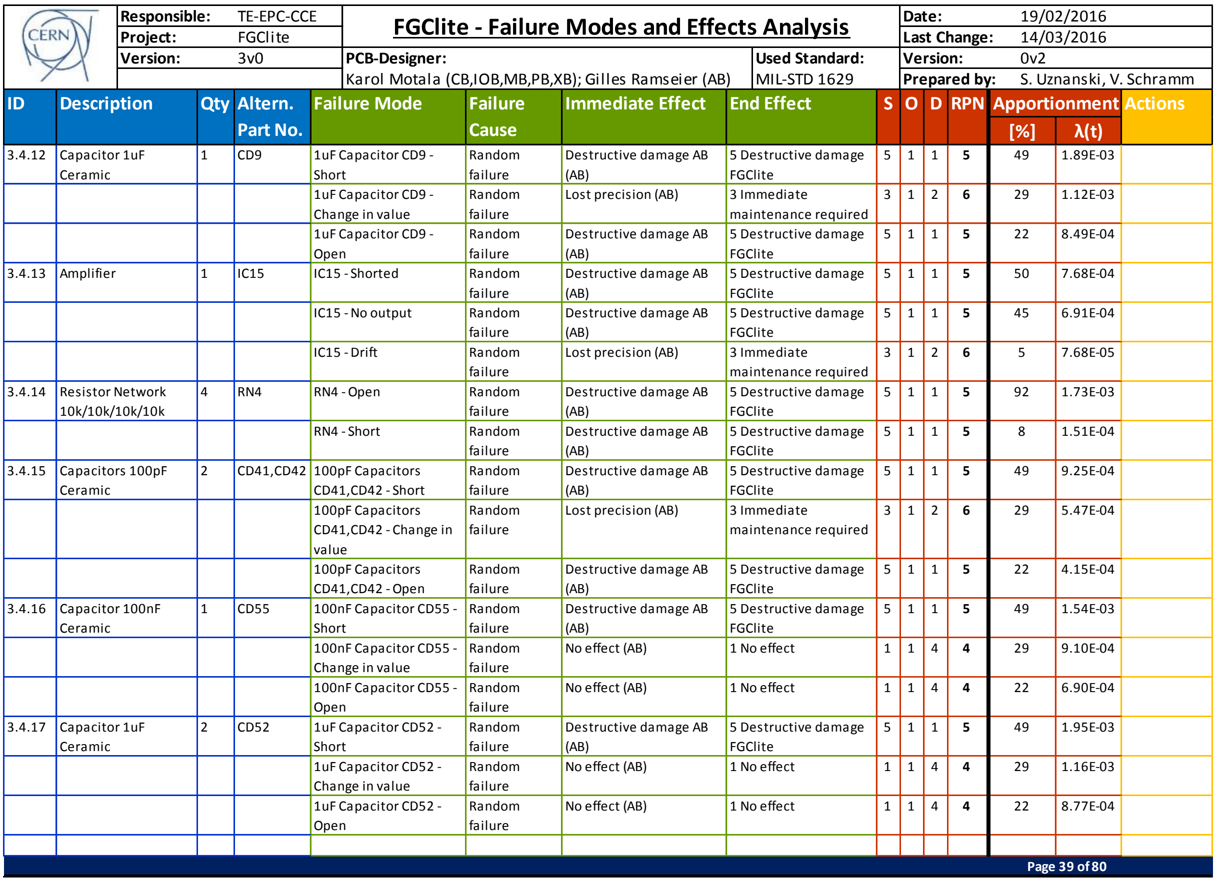

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - Failure Modes and Effects Analysis

PCB-Designer: Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)
Used Standard: MIL-STD 1629
Date: 19/02/2016
Last Change: 14/03/2016
Version: 0v2
Prepared by: S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment [%]	λ(t)	Actions
3.4.12	Capacitor 1uF Ceramic	1	CD9	1uF Capacitor CD9 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	49	1.89E-03	
				1uF Capacitor CD9 - Change in value	Random failure	Lost precision (AB)	3 Immediate maintenance required	3	1	2	**6**	29	1.12E-03	
				1uF Capacitor CD9 - Open	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	22	8.49E-04	
3.4.13	Amplifier	1	IC15	IC15 - Shorted	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	50	7.68E-04	
				IC15 - No output	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	45	6.91E-04	
				IC15 - Drift	Random failure	Lost precision (AB)	3 Immediate maintenance required	3	1	2	**6**	5	7.68E-05	
3.4.14	Resistor Network 10k/10k/10k/10k	4	RN4	RN4 - Open	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	92	1.73E-03	
				RN4 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	8	1.51E-04	
3.4.15	Capacitors 100pF Ceramic	2	CD41,CD42	100pF Capacitors CD41,CD42 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	49	9.25E-04	
				100pF Capacitors CD41,CD42 - Change in value	Random failure	Lost precision (AB)	3 Immediate maintenance required	3	1	2	**6**	29	5.47E-04	
				100pF Capacitors CD41,CD42 - Open	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	22	4.15E-04	
3.4.16	Capacitor 100nF Ceramic	1	CD55	100nF Capacitor CD55 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	49	1.54E-03	
				100nF Capacitor CD55 - Change in value	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	29	9.10E-04	
				100nF Capacitor CD55 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	22	6.90E-04	
3.4.17	Capacitor 1uF Ceramic	2	CD52	1uF Capacitor CD52 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	49	1.95E-03	
				1uF Capacitor CD52 - Change in value	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	29	1.16E-03	
				1uF Capacitor CD52 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	22	8.77E-04	

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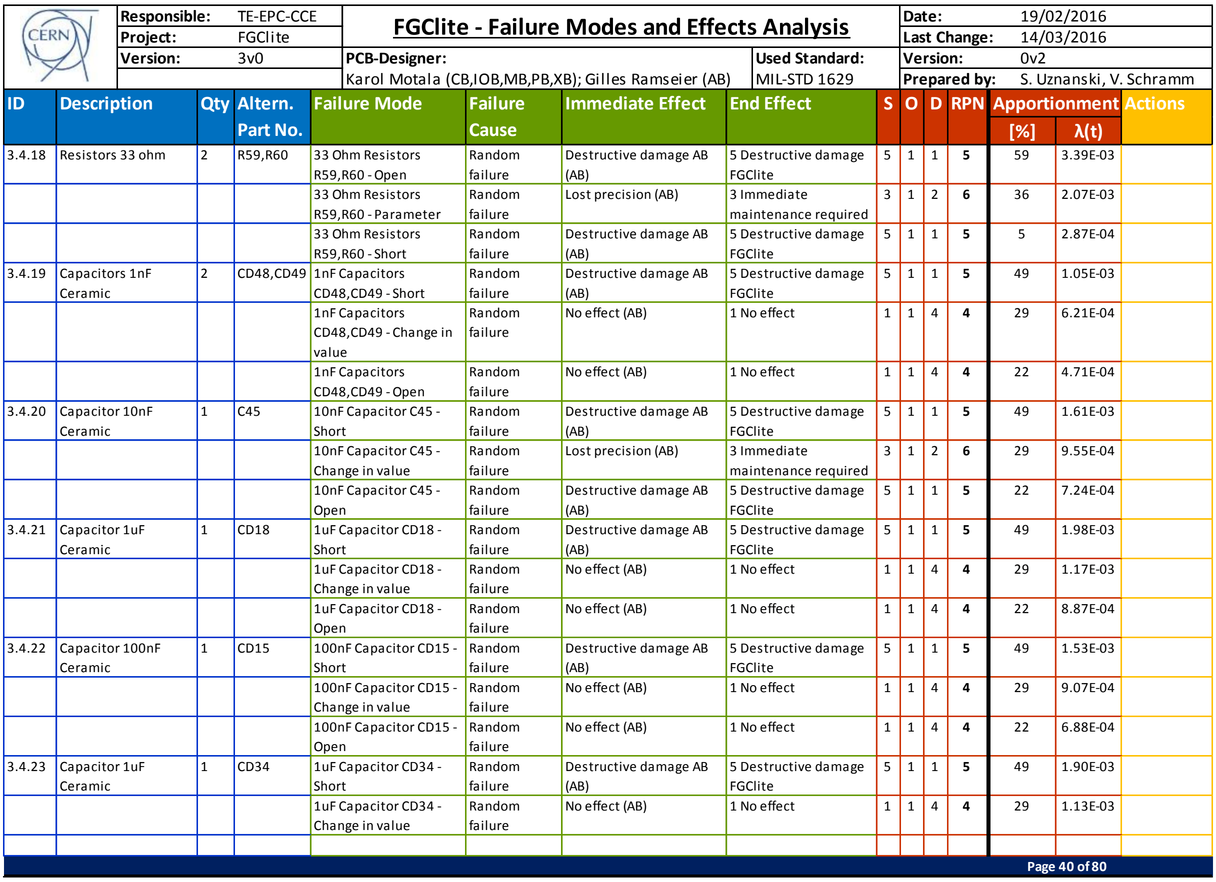

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PCB-Designer:
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Used Standard:
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Date: 19/02/2016
Last Change: 14/03/2016
Version: 0v2
Prepared by: S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment		Actions
												[%]	λ(t)	
3.4.18	Resistors 33 ohm	2	R59,R60	33 Ohm Resistors R59,R60 - Open	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	59	3.39E-03	
				33 Ohm Resistors R59,R60 - Parameter	Random failure	Lost precision (AB)	3 Immediate maintenance required	3	1	2	**6**	36	2.07E-03	
				33 Ohm Resistors R59,R60 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	5	2.87E-04	
3.4.19	Capacitors 1nF Ceramic	2	CD48,CD49	1nF Capacitors CD48,CD49 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	49	1.05E-03	
				1nF Capacitors CD48,CD49 - Change in value	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	29	6.21E-04	
				1nF Capacitors CD48,CD49 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	22	4.71E-04	
3.4.20	Capacitor 10nF Ceramic	1	C45	10nF Capacitor C45 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	49	1.61E-03	
				10nF Capacitor C45 - Change in value	Random failure	Lost precision (AB)	3 Immediate maintenance required	3	1	2	**6**	29	9.55E-04	
				10nF Capacitor C45 - Open	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	22	7.24E-04	
3.4.21	Capacitor 1uF Ceramic	1	CD18	1uF Capacitor CD18 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	49	1.98E-03	
				1uF Capacitor CD18 - Change in value	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	29	1.17E-03	
				1uF Capacitor CD18 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	22	8.87E-04	
3.4.22	Capacitor 100nF Ceramic	1	CD15	100nF Capacitor CD15 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	49	1.53E-03	
				100nF Capacitor CD15 - Change in value	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	29	9.07E-04	
				100nF Capacitor CD15 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	22	6.88E-04	
3.4.23	Capacitor 1uF Ceramic	1	CD34	1uF Capacitor CD34 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	49	1.90E-03	
				1uF Capacitor CD34 - Change in value	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	29	1.13E-03	

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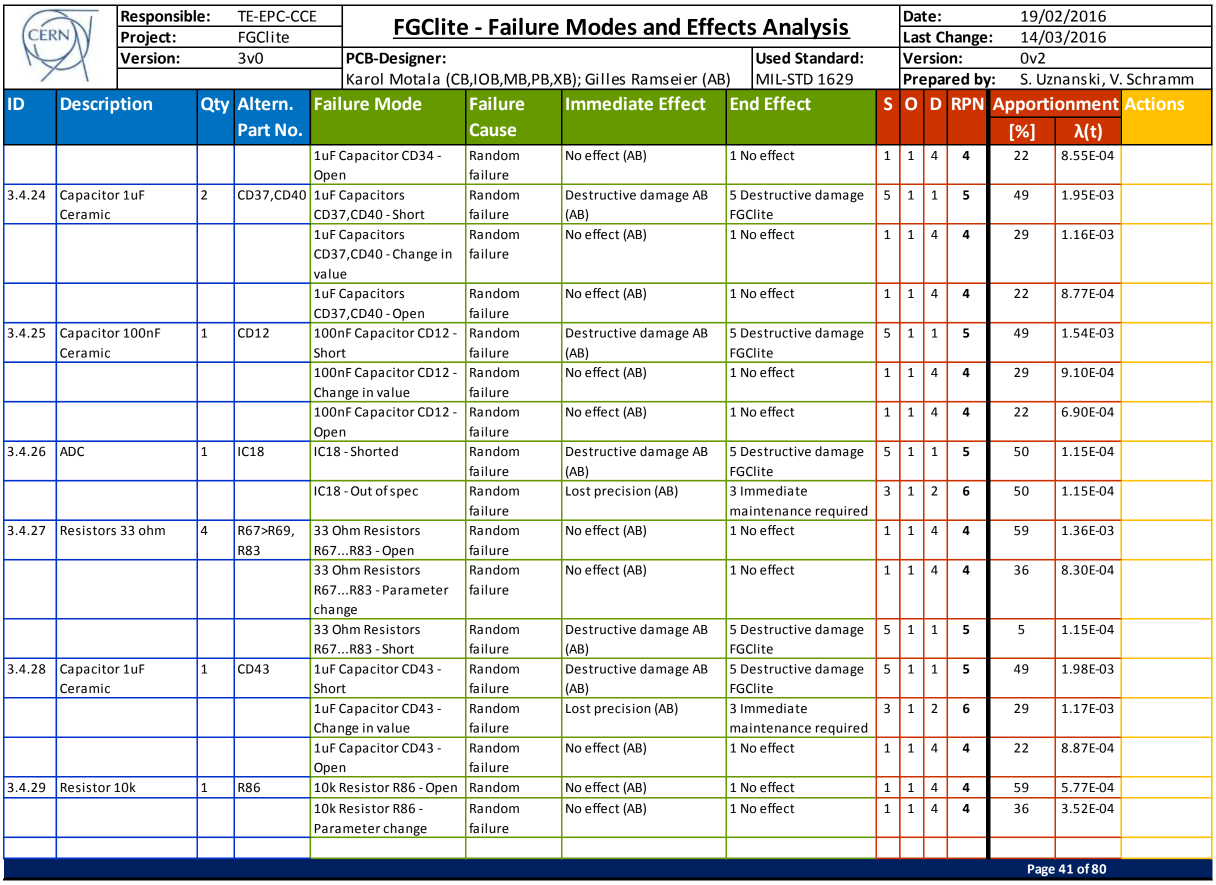

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PCB-Designer:
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Used Standard:
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Version: 0v2
Prepared by: S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment		Actions
												[%]	λ(t)	
				1uF Capacitor CD34 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	22	8.55E-04	
3.4.24	Capacitor 1uF Ceramic	2	CD37,CD40	1uF Capacitors CD37,CD40 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	49	1.95E-03	
				1uF Capacitors CD37,CD40 - Change in value	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	29	1.16E-03	
				1uF Capacitors CD37,CD40 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	22	8.77E-04	
3.4.25	Capacitor 100nF Ceramic	1	CD12	100nF Capacitor CD12 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	49	1.54E-03	
				100nF Capacitor CD12 - Change in value	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	29	9.10E-04	
				100nF Capacitor CD12 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	22	6.90E-04	
3.4.26	ADC	1	IC18	IC18 - Shorted	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	50	1.15E-04	
				IC18 - Out of spec	Random failure	Lost precision (AB)	3 Immediate maintenance required	3	1	2	**6**	50	1.15E-04	
3.4.27	Resistors 33 ohm	4	R67>R69, R83	33 Ohm Resistors R67...R83 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	59	1.36E-03	
				33 Ohm Resistors R67...R83 - Parameter change	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	36	8.30E-04	
				33 Ohm Resistors R67...R83 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	5	1.15E-04	
3.4.28	Capacitor 1uF Ceramic	1	CD43	1uF Capacitor CD43 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	49	1.98E-03	
				1uF Capacitor CD43 - Change in value	Random failure	Lost precision (AB)	3 Immediate maintenance required	3	1	2	**6**	29	1.17E-03	
				1uF Capacitor CD43 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	22	8.87E-04	
3.4.29	Resistor 10k	1	R86	10k Resistor R86 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	59	5.77E-04	
				10k Resistor R86 - Parameter change	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	36	3.52E-04	

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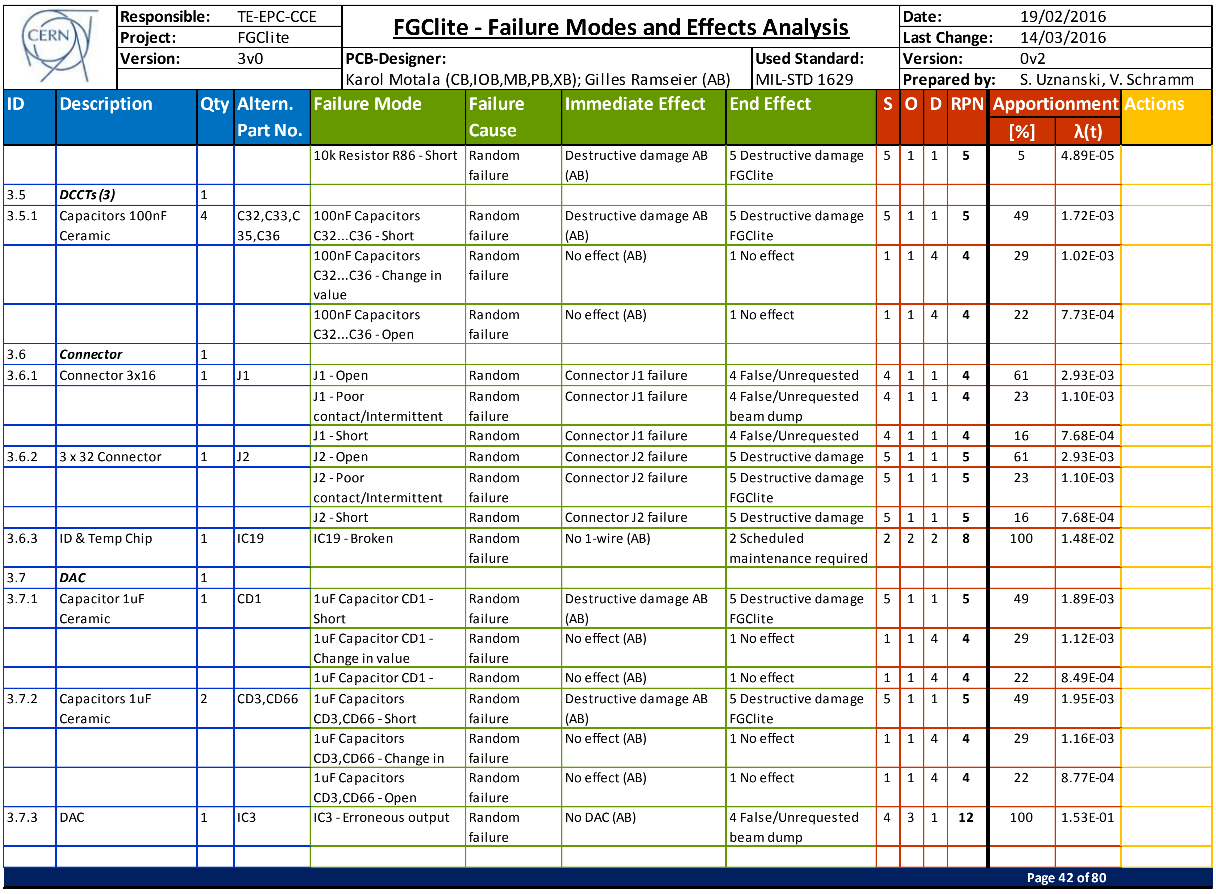

Responsible: TE-EPC-CCE
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PCB-Designer:
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Used Standard:
MIL-STD 1629

Date: 19/02/2016
Last Change: 14/03/2016
Version: 0v2
Prepared by: S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment		Actions
												[%]	λ(t)	
				10k Resistor R86 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	5	4.89E-05	
3.5	***DCCTs (3)***	1												
3.5.1	Capacitors 100nF Ceramic	4	C32,C33,C35,C36	100nF Capacitors C32...C36 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	49	1.72E-03	
				100nF Capacitors C32...C36 - Change in value	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	29	1.02E-03	
				100nF Capacitors C32...C36 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	22	7.73E-04	
3.6	***Connector***	1												
3.6.1	Connector 3x16	1	J1	J1 - Open	Random	Connector J1 failure	4 False/Unrequested	4	1	1	**4**	61	2.93E-03	
				J1 - Poor contact/Intermittent	Random failure	Connector J1 failure	4 False/Unrequested beam dump	4	1	1	**4**	23	1.10E-03	
				J1 - Short	Random	Connector J1 failure	4 False/Unrequested	4	1	1	**4**	16	7.68E-04	
3.6.2	3 x 32 Connector	1	J2	J2 - Open	Random	Connector J2 failure	5 Destructive damage	5	1	1	**5**	61	2.93E-03	
				J2 - Poor contact/Intermittent	Random failure	Connector J2 failure	5 Destructive damage FGClite	5	1	1	**5**	23	1.10E-03	
				J2 - Short	Random	Connector J2 failure	5 Destructive damage	5	1	1	**5**	16	7.68E-04	
3.6.3	ID & Temp Chip	1	IC19	IC19 - Broken	Random failure	No 1-wire (AB)	2 Scheduled maintenance required	2	2	2	**8**	100	1.48E-02	
3.7	***DAC***	1												
3.7.1	Capacitor 1uF Ceramic	1	CD1	1uF Capacitor CD1 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	49	1.89E-03	
				1uF Capacitor CD1 - Change in value	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	29	1.12E-03	
				1uF Capacitor CD1 -	Random	No effect (AB)	1 No effect	1	1	4	**4**	22	8.49E-04	
3.7.2	Capacitors 1uF Ceramic	2	CD3,CD66	1uF Capacitors CD3,CD66 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	49	1.95E-03	
				1uF Capacitors CD3,CD66 - Change in	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	29	1.16E-03	
				1uF Capacitors CD3,CD66 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	22	8.77E-04	
3.7.3	DAC	1	IC3	IC3 - Erroneous output	Random failure	No DAC (AB)	4 False/Unrequested beam dump	4	3	1	**12**	100	1.53E-01	

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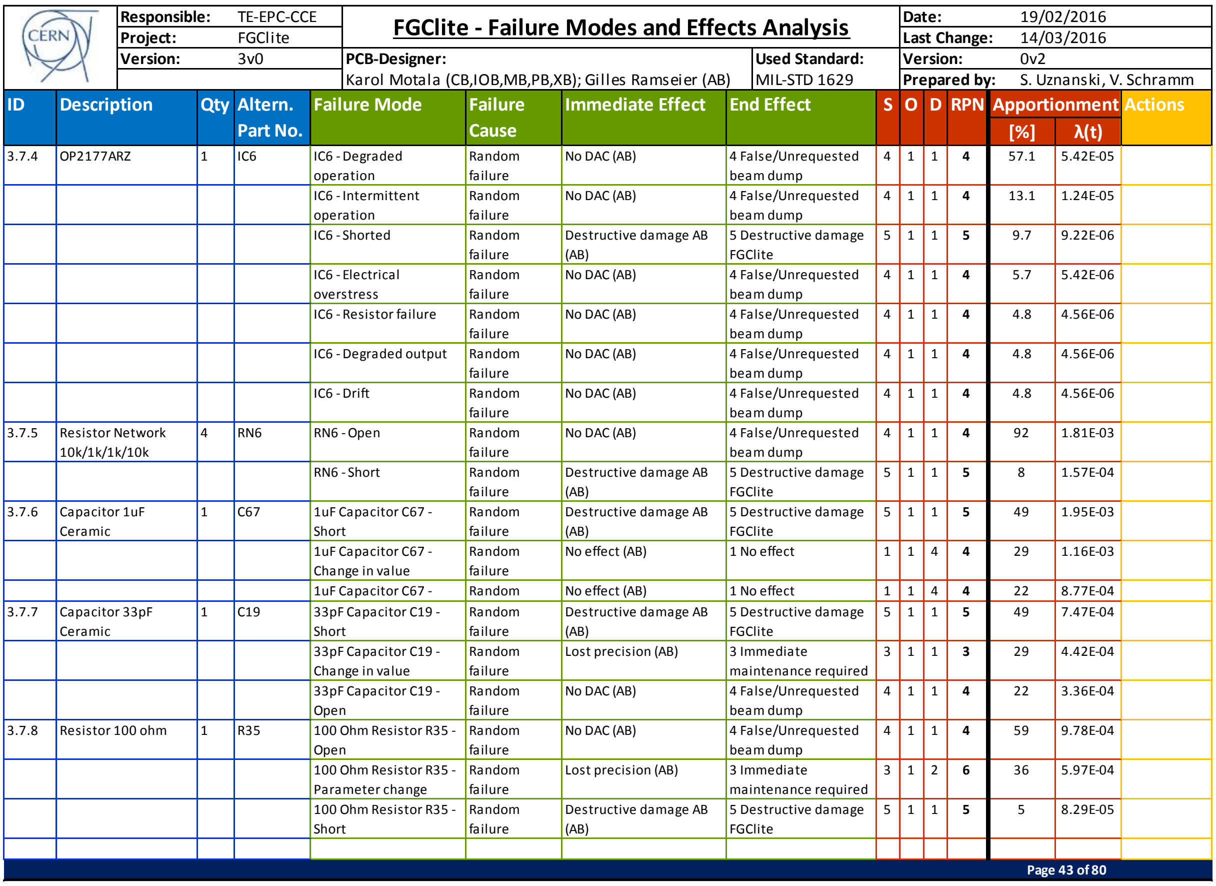

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PCB-Designer:
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Used Standard:
MIL-STD 1629

Date: 19/02/2016
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ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment		Actions
												[%]	λ(t)	
3.7.4	OP2177ARZ	1	IC6	IC6 - Degraded operation	Random failure	No DAC (AB)	4 False/Unrequested beam dump	4	1	1	**4**	57.1	5.42E-05	
				IC6 - Intermittent operation	Random failure	No DAC (AB)	4 False/Unrequested beam dump	4	1	1	**4**	13.1	1.24E-05	
				IC6 - Shorted	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	9.7	9.22E-06	
				IC6 - Electrical overstress	Random failure	No DAC (AB)	4 False/Unrequested beam dump	4	1	1	**4**	5.7	5.42E-06	
				IC6 - Resistor failure	Random failure	No DAC (AB)	4 False/Unrequested beam dump	4	1	1	**4**	4.8	4.56E-06	
				IC6 - Degraded output	Random failure	No DAC (AB)	4 False/Unrequested beam dump	4	1	1	**4**	4.8	4.56E-06	
				IC6 - Drift	Random failure	No DAC (AB)	4 False/Unrequested beam dump	4	1	1	**4**	4.8	4.56E-06	
3.7.5	Resistor Network 10k/1k/1k/10k	4	RN6	RN6 - Open	Random failure	No DAC (AB)	4 False/Unrequested beam dump	4	1	1	**4**	92	1.81E-03	
				RN6 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	8	1.57E-04	
3.7.6	Capacitor 1uF Ceramic	1	C67	1uF Capacitor C67 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	49	1.95E-03	
				1uF Capacitor C67 - Change in value	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	29	1.16E-03	
				1uF Capacitor C67 -	Random	No effect (AB)	1 No effect	1	1	4	**4**	22	8.77E-04	
3.7.7	Capacitor 33pF Ceramic	1	C19	33pF Capacitor C19 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	49	7.47E-04	
				33pF Capacitor C19 - Change in value	Random failure	Lost precision (AB)	3 Immediate maintenance required	3	1	1	**3**	29	4.42E-04	
				33pF Capacitor C19 - Open	Random failure	No DAC (AB)	4 False/Unrequested beam dump	4	1	1	**4**	22	3.36E-04	
3.7.8	Resistor 100 ohm	1	R35	100 Ohm Resistor R35 - Open	Random failure	No DAC (AB)	4 False/Unrequested beam dump	4	1	1	**4**	59	9.78E-04	
				100 Ohm Resistor R35 - Parameter change	Random failure	Lost precision (AB)	3 Immediate maintenance required	3	1	2	**6**	36	5.97E-04	
				100 Ohm Resistor R35 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	5	8.29E-05	

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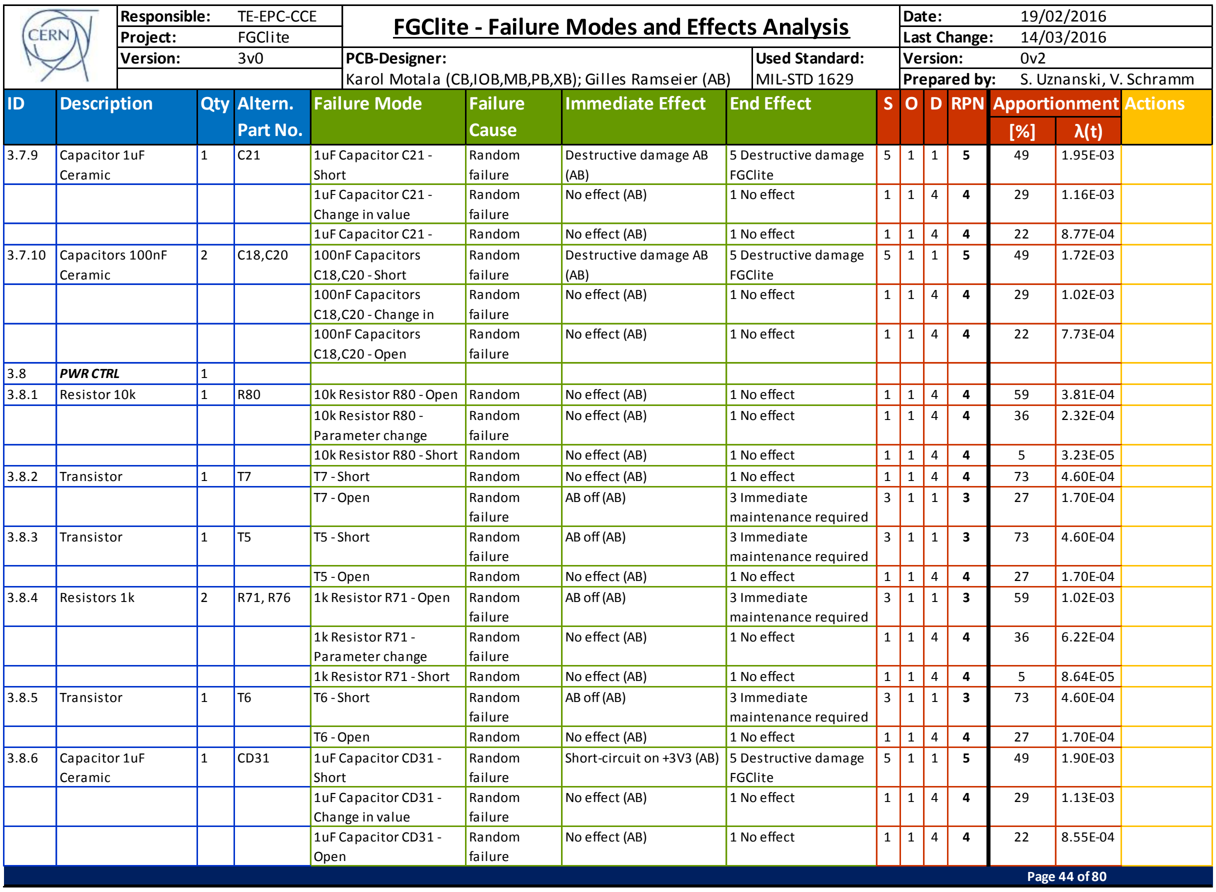

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ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment [%]	$\lambda(t)$	Actions
3.7.9	Capacitor 1uF Ceramic	1	C21	1uF Capacitor C21 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	5	49	1.95E-03	
				1uF Capacitor C21 - Change in value	Random failure	No effect (AB)	1 No effect	1	1	4	4	29	1.16E-03	
				1uF Capacitor C21 -	Random	No effect (AB)	1 No effect	1	1	4	4	22	8.77E-04	
3.7.10	Capacitors 100nF Ceramic	2	C18,C20	100nF Capacitors C18,C20 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	5	49	1.72E-03	
				100nF Capacitors C18,C20 - Change in	Random failure	No effect (AB)	1 No effect	1	1	4	4	29	1.02E-03	
				100nF Capacitors C18,C20 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	4	22	7.73E-04	
3.8	***PWR CTRL***	1												
3.8.1	Resistor 10k	1	R80	10k Resistor R80 - Open	Random	No effect (AB)	1 No effect	1	1	4	4	59	3.81E-04	
				10k Resistor R80 - Parameter change	Random failure	No effect (AB)	1 No effect	1	1	4	4	36	2.32E-04	
				10k Resistor R80 - Short	Random	No effect (AB)	1 No effect	1	1	4	4	5	3.23E-05	
3.8.2	Transistor	1	T7	T7 - Short	Random	No effect (AB)	1 No effect	1	1	4	4	73	4.60E-04	
				T7 - Open	Random failure	AB off (AB)	3 Immediate maintenance required	3	1	1	3	27	1.70E-04	
3.8.3	Transistor	1	T5	T5 - Short	Random failure	AB off (AB)	3 Immediate maintenance required	3	1	1	3	73	4.60E-04	
				T5 - Open	Random	No effect (AB)	1 No effect	1	1	4	4	27	1.70E-04	
3.8.4	Resistors 1k	2	R71, R76	1k Resistor R71 - Open	Random failure	AB off (AB)	3 Immediate maintenance required	3	1	1	3	59	1.02E-03	
				1k Resistor R71 - Parameter change	Random failure	No effect (AB)	1 No effect	1	1	4	4	36	6.22E-04	
				1k Resistor R71 - Short	Random	No effect (AB)	1 No effect	1	1	4	4	5	8.64E-05	
3.8.5	Transistor	1	T6	T6 - Short	Random failure	AB off (AB)	3 Immediate maintenance required	3	1	1	3	73	4.60E-04	
				T6 - Open	Random	No effect (AB)	1 No effect	1	1	4	4	27	1.70E-04	
3.8.6	Capacitor 1uF Ceramic	1	CD31	1uF Capacitor CD31 - Short	Random failure	Short-circuit on +3V3 (AB)	5 Destructive damage FGClite	5	1	1	5	49	1.90E-03	
				1uF Capacitor CD31 - Change in value	Random failure	No effect (AB)	1 No effect	1	1	4	4	29	1.13E-03	
				1uF Capacitor CD31 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	4	22	8.55E-04	

