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A 12 GHZ RF POWER SOURCE FOR THE CLIC STUDY

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Abstract

The CLIC RF frequency has been changed in 2008 from the initial 30 GHz to the European X-band 11.9942 GHz permitting beam independent power production using klystrons for accelerating structure testing. A design and fabrication contract for five klystrons at that frequency has been signed between three European Labs (CERN, PSI, INFN Trieste) and SLAC. France (CEA Saclay) is contributing a 12 GHz solid state modulator purchased at Scandinova to the CLIC study. RF pulses over 120 MW peak at 230 ns length will be obtained by using a novel SLED I type pulse compression scheme designed and fabricated at GYCOM in Nizhny Novgorod, Russia. The X-band power stand has been installed in the CLIC Test Facility CTF3 for independent structure testing in a bunker, but also allowing at a later stage, powering RF components in the CTF3 beam lines. The design of the facility, results from commissioning of RF components and the performance of the Test Facility are reported.

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Abstract

The CLIC RF frequency has been changed in 2008 from the initial 30 GHz to the European X-band 11.9942 GHz permitting beam independent power production using klystrons for CLIC accelerating structure testing. A design and fabrication contract for five klystrons at that frequency has been signed by different parties with SLAC. France (IRFU, CEA Saclay) is contributing a solid state modulator purchased in industry and specific 12 GHz RF network components to the CLIC study. RF pulses over 120 MW peak at 230 ns length will be obtained by using a novel SLED-I type pulse compression scheme designed and fabricated by IAP, Nizhny Novgorod, Russia. The X-band power test stand is being installed in the CLIC Test Facility CTF3 for independent structure and component testing in a bunker, but allowing, in a later stage, for powering RF components in the CTF3 beam lines. The design of the facility, results from commissioning of the RF power source and the expected performance of the Test Facility are reported.

INTRODUCTION

The CLIC study team is developing high gradient (> 100 MV/m) accelerating structures at break-down rates lower than $3 \cdot 10^{-7}$ per pulse*m for a 3 TeV linear electron-positron collider [1] where the 12 GHz main beam power would be transferred from a drive beam linac at 1GHz with very high transfer efficiency by means of so called PETS (Power Extraction and Transfer Structures). Nevertheless, 12 GHz klystron power would be needed for (pre-) processing and testing of components and, eventually, priming of PETS in special operating modes in test areas. So far, X-band klystron test facilities at 11.4 GHz are operated at SLAC and at KEK, and these facilities are used by the CLIC study in the frame of the X-band structure collaboration [2] for testing accelerating structures scaled to that frequency. However, aiming for a higher testing rate and for testing of structures and components at the European X-band frequency, test facilities will be needed at CERN. In the future it might be necessary to provide 12 GHz klystron power to components in the CTF3 beam-lines of the CLEX (CLIC Experimental Area) of the CTF3 [3]; therefore the first klystron-based power source needs to be installed in reasonable distance of CLEX bunker.

THE TEST FACILITY

The 12 GHz RF Test Stand consists of two parts located on different floors in the same building of the CTF3 (CLIC Test Facility): on the upper level, in the so-called klystron gallery, we install the power source and the RF network, connected by low-loss waveguide to the test bunker on the ground level, just below. Test Stand operation will be supervised from the local CTF3 control room.

General Layout

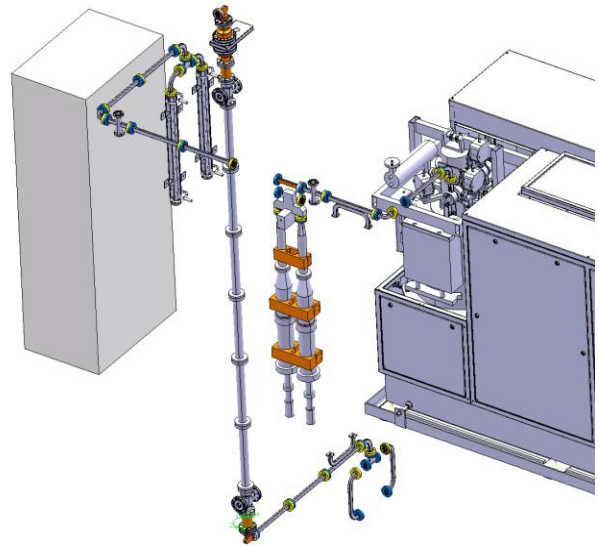


Figure.1: The 12 GHz power source plus RF network towards the structure test area on the level below.

Fig. 1 is showing a first possible layout for the power source commissioning (up-to the RF loads mounted in vertical) plus the low-loss waveguide connection to the testing area on the level below. The SLED-I pulse compressor (mounted in vertical after the directional coupler at the klystron exit) is temperature stabilized by cooling blocks plus thermal shielding.

50MW 12GHZ XL5 KLYSTRON[#]

The XL5 klystron design target is 50MW at a beam voltage below 450kV, an efficiency of 40%, a gain of 50dB and a 50MHz -3dB bandwidth. Because of the similarities with the successful existing SLAC XL4 11.424GHz klystron [4] and a desire to keep costs to a

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minimum, a design utilizing the XL4 beam formation and transport scheme was initiated. It was possible to keep the same gun, drift tunnel size, magnet and collector without sacrificing too much gain-bandwidth and peak-power performance. Since the frequency is higher and the drift tube sized for the lower frequency, the coupling between the beam and cavities suffers somewhat and this reduces both the gain-bandwidth and the peak power. However, by optimizing tuning for the required operating parameters, the design behaved similarly to the XL4 but requires an extra $\sim 20\text{kV}$ of beam voltage and hence a slight reduction in efficiency. In Fig. 2, the saturated output power for the XL4 (upper curve) and XL5 (lower curve) for various beam voltages are shown.

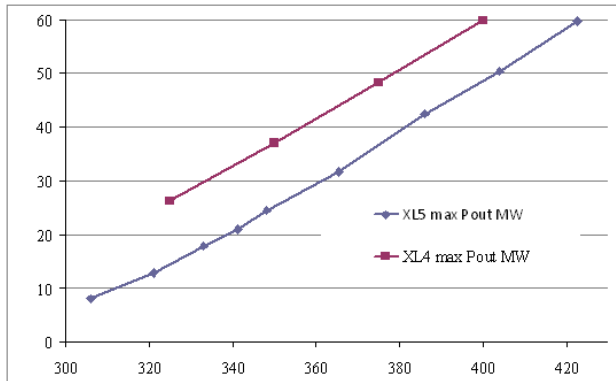


Figure 2: Saturated output power for XL4 and XL5.

Most of the major assemblies were kept the same as in the XL4 with minor modifications to the input window, gain and buncher cavities. From the exterior, the XL5 looks almost identical to an XL4 (Fig. 3). The final output cavity, dual-waveguide output, window assembly and mode converter were more substantially modified due to the required frequency and a desire to improve their robustness in terms of rf breakdown. Sharp edges and small structures in these existing parts were made less so, and the window is of larger