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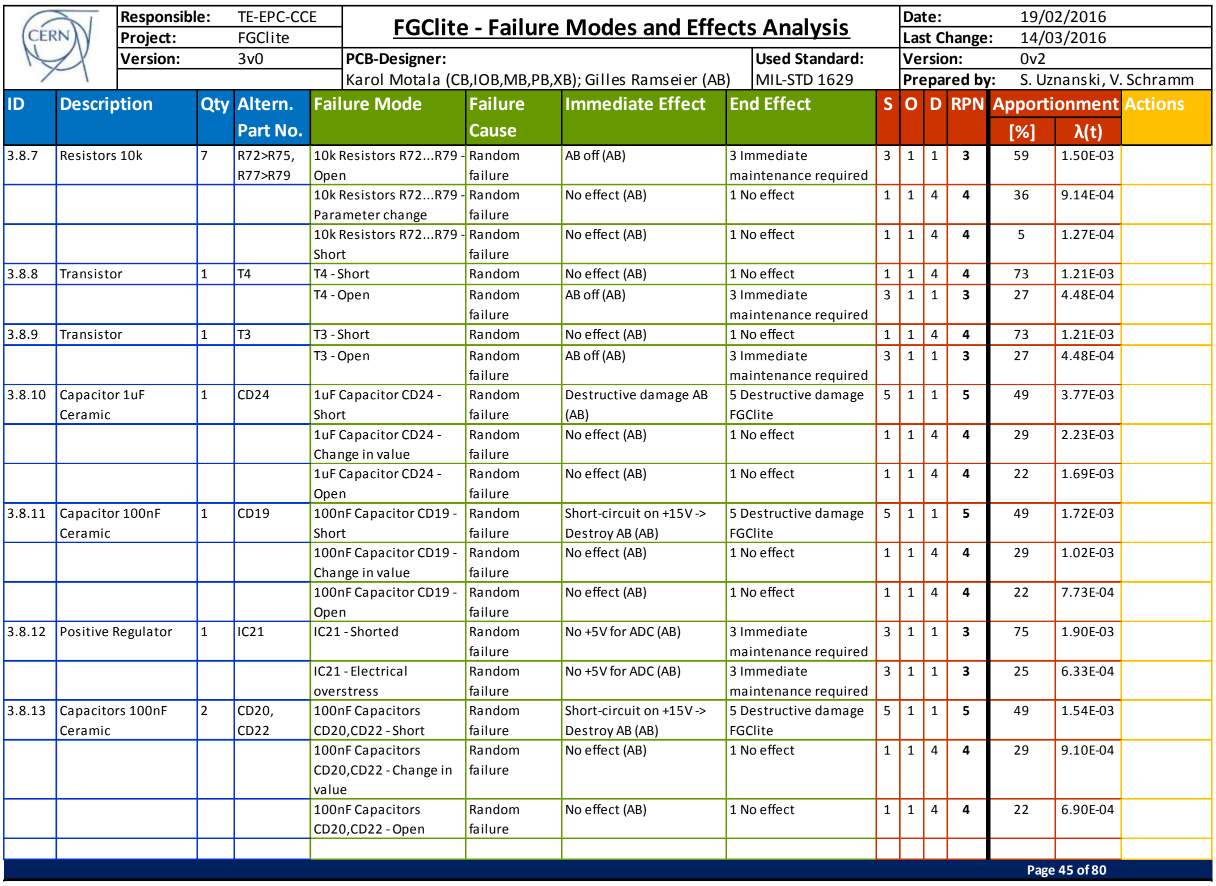

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - Failure Modes and Effects Analysis

PCB-Designer:
Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)
Used Standard:
MIL-STD 1629

Date: 19/02/2016
Last Change: 14/03/2016
Version: 0v2
Prepared by: S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment [%]	$\lambda(t)$	Actions
3.8.7	Resistors 10k	7	R72>R75, R77>R79	10k Resistors R72...R79 - Open	Random failure	AB off (AB)	3 Immediate maintenance required	3	1	1	3	59	1.50E-03	
				10k Resistors R72...R79 - Parameter change	Random failure	No effect (AB)	1 No effect	1	1	4	4	36	9.14E-04	
				10k Resistors R72...R79 - Short	Random failure	No effect (AB)	1 No effect	1	1	4	4	5	1.27E-04	
3.8.8	Transistor	1	T4	T4 - Short	Random	No effect (AB)	1 No effect	1	1	4	4	73	1.21E-03	
				T4 - Open	Random failure	AB off (AB)	3 Immediate maintenance required	3	1	1	3	27	4.48E-04	
3.8.9	Transistor	1	T3	T3 - Short	Random	No effect (AB)	1 No effect	1	1	4	4	73	1.21E-03	
				T3 - Open	Random failure	AB off (AB)	3 Immediate maintenance required	3	1	1	3	27	4.48E-04	
3.8.10	Capacitor 1uF Ceramic	1	CD24	1uF Capacitor CD24 - Short	Random failure	Destructive damage AB (AB)	5 Destructive damage FGClite	5	1	1	5	49	3.77E-03	
				1uF Capacitor CD24 - Change in value	Random failure	No effect (AB)	1 No effect	1	1	4	4	29	2.23E-03	
				1uF Capacitor CD24 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	4	22	1.69E-03	
3.8.11	Capacitor 100nF Ceramic	1	CD19	100nF Capacitor CD19 - Short	Random failure	Short-circuit on +15V -> Destroy AB (AB)	5 Destructive damage FGClite	5	1	1	5	49	1.72E-03	
				100nF Capacitor CD19 - Change in value	Random failure	No effect (AB)	1 No effect	1	1	4	4	29	1.02E-03	
				100nF Capacitor CD19 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	4	22	7.73E-04	
3.8.12	Positive Regulator	1	IC21	IC21 - Shorted	Random failure	No +5V for ADC (AB)	3 Immediate maintenance required	3	1	1	3	75	1.90E-03	
				IC21 - Electrical overstress	Random failure	No +5V for ADC (AB)	3 Immediate maintenance required	3	1	1	3	25	6.33E-04	
3.8.13	Capacitors 100nF Ceramic	2	CD20, CD22	100nF Capacitors CD20,CD22 - Short	Random failure	Short-circuit on +15V -> Destroy AB (AB)	5 Destructive damage FGClite	5	1	1	5	49	1.54E-03	
				100nF Capacitors CD20,CD22 - Change in value	Random failure	No effect (AB)	1 No effect	1	1	4	4	29	9.10E-04	
				100nF Capacitors CD20,CD22 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	4	22	6.90E-04	

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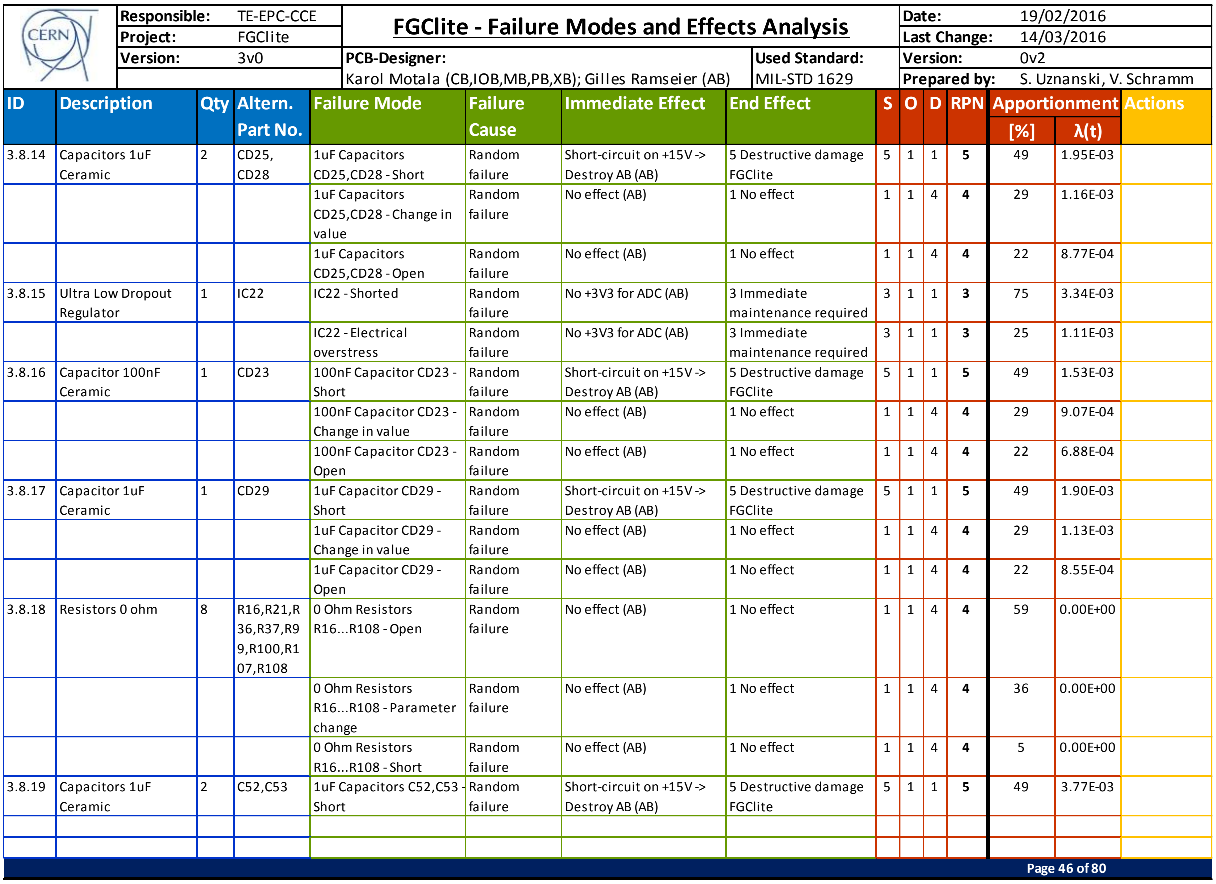

Responsible: TE-EPC-CCE	**FGClite - Failure Modes and Effects Analysis**		**Date:**	19/02/2016
Project: FGClite			**Last Change:**	14/03/2016
Version: 3v0	**PCB-Designer:**	**Used Standard:**	**Version:**	0v2
	Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)	MIL-STD 1629	**Prepared by:**	S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment		Actions
												[%]	λ(t)	
3.8.14	Capacitors 1uF Ceramic	2	CD25, CD28	1uF Capacitors CD25,CD28 - Short	Random failure	Short-circuit on +15V -> Destroy AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	49	1.95E-03	
				1uF Capacitors CD25,CD28 - Change in value	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	29	1.16E-03	
				1uF Capacitors CD25,CD28 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	22	8.77E-04	
3.8.15	Ultra Low Dropout Regulator	1	IC22	IC22 - Shorted	Random failure	No +3V3 for ADC (AB)	3 Immediate maintenance required	3	1	1	**3**	75	3.34E-03	
				IC22 - Electrical overstress	Random failure	No +3V3 for ADC (AB)	3 Immediate maintenance required	3	1	1	**3**	25	1.11E-03	
3.8.16	Capacitor 100nF Ceramic	1	CD23	100nF Capacitor CD23 - Short	Random failure	Short-circuit on +15V -> Destroy AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	49	1.53E-03	
				100nF Capacitor CD23 - Change in value	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	29	9.07E-04	
				100nF Capacitor CD23 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	22	6.88E-04	
3.8.17	Capacitor 1uF Ceramic	1	CD29	1uF Capacitor CD29 - Short	Random failure	Short-circuit on +15V -> Destroy AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	49	1.90E-03	
				1uF Capacitor CD29 - Change in value	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	29	1.13E-03	
				1uF Capacitor CD29 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	22	8.55E-04	
3.8.18	Resistors 0 ohm	8	R16,R21,R36,R37,R99,R100,R107,R108	0 Ohm Resistors R16...R108 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	59	0.00E+00	
				0 Ohm Resistors R16...R108 - Parameter change	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	36	0.00E+00	
				0 Ohm Resistors R16...R108 - Short	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	5	0.00E+00	
3.8.19	Capacitors 1uF Ceramic	2	C52,C53	1uF Capacitors C52,C53 - Short	Random failure	Short-circuit on +15V -> Destroy AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	49	3.77E-03	

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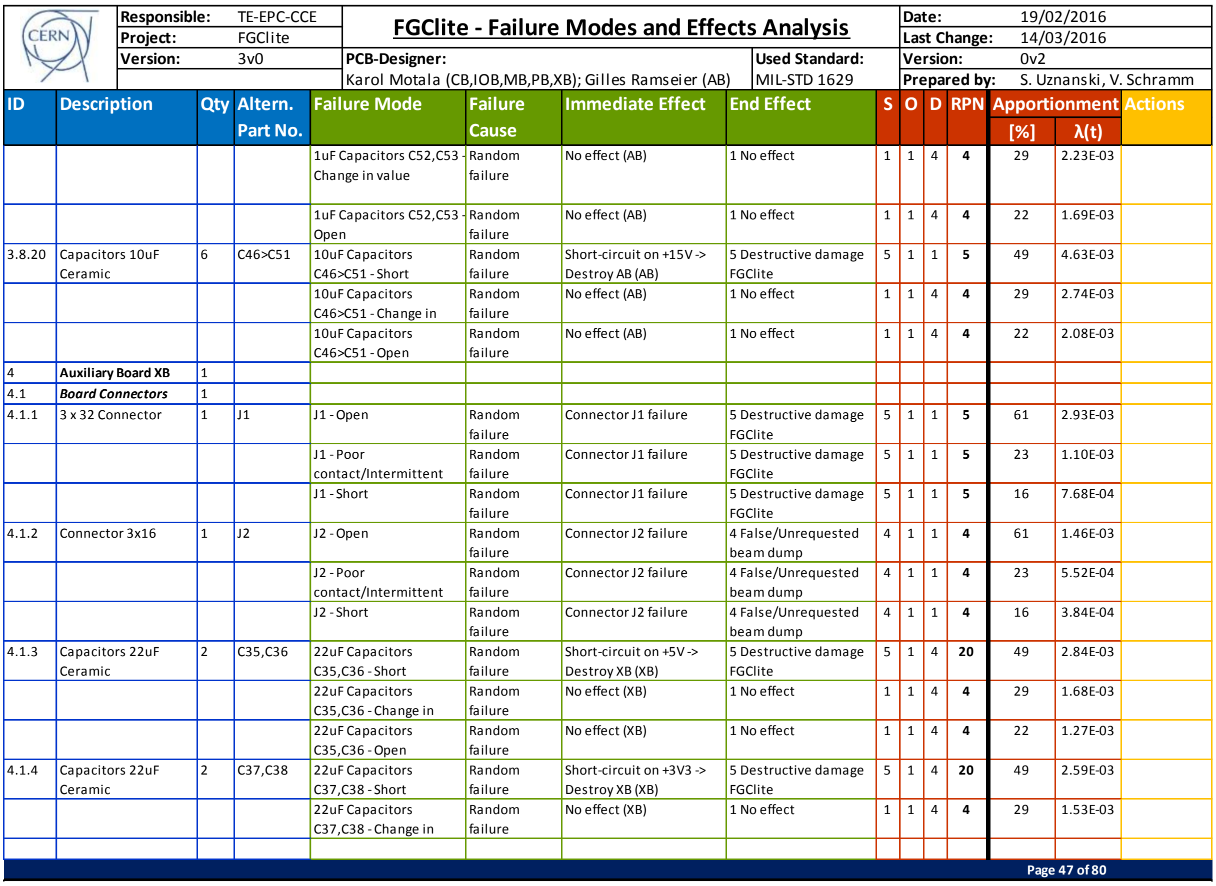

Responsible: TE-EPC-CCE	**FGClite - Failure Modes and Effects Analysis**		**Date:**	19/02/2016
Project: FGClite			**Last Change:**	14/03/2016
Version: 3v0	**PCB-Designer:**	**Used Standard:**	**Version:**	0v2
	Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)	MIL-STD 1629	**Prepared by:**	S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment		Actions
												[%]	λ(t)	
				1uF Capacitors C52,C53 - Change in value	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	29	2.23E-03	
				1uF Capacitors C52,C53 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	22	1.69E-03	
3.8.20	Capacitors 10uF Ceramic	6	C46>C51	10uF Capacitors C46>C51 - Short	Random failure	Short-circuit on +15V -> Destroy AB (AB)	5 Destructive damage FGClite	5	1	1	**5**	49	4.63E-03	
				10uF Capacitors C46>C51 - Change in	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	29	2.74E-03	
				10uF Capacitors C46>C51 - Open	Random failure	No effect (AB)	1 No effect	1	1	4	**4**	22	2.08E-03	
4	**Auxiliary Board XB**	1												
4.1	***Board Connectors***	1												
4.1.1	3 x 32 Connector	1	J1	J1 - Open	Random failure	Connector J1 failure	5 Destructive damage FGClite	5	1	1	**5**	61	2.93E-03	
				J1 - Poor contact/Intermittent	Random failure	Connector J1 failure	5 Destructive damage FGClite	5	1	1	**5**	23	1.10E-03	
				J1 - Short	Random failure	Connector J1 failure	5 Destructive damage FGClite	5	1	1	**5**	16	7.68E-04	
4.1.2	Connector 3x16	1	J2	J2 - Open	Random failure	Connector J2 failure	4 False/Unrequested beam dump	4	1	1	**4**	61	1.46E-03	
				J2 - Poor contact/Intermittent	Random failure	Connector J2 failure	4 False/Unrequested beam dump	4	1	1	**4**	23	5.52E-04	
				J2 - Short	Random failure	Connector J2 failure	4 False/Unrequested beam dump	4	1	1	**4**	16	3.84E-04	
4.1.3	Capacitors 22uF Ceramic	2	C35,C36	22uF Capacitors C35,C36 - Short	Random failure	Short-circuit on +5V -> Destroy XB (XB)	5 Destructive damage FGClite	5	1	4	**20**	49	2.84E-03	
				22uF Capacitors C35,C36 - Change in	Random failure	No effect (XB)	1 No effect	1	1	4	**4**	29	1.68E-03	
				22uF Capacitors C35,C36 - Open	Random failure	No effect (XB)	1 No effect	1	1	4	**4**	22	1.27E-03	
4.1.4	Capacitors 22uF Ceramic	2	C37,C38	22uF Capacitors C37,C38 - Short	Random failure	Short-circuit on +3V3 -> Destroy XB (XB)	5 Destructive damage FGClite	5	1	4	**20**	49	2.59E-03	
				22uF Capacitors C37,C38 - Change in	Random failure	No effect (XB)	1 No effect	1	1	4	**4**	29	1.53E-03	

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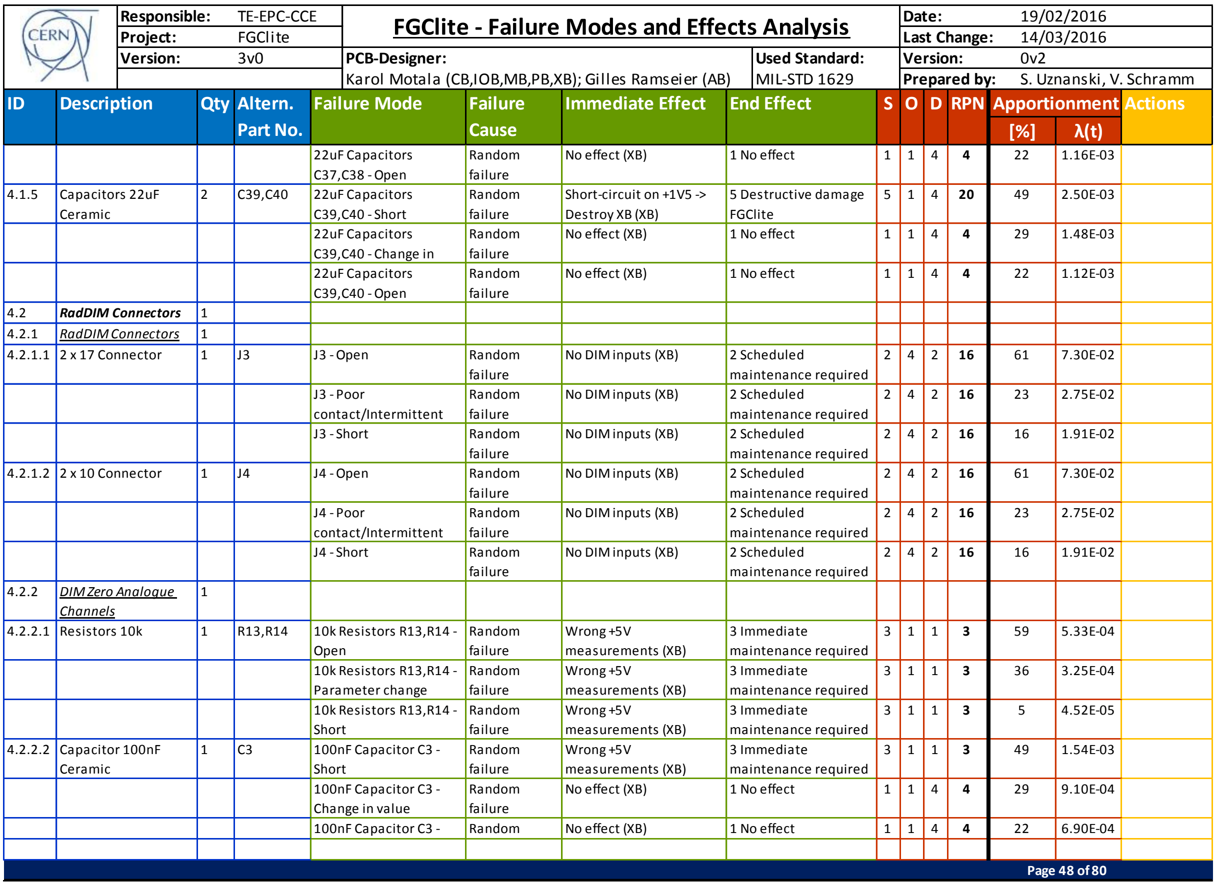

Responsible:	TE-EPC-CCE	**FGClite - Failure Modes and Effects Analysis**	**Date:** 19/02/2016
Project:	FGClite		**Last Change:** 14/03/2016
Version:	3v0	**PCB-Designer:**	**Used Standard:**
		Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)	MIL-STD 1629

Version: 0v2
Prepared by: S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment		Actions
												[%]	λ(t)	
				22uF Capacitors C37,C38 - Open	Random failure	No effect (XB)	1 No effect	1	1	4	**4**	22	1.16E-03	
4.1.5	Capacitors 22uF Ceramic	2	C39,C40	22uF Capacitors C39,C40 - Short	Random failure	Short-circuit on +1V5 -> Destroy XB (XB)	5 Destructive damage FGClite	5	1	4	**20**	49	2.50E-03	
				22uF Capacitors C39,C40 - Change in	Random failure	No effect (XB)	1 No effect	1	1	4	**4**	29	1.48E-03	
				22uF Capacitors C39,C40 - Open	Random failure	No effect (XB)	1 No effect	1	1	4	**4**	22	1.12E-03	
4.2	***RadDIM Connectors***	1												
4.2.1	*RadDIM Connectors*	1												
4.2.1.1	2 x 17 Connector	1	J3	J3 - Open	Random failure	No DIM inputs (XB)	2 Scheduled maintenance required	2	4	2	**16**	61	7.30E-02	
				J3 - Poor contact/Intermittent	Random failure	No DIM inputs (XB)	2 Scheduled maintenance required	2	4	2	**16**	23	2.75E-02	
				J3 - Short	Random failure	No DIM inputs (XB)	2 Scheduled maintenance required	2	4	2	**16**	16	1.91E-02	
4.2.1.2	2 x 10 Connector	1	J4	J4 - Open	Random failure	No DIM inputs (XB)	2 Scheduled maintenance required	2	4	2	**16**	61	7.30E-02	
				J4 - Poor contact/Intermittent	Random failure	No DIM inputs (XB)	2 Scheduled maintenance required	2	4	2	**16**	23	2.75E-02	
				J4 - Short	Random failure	No DIM inputs (XB)	2 Scheduled maintenance required	2	4	2	**16**	16	1.91E-02	
4.2.2	*DIM Zero Analogue Channels*	1												
4.2.2.1	Resistors 10k	1	R13,R14	10k Resistors R13,R14 - Open	Random failure	Wrong +5V measurements (XB)	3 Immediate maintenance required	3	1	1	**3**	59	5.33E-04	
				10k Resistors R13,R14 - Parameter change	Random failure	Wrong +5V measurements (XB)	3 Immediate maintenance required	3	1	1	**3**	36	3.25E-04	
				10k Resistors R13,R14 - Short	Random failure	Wrong +5V measurements (XB)	3 Immediate maintenance required	3	1	1	**3**	5	4.52E-05	
4.2.2.2	Capacitor 100nF Ceramic	1	C3	100nF Capacitor C3 - Short	Random failure	Wrong +5V measurements (XB)	3 Immediate maintenance required	3	1	1	**3**	49	1.54E-03	
				100nF Capacitor C3 - Change in value	Random failure	No effect (XB)	1 No effect	1	1	4	**4**	29	9.10E-04	
				100nF Capacitor C3 -	Random	No effect (XB)	1 No effect	1	1	4	**4**	22	6.90E-04	

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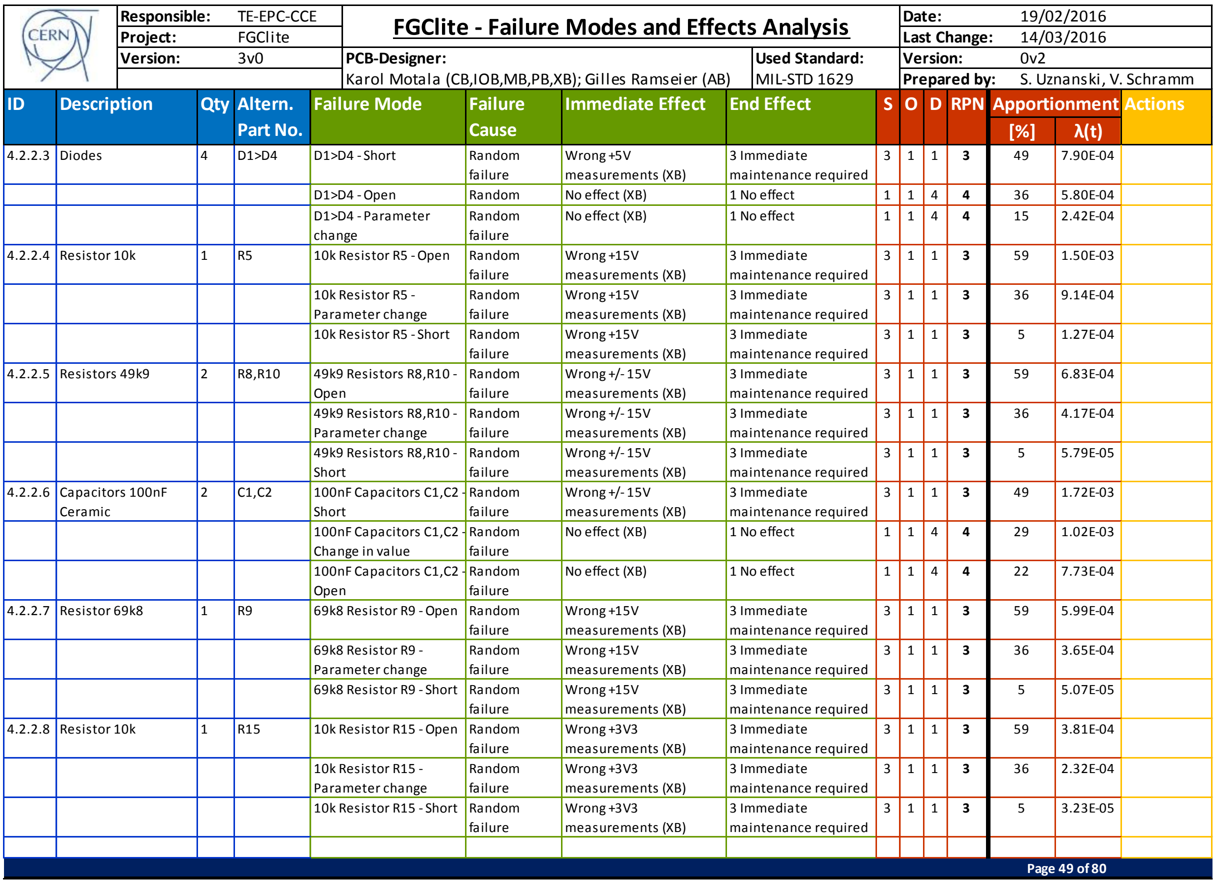

Responsible:	TE-EPC-CCE	**FGClite - Failure Modes and Effects Analysis**	**Date:** 19/02/2016
Project:	FGClite		**Last Change:** 14/03/2016
Version:	3v0	**PCB-Designer:**	**Used Standard:**
		Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)	MIL-STD 1629

Version: 0v2
Prepared by: S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment		Actions
												[%]	λ(t)	
4.2.2.3	Diodes	4	D1>D4	D1>D4 - Short	Random failure	Wrong +5V measurements (XB)	3 Immediate maintenance required	3	1	1	**3**	49	7.90E-04	
				D1>D4 - Open	Random	No effect (XB)	1 No effect	1	1	4	**4**	36	5.80E-04	
				D1>D4 - Parameter change	Random failure	No effect (XB)	1 No effect	1	1	4	**4**	15	2.42E-04	
4.2.2.4	Resistor 10k	1	R5	10k Resistor R5 - Open	Random failure	Wrong +15V measurements (XB)	3 Immediate maintenance required	3	1	1	**3**	59	1.50E-03	
				10k Resistor R5 - Parameter change	Random failure	Wrong +15V measurements (XB)	3 Immediate maintenance required	3	1	1	**3**	36	9.14E-04	
				10k Resistor R5 - Short	Random failure	Wrong +15V measurements (XB)	3 Immediate maintenance required	3	1	1	**3**	5	1.27E-04	
4.2.2.5	Resistors 49k9	2	R8,R10	49k9 Resistors R8,R10 - Open	Random failure	Wrong +/- 15V measurements (XB)	3 Immediate maintenance required	3	1	1	**3**	59	6.83E-04	
				49k9 Resistors R8,R10 - Parameter change	Random failure	Wrong +/- 15V measurements (XB)	3 Immediate maintenance required	3	1	1	**3**	36	4.17E-04	
				49k9 Resistors R8,R10 - Short	Random failure	Wrong +/- 15V measurements (XB)	3 Immediate maintenance required	3	1	1	**3**	5	5.79E-05	
4.2.2.6	Capacitors 100nF Ceramic	2	C1,C2	100nF Capacitors C1,C2 - Short	Random failure	Wrong +/- 15V measurements (XB)	3 Immediate maintenance required	3	1	1	**3**	49	1.72E-03	
				100nF Capacitors C1,C2 - Change in value	Random failure	No effect (XB)	1 No effect	1	1	4	**4**	29	1.02E-03	
				100nF Capacitors C1,C2 - Open	Random failure	No effect (XB)	1 No effect	1	1	4	**4**	22	7.73E-04	
4.2.2.7	Resistor 69k8	1	R9	69k8 Resistor R9 - Open	Random failure	Wrong +15V measurements (XB)	3 Immediate maintenance required	3	1	1	**3**	59	5.99E-04	
				69k8 Resistor R9 - Parameter change	Random failure	Wrong +15V measurements (XB)	3 Immediate maintenance required	3	1	1	**3**	36	3.65E-04	
				69k8 Resistor R9 - Short	Random failure	Wrong +15V measurements (XB)	3 Immediate maintenance required	3	1	1	**3**	5	5.07E-05	
4.2.2.8	Resistor 10k	1	R15	10k Resistor R15 - Open	Random failure	Wrong +3V3 measurements (XB)	3 Immediate maintenance required	3	1	1	**3**	59	3.81E-04	
				10k Resistor R15 - Parameter change	Random failure	Wrong +3V3 measurements (XB)	3 Immediate maintenance required	3	1	1	**3**	36	2.32E-04	
				10k Resistor R15 - Short	Random failure	Wrong +3V3 measurements (XB)	3 Immediate maintenance required	3	1	1	**3**	5	3.23E-05	

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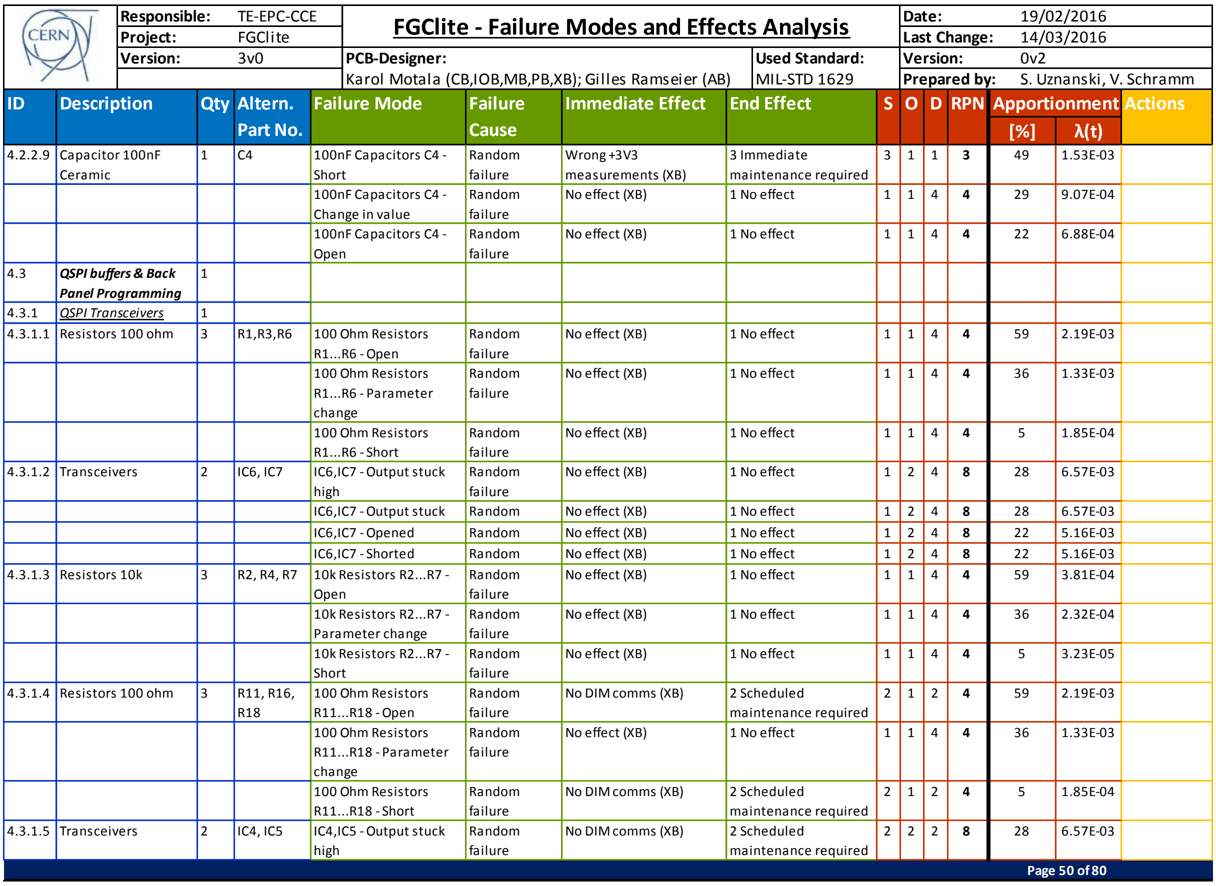

Responsible: TE-EPC-CCE	**FGClite - Failure Modes and Effects Analysis**		**Date:** 19/02/2016
Project: FGClite			**Last Change:** 14/03/2016
Version: 3v0	**PCB-Designer:**	**Used Standard:**	**Version:** 0v2
	Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)	MIL-STD 1629	**Prepared by:** S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment [%]	λ(t)	Actions
4.2.2.9	Capacitor 100nF Ceramic	1	C4	100nF Capacitors C4 - Short	Random failure	Wrong +3V3 measurements (XB)	3 Immediate maintenance required	3	1	1	**3**	49	1.53E-03	
				100nF Capacitors C4 - Change in value	Random failure	No effect (XB)	1 No effect	1	1	4	**4**	29	9.07E-04	
				100nF Capacitors C4 - Open	Random failure	No effect (XB)	1 No effect	1	1	4	**4**	22	6.88E-04	
4.3	***QSPI buffers & Back Panel Programming***	1												
4.3.1	*QSPI Transceivers*	1												
4.3.1.1	Resistors 100 ohm	3	R1,R3,R6	100 Ohm Resistors R1...R6 - Open	Random failure	No effect (XB)	1 No effect	1	1	4	**4**	59	2.19E-03	
				100 Ohm Resistors R1...R6 - Parameter change	Random failure	No effect (XB)	1 No effect	1	1	4	**4**	36	1.33E-03	
				100 Ohm Resistors R1...R6 - Short	Random failure	No effect (XB)	1 No effect	1	1	4	**4**	5	1.85E-04	
4.3.1.2	Transceivers	2	IC6, IC7	IC6,IC7 - Output stuck high	Random failure	No effect (XB)	1 No effect	1	2	4	**8**	28	6.57E-03	
				IC6,IC7 - Output stuck	Random	No effect (XB)	1 No effect	1	2	4	**8**	28	6.57E-03	
				IC6,IC7 - Opened	Random	No effect (XB)	1 No effect	1	2	4	**8**	22	5.16E-03	
				IC6,IC7 - Shorted	Random	No effect (XB)	1 No effect	1	2	4	**8**	22	5.16E-03	
4.3.1.3	Resistors 10k	3	R2, R4, R7	10k Resistors R2...R7 - Open	Random failure	No effect (XB)	1 No effect	1	1	4	**4**	59	3.81E-04	
				10k Resistors R2...R7 - Parameter change	Random failure	No effect (XB)	1 No effect	1	1	4	**4**	36	2.32E-04	
				10k Resistors R2...R7 - Short	Random failure	No effect (XB)	1 No effect	1	1	4	**4**	5	3.23E-05	
4.3.1.4	Resistors 100 ohm	3	R11, R16, R18	100 Ohm Resistors R11...R18 - Open	Random failure	No DIM comms (XB)	2 Scheduled maintenance required	2	1	2	**4**	59	2.19E-03	
				100 Ohm Resistors R11...R18 - Parameter change	Random failure	No effect (XB)	1 No effect	1	1	4	**4**	36	1.33E-03	
				100 Ohm Resistors R11...R18 - Short	Random failure	No DIM comms (XB)	2 Scheduled maintenance required	2	1	2	**4**	5	1.85E-04	
4.3.1.5	Transceivers	2	IC4, IC5	IC4,IC5 - Output stuck high	Random failure	No DIM comms (XB)	2 Scheduled maintenance required	2	2	2	**8**	28	6.57E-03	

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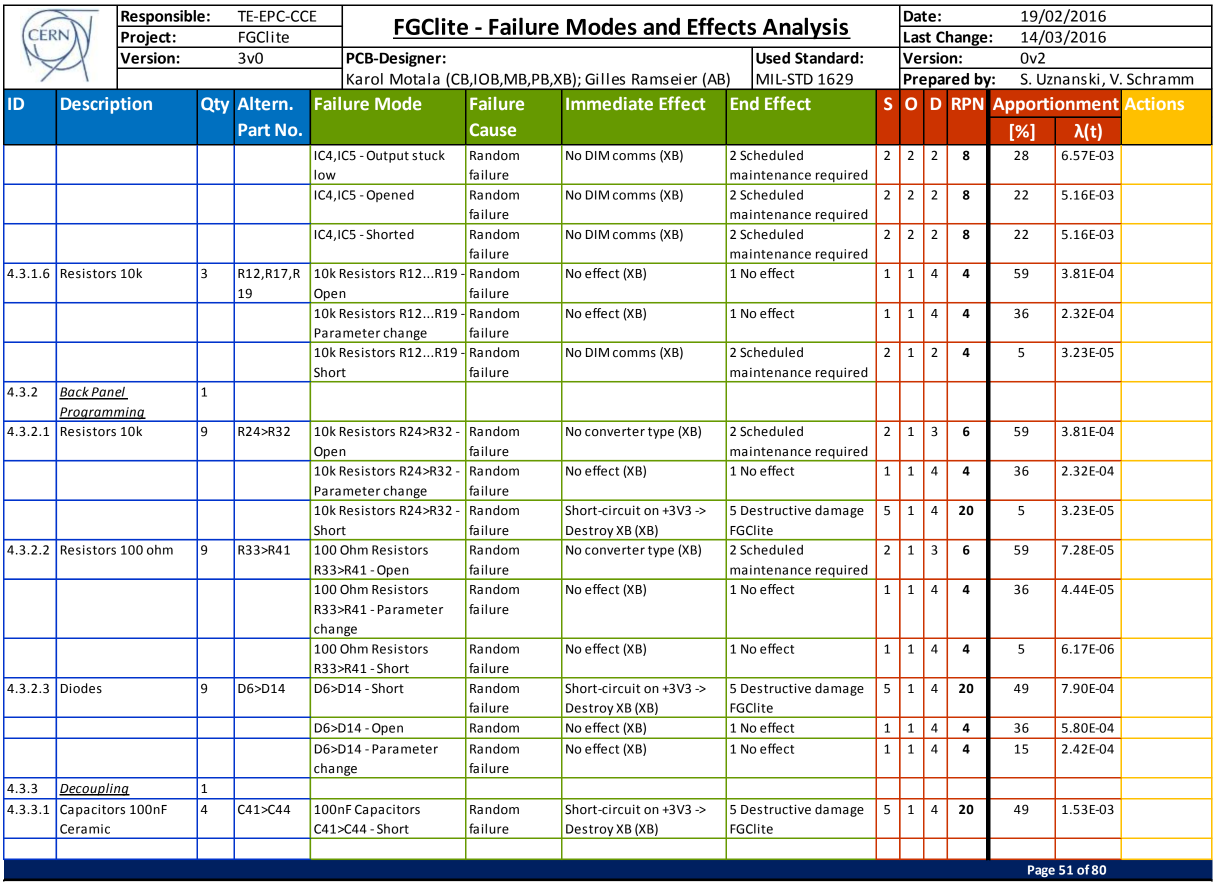

Responsible: TE-EPC-CCE	**FGClite - Failure Modes and Effects Analysis**		**Date:** 19/02/2016
Project: FGClite			**Last Change:** 14/03/2016
Version: 3v0	**PCB-Designer:**	**Used Standard:**	**Version:** 0v2
	Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)	MIL-STD 1629	**Prepared by:** S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment [%]	λ(t)	Actions
				IC4,IC5 - Output stuck low	Random failure	No DIM comms (XB)	2 Scheduled maintenance required	2	2	2	**8**	28	6.57E-03	
				IC4,IC5 - Opened	Random failure	No DIM comms (XB)	2 Scheduled maintenance required	2	2	2	**8**	22	5.16E-03	
				IC4,IC5 - Shorted	Random failure	No DIM comms (XB)	2 Scheduled maintenance required	2	2	2	**8**	22	5.16E-03	
4.3.1.6	Resistors 10k	3	R12,R17,R19	10k Resistors R12...R19 - Open	Random failure	No effect (XB)	1 No effect	1	1	4	**4**	59	3.81E-04	
				10k Resistors R12...R19 - Parameter change	Random failure	No effect (XB)	1 No effect	1	1	4	**4**	36	2.32E-04	
				10k Resistors R12...R19 - Short	Random failure	No DIM comms (XB)	2 Scheduled maintenance required	2	1	2	**4**	5	3.23E-05	
4.3.2	*Back Panel Programming*	1												
4.3.2.1	Resistors 10k	9	R24>R32	10k Resistors R24>R32 - Open	Random failure	No converter type (XB)	2 Scheduled maintenance required	2	1	3	**6**	59	3.81E-04	
				10k Resistors R24>R32 - Parameter change	Random failure	No effect (XB)	1 No effect	1	1	4	**4**	36	2.32E-04	
				10k Resistors R24>R32 - Short	Random failure	Short-circuit on +3V3 -> Destroy XB (XB)	5 Destructive damage FGClite	5	1	4	**20**	5	3.23E-05	
4.3.2.2	Resistors 100 ohm	9	R33>R41	100 Ohm Resistors R33>R41 - Open	Random failure	No converter type (XB)	2 Scheduled maintenance required	2	1	3	**6**	59	7.28E-05	
				100 Ohm Resistors R33>R41 - Parameter change	Random failure	No effect (XB)	1 No effect	1	1	4	**4**	36	4.44E-05	
				100 Ohm Resistors R33>R41 - Short	Random failure	No effect (XB)	1 No effect	1	1	4	**4**	5	6.17E-06	
4.3.2.3	Diodes	9	D6>D14	D6>D14 - Short	Random failure	Short-circuit on +3V3 -> Destroy XB (XB)	5 Destructive damage FGClite	5	1	4	**20**	49	7.90E-04	
				D6>D14 - Open	Random	No effect (XB)	1 No effect	1	1	4	**4**	36	5.80E-04	
				D6>D14 - Parameter change	Random failure	No effect (XB)	1 No effect	1	1	4	**4**	15	2.42E-04	
4.3.3	*Decoupling*	1												
4.3.3.1	Capacitors 100nF Ceramic	4	C41>C44	100nF Capacitors C41>C44 - Short	Random failure	Short-circuit on +3V3 -> Destroy XB (XB)	5 Destructive damage FGClite	5	1	4	**20**	49	1.53E-03	

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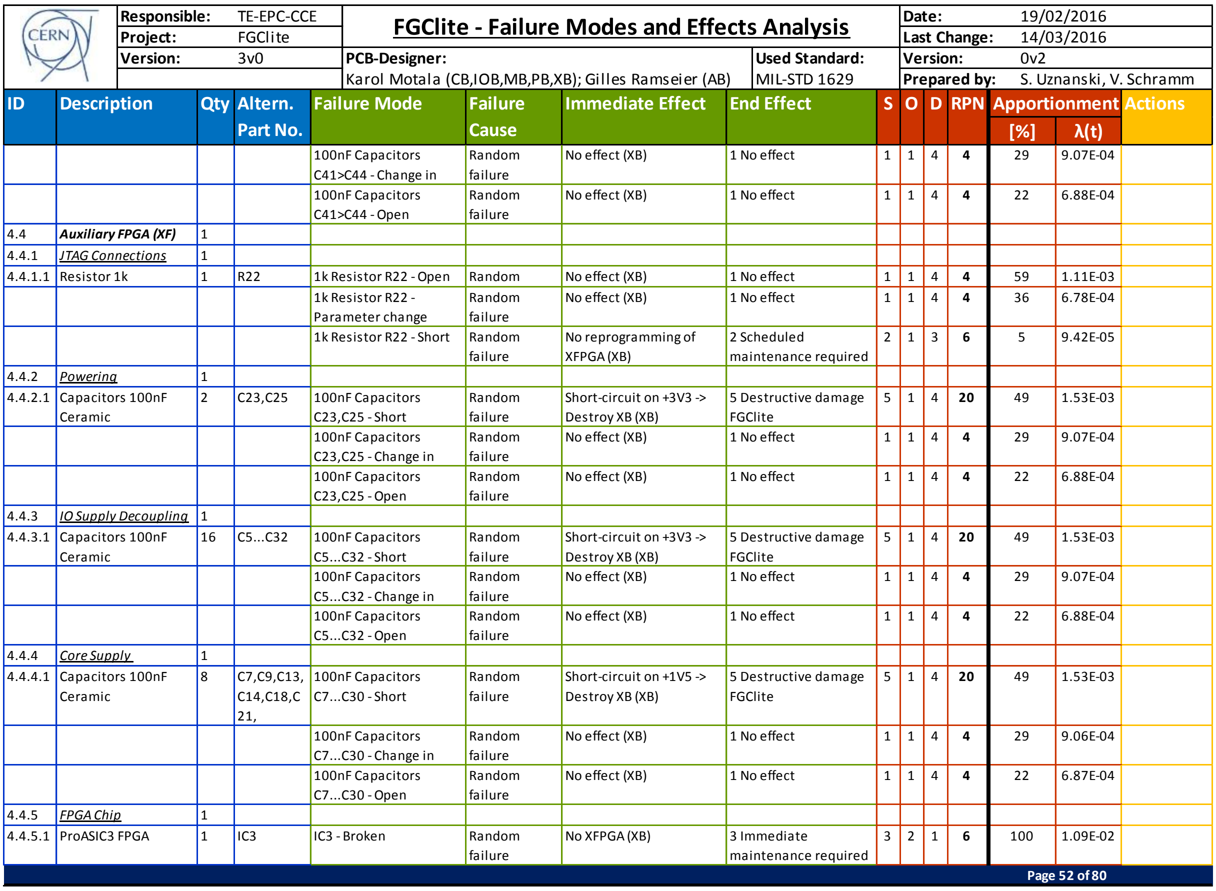

CERN	**Responsible:** TE-EPC-CCE **Project:** FGClite **Version:** 3v0	**FGClite - Failure Modes and Effects Analysis**		**Date:** 19/02/2016 **Last Change:** 14/03/2016
		PCB-Designer: Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)	**Used Standard:** MIL-STD 1629	**Version:** 0v2 **Prepared by:** S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment		Actions
												[%]	λ(t)	
				100nF Capacitors C41>C44 - Change in	Random failure	No effect (XB)	1 No effect	1	1	4	**4**	29	9.07E-04	
				100nF Capacitors C41>C44 - Open	Random failure	No effect (XB)	1 No effect	1	1	4	**4**	22	6.88E-04	
4.4	***Auxiliary FPGA (XF)***	1												
4.4.1	*JTAG Connections*	1												
4.4.1.1	Resistor 1k	1	R22	1k Resistor R22 - Open	Random	No effect (XB)	1 No effect	1	1	4	**4**	59	1.11E-03	
				1k Resistor R22 - Parameter change	Random failure	No effect (XB)	1 No effect	1	1	4	**4**	36	6.78E-04	
				1k Resistor R22 - Short	Random failure	No reprogramming of XFPGA (XB)	2 Scheduled maintenance required	2	1	3	**6**	5	9.42E-05	
4.4.2	*Powering*	1												
4.4.2.1	Capacitors 100nF Ceramic	2	C23,C25	100nF Capacitors C23,C25 - Short	Random failure	Short-circuit on +3V3 -> Destroy XB (XB)	5 Destructive damage FGClite	5	1	4	**20**	49	1.53E-03	
				100nF Capacitors C23,C25 - Change in	Random failure	No effect (XB)	1 No effect	1	1	4	**4**	29	9.07E-04	
				100nF Capacitors C23,C25 - Open	Random failure	No effect (XB)	1 No effect	1	1	4	**4**	22	6.88E-04	
4.4.3	*IO Supply Decoupling*	1												
4.4.3.1	Capacitors 100nF Ceramic	16	C5...C32	100nF Capacitors C5...C32 - Short	Random failure	Short-circuit on +3V3 -> Destroy XB (XB)	5 Destructive damage FGClite	5	1	4	**20**	49	1.53E-03	
				100nF Capacitors C5...C32 - Change in	Random failure	No effect (XB)	1 No effect	1	1	4	**4**	29	9.07E-04	
				100nF Capacitors C5...C32 - Open	Random failure	No effect (XB)	1 No effect	1	1	4	**4**	22	6.88E-04	
4.4.4	*Core Supply*	1												
4.4.4.1	Capacitors 100nF Ceramic	8	C7,C9,C13, C14,C18,C 21,	100nF Capacitors C7...C30 - Short	Random failure	Short-circuit on +1V5 -> Destroy XB (XB)	5 Destructive damage FGClite	5	1	4	**20**	49	1.53E-03	
				100nF Capacitors C7...C30 - Change in	Random failure	No effect (XB)	1 No effect	1	1	4	**4**	29	9.06E-04	
				100nF Capacitors C7...C30 - Open	Random failure	No effect (XB)	1 No effect	1	1	4	**4**	22	6.87E-04	
4.4.5	*FPGA Chip*	1												
4.4.5.1	ProASIC3 FPGA	1	IC3	IC3 - Broken	Random failure	No XFPGA (XB)	3 Immediate maintenance required	3	2	1	**6**	100	1.09E-02	

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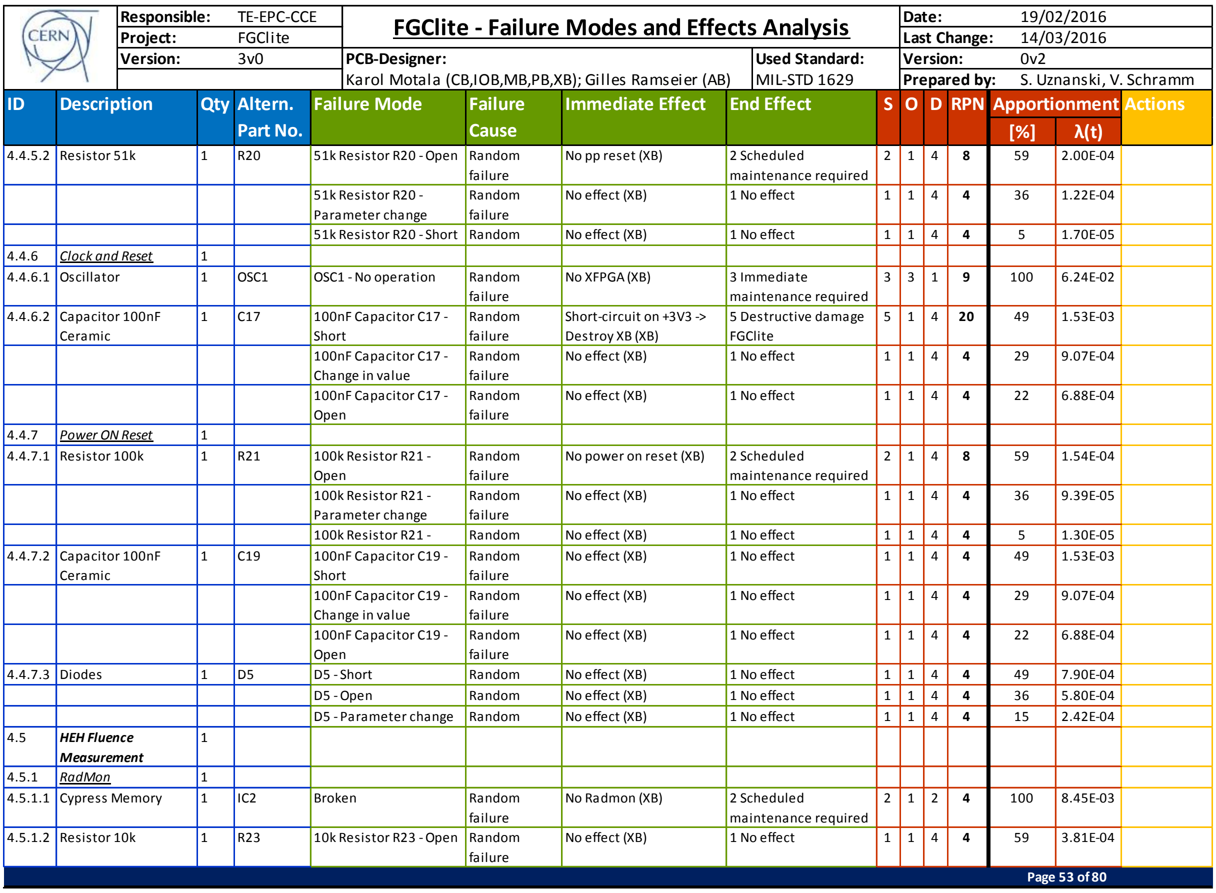

CERN	**Responsible:** TE-EPC-CCE **Project:** FGClite **Version:** 3v0	**FGClite - Failure Modes and Effects Analysis**		**Date:** 19/02/2016 **Last Change:** 14/03/2016
		PCB-Designer: Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)	**Used Standard:** MIL-STD 1629	**Version:** 0v2 **Prepared by:** S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment		Actions
												[%]	λ(t)	
4.4.5.2	Resistor 51k	1	R20	51k Resistor R20 - Open	Random failure	No pp reset (XB)	2 Scheduled maintenance required	2	1	4	**8**	59	2.00E-04	
				51k Resistor R20 - Parameter change	Random failure	No effect (XB)	1 No effect	1	1	4	**4**	36	1.22E-04	
				51k Resistor R20 - Short	Random	No effect (XB)	1 No effect	1	1	4	**4**	5	1.70E-05	
4.4.6	*Clock and Reset*	1												
4.4.6.1	Oscillator	1	OSC1	OSC1 - No operation	Random failure	No XFPGA (XB)	3 Immediate maintenance required	3	3	1	**9**	100	6.24E-02	
4.4.6.2	Capacitor 100nF Ceramic	1	C17	100nF Capacitor C17 - Short	Random failure	Short-circuit on +3V3 -> Destroy XB (XB)	5 Destructive damage FGClite	5	1	4	**20**	49	1.53E-03	
				100nF Capacitor C17 - Change in value	Random failure	No effect (XB)	1 No effect	1	1	4	**4**	29	9.07E-04	
				100nF Capacitor C17 - Open	Random failure	No effect (XB)	1 No effect	1	1	4	**4**	22	6.88E-04	
4.4.7	*Power ON Reset*	1												
4.4.7.1	Resistor 100k	1	R21	100k Resistor R21 - Open	Random failure	No power on reset (XB)	2 Scheduled maintenance required	2	1	4	**8**	59	1.54E-04	
				100k Resistor R21 - Parameter change	Random failure	No effect (XB)	1 No effect	1	1	4	**4**	36	9.39E-05	
				100k Resistor R21 -	Random	No effect (XB)	1 No effect	1	1	4	**4**	5	1.30E-05	
4.4.7.2	Capacitor 100nF Ceramic	1	C19	100nF Capacitor C19 - Short	Random failure	No effect (XB)	1 No effect	1	1	4	**4**	49	1.53E-03	
				100nF Capacitor C19 - Change in value	Random failure	No effect (XB)	1 No effect	1	1	4	**4**	29	9.07E-04	
				100nF Capacitor C19 - Open	Random failure	No effect (XB)	1 No effect	1	1	4	**4**	22	6.88E-04	
4.4.7.3	Diodes	1	D5	D5 - Short	Random	No effect (XB)	1 No effect	1	1	4	**4**	49	7.90E-04	
				D5 - Open	Random	No effect (XB)	1 No effect	1	1	4	**4**	36	5.80E-04	
				D5 - Parameter change	Random	No effect (XB)	1 No effect	1	1	4	**4**	15	2.42E-04	
4.5	***HEH Fluence Measurement***	1												
4.5.1	*RadMon*	1												
4.5.1.1	Cypress Memory	1	IC2	Broken	Random failure	No Radmon (XB)	2 Scheduled maintenance required	2	1	2	**4**	100	8.45E-03	
4.5.1.2	Resistor 10k	1	R23	10k Resistor R23 - Open	Random failure	No effect (XB)	1 No effect	1	1	4	**4**	59	3.81E-04	

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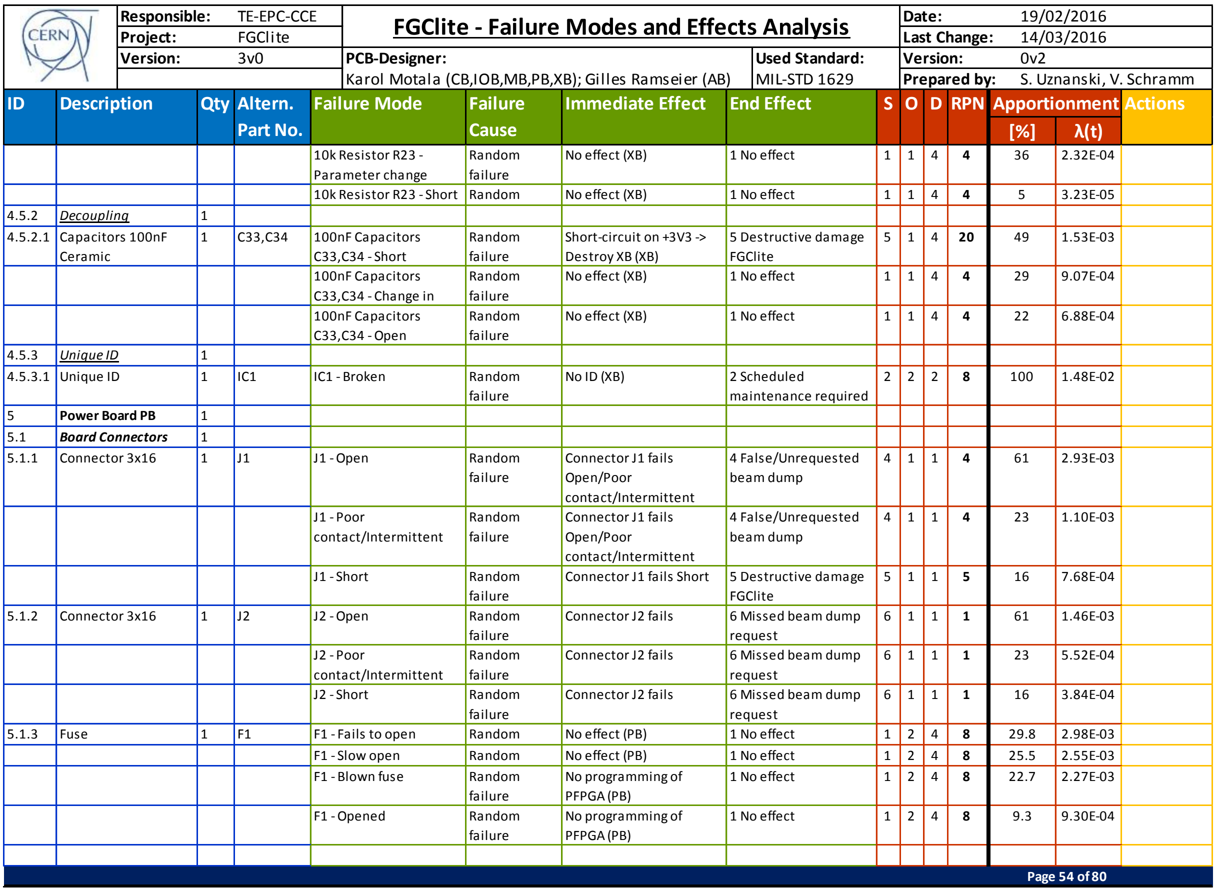

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - Failure Modes and Effects Analysis

PCB-Designer:
Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)
Used Standard:
MIL-STD 1629

Date: 19/02/2016
Last Change: 14/03/2016
Version: 0v2
Prepared by: S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment		Actions
												[%]	λ(t)	
				10k Resistor R23 - Parameter change	Random failure	No effect (XB)	1 No effect	1	1	4	**4**	36	2.32E-04	
				10k Resistor R23 - Short	Random	No effect (XB)	1 No effect	1	1	4	**4**	5	3.23E-05	
4.5.2	*Decoupling*	1												
4.5.2.1	Capacitors 100nF Ceramic	1	C33,C34	100nF Capacitors C33,C34 - Short	Random failure	Short-circuit on +3V3 -> Destroy XB (XB)	5 Destructive damage FGClite	5	1	4	**20**	49	1.53E-03	
				100nF Capacitors C33,C34 - Change in	Random failure	No effect (XB)	1 No effect	1	1	4	**4**	29	9.07E-04	
				100nF Capacitors C33,C34 - Open	Random failure	No effect (XB)	1 No effect	1	1	4	**4**	22	6.88E-04	
4.5.3	*Unique ID*	1												
4.5.3.1	Unique ID	1	IC1	IC1 - Broken	Random failure	No ID (XB)	2 Scheduled maintenance required	2	2	2	**8**	100	1.48E-02	
5	**Power Board PB**	1												
5.1	***Board Connectors***	1												
5.1.1	Connector 3x16	1	J1	J1 - Open	Random failure	Connector J1 fails Open/Poor contact/Intermittent	4 False/Unrequested beam dump	4	1	1	**4**	61	2.93E-03	
				J1 - Poor contact/Intermittent	Random failure	Connector J1 fails Open/Poor contact/Intermittent	4 False/Unrequested beam dump	4	1	1	**4**	23	1.10E-03	
				J1 - Short	Random failure	Connector J1 fails Short	5 Destructive damage FGClite	5	1	1	**5**	16	7.68E-04	
5.1.2	Connector 3x16	1	J2	J2 - Open	Random failure	Connector J2 fails	6 Missed beam dump request	6	1	1	**1**	61	1.46E-03	
				J2 - Poor contact/Intermittent	Random failure	Connector J2 fails	6 Missed beam dump request	6	1	1	**1**	23	5.52E-04	
				J2 - Short	Random failure	Connector J2 fails	6 Missed beam dump request	6	1	1	**1**	16	3.84E-04	
5.1.3	Fuse	1	F1	F1 - Fails to open	Random	No effect (PB)	1 No effect	1	2	4	**8**	29.8	2.98E-03	
				F1 - Slow open	Random	No effect (PB)	1 No effect	1	2	4	**8**	25.5	2.55E-03	
				F1 - Blown fuse	Random failure	No programming of PFPGA (PB)	1 No effect	1	2	4	**8**	22.7	2.27E-03	
				F1 - Opened	Random failure	No programming of PFPGA (PB)	1 No effect	1	2	4	**8**	9.3	9.30E-04	

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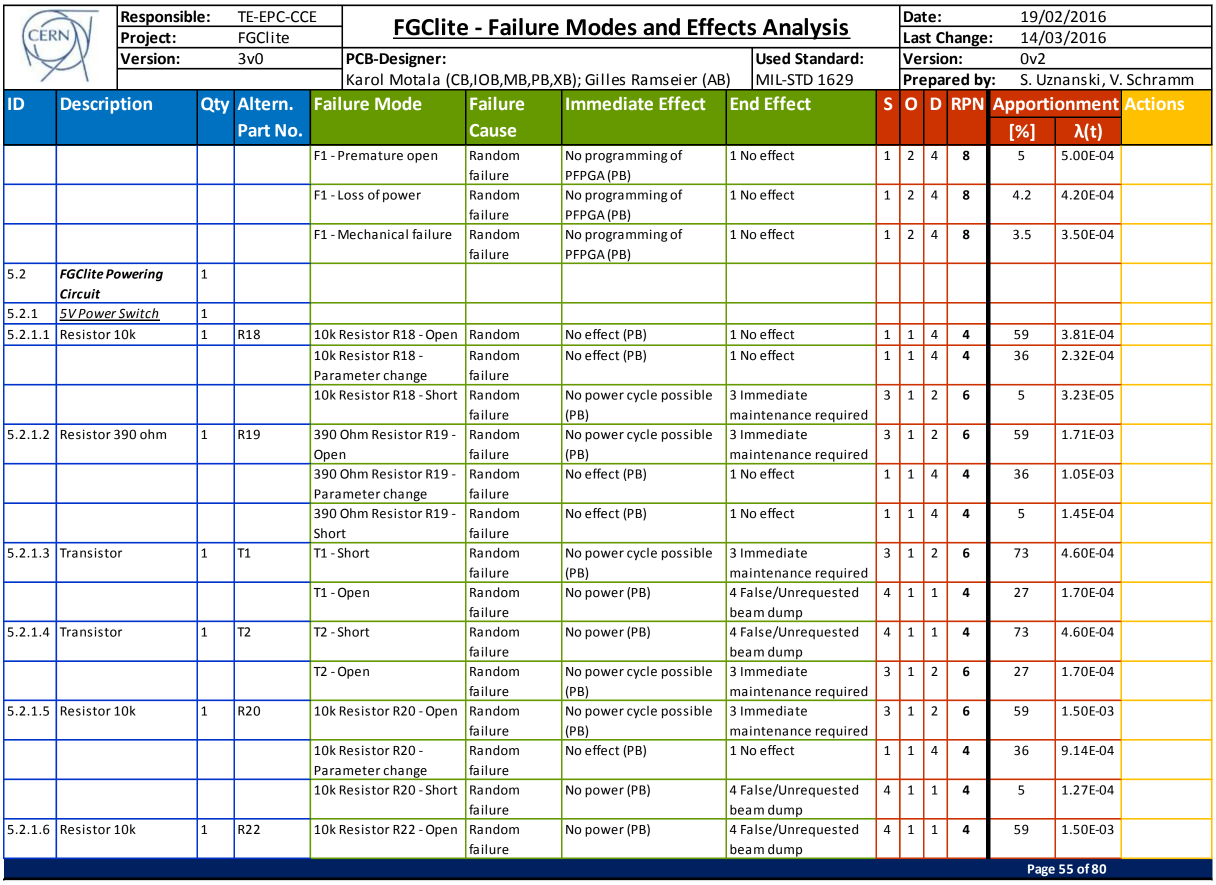

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - Failure Modes and Effects Analysis

PCB-Designer:
Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)
Used Standard:
MIL-STD 1629

Date: 19/02/2016
Last Change: 14/03/2016
Version: 0v2
Prepared by: S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment		Actions
												[%]	λ(t)	
				F1 - Premature open	Random failure	No programming of PFPGA (PB)	1 No effect	1	2	4	**8**	5	5.00E-04	
				F1 - Loss of power	Random failure	No programming of PFPGA (PB)	1 No effect	1	2	4	**8**	4.2	4.20E-04	
				F1 - Mechanical failure	Random failure	No programming of PFPGA (PB)	1 No effect	1	2	4	**8**	3.5	3.50E-04	
5.2	***FGClite Powering Circuit***	1												
5.2.1	*5V Power Switch*	1												
5.2.1.1	Resistor 10k	1	R18	10k Resistor R18 - Open	Random	No effect (PB)	1 No effect	1	1	4	**4**	59	3.81E-04	
				10k Resistor R18 - Parameter change	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	36	2.32E-04	
				10k Resistor R18 - Short	Random failure	No power cycle possible (PB)	3 Immediate maintenance required	3	1	2	**6**	5	3.23E-05	
5.2.1.2	Resistor 390 ohm	1	R19	390 Ohm Resistor R19 - Open	Random failure	No power cycle possible (PB)	3 Immediate maintenance required	3	1	2	**6**	59	1.71E-03	
				390 Ohm Resistor R19 - Parameter change	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	36	1.05E-03	
				390 Ohm Resistor R19 - Short	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	5	1.45E-04	
5.2.1.3	Transistor	1	T1	T1 - Short	Random failure	No power cycle possible (PB)	3 Immediate maintenance required	3	1	2	**6**	73	4.60E-04	
				T1 - Open	Random failure	No power (PB)	4 False/Unrequested beam dump	4	1	1	**4**	27	1.70E-04	
5.2.1.4	Transistor	1	T2	T2 - Short	Random failure	No power (PB)	4 False/Unrequested beam dump	4	1	1	**4**	73	4.60E-04	
				T2 - Open	Random failure	No power cycle possible (PB)	3 Immediate maintenance required	3	1	2	**6**	27	1.70E-04	
5.2.1.5	Resistor 10k	1	R20	10k Resistor R20 - Open	Random failure	No power cycle possible (PB)	3 Immediate maintenance required	3	1	2	**6**	59	1.50E-03	
				10k Resistor R20 - Parameter change	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	36	9.14E-04	
				10k Resistor R20 - Short	Random failure	No power (PB)	4 False/Unrequested beam dump	4	1	1	**4**	5	1.27E-04	
5.2.1.6	Resistor 10k	1	R22	10k Resistor R22 - Open	Random failure	No power (PB)	4 False/Unrequested beam dump	4	1	1	**4**	59	1.50E-03	

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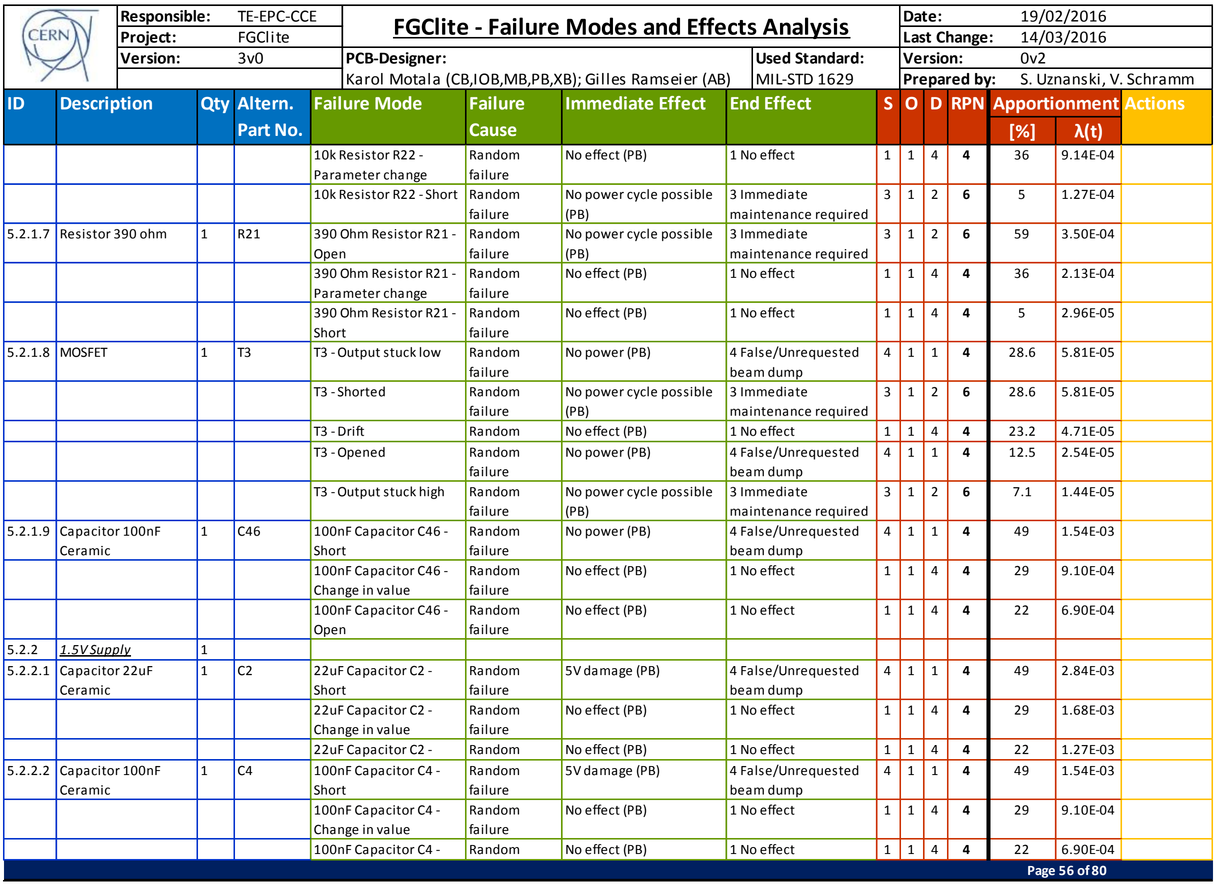

Responsible: TE-EPC-CCE	**FGClite - Failure Modes and Effects Analysis**		**Date:** 19/02/2016
Project: FGClite			**Last Change:** 14/03/2016
Version: 3v0	**PCB-Designer:**	**Used Standard:**	**Version:** 0v2
	Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)	MIL-STD 1629	**Prepared by:** S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment		Actions
												[%]	λ(t)	
				10k Resistor R22 - Parameter change	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	36	9.14E-04	
				10k Resistor R22 - Short	Random failure	No power cycle possible (PB)	3 Immediate maintenance required	3	1	2	**6**	5	1.27E-04	
5.2.1.7	Resistor 390 ohm	1	R21	390 Ohm Resistor R21 - Open	Random failure	No power cycle possible (PB)	3 Immediate maintenance required	3	1	2	**6**	59	3.50E-04	
				390 Ohm Resistor R21 - Parameter change	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	36	2.13E-04	
				390 Ohm Resistor R21 - Short	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	5	2.96E-05	
5.2.1.8	MOSFET	1	T3	T3 - Output stuck low	Random failure	No power (PB)	4 False/Unrequested beam dump	4	1	1	**4**	28.6	5.81E-05	
				T3 - Shorted	Random failure	No power cycle possible (PB)	3 Immediate maintenance required	3	1	2	**6**	28.6	5.81E-05	
				T3 - Drift	Random	No effect (PB)	1 No effect	1	1	4	**4**	23.2	4.71E-05	
				T3 - Opened	Random failure	No power (PB)	4 False/Unrequested beam dump	4	1	1	**4**	12.5	2.54E-05	
				T3 - Output stuck high	Random failure	No power cycle possible (PB)	3 Immediate maintenance required	3	1	2	**6**	7.1	1.44E-05	
5.2.1.9	Capacitor 100nF Ceramic	1	C46	100nF Capacitor C46 - Short	Random failure	No power (PB)	4 False/Unrequested beam dump	4	1	1	**4**	49	1.54E-03	
				100nF Capacitor C46 - Change in value	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	29	9.10E-04	
				100nF Capacitor C46 - Open	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	22	6.90E-04	
5.2.2	*1.5V Supply*	1												
5.2.2.1	Capacitor 22uF Ceramic	1	C2	22uF Capacitor C2 - Short	Random failure	5V damage (PB)	4 False/Unrequested beam dump	4	1	1	**4**	49	2.84E-03	
				22uF Capacitor C2 - Change in value	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	29	1.68E-03	
				22uF Capacitor C2 -	Random	No effect (PB)	1 No effect	1	1	4	**4**	22	1.27E-03	
5.2.2.2	Capacitor 100nF Ceramic	1	C4	100nF Capacitor C4 - Short	Random failure	5V damage (PB)	4 False/Unrequested beam dump	4	1	1	**4**	49	1.54E-03	
				100nF Capacitor C4 - Change in value	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	29	9.10E-04	
				100nF Capacitor C4 -	Random	No effect (PB)	1 No effect	1	1	4	**4**	22	6.90E-04	

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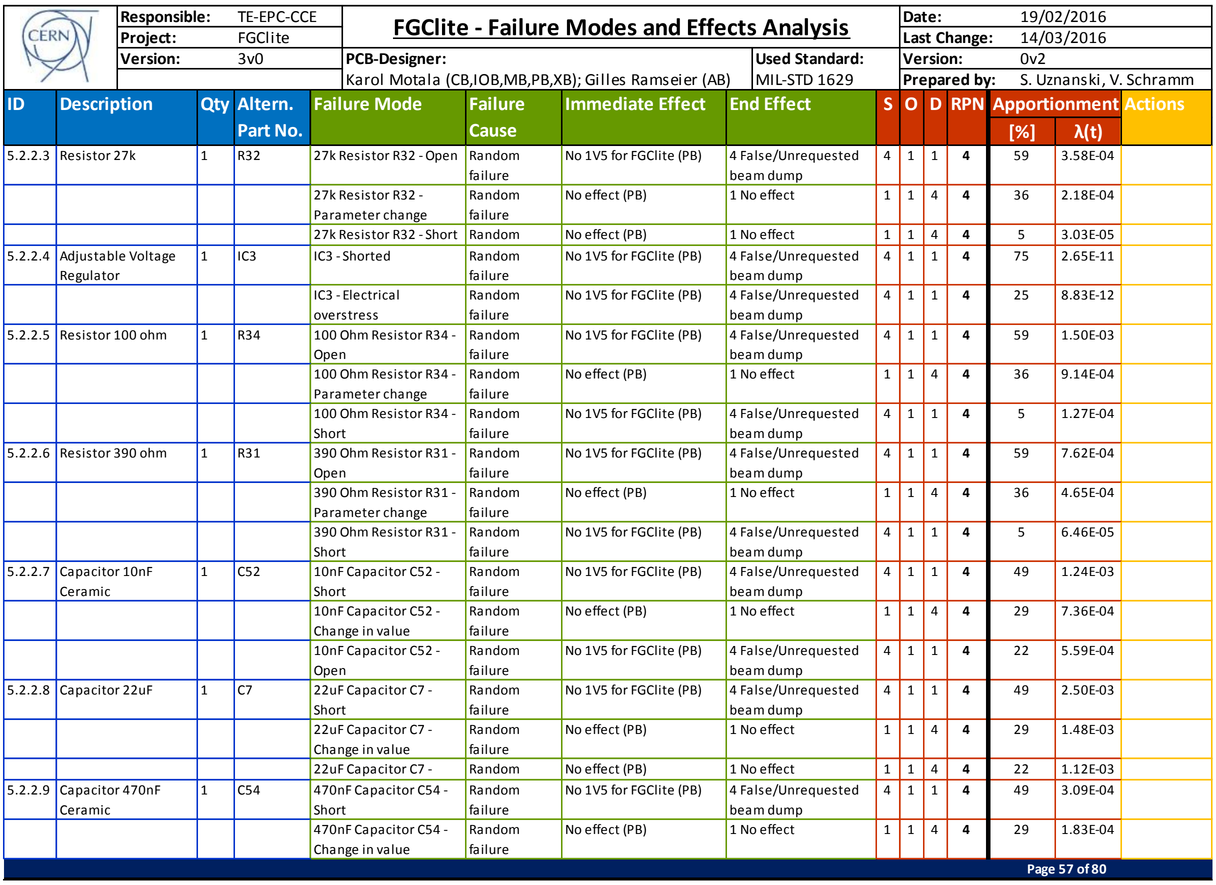

Responsible: TE-EPC-CCE	**FGClite - Failure Modes and Effects Analysis**		**Date:** 19/02/2016
Project: FGClite			**Last Change:** 14/03/2016
Version: 3v0	**PCB-Designer:**	**Used Standard:**	**Version:** 0v2
	Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)	MIL-STD 1629	**Prepared by:** S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment		Actions
												[%]	λ(t)	
5.2.2.3	Resistor 27k	1	R32	27k Resistor R32 - Open	Random failure	No 1V5 for FGClite (PB)	4 False/Unrequested beam dump	4	1	1	**4**	59	3.58E-04	
				27k Resistor R32 - Parameter change	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	36	2.18E-04	
				27k Resistor R32 - Short	Random	No effect (PB)	1 No effect	1	1	4	**4**	5	3.03E-05	
5.2.2.4	Adjustable Voltage Regulator	1	IC3	IC3 - Shorted	Random failure	No 1V5 for FGClite (PB)	4 False/Unrequested beam dump	4	1	1	**4**	75	2.65E-11	
				IC3 - Electrical overstress	Random failure	No 1V5 for FGClite (PB)	4 False/Unrequested beam dump	4	1	1	**4**	25	8.83E-12	
5.2.2.5	Resistor 100 ohm	1	R34	100 Ohm Resistor R34 - Open	Random failure	No 1V5 for FGClite (PB)	4 False/Unrequested beam dump	4	1	1	**4**	59	1.50E-03	
				100 Ohm Resistor R34 - Parameter change	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	36	9.14E-04	
				100 Ohm Resistor R34 - Short	Random failure	No 1V5 for FGClite (PB)	4 False/Unrequested beam dump	4	1	1	**4**	5	1.27E-04	
5.2.2.6	Resistor 390 ohm	1	R31	390 Ohm Resistor R31 - Open	Random failure	No 1V5 for FGClite (PB)	4 False/Unrequested beam dump	4	1	1	**4**	59	7.62E-04	
				390 Ohm Resistor R31 - Parameter change	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	36	4.65E-04	
				390 Ohm Resistor R31 - Short	Random failure	No 1V5 for FGClite (PB)	4 False/Unrequested beam dump	4	1	1	**4**	5	6.46E-05	
5.2.2.7	Capacitor 10nF Ceramic	1	C52	10nF Capacitor C52 - Short	Random failure	No 1V5 for FGClite (PB)	4 False/Unrequested beam dump	4	1	1	**4**	49	1.24E-03	
				10nF Capacitor C52 - Change in value	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	29	7.36E-04	
				10nF Capacitor C52 - Open	Random failure	No 1V5 for FGClite (PB)	4 False/Unrequested beam dump	4	1	1	**4**	22	5.59E-04	
5.2.2.8	Capacitor 22uF	1	C7	22uF Capacitor C7 - Short	Random failure	No 1V5 for FGClite (PB)	4 False/Unrequested beam dump	4	1	1	**4**	49	2.50E-03	
				22uF Capacitor C7 - Change in value	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	29	1.48E-03	
				22uF Capacitor C7 -	Random	No effect (PB)	1 No effect	1	1	4	**4**	22	1.12E-03	
5.2.2.9	Capacitor 470nF Ceramic	1	C54	470nF Capacitor C54 - Short	Random failure	No 1V5 for FGClite (PB)	4 False/Unrequested beam dump	4	1	1	**4**	49	3.09E-04	
				470nF Capacitor C54 - Change in value	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	29	1.83E-04	

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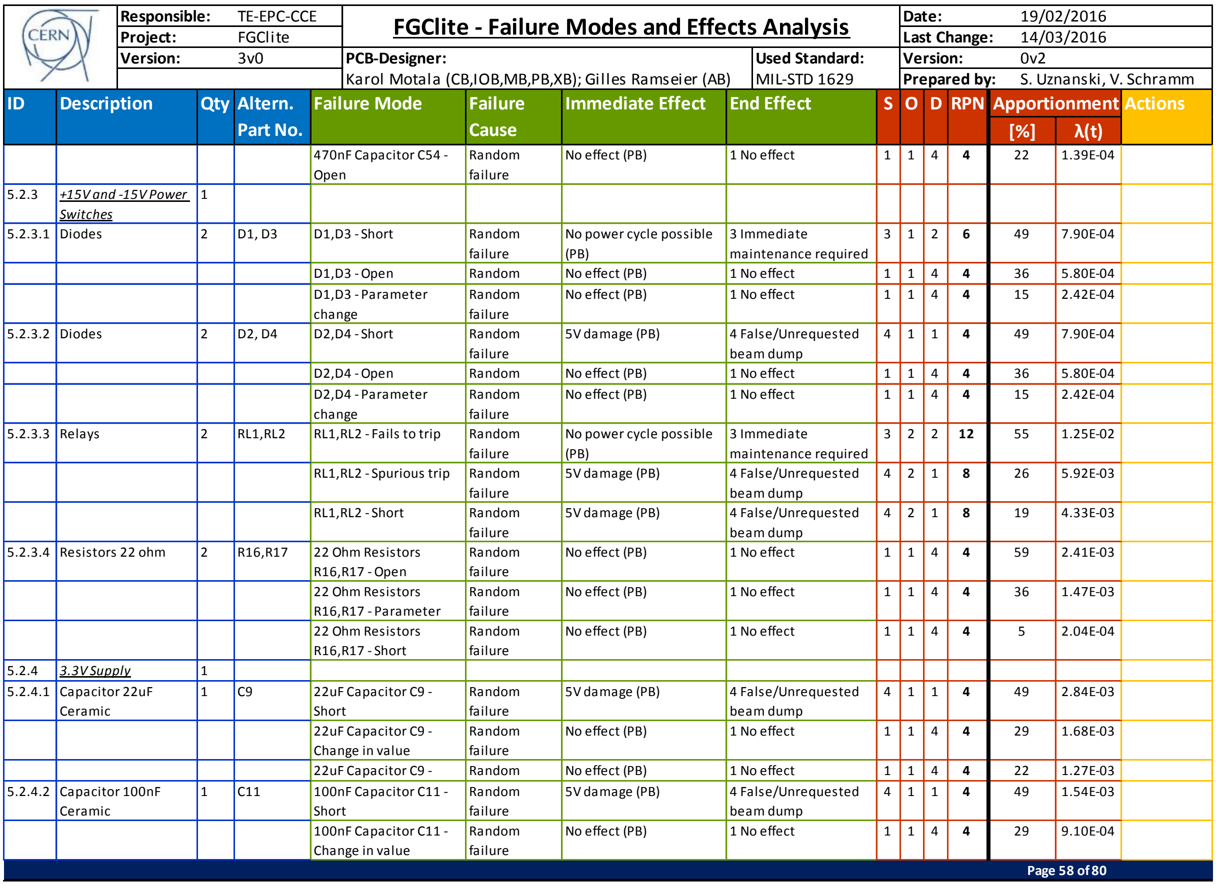

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - Failure Modes and Effects Analysis

PCB-Designer:
Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)

Used Standard:
MIL-STD 1629

Date: 19/02/2016
Last Change: 14/03/2016
Version: 0v2
Prepared by: S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment		Actions
												[%]	λ(t)	
				470nF Capacitor C54 - Open	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	22	1.39E-04	
5.2.3	*+15V and -15V Power Switches*	1												
5.2.3.1	Diodes	2	D1, D3	D1,D3 - Short	Random failure	No power cycle possible (PB)	3 Immediate maintenance required	3	1	2	**6**	49	7.90E-04	
				D1,D3 - Open	Random	No effect (PB)	1 No effect	1	1	4	**4**	36	5.80E-04	
				D1,D3 - Parameter change	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	15	2.42E-04	
5.2.3.2	Diodes	2	D2, D4	D2,D4 - Short	Random failure	5V damage (PB)	4 False/Unrequested beam dump	4	1	1	**4**	49	7.90E-04	
				D2,D4 - Open	Random	No effect (PB)	1 No effect	1	1	4	**4**	36	5.80E-04	
				D2,D4 - Parameter change	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	15	2.42E-04	
5.2.3.3	Relays	2	RL1,RL2	RL1,RL2 - Fails to trip	Random failure	No power cycle possible (PB)	3 Immediate maintenance required	3	2	2	**12**	55	1.25E-02	
				RL1,RL2 - Spurious trip	Random failure	5V damage (PB)	4 False/Unrequested beam dump	4	2	1	**8**	26	5.92E-03	
				RL1,RL2 - Short	Random failure	5V damage (PB)	4 False/Unrequested beam dump	4	2	1	**8**	19	4.33E-03	
5.2.3.4	Resistors 22 ohm	2	R16,R17	22 Ohm Resistors R16,R17 - Open	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	59	2.41E-03	
				22 Ohm Resistors R16,R17 - Parameter	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	36	1.47E-03	
				22 Ohm Resistors R16,R17 - Short	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	5	2.04E-04	
5.2.4	*3.3V Supply*	1												
5.2.4.1	Capacitor 22uF Ceramic	1	C9	22uF Capacitor C9 - Short	Random failure	5V damage (PB)	4 False/Unrequested beam dump	4	1	1	**4**	49	2.84E-03	
				22uF Capacitor C9 - Change in value	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	29	1.68E-03	
				22uF Capacitor C9 -	Random	No effect (PB)	1 No effect	1	1	4	**4**	22	1.27E-03	
5.2.4.2	Capacitor 100nF Ceramic	1	C11	100nF Capacitor C11 - Short	Random failure	5V damage (PB)	4 False/Unrequested beam dump	4	1	1	**4**	49	1.54E-03	
				100nF Capacitor C11 - Change in value	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	29	9.10E-04	

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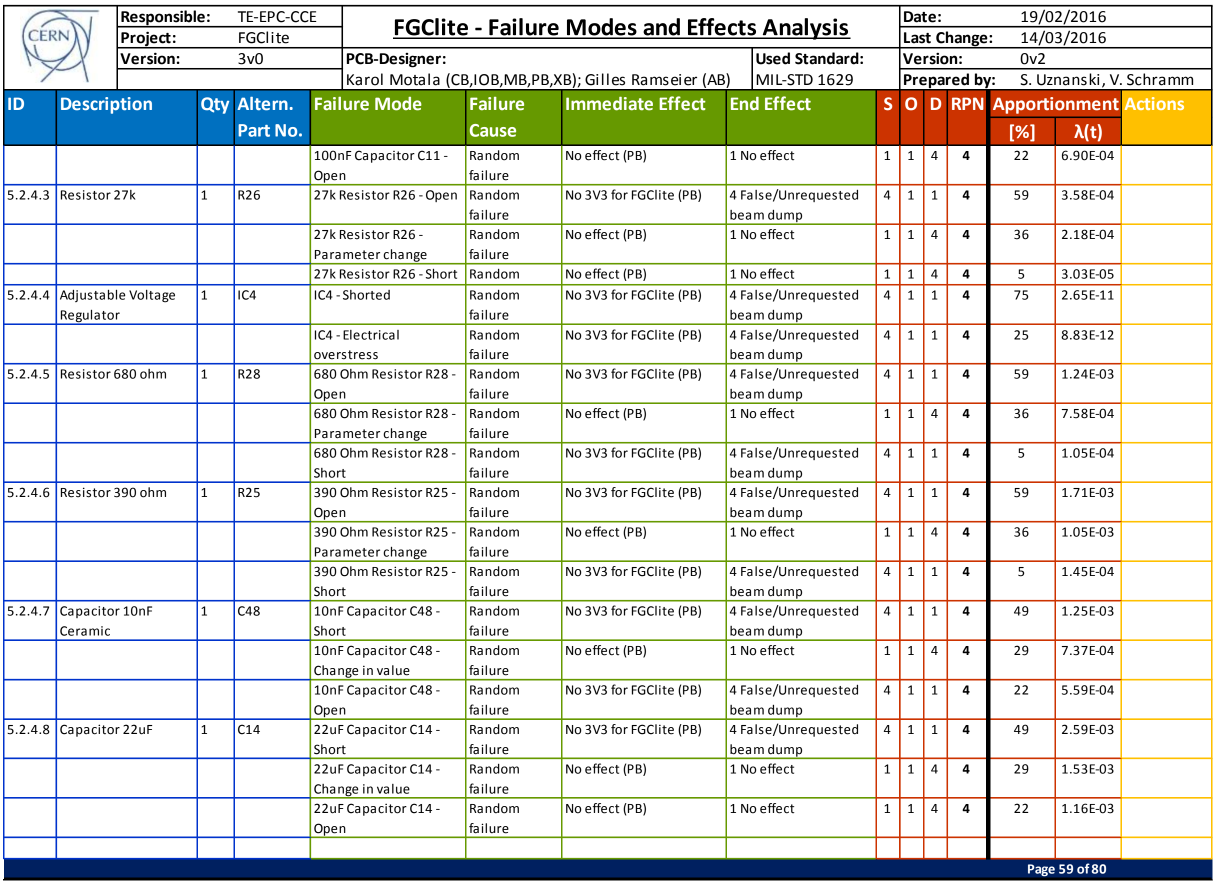

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - Failure Modes and Effects Analysis

PCB-Designer:
Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)

Used Standard:
MIL-STD 1629

Date: 19/02/2016
Last Change: 14/03/2016
Version: 0v2
Prepared by: S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment		Actions
												[%]	λ(t)	
				100nF Capacitor C11 - Open	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	22	6.90E-04	
5.2.4.3	Resistor 27k	1	R26	27k Resistor R26 - Open	Random failure	No 3V3 for FGClite (PB)	4 False/Unrequested beam dump	4	1	1	**4**	59	3.58E-04	
				27k Resistor R26 - Parameter change	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	36	2.18E-04	
				27k Resistor R26 - Short	Random	No effect (PB)	1 No effect	1	1	4	**4**	5	3.03E-05	
5.2.4.4	Adjustable Voltage Regulator	1	IC4	IC4 - Shorted	Random failure	No 3V3 for FGClite (PB)	4 False/Unrequested beam dump	4	1	1	**4**	75	2.65E-11	
				IC4 - Electrical overstress	Random failure	No 3V3 for FGClite (PB)	4 False/Unrequested beam dump	4	1	1	**4**	25	8.83E-12	
5.2.4.5	Resistor 680 ohm	1	R28	680 Ohm Resistor R28 - Open	Random failure	No 3V3 for FGClite (PB)	4 False/Unrequested beam dump	4	1	1	**4**	59	1.24E-03	
				680 Ohm Resistor R28 - Parameter change	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	36	7.58E-04	
				680 Ohm Resistor R28 - Short	Random failure	No 3V3 for FGClite (PB)	4 False/Unrequested beam dump	4	1	1	**4**	5	1.05E-04	
5.2.4.6	Resistor 390 ohm	1	R25	390 Ohm Resistor R25 - Open	Random failure	No 3V3 for FGClite (PB)	4 False/Unrequested beam dump	4	1	1	**4**	59	1.71E-03	
				390 Ohm Resistor R25 - Parameter change	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	36	1.05E-03	
				390 Ohm Resistor R25 - Short	Random failure	No 3V3 for FGClite (PB)	4 False/Unrequested beam dump	4	1	1	**4**	5	1.45E-04	
5.2.4.7	Capacitor 10nF Ceramic	1	C48	10nF Capacitor C48 - Short	Random failure	No 3V3 for FGClite (PB)	4 False/Unrequested beam dump	4	1	1	**4**	49	1.25E-03	
				10nF Capacitor C48 - Change in value	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	29	7.37E-04	
				10nF Capacitor C48 - Open	Random failure	No 3V3 for FGClite (PB)	4 False/Unrequested beam dump	4	1	1	**4**	22	5.59E-04	
5.2.4.8	Capacitor 22uF	1	C14	22uF Capacitor C14 - Short	Random failure	No 3V3 for FGClite (PB)	4 False/Unrequested beam dump	4	1	1	**4**	49	2.59E-03	
				22uF Capacitor C14 - Change in value	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	29	1.53E-03	
				22uF Capacitor C14 - Open	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	22	1.16E-03	

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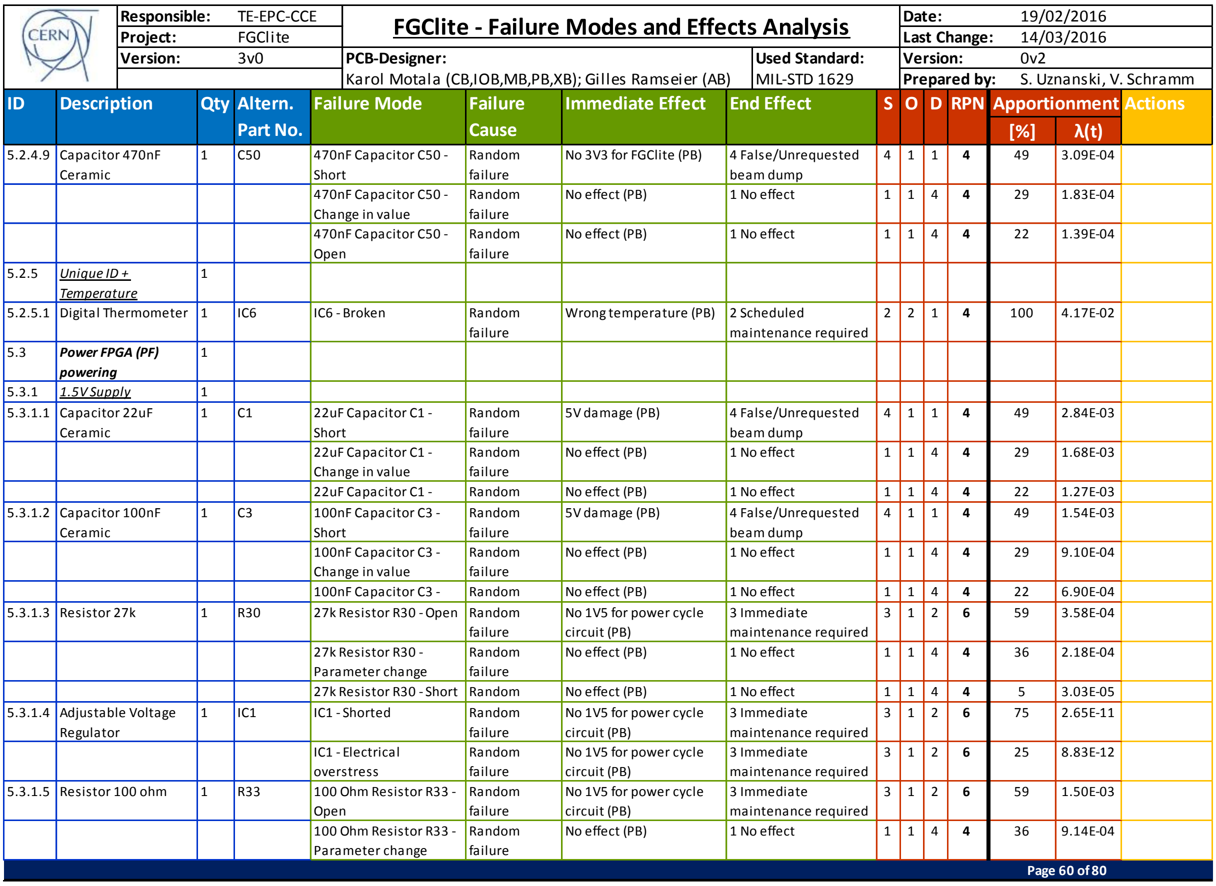

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - Failure Modes and Effects Analysis

PCB-Designer: Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)
Used Standard: MIL-STD 1629

Date: 19/02/2016
Last Change: 14/03/2016
Version: 0v2
Prepared by: S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment [%]	λ(t)	Actions
5.2.4.9	Capacitor 470nF Ceramic	1	C50	470nF Capacitor C50 - Short	Random failure	No 3V3 for FGClite (PB)	4 False/Unrequested beam dump	4	1	1	**4**	49	3.09E-04	
				470nF Capacitor C50 - Change in value	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	29	1.83E-04	
				470nF Capacitor C50 - Open	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	22	1.39E-04	
5.2.5	*Unique ID + Temperature*	1												
5.2.5.1	Digital Thermometer	1	IC6	IC6 - Broken	Random failure	Wrong temperature (PB)	2 Scheduled maintenance required	2	2	1	**4**	100	4.17E-02	
5.3	***Power FPGA (PF) powering***	1												
5.3.1	*1.5V Supply*	1												
5.3.1.1	Capacitor 22uF Ceramic	1	C1	22uF Capacitor C1 - Short	Random failure	5V damage (PB)	4 False/Unrequested beam dump	4	1	1	**4**	49	2.84E-03	
				22uF Capacitor C1 - Change in value	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	29	1.68E-03	
				22uF Capacitor C1 -	Random	No effect (PB)	1 No effect	1	1	4	**4**	22	1.27E-03	
5.3.1.2	Capacitor 100nF Ceramic	1	C3	100nF Capacitor C3 - Short	Random failure	5V damage (PB)	4 False/Unrequested beam dump	4	1	1	**4**	49	1.54E-03	
				100nF Capacitor C3 - Change in value	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	29	9.10E-04	
				100nF Capacitor C3 -	Random	No effect (PB)	1 No effect	1	1	4	**4**	22	6.90E-04	
5.3.1.3	Resistor 27k	1	R30	27k Resistor R30 - Open	Random failure	No 1V5 for power cycle circuit (PB)	3 Immediate maintenance required	3	1	2	**6**	59	3.58E-04	
				27k Resistor R30 - Parameter change	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	36	2.18E-04	
				27k Resistor R30 - Short	Random	No effect (PB)	1 No effect	1	1	4	**4**	5	3.03E-05	
5.3.1.4	Adjustable Voltage Regulator	1	IC1	IC1 - Shorted	Random failure	No 1V5 for power cycle circuit (PB)	3 Immediate maintenance required	3	1	2	**6**	75	2.65E-11	
				IC1 - Electrical overstress	Random failure	No 1V5 for power cycle circuit (PB)	3 Immediate maintenance required	3	1	2	**6**	25	8.83E-12	
5.3.1.5	Resistor 100 ohm	1	R33	100 Ohm Resistor R33 - Open	Random failure	No 1V5 for power cycle circuit (PB)	3 Immediate maintenance required	3	1	2	**6**	59	1.50E-03	
				100 Ohm Resistor R33 - Parameter change	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	36	9.14E-04	

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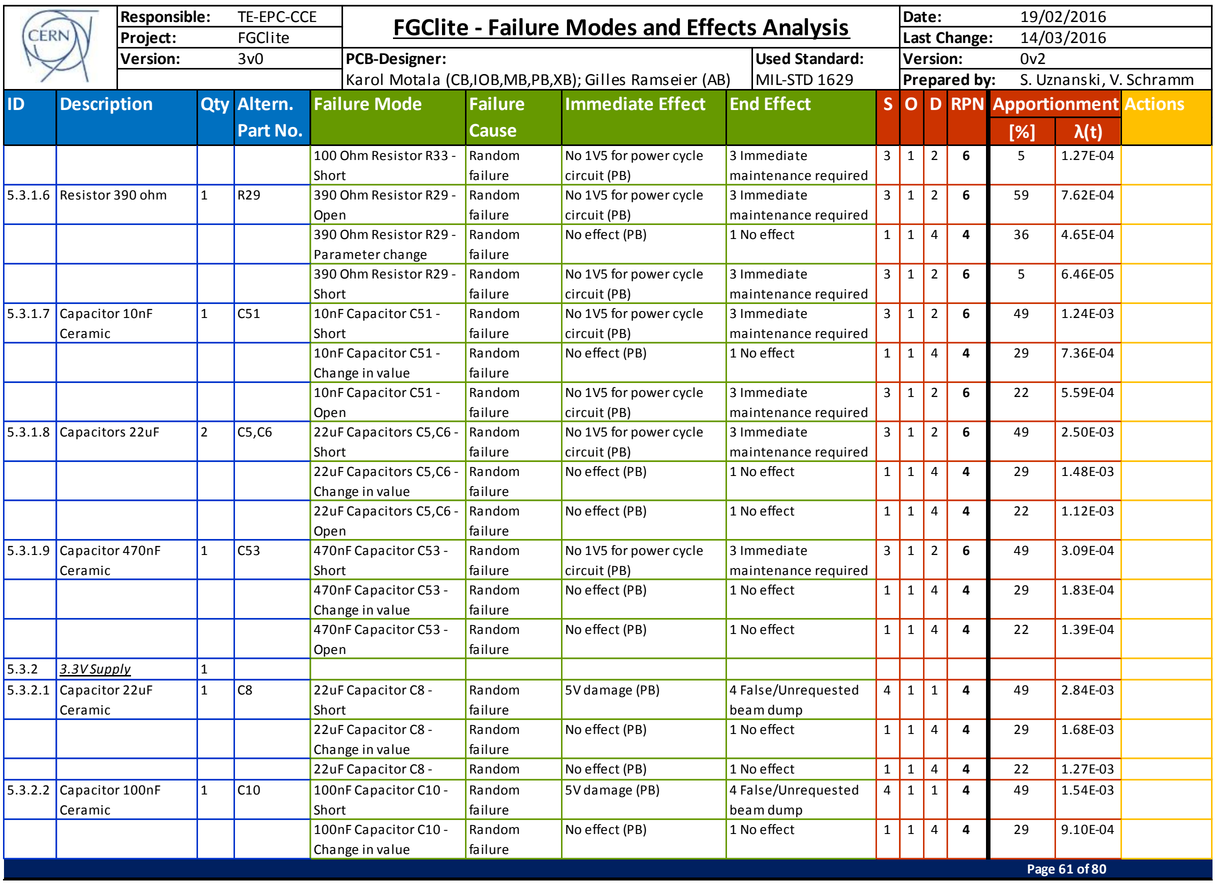

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - Failure Modes and Effects Analysis

PCB-Designer: Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)
Used Standard: MIL-STD 1629

Date: 19/02/2016
Last Change: 14/03/2016
Version: 0v2
Prepared by: S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment [%]	λ(t)	Actions
				100 Ohm Resistor R33 - Short	Random failure	No 1V5 for power cycle circuit (PB)	3 Immediate maintenance required	3	1	2	**6**	5	1.27E-04	
5.3.1.6	Resistor 390 ohm	1	R29	390 Ohm Resistor R29 - Open	Random failure	No 1V5 for power cycle circuit (PB)	3 Immediate maintenance required	3	1	2	**6**	59	7.62E-04	
				390 Ohm Resistor R29 - Parameter change	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	36	4.65E-04	
				390 Ohm Resistor R29 - Short	Random failure	No 1V5 for power cycle circuit (PB)	3 Immediate maintenance required	3	1	2	**6**	5	6.46E-05	
5.3.1.7	Capacitor 10nF Ceramic	1	C51	10nF Capacitor C51 - Short	Random failure	No 1V5 for power cycle circuit (PB)	3 Immediate maintenance required	3	1	2	**6**	49	1.24E-03	
				10nF Capacitor C51 - Change in value	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	29	7.36E-04	
				10nF Capacitor C51 - Open	Random failure	No 1V5 for power cycle circuit (PB)	3 Immediate maintenance required	3	1	2	**6**	22	5.59E-04	
5.3.1.8	Capacitors 22uF	2	C5,C6	22uF Capacitors C5,C6 - Short	Random failure	No 1V5 for power cycle circuit (PB)	3 Immediate maintenance required	3	1	2	**6**	49	2.50E-03	
				22uF Capacitors C5,C6 - Change in value	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	29	1.48E-03	
				22uF Capacitors C5,C6 - Open	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	22	1.12E-03	
5.3.1.9	Capacitor 470nF Ceramic	1	C53	470nF Capacitor C53 - Short	Random failure	No 1V5 for power cycle circuit (PB)	3 Immediate maintenance required	3	1	2	**6**	49	3.09E-04	
				470nF Capacitor C53 - Change in value	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	29	1.83E-04	
				470nF Capacitor C53 - Open	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	22	1.39E-04	
5.3.2	*3.3V Supply*	1												
5.3.2.1	Capacitor 22uF Ceramic	1	C8	22uF Capacitor C8 - Short	Random failure	5V damage (PB)	4 False/Unrequested beam dump	4	1	1	**4**	49	2.84E-03	
				22uF Capacitor C8 - Change in value	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	29	1.68E-03	
				22uF Capacitor C8 -	Random	No effect (PB)	1 No effect	1	1	4	**4**	22	1.27E-03	
5.3.2.2	Capacitor 100nF Ceramic	1	C10	100nF Capacitor C10 - Short	Random failure	5V damage (PB)	4 False/Unrequested beam dump	4	1	1	**4**	49	1.54E-03	
				100nF Capacitor C10 - Change in value	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	29	9.10E-04	

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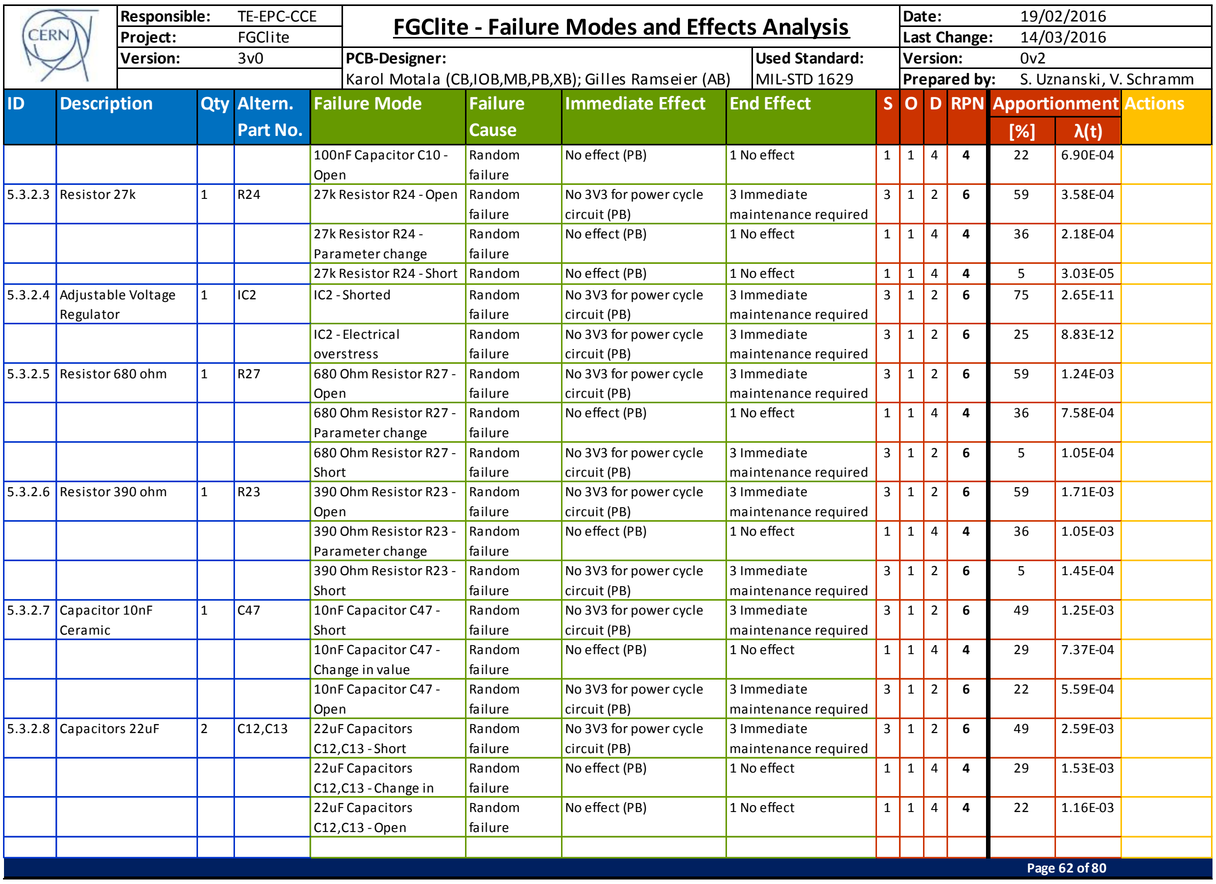

Responsible:	TE-EPC-CCE	**FGClite - Failure Modes and Effects Analysis**	**Date:** 19/02/2016
Project:	FGClite		**Last Change:** 14/03/2016
Version:	3v0	**PCB-Designer:** Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)	**Used Standard:** MIL-STD 1629 / **Version:** 0v2
			Prepared by: S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment [%]	λ(t)	Actions
				100nF Capacitor C10 - Open	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	22	6.90E-04	
5.3.2.3	Resistor 27k	1	R24	27k Resistor R24 - Open	Random failure	No 3V3 for power cycle circuit (PB)	3 Immediate maintenance required	3	1	2	**6**	59	3.58E-04	
				27k Resistor R24 - Parameter change	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	36	2.18E-04	
				27k Resistor R24 - Short	Random	No effect (PB)	1 No effect	1	1	4	**4**	5	3.03E-05	
5.3.2.4	Adjustable Voltage Regulator	1	IC2	IC2 - Shorted	Random failure	No 3V3 for power cycle circuit (PB)	3 Immediate maintenance required	3	1	2	**6**	75	2.65E-11	
				IC2 - Electrical overstress	Random failure	No 3V3 for power cycle circuit (PB)	3 Immediate maintenance required	3	1	2	**6**	25	8.83E-12	
5.3.2.5	Resistor 680 ohm	1	R27	680 Ohm Resistor R27 - Open	Random failure	No 3V3 for power cycle circuit (PB)	3 Immediate maintenance required	3	1	2	**6**	59	1.24E-03	
				680 Ohm Resistor R27 - Parameter change	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	36	7.58E-04	
				680 Ohm Resistor R27 - Short	Random failure	No 3V3 for power cycle circuit (PB)	3 Immediate maintenance required	3	1	2	**6**	5	1.05E-04	
5.3.2.6	Resistor 390 ohm	1	R23	390 Ohm Resistor R23 - Open	Random failure	No 3V3 for power cycle circuit (PB)	3 Immediate maintenance required	3	1	2	**6**	59	1.71E-03	
				390 Ohm Resistor R23 - Parameter change	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	36	1.05E-03	
				390 Ohm Resistor R23 - Short	Random failure	No 3V3 for power cycle circuit (PB)	3 Immediate maintenance required	3	1	2	**6**	5	1.45E-04	
5.3.2.7	Capacitor 10nF Ceramic	1	C47	10nF Capacitor C47 - Short	Random failure	No 3V3 for power cycle circuit (PB)	3 Immediate maintenance required	3	1	2	**6**	49	1.25E-03	
				10nF Capacitor C47 - Change in value	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	29	7.37E-04	
				10nF Capacitor C47 - Open	Random failure	No 3V3 for power cycle circuit (PB)	3 Immediate maintenance required	3	1	2	**6**	22	5.59E-04	
5.3.2.8	Capacitors 22uF	2	C12,C13	22uF Capacitors C12,C13 - Short	Random failure	No 3V3 for power cycle circuit (PB)	3 Immediate maintenance required	3	1	2	**6**	49	2.59E-03	
				22uF Capacitors C12,C13 - Change in	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	29	1.53E-03	
				22uF Capacitors C12,C13 - Open	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	22	1.16E-03	

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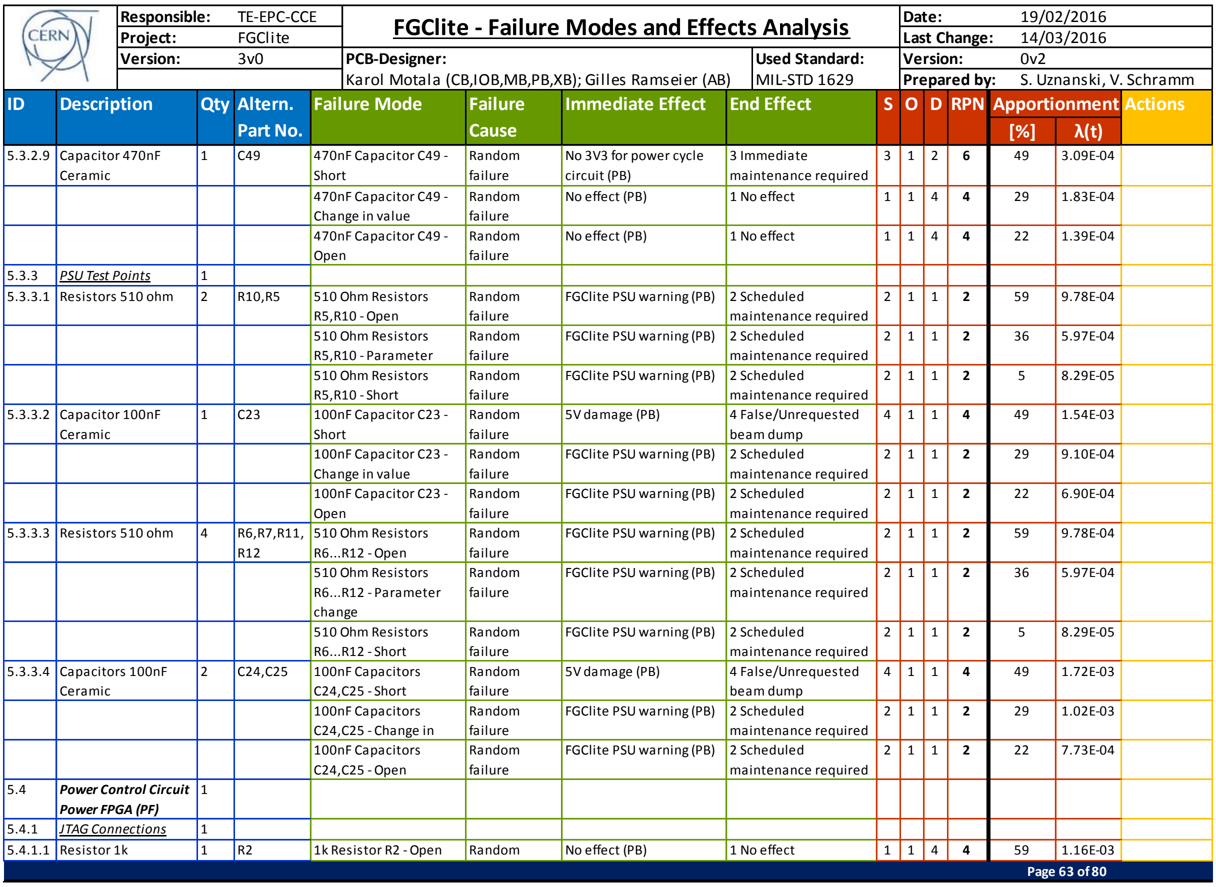

Responsible:	TE-EPC-CCE	**FGClite - Failure Modes and Effects Analysis**	**Date:** 19/02/2016
Project:	FGClite		**Last Change:** 14/03/2016
Version:	3v0	**PCB-Designer:** Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)	**Used Standard:** MIL-STD 1629 / **Version:** 0v2
			Prepared by: S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment [%]	λ(t)	Actions
5.3.2.9	Capacitor 470nF Ceramic	1	C49	470nF Capacitor C49 - Short	Random failure	No 3V3 for power cycle circuit (PB)	3 Immediate maintenance required	3	1	2	**6**	49	3.09E-04	
				470nF Capacitor C49 - Change in value	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	29	1.83E-04	
				470nF Capacitor C49 - Open	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	22	1.39E-04	
5.3.3	*PSU Test Points*	1												
5.3.3.1	Resistors 510 ohm	2	R10,R5	510 Ohm Resistors R5,R10 - Open	Random failure	FGClite PSU warning (PB)	2 Scheduled maintenance required	2	1	1	**2**	59	9.78E-04	
				510 Ohm Resistors R5,R10 - Parameter	Random failure	FGClite PSU warning (PB)	2 Scheduled maintenance required	2	1	1	**2**	36	5.97E-04	
				510 Ohm Resistors R5,R10 - Short	Random failure	FGClite PSU warning (PB)	2 Scheduled maintenance required	2	1	1	**2**	5	8.29E-05	
5.3.3.2	Capacitor 100nF Ceramic	1	C23	100nF Capacitor C23 - Short	Random failure	5V damage (PB)	4 False/Unrequested beam dump	4	1	1	**4**	49	1.54E-03	
				100nF Capacitor C23 - Change in value	Random failure	FGClite PSU warning (PB)	2 Scheduled maintenance required	2	1	1	**2**	29	9.10E-04	
				100nF Capacitor C23 - Open	Random failure	FGClite PSU warning (PB)	2 Scheduled maintenance required	2	1	1	**2**	22	6.90E-04	
5.3.3.3	Resistors 510 ohm	4	R6,R7,R11, R12	510 Ohm Resistors R6...R12 - Open	Random failure	FGClite PSU warning (PB)	2 Scheduled maintenance required	2	1	1	**2**	59	9.78E-04	
				510 Ohm Resistors R6...R12 - Parameter change	Random failure	FGClite PSU warning (PB)	2 Scheduled maintenance required	2	1	1	**2**	36	5.97E-04	
				510 Ohm Resistors R6...R12 - Short	Random failure	FGClite PSU warning (PB)	2 Scheduled maintenance required	2	1	1	**2**	5	8.29E-05	
5.3.3.4	Capacitors 100nF Ceramic	2	C24,C25	100nF Capacitors C24,C25 - Short	Random failure	5V damage (PB)	4 False/Unrequested beam dump	4	1	1	**4**	49	1.72E-03	
				100nF Capacitors C24,C25 - Change in	Random failure	FGClite PSU warning (PB)	2 Scheduled maintenance required	2	1	1	**2**	29	1.02E-03	
				100nF Capacitors C24,C25 - Open	Random failure	FGClite PSU warning (PB)	2 Scheduled maintenance required	2	1	1	**2**	22	7.73E-04	
5.4	***Power Control Circuit Power FPGA (PF)***	1												
5.4.1	*JTAG Connections*	1												
5.4.1.1	Resistor 1k	1	R2	1k Resistor R2 - Open	Random	No effect (PB)	1 No effect	1	1	4	**4**	59	1.16E-03	

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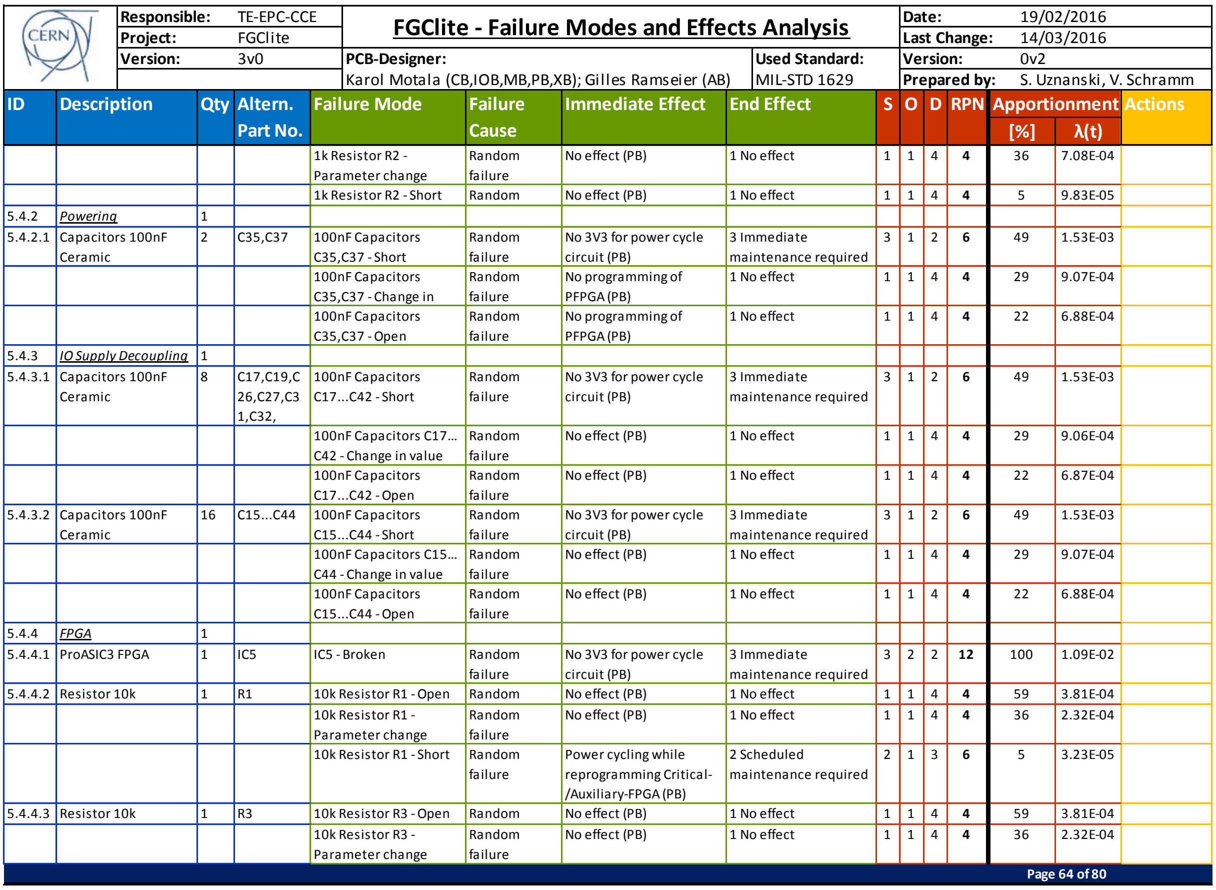

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - Failure Modes and Effects Analysis

PCB-Designer: Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)
Used Standard: MIL-STD 1629

Date: 19/02/2016
Last Change: 14/03/2016
Version: 0v2
Prepared by: S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment		Actions
												[%]	λ(t)	
				1k Resistor R2 - Parameter change	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	36	7.08E-04	
				1k Resistor R2 - Short	Random	No effect (PB)	1 No effect	1	1	4	**4**	5	9.83E-05	
5.4.2	*Powering*	1												
5.4.2.1	Capacitors 100nF Ceramic	2	C35,C37	100nF Capacitors C35,C37 - Short	Random failure	No 3V3 for power cycle circuit (PB)	3 Immediate maintenance required	3	1	2	**6**	49	1.53E-03	
				100nF Capacitors C35,C37 - Change in	Random failure	No programming of PFPGA (PB)	1 No effect	1	1	4	**4**	29	9.07E-04	
				100nF Capacitors C35,C37 - Open	Random failure	No programming of PFPGA (PB)	1 No effect	1	1	4	**4**	22	6.88E-04	
5.4.3	*IO Supply Decoupling*	1												
5.4.3.1	Capacitors 100nF Ceramic	8	C17,C19,C26,C27,C31,C32,	100nF Capacitors C17...C42 - Short	Random failure	No 3V3 for power cycle circuit (PB)	3 Immediate maintenance required	3	1	2	**6**	49	1.53E-03	
				100nF Capacitors C17... C42 - Change in value	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	29	9.06E-04	
				100nF Capacitors C17...C42 - Open	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	22	6.87E-04	
5.4.3.2	Capacitors 100nF Ceramic	16	C15...C44	100nF Capacitors C15...C44 - Short	Random failure	No 3V3 for power cycle circuit (PB)	3 Immediate maintenance required	3	1	2	**6**	49	1.53E-03	
				100nF Capacitors C15... C44 - Change in value	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	29	9.07E-04	
				100nF Capacitors C15...C44 - Open	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	22	6.88E-04	
5.4.4	*FPGA*	1												
5.4.4.1	ProASIC3 FPGA	1	IC5	IC5 - Broken	Random failure	No 3V3 for power cycle circuit (PB)	3 Immediate maintenance required	3	2	2	**12**	100	1.09E-02	
5.4.4.2	Resistor 10k	1	R1	10k Resistor R1 - Open	Random	No effect (PB)	1 No effect	1	1	4	**4**	59	3.81E-04	
				10k Resistor R1 - Parameter change	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	36	2.32E-04	
				10k Resistor R1 - Short	Random failure	Power cycling while reprogramming Critical-/Auxiliary-FPGA (PB)	2 Scheduled maintenance required	2	1	3	**6**	5	3.23E-05	
5.4.4.3	Resistor 10k	1	R3	10k Resistor R3 - Open	Random	No effect (PB)	1 No effect	1	1	4	**4**	59	3.81E-04	
				10k Resistor R3 - Parameter change	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	36	2.32E-04	

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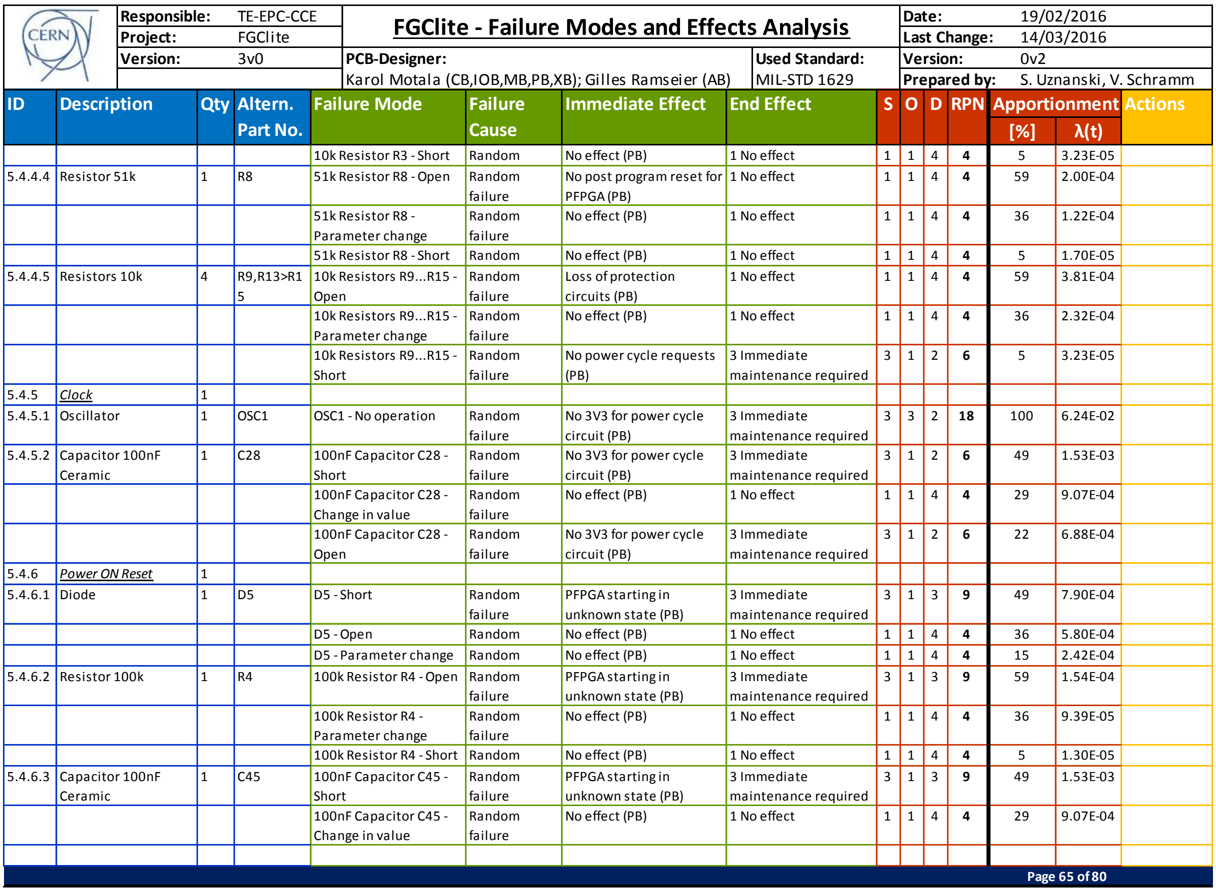

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - Failure Modes and Effects Analysis

PCB-Designer: Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)
Used Standard: MIL-STD 1629

Date: 19/02/2016
Last Change: 14/03/2016
Version: 0v2
Prepared by: S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment		Actions
												[%]	λ(t)	
				10k Resistor R3 - Short	Random	No effect (PB)	1 No effect	1	1	4	**4**	5	3.23E-05	
5.4.4.4	Resistor 51k	1	R8	51k Resistor R8 - Open	Random failure	No post program reset for PFPGA (PB)	1 No effect	1	1	4	**4**	59	2.00E-04	
				51k Resistor R8 - Parameter change	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	36	1.22E-04	
				51k Resistor R8 - Short	Random	No effect (PB)	1 No effect	1	1	4	**4**	5	1.70E-05	
5.4.4.5	Resistors 10k	4	R9,R13>R15	10k Resistors R9...R15 - Open	Random failure	Loss of protection circuits (PB)	1 No effect	1	1	4	**4**	59	3.81E-04	
				10k Resistors R9...R15 - Parameter change	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	36	2.32E-04	
				10k Resistors R9...R15 - Short	Random failure	No power cycle requests (PB)	3 Immediate maintenance required	3	1	2	**6**	5	3.23E-05	
5.4.5	*Clock*	1												
5.4.5.1	Oscillator	1	OSC1	OSC1 - No operation	Random failure	No 3V3 for power cycle circuit (PB)	3 Immediate maintenance required	3	3	2	**18**	100	6.24E-02	
5.4.5.2	Capacitor 100nF Ceramic	1	C28	100nF Capacitor C28 - Short	Random failure	No 3V3 for power cycle circuit (PB)	3 Immediate maintenance required	3	1	2	**6**	49	1.53E-03	
				100nF Capacitor C28 - Change in value	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	29	9.07E-04	
				100nF Capacitor C28 - Open	Random failure	No 3V3 for power cycle circuit (PB)	3 Immediate maintenance required	3	1	2	**6**	22	6.88E-04	
5.4.6	*Power ON Reset*	1												
5.4.6.1	Diode	1	D5	D5 - Short	Random failure	PFPGA starting in unknown state (PB)	3 Immediate maintenance required	3	1	3	**9**	49	7.90E-04	
				D5 - Open	Random	No effect (PB)	1 No effect	1	1	4	**4**	36	5.80E-04	
				D5 - Parameter change	Random	No effect (PB)	1 No effect	1	1	4	**4**	15	2.42E-04	
5.4.6.2	Resistor 100k	1	R4	100k Resistor R4 - Open	Random failure	PFPGA starting in unknown state (PB)	3 Immediate maintenance required	3	1	3	**9**	59	1.54E-04	
				100k Resistor R4 - Parameter change	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	36	9.39E-05	
				100k Resistor R4 - Short	Random	No effect (PB)	1 No effect	1	1	4	**4**	5	1.30E-05	
5.4.6.3	Capacitor 100nF Ceramic	1	C45	100nF Capacitor C45 - Short	Random failure	PFPGA starting in unknown state (PB)	3 Immediate maintenance required	3	1	3	**9**	49	1.53E-03	
				100nF Capacitor C45 - Change in value	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	29	9.07E-04	

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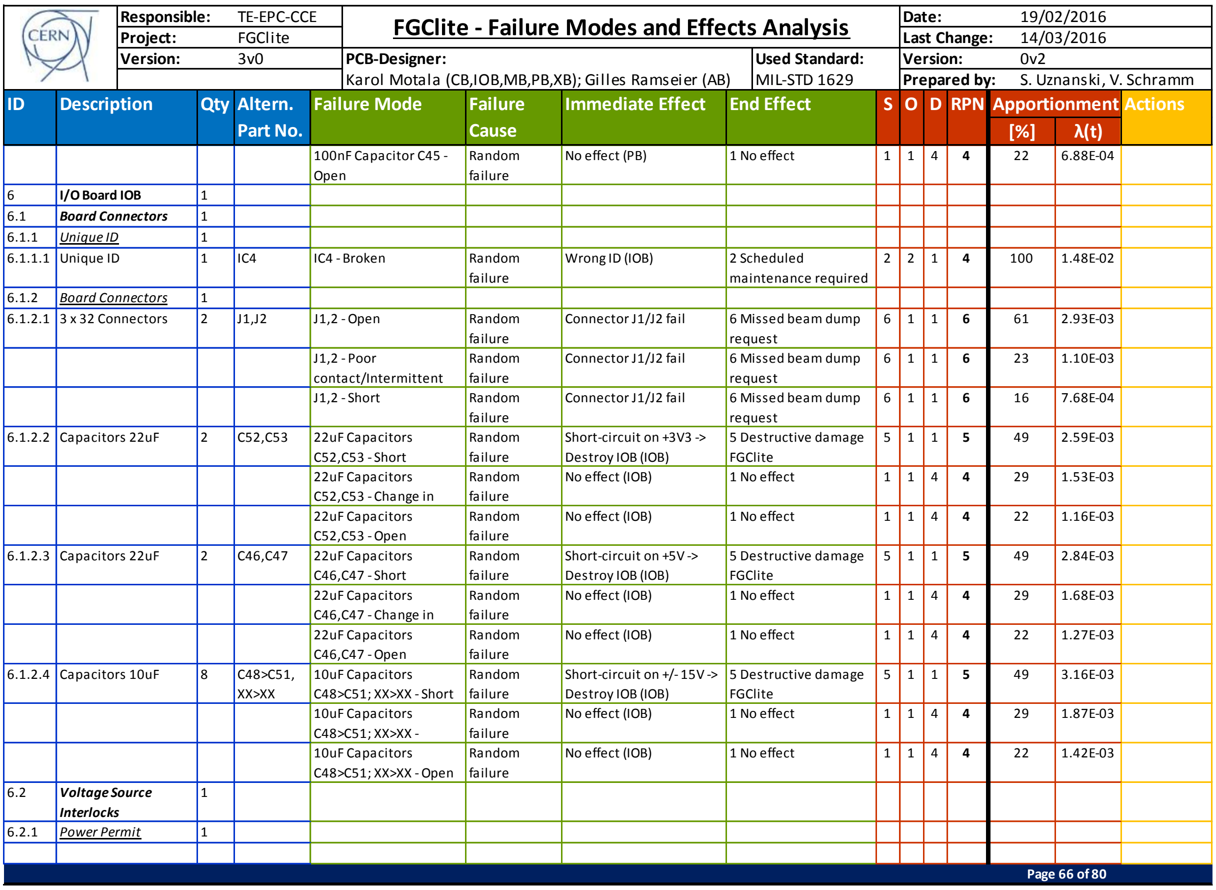

Responsible: TE-EPC-CCE	**FGClite - Failure Modes and Effects Analysis**		**Date:** 19/02/2016
Project: FGClite			**Last Change:** 14/03/2016
Version: 3v0	**PCB-Designer:**	**Used Standard:**	**Version:** 0v2
	Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)	MIL-STD 1629	**Prepared by:** S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment		Actions
												[%]	λ(t)	
				100nF Capacitor C45 - Open	Random failure	No effect (PB)	1 No effect	1	1	4	**4**	22	6.88E-04	
6	**I/O Board IOB**	1												
6.1	***Board Connectors***	1												
6.1.1	*Unique ID*	1												
6.1.1.1	Unique ID	1	IC4	IC4 - Broken	Random failure	Wrong ID (IOB)	2 Scheduled maintenance required	2	2	1	**4**	100	1.48E-02	
6.1.2	*Board Connectors*	1												
6.1.2.1	3 x 32 Connectors	2	J1,J2	J1,2 - Open	Random failure	Connector J1/J2 fail	6 Missed beam dump request	6	1	1	**6**	61	2.93E-03	
				J1,2 - Poor contact/Intermittent	Random failure	Connector J1/J2 fail	6 Missed beam dump request	6	1	1	**6**	23	1.10E-03	
				J1,2 - Short	Random failure	Connector J1/J2 fail	6 Missed beam dump request	6	1	1	**6**	16	7.68E-04	
6.1.2.2	Capacitors 22uF	2	C52,C53	22uF Capacitors C52,C53 - Short	Random failure	Short-circuit on +3V3 -> Destroy IOB (IOB)	5 Destructive damage FGClite	5	1	1	**5**	49	2.59E-03	
				22uF Capacitors C52,C53 - Change in	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	29	1.53E-03	
				22uF Capacitors C52,C53 - Open	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	22	1.16E-03	
6.1.2.3	Capacitors 22uF	2	C46,C47	22uF Capacitors C46,C47 - Short	Random failure	Short-circuit on +5V -> Destroy IOB (IOB)	5 Destructive damage FGClite	5	1	1	**5**	49	2.84E-03	
				22uF Capacitors C46,C47 - Change in	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	29	1.68E-03	
				22uF Capacitors C46,C47 - Open	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	22	1.27E-03	
6.1.2.4	Capacitors 10uF	8	C48>C51, XX>XX	10uF Capacitors C48>C51; XX>XX - Short	Random failure	Short-circuit on +/- 15V -> Destroy IOB (IOB)	5 Destructive damage FGClite	5	1	1	**5**	49	3.16E-03	
				10uF Capacitors C48>C51; XX>XX -	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	29	1.87E-03	
				10uF Capacitors C48>C51; XX>XX - Open	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	22	1.42E-03	
6.2	***Voltage Source Interlocks***	1												
6.2.1	*Power Permit*	1												

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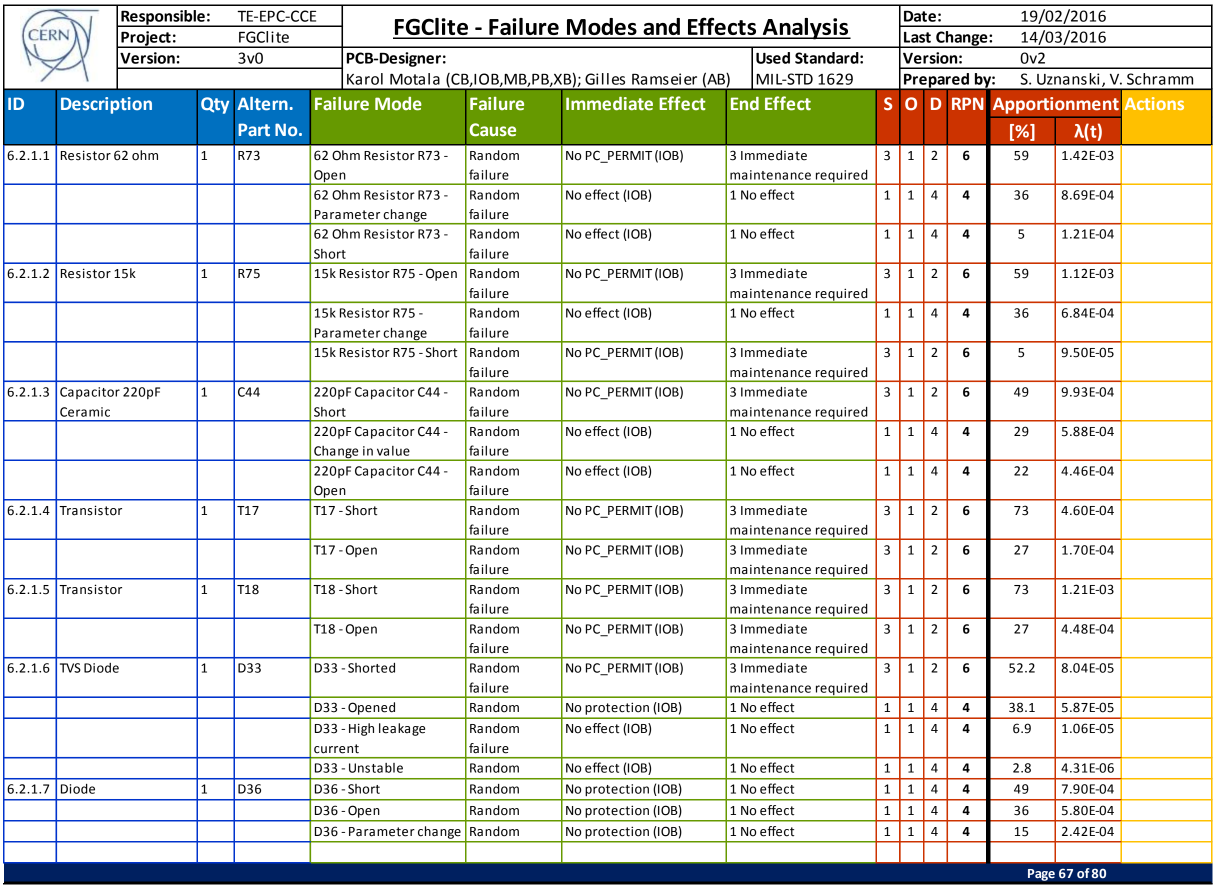

Responsible: TE-EPC-CCE	**FGClite - Failure Modes and Effects Analysis**		**Date:** 19/02/2016
Project: FGClite			**Last Change:** 14/03/2016
Version: 3v0	**PCB-Designer:**	**Used Standard:**	**Version:** 0v2
	Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)	MIL-STD 1629	**Prepared by:** S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment		Actions
												[%]	λ(t)	
6.2.1.1	Resistor 62 ohm	1	R73	62 Ohm Resistor R73 - Open	Random failure	No PC_PERMIT (IOB)	3 Immediate maintenance required	3	1	2	**6**	59	1.42E-03	
				62 Ohm Resistor R73 - Parameter change	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	36	8.69E-04	
				62 Ohm Resistor R73 - Short	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	5	1.21E-04	
6.2.1.2	Resistor 15k	1	R75	15k Resistor R75 - Open	Random failure	No PC_PERMIT (IOB)	3 Immediate maintenance required	3	1	2	**6**	59	1.12E-03	
				15k Resistor R75 - Parameter change	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	36	6.84E-04	
				15k Resistor R75 - Short	Random failure	No PC_PERMIT (IOB)	3 Immediate maintenance required	3	1	2	**6**	5	9.50E-05	
6.2.1.3	Capacitor 220pF Ceramic	1	C44	220pF Capacitor C44 - Short	Random failure	No PC_PERMIT (IOB)	3 Immediate maintenance required	3	1	2	**6**	49	9.93E-04	
				220pF Capacitor C44 - Change in value	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	29	5.88E-04	
				220pF Capacitor C44 - Open	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	22	4.46E-04	
6.2.1.4	Transistor	1	T17	T17 - Short	Random failure	No PC_PERMIT (IOB)	3 Immediate maintenance required	3	1	2	**6**	73	4.60E-04	
				T17 - Open	Random failure	No PC_PERMIT (IOB)	3 Immediate maintenance required	3	1	2	**6**	27	1.70E-04	
6.2.1.5	Transistor	1	T18	T18 - Short	Random failure	No PC_PERMIT (IOB)	3 Immediate maintenance required	3	1	2	**6**	73	1.21E-03	
				T18 - Open	Random failure	No PC_PERMIT (IOB)	3 Immediate maintenance required	3	1	2	**6**	27	4.48E-04	
6.2.1.6	TVS Diode	1	D33	D33 - Shorted	Random failure	No PC_PERMIT (IOB)	3 Immediate maintenance required	3	1	2	**6**	52.2	8.04E-05	
				D33 - Opened	Random	No protection (IOB)	1 No effect	1	1	4	**4**	38.1	5.87E-05	
				D33 - High leakage current	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	6.9	1.06E-05	
				D33 - Unstable	Random	No effect (IOB)	1 No effect	1	1	4	**4**	2.8	4.31E-06	
6.2.1.7	Diode	1	D36	D36 - Short	Random	No protection (IOB)	1 No effect	1	1	4	**4**	49	7.90E-04	
				D36 - Open	Random	No protection (IOB)	1 No effect	1	1	4	**4**	36	5.80E-04	
				D36 - Parameter change	Random	No protection (IOB)	1 No effect	1	1	4	**4**	15	2.42E-04	

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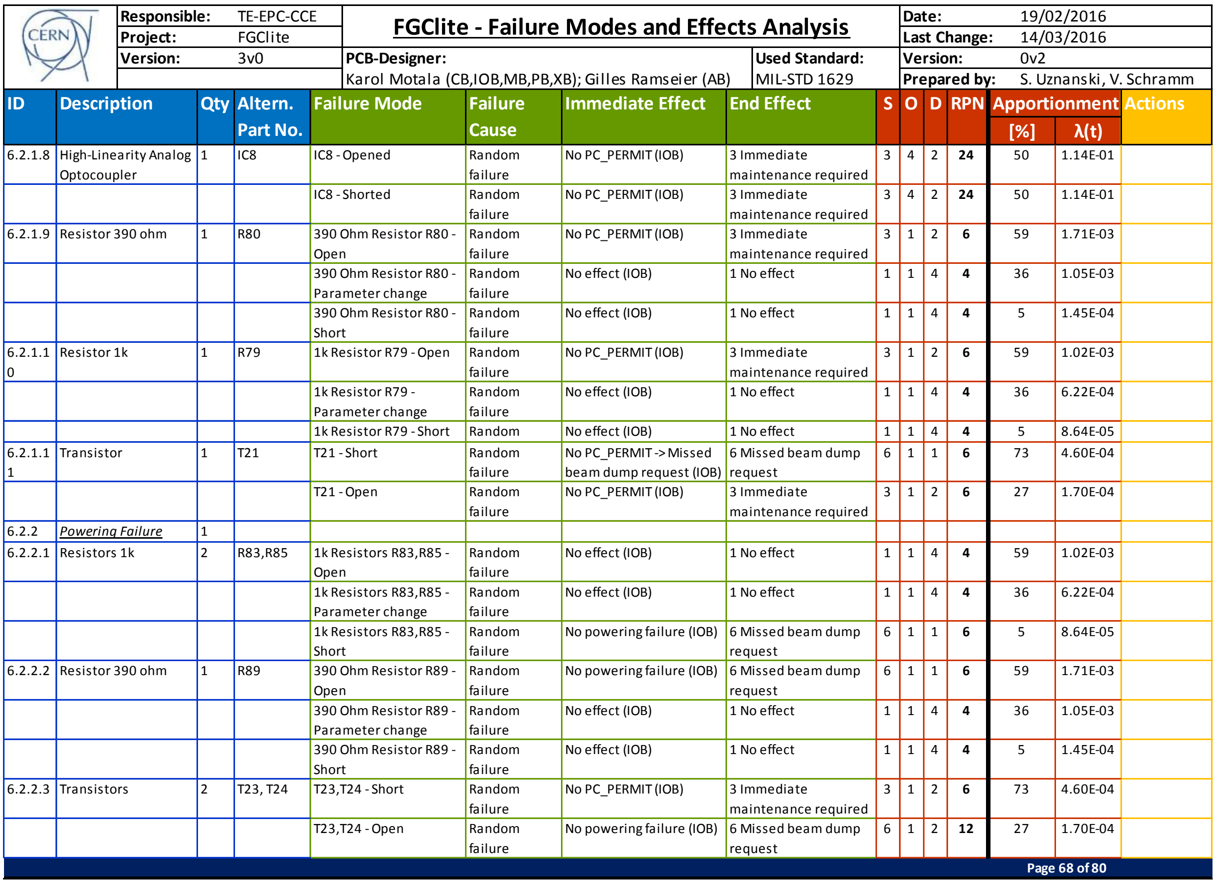

Responsible: TE-EPC-CCE
Project: FGClite
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FGClite - Failure Modes and Effects Analysis

PCB-Designer: Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)
Used Standard: MIL-STD 1629
Date: 19/02/2016
Last Change: 14/03/2016
Version: 0v2
Prepared by: S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment		Actions
												[%]	λ(t)	
6.2.1.8	High-Linearity Analog Optocoupler	1	IC8	IC8 - Opened	Random failure	No PC_PERMIT (IOB)	3 Immediate maintenance required	3	4	2	**24**	50	1.14E-01	
				IC8 - Shorted	Random failure	No PC_PERMIT (IOB)	3 Immediate maintenance required	3	4	2	**24**	50	1.14E-01	
6.2.1.9	Resistor 390 ohm	1	R80	390 Ohm Resistor R80 - Open	Random failure	No PC_PERMIT (IOB)	3 Immediate maintenance required	3	1	2	**6**	59	1.71E-03	
				390 Ohm Resistor R80 - Parameter change	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	36	1.05E-03	
				390 Ohm Resistor R80 - Short	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	5	1.45E-04	
6.2.1.10	Resistor 1k	1	R79	1k Resistor R79 - Open	Random failure	No PC_PERMIT (IOB)	3 Immediate maintenance required	3	1	2	**6**	59	1.02E-03	
				1k Resistor R79 - Parameter change	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	36	6.22E-04	
				1k Resistor R79 - Short	Random	No effect (IOB)	1 No effect	1	1	4	**4**	5	8.64E-05	
6.2.1.11	Transistor	1	T21	T21 - Short	Random failure	No PC_PERMIT -> Missed beam dump request (IOB)	6 Missed beam dump request	6	1	1	**6**	73	4.60E-04	
				T21 - Open	Random failure	No PC_PERMIT (IOB)	3 Immediate maintenance required	3	1	2	**6**	27	1.70E-04	
6.2.2	*Powering Failure*	1												
6.2.2.1	Resistors 1k	2	R83,R85	1k Resistors R83,R85 - Open	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	59	1.02E-03	
				1k Resistors R83,R85 - Parameter change	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	36	6.22E-04	
				1k Resistors R83,R85 - Short	Random failure	No powering failure (IOB)	6 Missed beam dump request	6	1	1	**6**	5	8.64E-05	
6.2.2.2	Resistor 390 ohm	1	R89	390 Ohm Resistor R89 - Open	Random failure	No powering failure (IOB)	6 Missed beam dump request	6	1	1	**6**	59	1.71E-03	
				390 Ohm Resistor R89 - Parameter change	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	36	1.05E-03	
				390 Ohm Resistor R89 - Short	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	5	1.45E-04	
6.2.2.3	Transistors	2	T23, T24	T23,T24 - Short	Random failure	No PC_PERMIT (IOB)	3 Immediate maintenance required	3	1	2	**6**	73	4.60E-04	
				T23,T24 - Open	Random failure	No powering failure (IOB)	6 Missed beam dump request	6	1	2	**12**	27	1.70E-04	

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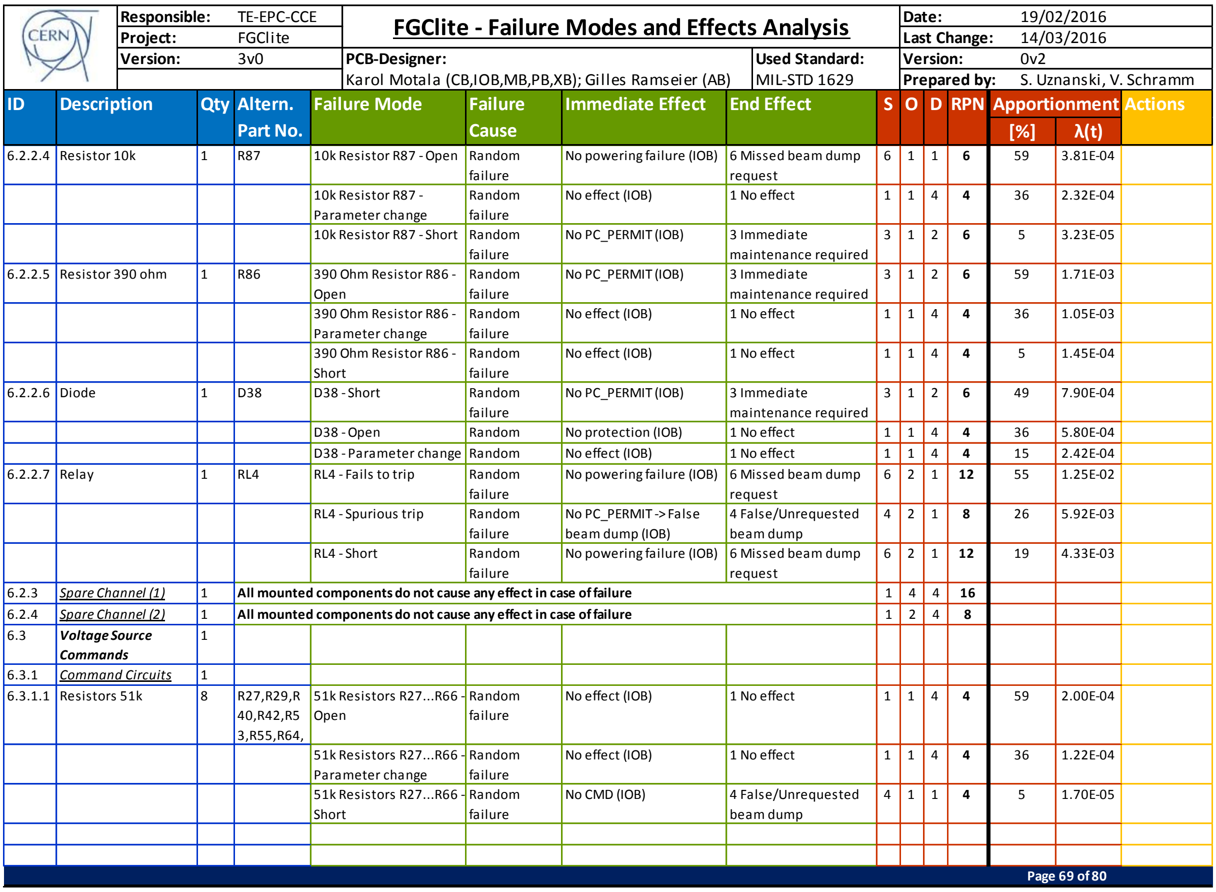

Responsible: TE-EPC-CCE
Project: FGClite
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FGClite - Failure Modes and Effects Analysis

PCB-Designer: Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)
Used Standard: MIL-STD 1629
Date: 19/02/2016
Last Change: 14/03/2016
Version: 0v2
Prepared by: S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment		Actions
												[%]	λ(t)	
6.2.2.4	Resistor 10k	1	R87	10k Resistor R87 - Open	Random failure	No powering failure (IOB)	6 Missed beam dump request	6	1	1	**6**	59	3.81E-04	
				10k Resistor R87 - Parameter change	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	36	2.32E-04	
				10k Resistor R87 - Short	Random failure	No PC_PERMIT (IOB)	3 Immediate maintenance required	3	1	2	**6**	5	3.23E-05	
6.2.2.5	Resistor 390 ohm	1	R86	390 Ohm Resistor R86 - Open	Random failure	No PC_PERMIT (IOB)	3 Immediate maintenance required	3	1	2	**6**	59	1.71E-03	
				390 Ohm Resistor R86 - Parameter change	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	36	1.05E-03	
				390 Ohm Resistor R86 - Short	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	5	1.45E-04	
6.2.2.6	Diode	1	D38	D38 - Short	Random failure	No PC_PERMIT (IOB)	3 Immediate maintenance required	3	1	2	**6**	49	7.90E-04	
				D38 - Open	Random	No protection (IOB)	1 No effect	1	1	4	**4**	36	5.80E-04	
				D38 - Parameter change	Random	No effect (IOB)	1 No effect	1	1	4	**4**	15	2.42E-04	
6.2.2.7	Relay	1	RL4	RL4 - Fails to trip	Random failure	No powering failure (IOB)	6 Missed beam dump request	6	2	1	**12**	55	1.25E-02	
				RL4 - Spurious trip	Random failure	No PC_PERMIT -> False beam dump (IOB)	4 False/Unrequested beam dump	4	2	1	**8**	26	5.92E-03	
				RL4 - Short	Random failure	No powering failure (IOB)	6 Missed beam dump request	6	2	1	**12**	19	4.33E-03	
6.2.3	*Spare Channel (1)*	1	**All mounted components do not cause any effect in case of failure**					1	4	4	**16**			
6.2.4	*Spare Channel (2)*	1	**All mounted components do not cause any effect in case of failure**					1	2	4	**8**			
6.3	***Voltage Source Commands***	1												
6.3.1	*Command Circuits*	1												
6.3.1.1	Resistors 51k	8	R27,R29,R40,R42,R53,R55,R64,	51k Resistors R27...R66 - Open	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	59	2.00E-04	
				51k Resistors R27...R66 - Parameter change	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	36	1.22E-04	
				51k Resistors R27...R66 - Short	Random failure	No CMD (IOB)	4 False/Unrequested beam dump	4	1	1	**4**	5	1.70E-05	

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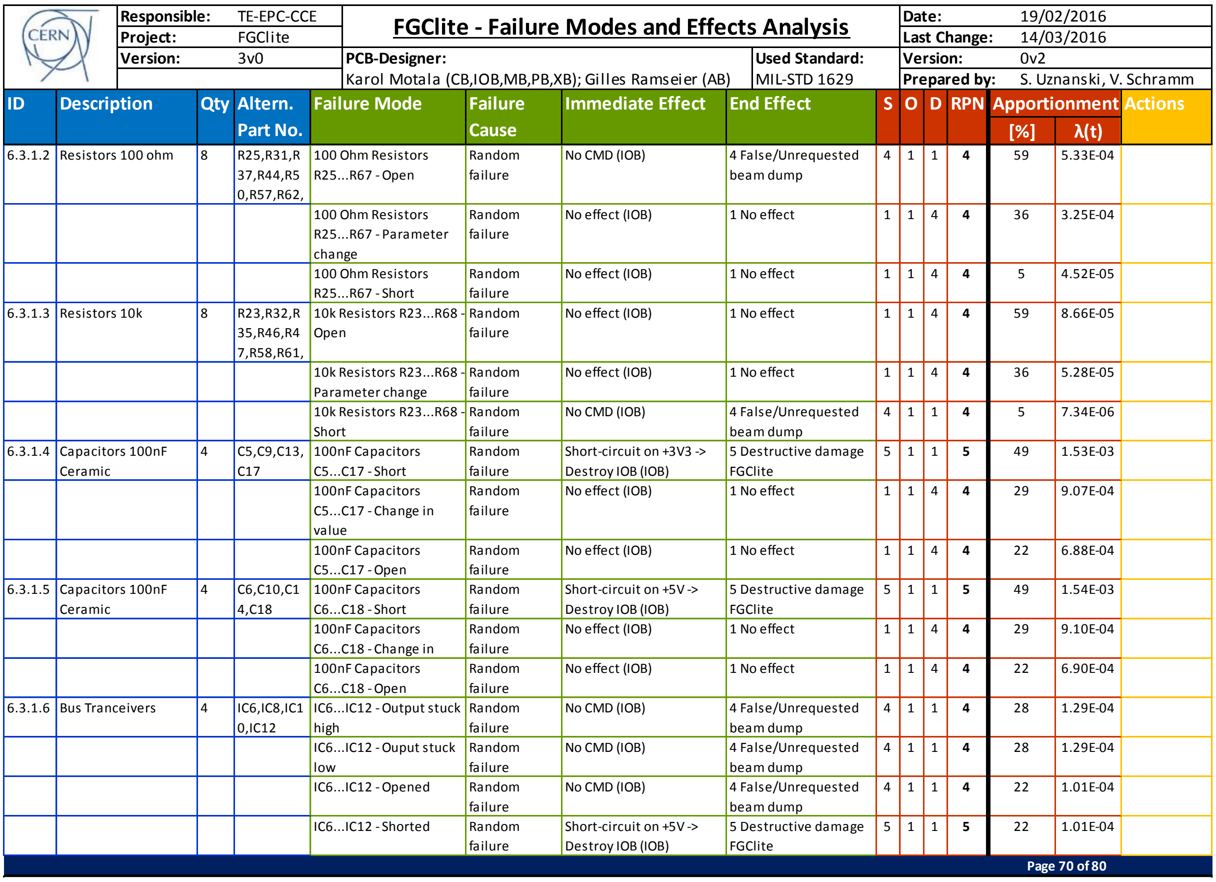

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - Failure Modes and Effects Analysis

PCB-Designer: Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)
Used Standard: MIL-STD 1629
Date: 19/02/2016
Last Change: 14/03/2016
Version: 0v2
Prepared by: S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment [%]	λ(t)	Actions
6.3.1.2	Resistors 100 ohm	8	R25,R31,R37,R44,R50,R57,R62,	100 Ohm Resistors R25...R67 - Open	Random failure	No CMD (IOB)	4 False/Unrequested beam dump	4	1	1	**4**	59	5.33E-04	
				100 Ohm Resistors R25...R67 - Parameter change	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	36	3.25E-04	
				100 Ohm Resistors R25...R67 - Short	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	5	4.52E-05	
6.3.1.3	Resistors 10k	8	R23,R32,R35,R46,R47,R58,R61,	10k Resistors R23...R68 - Open	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	59	8.66E-05	
				10k Resistors R23...R68 - Parameter change	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	36	5.28E-05	
				10k Resistors R23...R68 - Short	Random failure	No CMD (IOB)	4 False/Unrequested beam dump	4	1	1	**4**	5	7.34E-06	
6.3.1.4	Capacitors 100nF Ceramic	4	C5,C9,C13,C17	100nF Capacitors C5...C17 - Short	Random failure	Short-circuit on +3V3 -> Destroy IOB (IOB)	5 Destructive damage FGClite	5	1	1	**5**	49	1.53E-03	
				100nF Capacitors C5...C17 - Change in value	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	29	9.07E-04	
				100nF Capacitors C5...C17 - Open	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	22	6.88E-04	
6.3.1.5	Capacitors 100nF Ceramic	4	C6,C10,C14,C18	100nF Capacitors C6...C18 - Short	Random failure	Short-circuit on +5V -> Destroy IOB (IOB)	5 Destructive damage FGClite	5	1	1	**5**	49	1.54E-03	
				100nF Capacitors C6...C18 - Change in	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	29	9.10E-04	
				100nF Capacitors C6...C18 - Open	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	22	6.90E-04	
6.3.1.6	Bus Tranceivers	4	IC6,IC8,IC10,IC12	IC6...IC12 - Output stuck high	Random failure	No CMD (IOB)	4 False/Unrequested beam dump	4	1	1	**4**	28	1.29E-04	
				IC6...IC12 - Ouput stuck low	Random failure	No CMD (IOB)	4 False/Unrequested beam dump	4	1	1	**4**	28	1.29E-04	
				IC6...IC12 - Opened	Random failure	No CMD (IOB)	4 False/Unrequested beam dump	4	1	1	**4**	22	1.01E-04	
				IC6...IC12 - Shorted	Random failure	Short-circuit on +5V -> Destroy IOB (IOB)	5 Destructive damage FGClite	5	1	1	**5**	22	1.01E-04	

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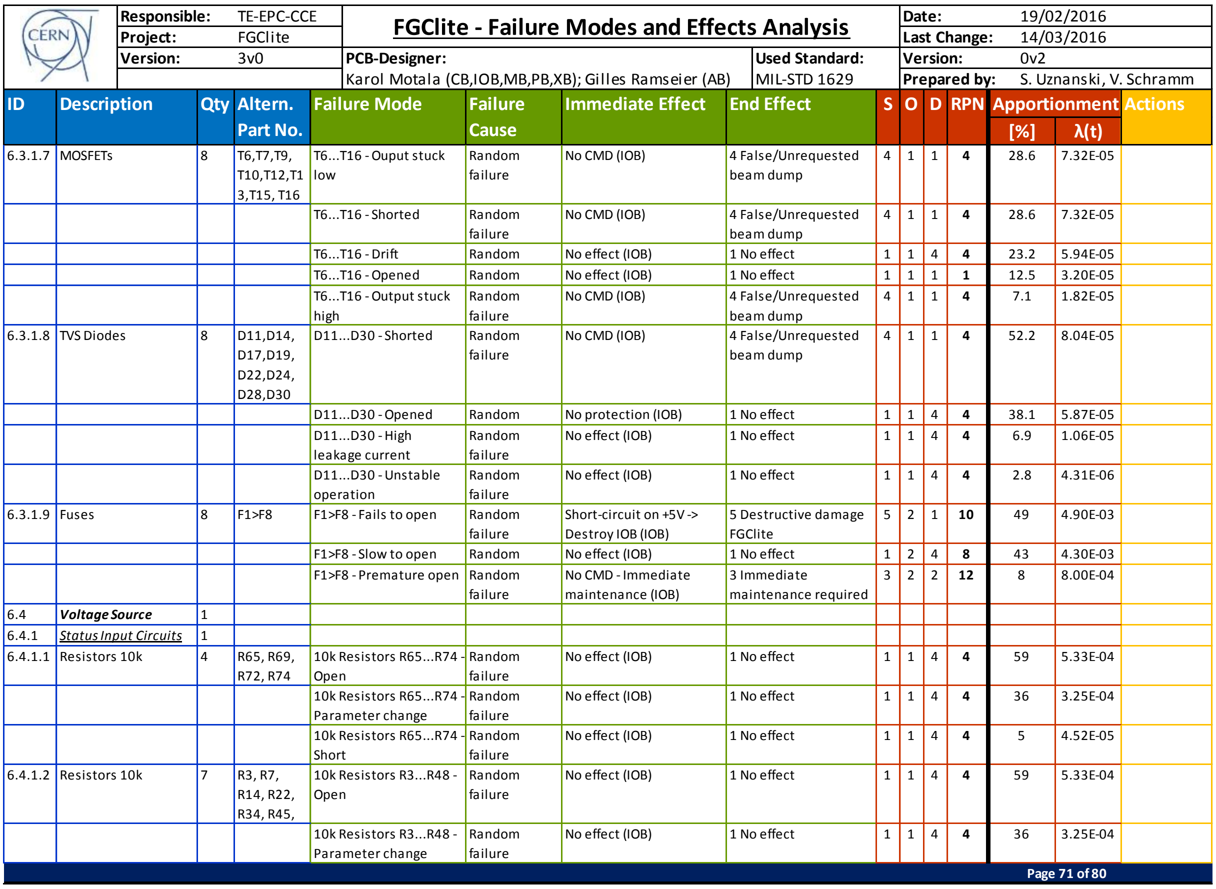

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - Failure Modes and Effects Analysis

PCB-Designer: Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)
Used Standard: MIL-STD 1629
Date: 19/02/2016
Last Change: 14/03/2016
Version: 0v2
Prepared by: S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment [%]	λ(t)	Actions
6.3.1.7	MOSFETs	8	T6,T7,T9, T10,T12,T13,T15, T16	T6...T16 - Ouput stuck low	Random failure	No CMD (IOB)	4 False/Unrequested beam dump	4	1	1	**4**	28.6	7.32E-05	
				T6...T16 - Shorted	Random failure	No CMD (IOB)	4 False/Unrequested beam dump	4	1	1	**4**	28.6	7.32E-05	
				T6...T16 - Drift	Random	No effect (IOB)	1 No effect	1	1	4	**4**	23.2	5.94E-05	
				T6...T16 - Opened	Random	No effect (IOB)	1 No effect	1	1	1	**1**	12.5	3.20E-05	
				T6...T16 - Output stuck high	Random failure	No CMD (IOB)	4 False/Unrequested beam dump	4	1	1	**4**	7.1	1.82E-05	
6.3.1.8	TVS Diodes	8	D11,D14, D17,D19, D22,D24, D28,D30	D11...D30 - Shorted	Random failure	No CMD (IOB)	4 False/Unrequested beam dump	4	1	1	**4**	52.2	8.04E-05	
				D11...D30 - Opened	Random	No protection (IOB)	1 No effect	1	1	4	**4**	38.1	5.87E-05	
				D11...D30 - High leakage current	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	6.9	1.06E-05	
				D11...D30 - Unstable operation	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	2.8	4.31E-06	
6.3.1.9	Fuses	8	F1>F8	F1>F8 - Fails to open	Random failure	Short-circuit on +5V -> Destroy IOB (IOB)	5 Destructive damage FGClite	5	2	1	**10**	49	4.90E-03	
				F1>F8 - Slow to open	Random	No effect (IOB)	1 No effect	1	2	4	**8**	43	4.30E-03	
				F1>F8 - Premature open	Random failure	No CMD - Immediate maintenance (IOB)	3 Immediate maintenance required	3	2	2	**12**	8	8.00E-04	
6.4	***Voltage Source***	1												
6.4.1	*Status Input Circuits*	1												
6.4.1.1	Resistors 10k	4	R65, R69, R72, R74	10k Resistors R65...R74 - Open	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	59	5.33E-04	
				10k Resistors R65...R74 - Parameter change	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	36	3.25E-04	
				10k Resistors R65...R74 - Short	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	5	4.52E-05	
6.4.1.2	Resistors 10k	7	R3, R7, R14, R22, R34, R45,	10k Resistors R3...R48 - Open	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	59	5.33E-04	
				10k Resistors R3...R48 - Parameter change	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	36	3.25E-04	

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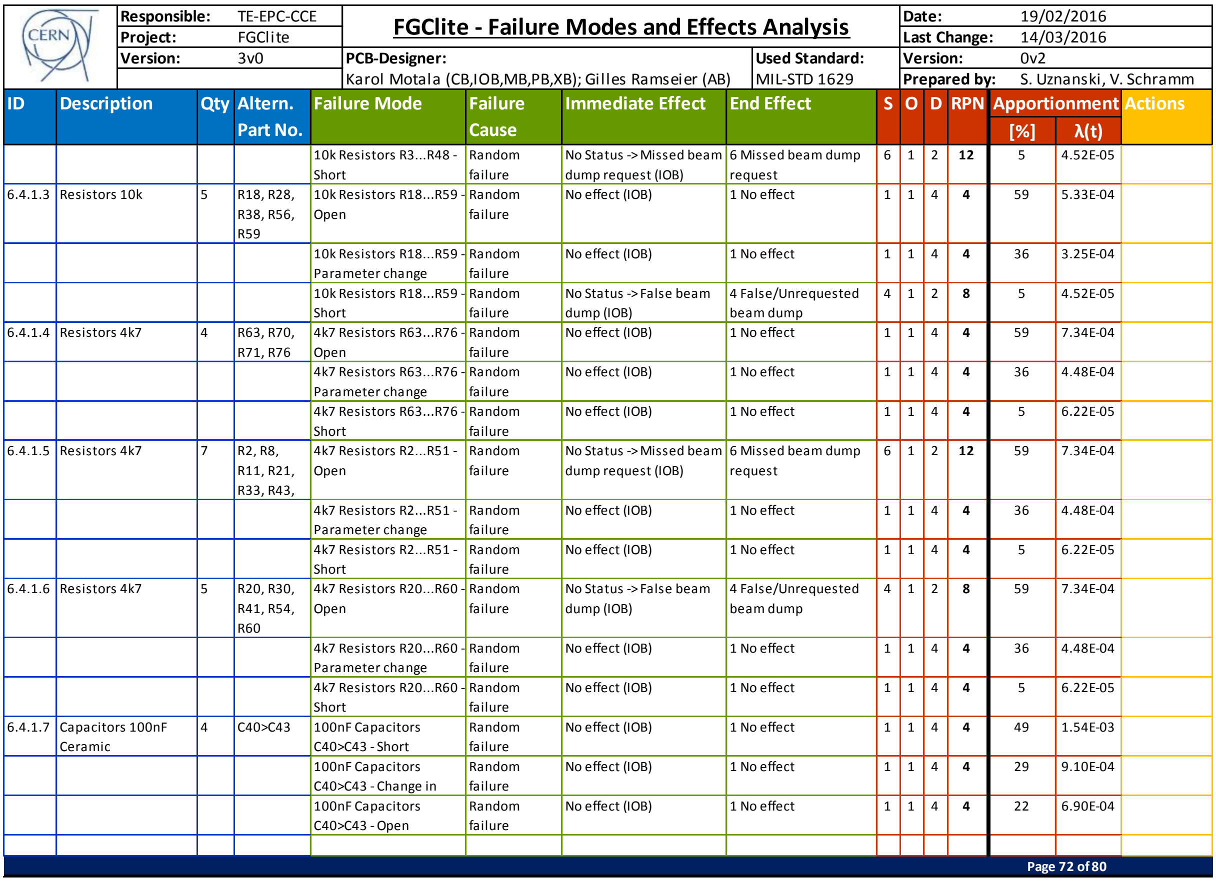

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - Failure Modes and Effects Analysis

PCB-Designer: Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)
Used Standard: MIL-STD 1629

Date: 19/02/2016
Last Change: 14/03/2016
Version: 0v2
Prepared by: S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment		Actions
												[%]	λ(t)	
				10k Resistors R3...R48 - Short	Random failure	No Status -> Missed beam dump request (IOB)	6 Missed beam dump request	6	1	2	**12**	5	4.52E-05	
6.4.1.3	Resistors 10k	5	R18, R28, R38, R56, R59	10k Resistors R18...R59 - Open	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	59	5.33E-04	
				10k Resistors R18...R59 - Parameter change	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	36	3.25E-04	
				10k Resistors R18...R59 - Short	Random failure	No Status -> False beam dump (IOB)	4 False/Unrequested beam dump	4	1	2	**8**	5	4.52E-05	
6.4.1.4	Resistors 4k7	4	R63, R70, R71, R76	4k7 Resistors R63...R76 - Open	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	59	7.34E-04	
				4k7 Resistors R63...R76 - Parameter change	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	36	4.48E-04	
				4k7 Resistors R63...R76 - Short	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	5	6.22E-05	
6.4.1.5	Resistors 4k7	7	R2, R8, R11, R21, R33, R43,	4k7 Resistors R2...R51 - Open	Random failure	No Status -> Missed beam dump request (IOB)	6 Missed beam dump request	6	1	2	**12**	59	7.34E-04	
				4k7 Resistors R2...R51 - Parameter change	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	36	4.48E-04	
				4k7 Resistors R2...R51 - Short	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	5	6.22E-05	
6.4.1.6	Resistors 4k7	5	R20, R30, R41, R54, R60	4k7 Resistors R20...R60 - Open	Random failure	No Status -> False beam dump (IOB)	4 False/Unrequested beam dump	4	1	2	**8**	59	7.34E-04	
				4k7 Resistors R20...R60 - Parameter change	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	36	4.48E-04	
				4k7 Resistors R20...R60 - Short	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	5	6.22E-05	
6.4.1.7	Capacitors 100nF Ceramic	4	C40>C43	100nF Capacitors C40>C43 - Short	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	49	1.54E-03	
				100nF Capacitors C40>C43 - Change in	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	29	9.10E-04	
				100nF Capacitors C40>C43 - Open	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	22	6.90E-04	

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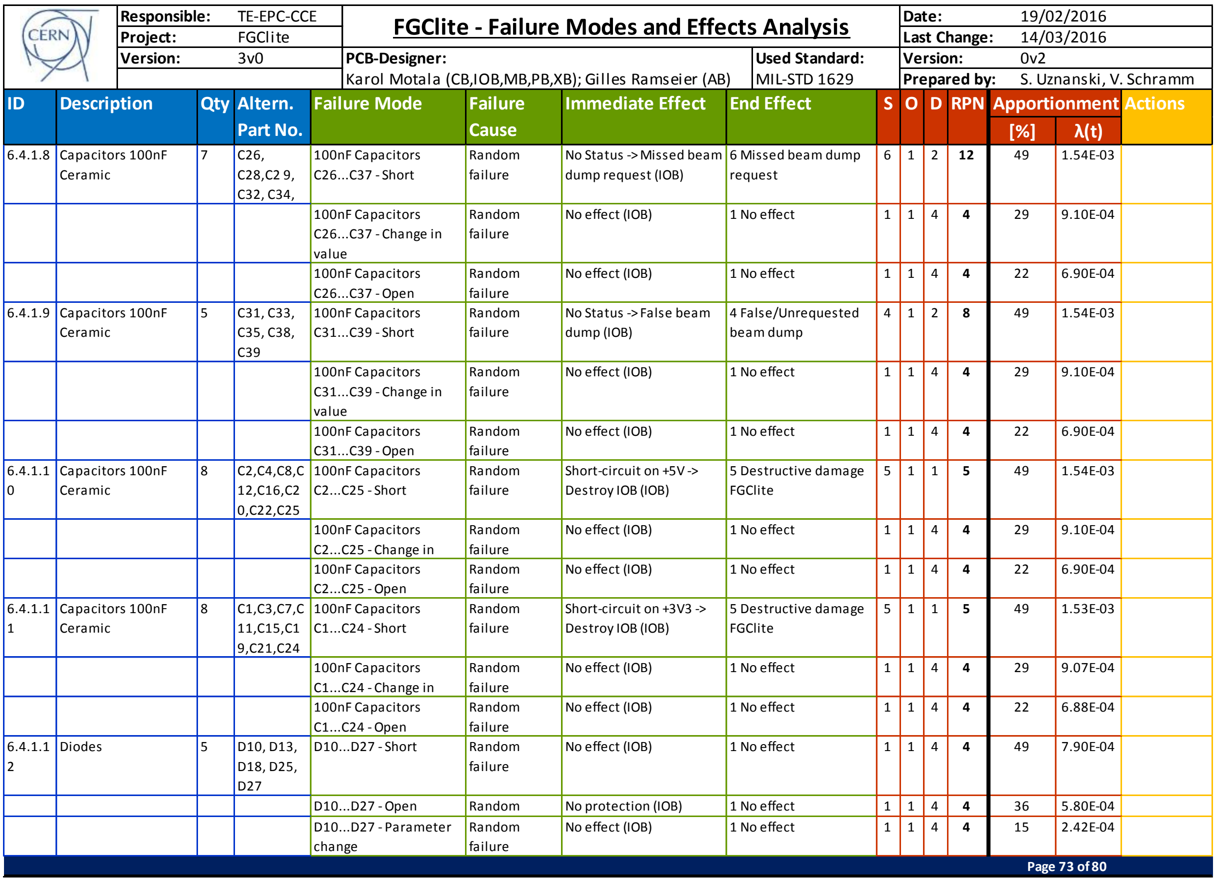

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - Failure Modes and Effects Analysis

PCB-Designer: Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)
Used Standard: MIL-STD 1629

Date: 19/02/2016
Last Change: 14/03/2016
Version: 0v2
Prepared by: S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment		Actions
												[%]	λ(t)	
6.4.1.8	Capacitors 100nF Ceramic	7	C26, C28,C2 9, C32, C34,	100nF Capacitors C26...C37 - Short	Random failure	No Status -> Missed beam dump request (IOB)	6 Missed beam dump request	6	1	2	**12**	49	1.54E-03	
				100nF Capacitors C26...C37 - Change in value	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	29	9.10E-04	
				100nF Capacitors C26...C37 - Open	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	22	6.90E-04	
6.4.1.9	Capacitors 100nF Ceramic	5	C31, C33, C35, C38, C39	100nF Capacitors C31...C39 - Short	Random failure	No Status -> False beam dump (IOB)	4 False/Unrequested beam dump	4	1	2	**8**	49	1.54E-03	
				100nF Capacitors C31...C39 - Change in value	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	29	9.10E-04	
				100nF Capacitors C31...C39 - Open	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	22	6.90E-04	
6.4.1.10	Capacitors 100nF Ceramic	8	C2,C4,C8,C12,C16,C20,C22,C25	100nF Capacitors C2...C25 - Short	Random failure	Short-circuit on +5V -> Destroy IOB (IOB)	5 Destructive damage FGClite	5	1	1	**5**	49	1.54E-03	
				100nF Capacitors C2...C25 - Change in	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	29	9.10E-04	
				100nF Capacitors C2...C25 - Open	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	22	6.90E-04	
6.4.1.11	Capacitors 100nF Ceramic	8	C1,C3,C7,C11,C15,C19,C21,C24	100nF Capacitors C1...C24 - Short	Random failure	Short-circuit on +3V3 -> Destroy IOB (IOB)	5 Destructive damage FGClite	5	1	1	**5**	49	1.53E-03	
				100nF Capacitors C1...C24 - Change in	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	29	9.07E-04	
				100nF Capacitors C1...C24 - Open	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	22	6.88E-04	
6.4.1.12	Diodes	5	D10, D13, D18, D25, D27	D10...D27 - Short	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	49	7.90E-04	
				D10...D27 - Open	Random failure	No protection (IOB)	1 No effect	1	1	4	**4**	36	5.80E-04	
				D10...D27 - Parameter change	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	15	2.42E-04	

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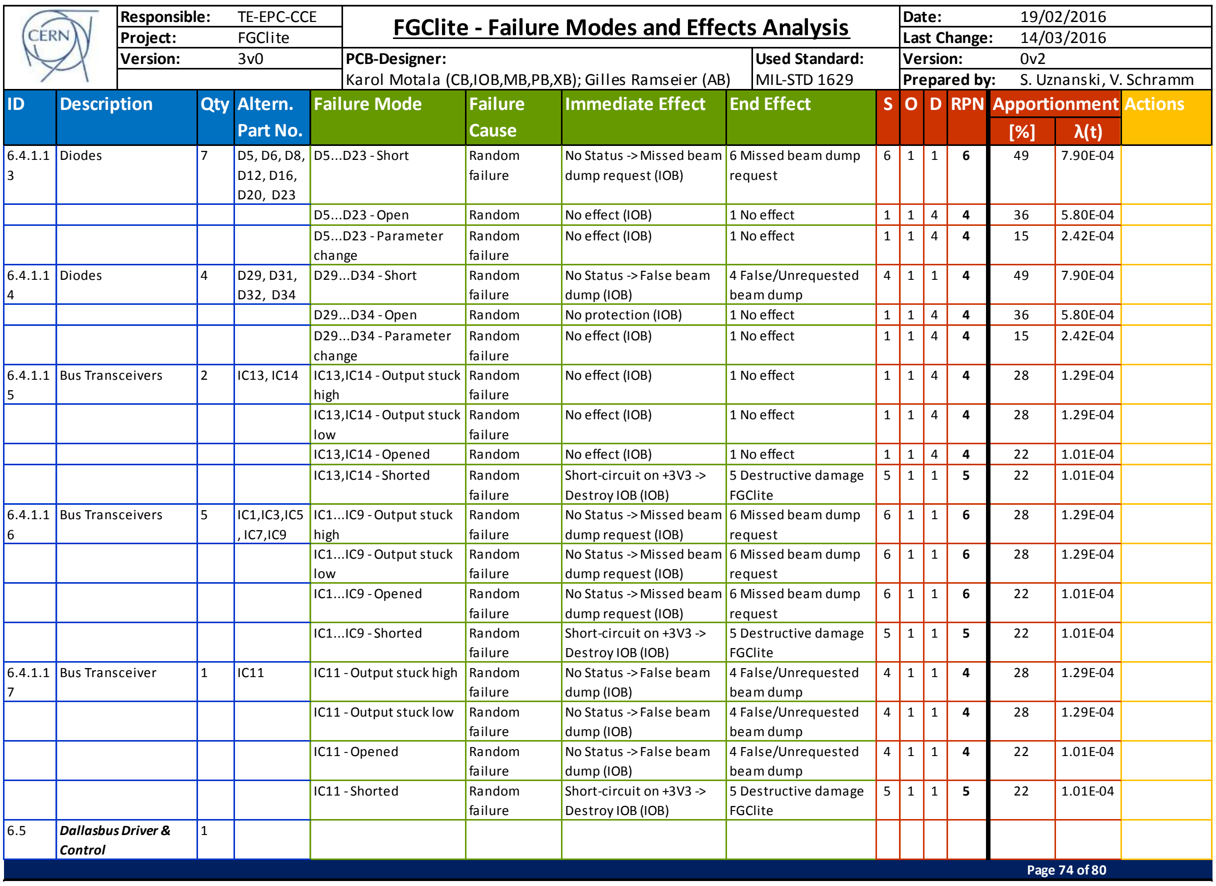

Responsible:	TE-EPC-CCE	**FGClite - Failure Modes and Effects Analysis**		**Date:**	19/02/2016
Project:	FGClite			**Last Change:**	14/03/2016
Version:	3v0	**PCB-Designer:**	**Used Standard:**	**Version:**	0v2
		Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)	MIL-STD 1629	**Prepared by:**	S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment		Actions
												[%]	λ(t)	
6.4.1.13	Diodes	7	D5, D6, D8, D12, D16, D20, D23	D5...D23 - Short	Random failure	No Status -> Missed beam dump request (IOB)	6 Missed beam dump request	6	1	1	6	49	7.90E-04	
				D5...D23 - Open	Random	No effect (IOB)	1 No effect	1	1	4	4	36	5.80E-04	
				D5...D23 - Parameter change	Random failure	No effect (IOB)	1 No effect	1	1	4	4	15	2.42E-04	
6.4.1.14	Diodes	4	D29, D31, D32, D34	D29...D34 - Short	Random failure	No Status -> False beam dump (IOB)	4 False/Unrequested beam dump	4	1	1	4	49	7.90E-04	
				D29...D34 - Open	Random	No protection (IOB)	1 No effect	1	1	4	4	36	5.80E-04	
				D29...D34 - Parameter change	Random failure	No effect (IOB)	1 No effect	1	1	4	4	15	2.42E-04	
6.4.1.15	Bus Transceivers	2	IC13, IC14	IC13,IC14 - Output stuck high	Random failure	No effect (IOB)	1 No effect	1	1	4	4	28	1.29E-04	
				IC13,IC14 - Output stuck low	Random failure	No effect (IOB)	1 No effect	1	1	4	4	28	1.29E-04	
				IC13,IC14 - Opened	Random	No effect (IOB)	1 No effect	1	1	4	4	22	1.01E-04	
				IC13,IC14 - Shorted	Random failure	Short-circuit on +3V3 -> Destroy IOB (IOB)	5 Destructive damage FGClite	5	1	1	5	22	1.01E-04	
6.4.1.16	Bus Transceivers	5	IC1,IC3,IC5, IC7,IC9	IC1...IC9 - Output stuck high	Random failure	No Status -> Missed beam dump request (IOB)	6 Missed beam dump request	6	1	1	6	28	1.29E-04	
				IC1...IC9 - Output stuck low	Random failure	No Status -> Missed beam dump request (IOB)	6 Missed beam dump request	6	1	1	6	28	1.29E-04	
				IC1...IC9 - Opened	Random failure	No Status -> Missed beam dump request (IOB)	6 Missed beam dump request	6	1	1	6	22	1.01E-04	
				IC1...IC9 - Shorted	Random failure	Short-circuit on +3V3 -> Destroy IOB (IOB)	5 Destructive damage FGClite	5	1	1	5	22	1.01E-04	
6.4.1.17	Bus Transceiver	1	IC11	IC11 - Output stuck high	Random failure	No Status -> False beam dump (IOB)	4 False/Unrequested beam dump	4	1	1	4	28	1.29E-04	
				IC11 - Output stuck low	Random failure	No Status -> False beam dump (IOB)	4 False/Unrequested beam dump	4	1	1	4	28	1.29E-04	
				IC11 - Opened	Random failure	No Status -> False beam dump (IOB)	4 False/Unrequested beam dump	4	1	1	4	22	1.01E-04	
				IC11 - Shorted	Random failure	Short-circuit on +3V3 -> Destroy IOB (IOB)	5 Destructive damage FGClite	5	1	1	5	22	1.01E-04	
6.5	***Dallasbus Driver & Control***	1												

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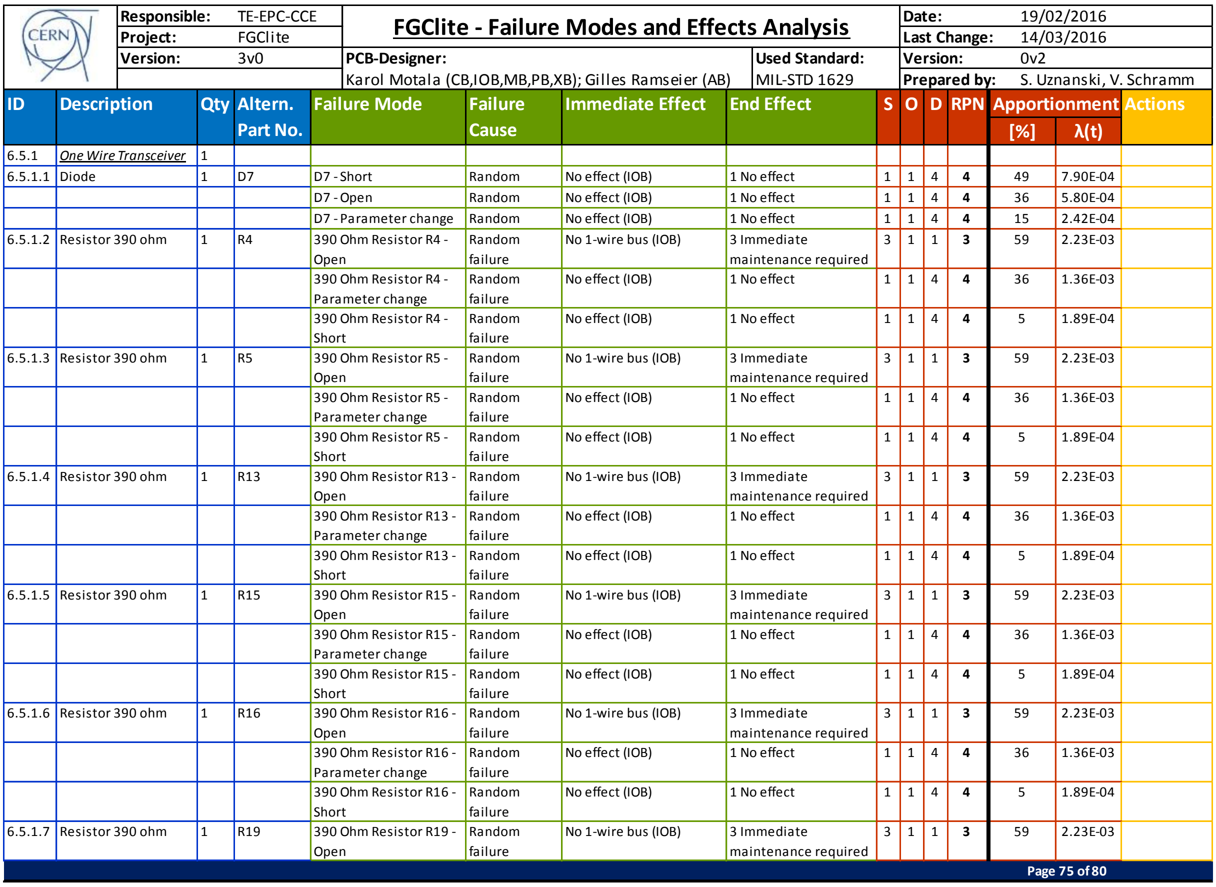

Responsible:	TE-EPC-CCE	**FGClite - Failure Modes and Effects Analysis**		**Date:**	19/02/2016
Project:	FGClite			**Last Change:**	14/03/2016
Version:	3v0	**PCB-Designer:**	**Used Standard:**	**Version:**	0v2
		Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)	MIL-STD 1629	**Prepared by:**	S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment		Actions
												[%]	λ(t)	
6.5.1	*One Wire Transceiver*	1												
6.5.1.1	Diode	1	D7	D7 - Short	Random	No effect (IOB)	1 No effect	1	1	4	4	49	7.90E-04	
				D7 - Open	Random	No effect (IOB)	1 No effect	1	1	4	4	36	5.80E-04	
				D7 - Parameter change	Random	No effect (IOB)	1 No effect	1	1	4	4	15	2.42E-04	
6.5.1.2	Resistor 390 ohm	1	R4	390 Ohm Resistor R4 - Open	Random failure	No 1-wire bus (IOB)	3 Immediate maintenance required	3	1	1	3	59	2.23E-03	
				390 Ohm Resistor R4 - Parameter change	Random failure	No effect (IOB)	1 No effect	1	1	4	4	36	1.36E-03	
				390 Ohm Resistor R4 - Short	Random failure	No effect (IOB)	1 No effect	1	1	4	4	5	1.89E-04	
6.5.1.3	Resistor 390 ohm	1	R5	390 Ohm Resistor R5 - Open	Random failure	No 1-wire bus (IOB)	3 Immediate maintenance required	3	1	1	3	59	2.23E-03	
				390 Ohm Resistor R5 - Parameter change	Random failure	No effect (IOB)	1 No effect	1	1	4	4	36	1.36E-03	
				390 Ohm Resistor R5 - Short	Random failure	No effect (IOB)	1 No effect	1	1	4	4	5	1.89E-04	
6.5.1.4	Resistor 390 ohm	1	R13	390 Ohm Resistor R13 - Open	Random failure	No 1-wire bus (IOB)	3 Immediate maintenance required	3	1	1	3	59	2.23E-03	
				390 Ohm Resistor R13 - Parameter change	Random failure	No effect (IOB)	1 No effect	1	1	4	4	36	1.36E-03	
				390 Ohm Resistor R13 - Short	Random failure	No effect (IOB)	1 No effect	1	1	4	4	5	1.89E-04	
6.5.1.5	Resistor 390 ohm	1	R15	390 Ohm Resistor R15 - Open	Random failure	No 1-wire bus (IOB)	3 Immediate maintenance required	3	1	1	3	59	2.23E-03	
				390 Ohm Resistor R15 - Parameter change	Random failure	No effect (IOB)	1 No effect	1	1	4	4	36	1.36E-03	
				390 Ohm Resistor R15 - Short	Random failure	No effect (IOB)	1 No effect	1	1	4	4	5	1.89E-04	
6.5.1.6	Resistor 390 ohm	1	R16	390 Ohm Resistor R16 - Open	Random failure	No 1-wire bus (IOB)	3 Immediate maintenance required	3	1	1	3	59	2.23E-03	
				390 Ohm Resistor R16 - Parameter change	Random failure	No effect (IOB)	1 No effect	1	1	4	4	36	1.36E-03	
				390 Ohm Resistor R16 - Short	Random failure	No effect (IOB)	1 No effect	1	1	4	4	5	1.89E-04	
6.5.1.7	Resistor 390 ohm	1	R19	390 Ohm Resistor R19 - Open	Random failure	No 1-wire bus (IOB)	3 Immediate maintenance required	3	1	1	3	59	2.23E-03	

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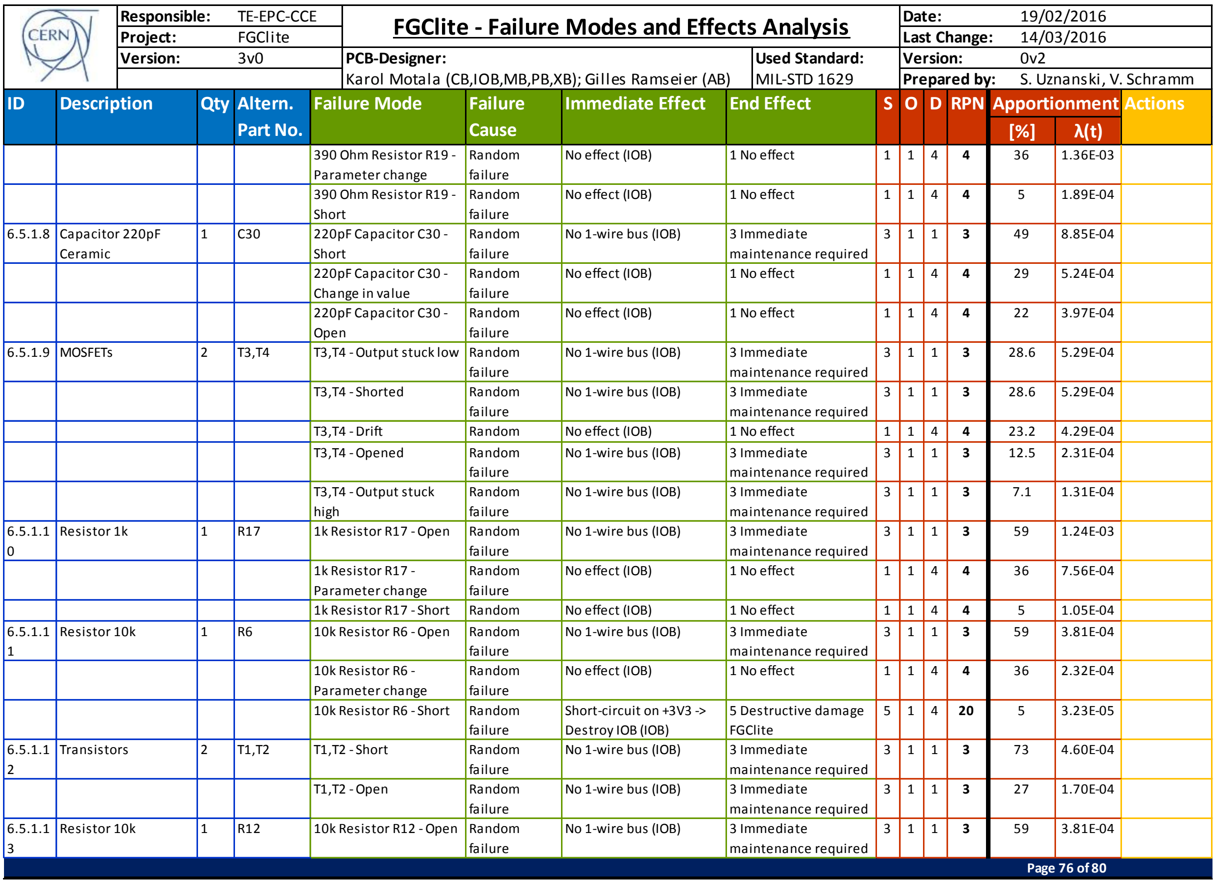

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - Failure Modes and Effects Analysis

Date: 19/02/2016
Last Change: 14/03/2016
Version: 0v2
PCB-Designer: Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)
Used Standard: MIL-STD 1629
Prepared by: S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment		Actions
												[%]	λ(t)	
				390 Ohm Resistor R19 - Parameter change	Random failure	No effect (IOB)	1 No effect	1	1	4	4	36	1.36E-03	
				390 Ohm Resistor R19 - Short	Random failure	No effect (IOB)	1 No effect	1	1	4	4	5	1.89E-04	
6.5.1.8	Capacitor 220pF Ceramic	1	C30	220pF Capacitor C30 - Short	Random failure	No 1-wire bus (IOB)	3 Immediate maintenance required	3	1	1	3	49	8.85E-04	
				220pF Capacitor C30 - Change in value	Random failure	No effect (IOB)	1 No effect	1	1	4	4	29	5.24E-04	
				220pF Capacitor C30 - Open	Random failure	No effect (IOB)	1 No effect	1	1	4	4	22	3.97E-04	
6.5.1.9	MOSFETs	2	T3,T4	T3,T4 - Output stuck low	Random failure	No 1-wire bus (IOB)	3 Immediate maintenance required	3	1	1	3	28.6	5.29E-04	
				T3,T4 - Shorted	Random failure	No 1-wire bus (IOB)	3 Immediate maintenance required	3	1	1	3	28.6	5.29E-04	
				T3,T4 - Drift	Random	No effect (IOB)	1 No effect	1	1	4	4	23.2	4.29E-04	
				T3,T4 - Opened	Random failure	No 1-wire bus (IOB)	3 Immediate maintenance required	3	1	1	3	12.5	2.31E-04	
				T3,T4 - Output stuck high	Random failure	No 1-wire bus (IOB)	3 Immediate maintenance required	3	1	1	3	7.1	1.31E-04	
6.5.1.10	Resistor 1k	1	R17	1k Resistor R17 - Open	Random failure	No 1-wire bus (IOB)	3 Immediate maintenance required	3	1	1	3	59	1.24E-03	
				1k Resistor R17 - Parameter change	Random failure	No effect (IOB)	1 No effect	1	1	4	4	36	7.56E-04	
				1k Resistor R17 - Short	Random	No effect (IOB)	1 No effect	1	1	4	4	5	1.05E-04	
6.5.1.11	Resistor 10k	1	R6	10k Resistor R6 - Open	Random failure	No 1-wire bus (IOB)	3 Immediate maintenance required	3	1	1	3	59	3.81E-04	
				10k Resistor R6 - Parameter change	Random failure	No effect (IOB)	1 No effect	1	1	4	4	36	2.32E-04	
				10k Resistor R6 - Short	Random failure	Short-circuit on +3V3 -> Destroy IOB (IOB)	5 Destructive damage FGClite	5	1	4	20	5	3.23E-05	
6.5.1.12	Transistors	2	T1,T2	T1,T2 - Short	Random failure	No 1-wire bus (IOB)	3 Immediate maintenance required	3	1	1	3	73	4.60E-04	
				T1,T2 - Open	Random failure	No 1-wire bus (IOB)	3 Immediate maintenance required	3	1	1	3	27	1.70E-04	
6.5.1.13	Resistor 10k	1	R12	10k Resistor R12 - Open	Random failure	No 1-wire bus (IOB)	3 Immediate maintenance required	3	1	1	3	59	3.81E-04	

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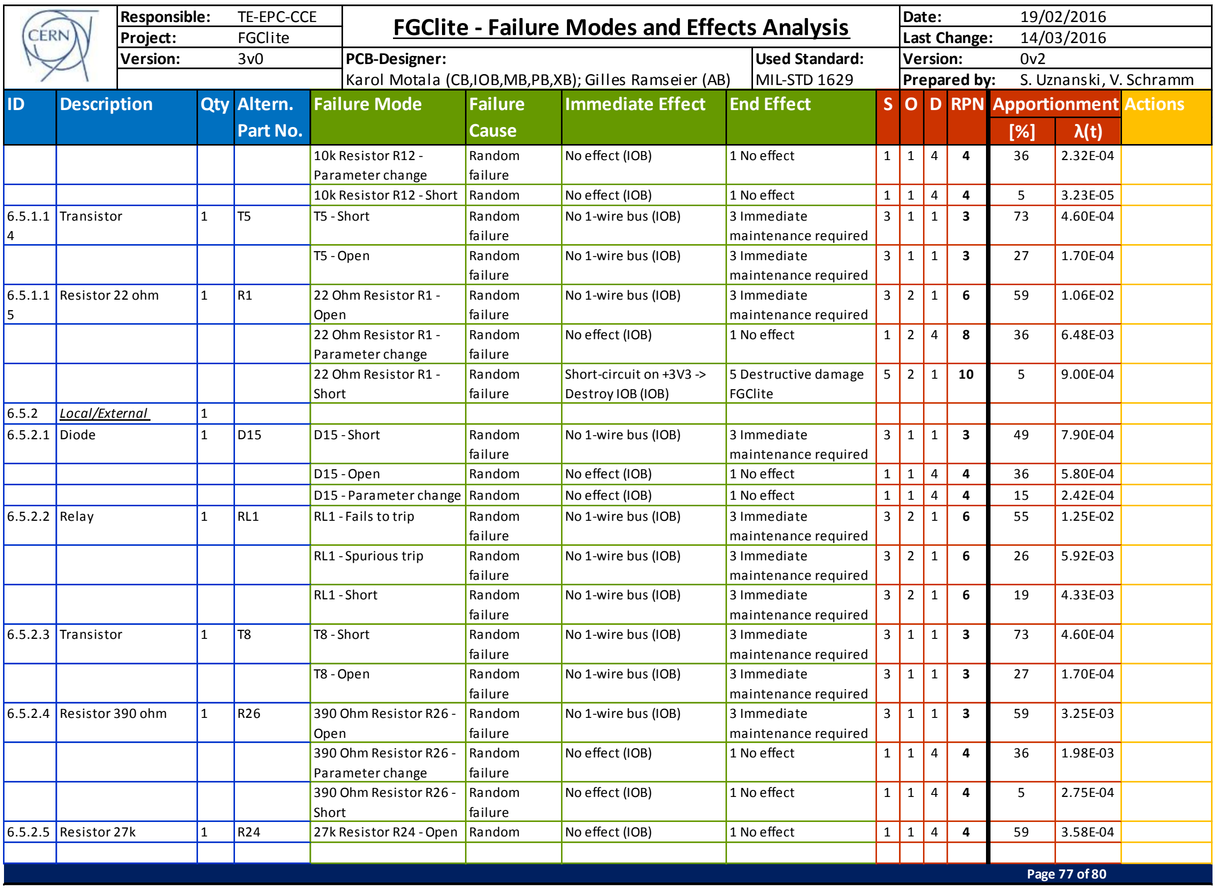

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - Failure Modes and Effects Analysis

Date: 19/02/2016
Last Change: 14/03/2016
Version: 0v2
PCB-Designer: Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)
Used Standard: MIL-STD 1629
Prepared by: S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment		Actions
												[%]	λ(t)	
				10k Resistor R12 - Parameter change	Random failure	No effect (IOB)	1 No effect	1	1	4	4	36	2.32E-04	
				10k Resistor R12 - Short	Random	No effect (IOB)	1 No effect	1	1	4	4	5	3.23E-05	
6.5.1.14	Transistor	1	T5	T5 - Short	Random failure	No 1-wire bus (IOB)	3 Immediate maintenance required	3	1	1	3	73	4.60E-04	
				T5 - Open	Random failure	No 1-wire bus (IOB)	3 Immediate maintenance required	3	1	1	3	27	1.70E-04	
6.5.1.15	Resistor 22 ohm	1	R1	22 Ohm Resistor R1 - Open	Random failure	No 1-wire bus (IOB)	3 Immediate maintenance required	3	2	1	6	59	1.06E-02	
				22 Ohm Resistor R1 - Parameter change	Random failure	No effect (IOB)	1 No effect	1	2	4	8	36	6.48E-03	
				22 Ohm Resistor R1 - Short	Random failure	Short-circuit on +3V3 -> Destroy IOB (IOB)	5 Destructive damage FGClite	5	2	1	10	5	9.00E-04	
6.5.2	*Local/External*	1												
6.5.2.1	Diode	1	D15	D15 - Short	Random failure	No 1-wire bus (IOB)	3 Immediate maintenance required	3	1	1	3	49	7.90E-04	
				D15 - Open	Random	No effect (IOB)	1 No effect	1	1	4	4	36	5.80E-04	
				D15 - Parameter change	Random	No effect (IOB)	1 No effect	1	1	4	4	15	2.42E-04	
6.5.2.2	Relay	1	RL1	RL1 - Fails to trip	Random failure	No 1-wire bus (IOB)	3 Immediate maintenance required	3	2	1	6	55	1.25E-02	
				RL1 - Spurious trip	Random failure	No 1-wire bus (IOB)	3 Immediate maintenance required	3	2	1	6	26	5.92E-03	
				RL1 - Short	Random failure	No 1-wire bus (IOB)	3 Immediate maintenance required	3	2	1	6	19	4.33E-03	
6.5.2.3	Transistor	1	T8	T8 - Short	Random failure	No 1-wire bus (IOB)	3 Immediate maintenance required	3	1	1	3	73	4.60E-04	
				T8 - Open	Random failure	No 1-wire bus (IOB)	3 Immediate maintenance required	3	1	1	3	27	1.70E-04	
6.5.2.4	Resistor 390 ohm	1	R26	390 Ohm Resistor R26 - Open	Random failure	No 1-wire bus (IOB)	3 Immediate maintenance required	3	1	1	3	59	3.25E-03	
				390 Ohm Resistor R26 - Parameter change	Random failure	No effect (IOB)	1 No effect	1	1	4	4	36	1.98E-03	
				390 Ohm Resistor R26 - Short	Random failure	No effect (IOB)	1 No effect	1	1	4	4	5	2.75E-04	
6.5.2.5	Resistor 27k	1	R24	27k Resistor R24 - Open	Random	No effect (IOB)	1 No effect	1	1	4	4	59	3.58E-04	

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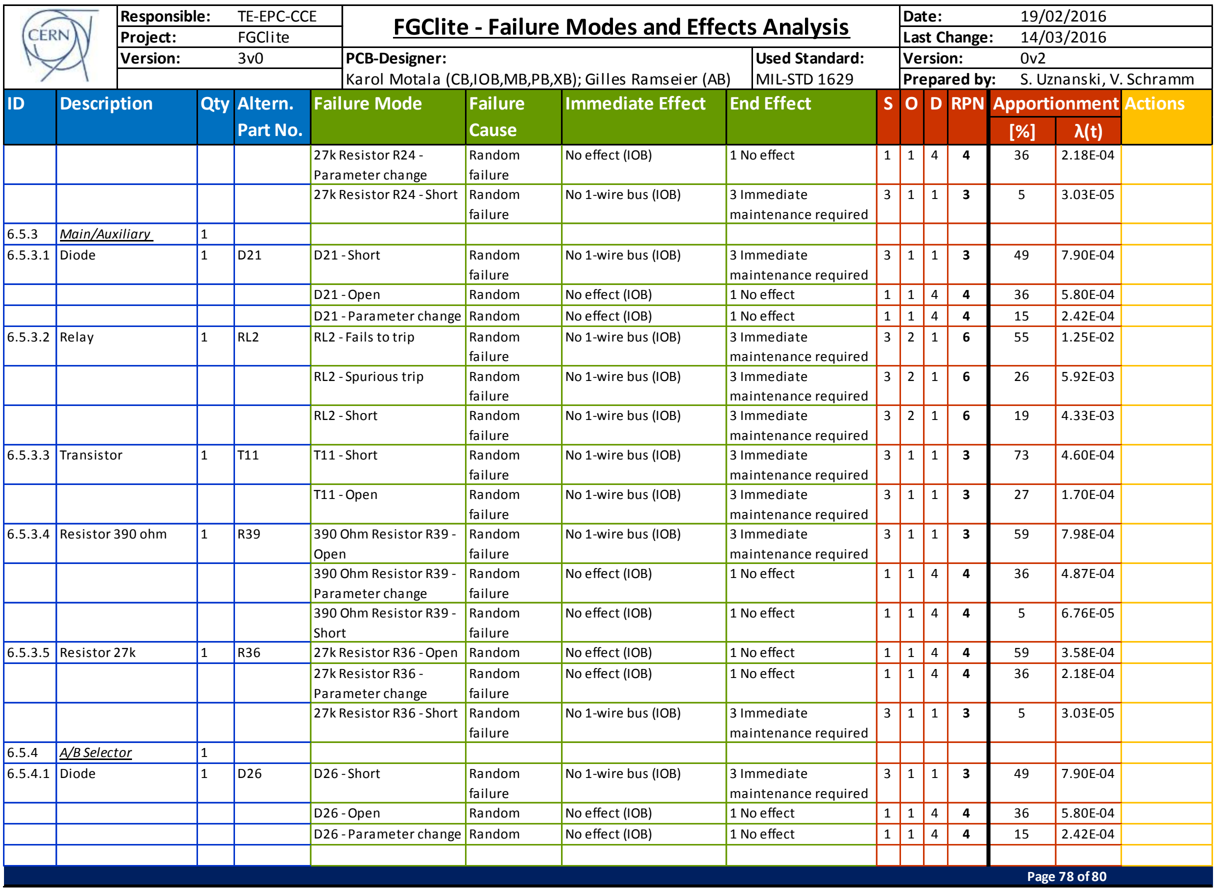

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - Failure Modes and Effects Analysis

PCB-Designer: Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)
Used Standard: MIL-STD 1629
Date: 19/02/2016
Last Change: 14/03/2016
Version: 0v2
Prepared by: S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment [%]	λ(t)	Actions
				27k Resistor R24 - Parameter change	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	36	2.18E-04	
				27k Resistor R24 - Short	Random failure	No 1-wire bus (IOB)	3 Immediate maintenance required	3	1	1	**3**	5	3.03E-05	
6.5.3	*Main/Auxiliary*	1												
6.5.3.1	Diode	1	D21	D21 - Short	Random failure	No 1-wire bus (IOB)	3 Immediate maintenance required	3	1	1	**3**	49	7.90E-04	
				D21 - Open	Random	No effect (IOB)	1 No effect	1	1	4	**4**	36	5.80E-04	
				D21 - Parameter change	Random	No effect (IOB)	1 No effect	1	1	4	**4**	15	2.42E-04	
6.5.3.2	Relay	1	RL2	RL2 - Fails to trip	Random failure	No 1-wire bus (IOB)	3 Immediate maintenance required	3	2	1	**6**	55	1.25E-02	
				RL2 - Spurious trip	Random failure	No 1-wire bus (IOB)	3 Immediate maintenance required	3	2	1	**6**	26	5.92E-03	
				RL2 - Short	Random failure	No 1-wire bus (IOB)	3 Immediate maintenance required	3	2	1	**6**	19	4.33E-03	
6.5.3.3	Transistor	1	T11	T11 - Short	Random failure	No 1-wire bus (IOB)	3 Immediate maintenance required	3	1	1	**3**	73	4.60E-04	
				T11 - Open	Random failure	No 1-wire bus (IOB)	3 Immediate maintenance required	3	1	1	**3**	27	1.70E-04	
6.5.3.4	Resistor 390 ohm	1	R39	390 Ohm Resistor R39 - Open	Random failure	No 1-wire bus (IOB)	3 Immediate maintenance required	3	1	1	**3**	59	7.98E-04	
				390 Ohm Resistor R39 - Parameter change	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	36	4.87E-04	
				390 Ohm Resistor R39 - Short	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	5	6.76E-05	
6.5.3.5	Resistor 27k	1	R36	27k Resistor R36 - Open	Random	No effect (IOB)	1 No effect	1	1	4	**4**	59	3.58E-04	
				27k Resistor R36 - Parameter change	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	36	2.18E-04	
				27k Resistor R36 - Short	Random failure	No 1-wire bus (IOB)	3 Immediate maintenance required	3	1	1	**3**	5	3.03E-05	
6.5.4	*A/B Selector*	1												
6.5.4.1	Diode	1	D26	D26 - Short	Random failure	No 1-wire bus (IOB)	3 Immediate maintenance required	3	1	1	**3**	49	7.90E-04	
				D26 - Open	Random	No effect (IOB)	1 No effect	1	1	4	**4**	36	5.80E-04	
				D26 - Parameter change	Random	No effect (IOB)	1 No effect	1	1	4	**4**	15	2.42E-04	

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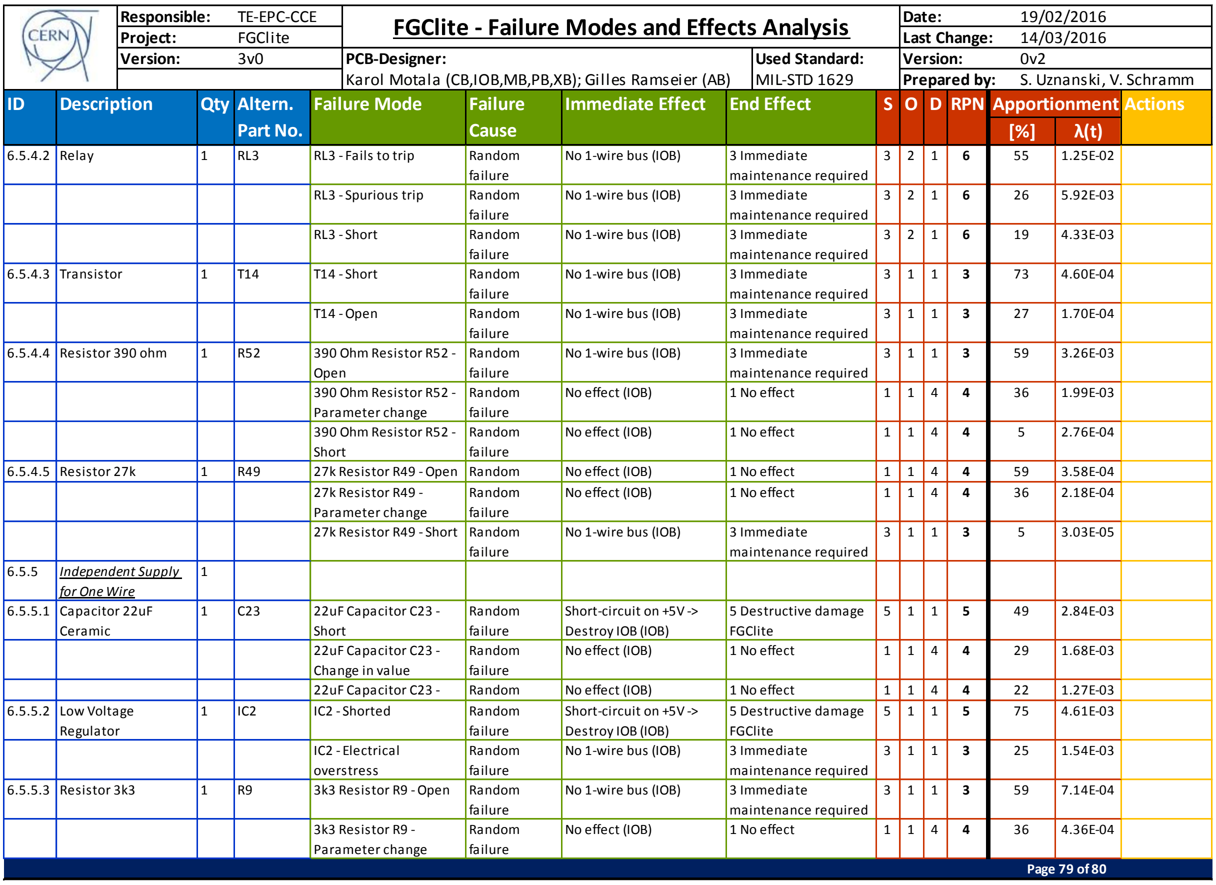

Responsible: TE-EPC-CCE
Project: FGClite
Version: 3v0

FGClite - Failure Modes and Effects Analysis

PCB-Designer: Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)
Used Standard: MIL-STD 1629
Date: 19/02/2016
Last Change: 14/03/2016
Version: 0v2
Prepared by: S. Uznanski, V. Schramm

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment [%]	λ(t)	Actions
6.5.4.2	Relay	1	RL3	RL3 - Fails to trip	Random failure	No 1-wire bus (IOB)	3 Immediate maintenance required	3	2	1	**6**	55	1.25E-02	
				RL3 - Spurious trip	Random failure	No 1-wire bus (IOB)	3 Immediate maintenance required	3	2	1	**6**	26	5.92E-03	
				RL3 - Short	Random failure	No 1-wire bus (IOB)	3 Immediate maintenance required	3	2	1	**6**	19	4.33E-03	
6.5.4.3	Transistor	1	T14	T14 - Short	Random failure	No 1-wire bus (IOB)	3 Immediate maintenance required	3	1	1	**3**	73	4.60E-04	
				T14 - Open	Random failure	No 1-wire bus (IOB)	3 Immediate maintenance required	3	1	1	**3**	27	1.70E-04	
6.5.4.4	Resistor 390 ohm	1	R52	390 Ohm Resistor R52 - Open	Random failure	No 1-wire bus (IOB)	3 Immediate maintenance required	3	1	1	**3**	59	3.26E-03	
				390 Ohm Resistor R52 - Parameter change	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	36	1.99E-03	
				390 Ohm Resistor R52 - Short	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	5	2.76E-04	
6.5.4.5	Resistor 27k	1	R49	27k Resistor R49 - Open	Random	No effect (IOB)	1 No effect	1	1	4	**4**	59	3.58E-04	
				27k Resistor R49 - Parameter change	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	36	2.18E-04	
				27k Resistor R49 - Short	Random failure	No 1-wire bus (IOB)	3 Immediate maintenance required	3	1	1	**3**	5	3.03E-05	
6.5.5	*Independent Supply for One Wire*	1												
6.5.5.1	Capacitor 22uF Ceramic	1	C23	22uF Capacitor C23 - Short	Random failure	Short-circuit on +5V -> Destroy IOB (IOB)	5 Destructive damage FGClite	5	1	1	**5**	49	2.84E-03	
				22uF Capacitor C23 - Change in value	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	29	1.68E-03	
				22uF Capacitor C23 -	Random	No effect (IOB)	1 No effect	1	1	4	**4**	22	1.27E-03	
6.5.5.2	Low Voltage Regulator	1	IC2	IC2 - Shorted	Random failure	Short-circuit on +5V -> Destroy IOB (IOB)	5 Destructive damage FGClite	5	1	1	**5**	75	4.61E-03	
				IC2 - Electrical overstress	Random failure	No 1-wire bus (IOB)	3 Immediate maintenance required	3	1	1	**3**	25	1.54E-03	
6.5.5.3	Resistor 3k3	1	R9	3k3 Resistor R9 - Open	Random failure	No 1-wire bus (IOB)	3 Immediate maintenance required	3	1	1	**3**	59	7.14E-04	
				3k3 Resistor R9 - Parameter change	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	36	4.36E-04	

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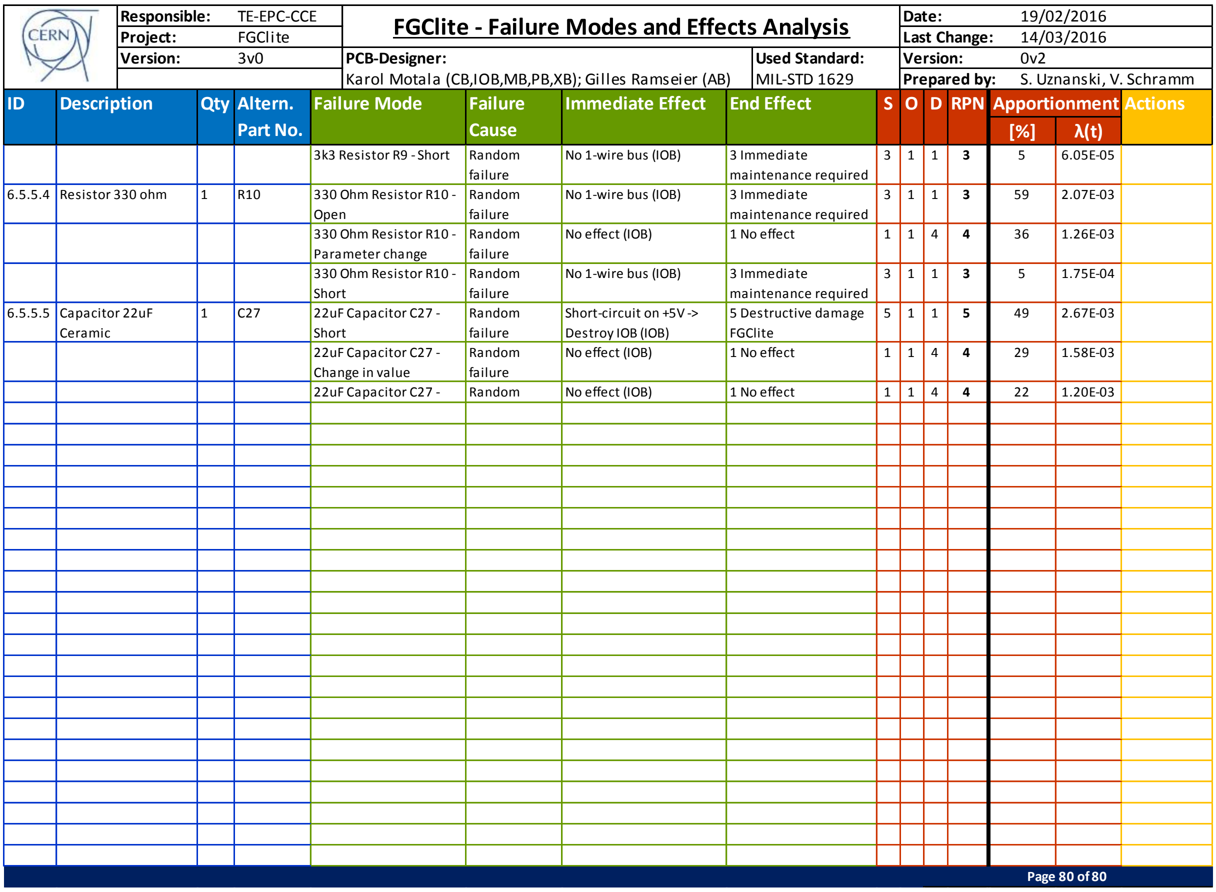

Responsible:	TE-EPC-CCE	**Date:**	19/02/2016
Project:	FGClite	**Last Change:**	14/03/2016
Version:	3v0	**Version:**	0v2
PCB-Designer:	Karol Motala (CB,IOB,MB,PB,XB); Gilles Ramseier (AB)	**Prepared by:**	S. Uznanski, V. Schramm
Used Standard:	MIL-STD 1629		

FGClite - Failure Modes and Effects Analysis

ID	Description	Qty	Altern. Part No.	Failure Mode	Failure Cause	Immediate Effect	End Effect	S	O	D	RPN	Apportionment [%]	λ(t)	Actions
				3k3 Resistor R9 - Short	Random failure	No 1-wire bus (IOB)	3 Immediate maintenance required	3	1	1	**3**	5	6.05E-05	
6.5.5.4	Resistor 330 ohm	1	R10	330 Ohm Resistor R10 - Open	Random failure	No 1-wire bus (IOB)	3 Immediate maintenance required	3	1	1	**3**	59	2.07E-03	
				330 Ohm Resistor R10 - Parameter change	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	36	1.26E-03	
				330 Ohm Resistor R10 - Short	Random failure	No 1-wire bus (IOB)	3 Immediate maintenance required	3	1	1	**3**	5	1.75E-04	
6.5.5.5	Capacitor 22uF Ceramic	1	C27	22uF Capacitor C27 - Short	Random failure	Short-circuit on +5V -> Destroy IOB (IOB)	5 Destructive damage FGClite	5	1	1	**5**	49	2.67E-03	
				22uF Capacitor C27 - Change in value	Random failure	No effect (IOB)	1 No effect	1	1	4	**4**	29	1.58E-03	
				22uF Capacitor C27 -	Random	No effect (IOB)	1 No effect	1	1	4	**4**	22	1.20E-03	

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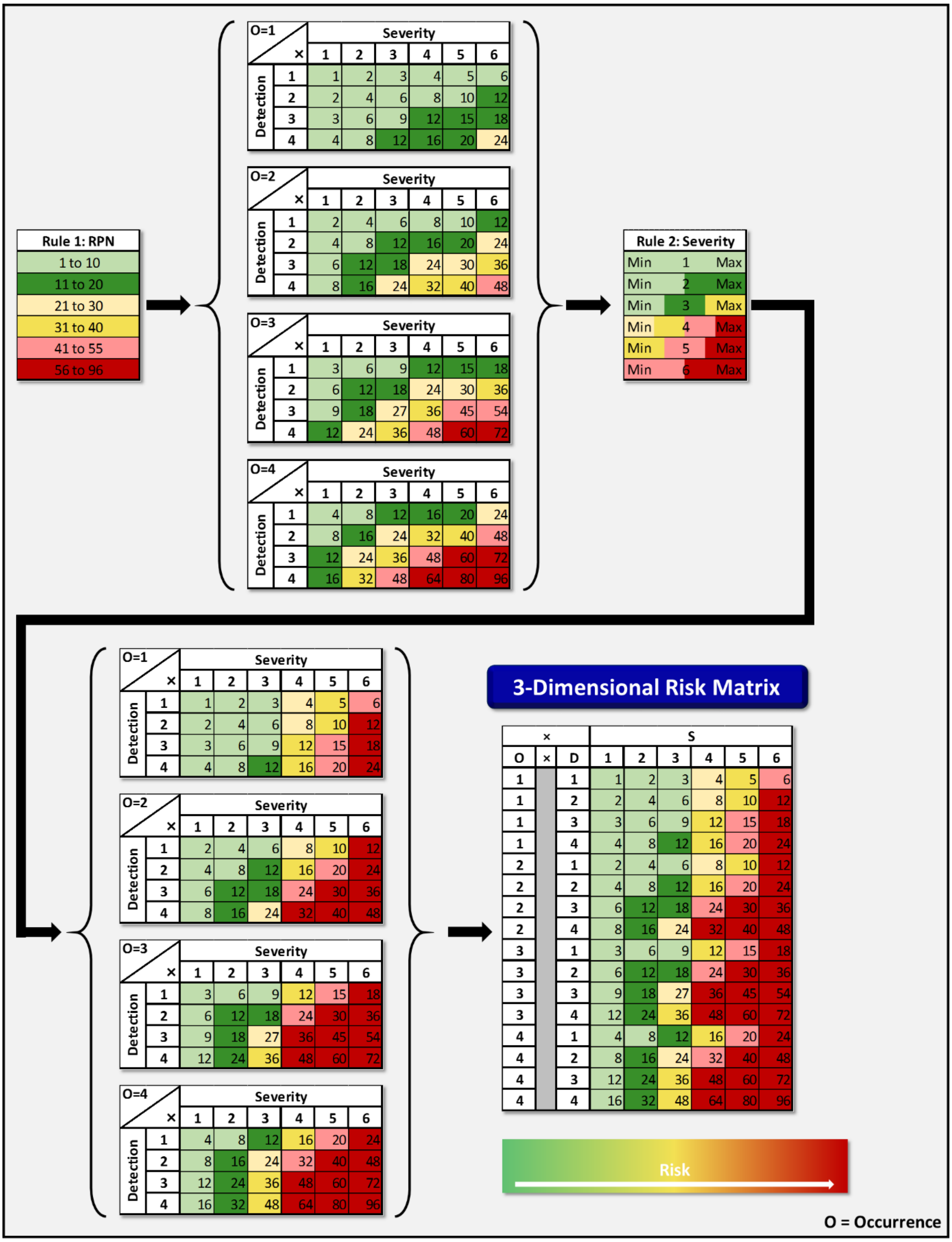
- **3-Dimensional Risk Matrix:**



Rule 1: RPN
1 to 10
11 to 20
21 to 30
31 to 40
41 to 55
56 to 96

O=1		Severity					
	×	1	2	3	4	5	6
Detection	1	1	2	3	4	5	6
	2	2	4	6	8	10	12
	3	3	6	9	12	15	18
	4	4	8	12	16	20	24

O=2		Severity					
	×	1	2	3	4	5	6
Detection	1	2	4	6	8	10	12
	2	4	8	12	16	20	24
	3	6	12	18	24	30	36
	4	8	16	24	32	40	48

O=3		Severity					
	×	1	2	3	4	5	6
Detection	1	3	6	9	12	15	18
	2	6	12	18	24	30	36
	3	9	18	27	36	45	54
	4	12	24	36	48	60	72

O=4		Severity					
	×	1	2	3	4	5	6
Detection	1	4	8	12	16	20	24
	2	8	16	24	32	40	48
	3	12	24	36	48	60	72
	4	16	32	48	64	80	96

Rule 2: Severity		
Min	1	Max
Min	2	Max
Min	3	Max
Min	4	Max
Min	5	Max
Min	6	Max

O=1		Severity					
	×	1	2	3	4	5	6
Detection	1	1	2	3	4	5	6
	2	2	4	6	8	10	12
	3	3	6	9	12	15	18
	4	4	8	12	16	20	24

O=2		Severity					
	×	1	2	3	4	5	6
Detection	1	2	4	6	8	10	12
	2	4	8	12	16	20	24
	3	6	12	18	24	30	36
	4	8	16	24	32	40	48

O=3		Severity					
	×	1	2	3	4	5	6
Detection	1	3	6	9	12	15	18
	2	6	12	18	24	30	36
	3	9	18	27	36	45	54
	4	12	24	36	48	60	72

O=4		Severity					
	×	1	2	3	4	5	6
Detection	1	4	8	12	16	20	24
	2	8	16	24	32	40	48
	3	12	24	36	48	60	72
	4	16	32	48	64	80	96

3-Dimensional Risk Matrix

×			S					
O	×	D	1	2	3	4	5	6
1		1	1	2	3	4	5	6
1		2	2	4	6	8	10	12
1		3	3	6	9	12	15	18
1		4	4	8	12	16	20	24
2		1	2	4	6	8	10	12
2		2	4	8	12	16	20	24
2		3	6	12	18	24	30	36
2		4	8	16	24	32	40	48
3		1	3	6	9	12	15	18
3		2	6	12	18	24	30	36
3		3	9	18	27	36	45	54
3		4	12	24	36	48	60	72
4		1	4	8	12	16	20	24
4		2	8	16	24	32	40	48
4		3	12	24	36	48	60	72
4		4	16	32	48	64	80	96

O = Occurrence

After applying rule 1 which is in fact only used as a basic structure, rule 2 considers each severity column of the four tables and increases the colour of the first row cell to the set minimum colour for this severity. If it is increased, the following rows get also increased by the same step of the colour scale. Coloured cells which are higher than the severity maximum of rule 2 were set to the maximum.

4.3.2 Failure Data from Repairs

Genuine data from the TE-EPC-Database							Comments
Designation	Barcode	Reparation Date	Problem	Solution	Faults		
FGC2 Generic Cassette	HCRFMBA___ GL000112	10/02/2016	fgc.psu_fgc = 5.07V, 15.00V, -8.99V	changement R21 carte DIPS	Resistor		
FGC2 COD Cassette	HCRFMCA___ GL000214	10/02/2016	impossible de reprogrammer V8 (P5)	Changement IC7, carte CPU	PLD fault,reprogramation PLD		
FGC2 Generic Cassette	HCRFMBA___ GL000468	03/02/2016	Impossible de reprogrammer P6	Changement carte memoire : OK	Xilinx		All failures occurred on different PCBs. The same reparation day has probably organization-al reasons
FGC2 Generic Cassette	HCRFMBA___ GL000480	03/02/2016	Impossible de reprogrammer P9	Changement IC21 (Analog Card)	Xilinx		
FGC2 Generic Cassette	HCRFMBA___ GL000507	03/02/2016	Impossible de reprogrammer (P12)	Changement IC1 (carte DIPS)	Xilinx		
FGC2 Generic Cassette	HCRFMBA___ GL000709	03/02/2016	Pas de leds allumees en face avant	Changement IC3 (carte NDI)	Xilinx		
FGC2 Generic Cassette	HCRFMBA___ JT000005	03/02/2016	Impossible de reprogrammer P8	Changement IC5 (carte DIG)	Xilinx		
FGC2 Generic Cassette	HCRFMBA___ JT000142	03/02/2016	Pas de leds allummees + Power cycle toutes les 7 secondes	Changement IC8 (carte memoire)	Xilinx		
FGC2 COD Cassette	HCRFMCA___ JT000161	03/02/2016	Impossible de reprogrammer (P8)	Changement IC5 (carte DIG)	PLD fault,reprogramation PLD		
FGC2 COD Cassette	HCRFMCA___ JT000005	03/02/2016	Pas de led allumees en face avant mais Power Cycle (clignotte toute les 7 secondes)	Changement IC2 (carte CPU)	Xilinx		
FGC2 Generic Cassette	HCRFMBA___ GL000861	04/11/2015	le fgc n'arrive pas a passer dans le main program et reboot	carte memoire: fil de cuivre (longueur 2 mm) coincé dans IC4 reliant pin 16,15,14	Other		
FGC2 Generic Cassette	HCRFMBA___ GL000791	04/11/2015	le bouton "reset" ne fonctionne pas	changement du bouton reset	Component		Fault: Pushbutton
FGC2 Generic Cassette	HCRFMBA___ JT000203	28/10/2015	Ne passe pas dans le Main program. "single bit error HC 16, Single bit error C32"	Changement carte memoire,(carte memoire JT 264 defectueuse)	Component		Fault: PCB
FGC2 Generic Cassette	HCRFMBA___ JT000314	28/10/2015	Faulty reports single bit error in boots	Changement IC2 sur carte Mem.	Component		Fault: RAM
FGC2 COD Cassette	HCRFMCA___ GL000688	28/10/2015	Ne passe pas dans le "main Program" et redemarre au bout de 7 s.	Changement transistor T2 sur carte SAR	Transistor		
FGC2 Generic Cassette	HCRFMBA___ GL000076	27/02/2015	Default constater sur la carte DIGITAL I/O. Test sur testeur lecture des status en defaut	Test des commandes de 1 a 8 Changer les circuits IC1 IC2 act245 Apres test toujours des defaults Changement du IC5 Xilinx 95128 Reprogrammation et test de la carte DIGITAL I/O OK Remontage dans le module test general => OK			Fault: Xilinx
FGC2 COD Cassette	HCRFMCA___ PM002009	10/09/2014	carte DIPS lecture des PSU erreur	Changement de la carte DIPS Apres test au labo et reprogrammation des FPGA et soft = OK			Fault: PCB
FGC2 COD Cassette	HCRFMCA___ GL000428	28/08/2013	Les leds restent allumées orange;	Le bouton de "teste led reste enfoncé". J'ai fraisé le panneau trou de passage des boutons. Test de fonctionnement du module OK			Fault: Other (Mechanical)
FGC2 COD Cassette	HCRFMCA___ GL000200	11/10/2012	Carte SAR defectueuse HCRFBGA___-GL000289	Changer la carte SAR : HCRFBGA___-GL000500			Fault: PCB
FGC2 COD Cassette	HCRFMCA___ GL000200	03/10/2012	DAC_Fault.	Test de la carte SAR sur testeur ; changer le DAC	ADC		Fault: DAC
FGC2 COD Cassette	HCRFMCA___ GL000500	16/09/2011	Plusieurs pannes ,pannes repetees dans la machines Erreur sur la lectures des tensions PSU Sur le testeur ,impossible de configurer les FPGA Erreur sur ADC Diag (carte DIPS)	Echanger l' ADC de la carte DIPS (ADS 7852) Impossible de programmer les FPGA ,liaison JTAG erreur Apres changement du XC 95144-pq160 et du ic XC 9536 Verification de s programmes des XILINX Module en test	ADC XC 7852 XC 95144 PQ160 (DIPS) XC 9536 (DIPS)		
FGC2 Generic Cassette	HCRFMBA___ JT000294	25/05/2011	Channel B very noisy	Test effectue au labo par Gilles Ramseier sur banc de test . resultats ov +10v _10v CH A 5n 5n 6n CH B 5n 6n 6n 146ppm = F			Fault: Other
FGC2 COD Cassette	HCRFMCA___ GL000719	17/02/2011	erreur sur ADC I_Meas (la difference entre l'erreur du canal A et du Canal B est trop importante)	Changer les ADC	ADC		
FGC2 COD Cassette	HCRFMCA___ GL000108	11/02/2011	Toutes les leds eteintes	Apres test dans sur testeur des cartes separement,remontage dans le boitier rien d'anomal .Mise sous tension pour chaffe ,de nouveau les leds eteintes			Fault: Other
FGC2 Generic Cassette	HCRFMBA___ JT000001	10/02/2011	Pin 1 du connecteur WorldFip cassé	Changer le connecteur WorldFip sur carte NDI ,test ,OK	Connection		
FGC2 COD Cassette	HCRFMCA___ JT000239	10/02/2011	Warning ID Flt non resetable	Test sur le testeur ,test des cartes separements ,carte NDI refait soudure sur bouton reset			Fault: Solder

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Genuine data from the TE-EPC-Database

Designation	Barcode	Reparation Date	Problem	Solution	Faults		Comments
FGC2 COD Cassette	HCRFMCA___JT000016	22/09/2010	Au passage dans le main programme, les trois leds PIC/DCCT/VS clignotent en rouge --> Bus error. La carte SAR semble avoir un probl?me : JtagInter : pbs pin 89,8,58,56,55,34,31,30,15 deu IC14 Unknown Lors de la mise sous tension de le carte, on voit que le -15V ana est présent (ne devrait pas l??tre). Par contre la tension +5V et +15V ana est bien off.	le probl?me provient du transistor T2. remplacement du transistor. tout est OK maintenant. Mise a jour de la version PLD 6. Cette version permet d?éviter la casse possible du transistor.	Transistor		
FGC2 Generic Cassette	HCRFMBA___GL000536	20/09/2010	remplacement de la carte analogique (celle qui a été mise a la place avait une corruption du CPLD.)	ok maintenant.	Analogic Control		Fault: PCB
FGC2 Generic Cassette	HCRFMBA___GL000408	16/09/2010	pin 1 du connecteur WFIP cassé	remplacement du connecteur. OK maintenant.	Connection		
FGC2 NDI-150A:Network/ Diagnostic Interface (Vref fix)	HCRFBBB___JT000206	18/06/2010	Impossible de programmer le Xilinx de la carte NDI IC3. fail test 36 : JtagProg,2 !Data error or timeout	le composant IC3 est casse. changement du Xilinx	Xilinx		
FGC2 MEM-250:Memory Board	HCRFBDA___JT000132	09/03/2010	fail au test: 37: memHSet,0 Mem HC16 error add0780 read0010 42: memHC16 ADD: 0x07580 EXP: 0x0080 GOT: 0x0090 ... le probl?me est présent de l' adresse 0x07580 a l'adresse 0x075FE toutes les adresses paires	la ligne de data 20 est toujours lu comme étant égale a 1 durant. Le probl?me se reproduit au adresse 0x17580, 0x27580... changement de la RAM IC14 (un bloc interne de la RAM doit etre casse). OK maintenant	RAM		
FGC2 SAR-400:SAR ADC/DAC Interface	HCRFBGA___JT000032	05/03/2010	la tension de reference +10V est mesurée par le testeur a +11V	Le probleme vient d'un desequilibre sur le reseau de resistance. le gain sur le montage inverseur n'etait plus egale a 1 d'ou une tension differente de 10V. Changement du reseau de resistance. Ok	Resistor		
FGC2 SAR-400:SAR ADC/DAC Interface	HCRFBGA___GL000049	05/03/2010	la tension de reference +10V est mesurée a -10V.	l'AOP IC3 est casse	IC3		Fault: OpAmp
FGC2 SAR-400:SAR ADC/DAC Interface	HCRFBGA___GL000023	04/03/2010	Au testeur, erreur au test 35: AnaPower,ON,2404,2783,100 DUT +15V - Meas:1391 mV Exp:2683 to 2883 mV	le transistor T2 etait cassé. changement de du transistor. OK maintenant.	Transistor		
FGC2 SAR-400:SAR ADC/DAC Interface	HCRFBGA___JT000051	04/03/2010	probleme lors de la lecture de la reference +10V valeur de la reference = 9,09V au lieu de 10V	le deux resistances utilisees sur le reseau de resistance RN1 ne sont pas egales. le rapport n'est donc pas egale a 1 d' ou la tension de 9.09V. changement du reseau de resistance. OK maintenant	Resistor		
FGC2 SAR-400:SAR ADC/DAC Interface	HCRFBGA___GL000101	04/03/2010	erreur lors du test JtagVerify	une limaille etait present sur le Xilinx IC14. supression de la limaille. tous est OK maintenant	Other		
FGC2 SD-350:Delta-Sigma ADC/DAC Interface	HCRFBFA___GL000801	02/03/2010	probleme au testeur : test 133 : AnaPoiwer,OFF,0,0,150 DUT +5V - Meas:2387 mV Exp: -150 to 150mV DUT +15V - Meas:27780mV Exp: -150 to 150mV	le Xilinx IC19 etait cassé. La sequence entre les lignes ~P_ON et ~P_DIS etait mauvaise ce qui mettait sous tension la partie analogique au lieu de l'eteindre. Changement du Xilinx. OK maintenant	Xilinx		
FGC2 SD-350:Delta-Sigma ADC/DAC Interface	HCRFBFA___GL000150	26/02/2010	via casses.	trop de via cassé. la carte est gardée pour piece	Via		
FGC2 SD-350:Delta-Sigma ADC/DAC Interface	HCRFBFA___GL000131	25/02/2010	Cette carte SD est revenu de la production de Glentronic en panne. au testeur : test 138 failed (sdFlashErase,B) error erasing Flash:700ms timeout la rapport de test acroché a la carte provenant de Glentronic montrait un soucis lors du test 44:sdFlashDataBus,B walking Data: exp:0x01 got:0x4001 etc... --> la ligne 14 des Datas semblait etre collée a 1.	soudure refaire sur la ligne BFLASHDA14 Nettoyage du Xilinx IC24 car presence de de poussiere et bille de soudure. --> possible probleme de court circuit. Test de la carte au testeur, tout est OK maintenant.	Solder		
FGC2 NDI-150A:Network /Diagnostic Interface (Vref fix)	HCRFBBB___JT000281	18/02/2010	les pins 63 (C62PROG) et 14 (+5V switch) Du xilinx IC3 etait detecté comme stuck low.	changement de la diode D8 sur la carte NDI --> court circuit franc entre le GND et le +5V swith	DS2409P		Fault: Diode
FGC2 COD Cassette	HCRFMCA___GL000160	15/02/2010	probleme sur la carte MEM. Au test 37:memSet,0 lit 0x8000 au lieu de 0x0000 surement un probleme de via	changement de la carte MEM HCRFBDA___-GL000263 par la carte HCRFBDA___-GL000098	Via		

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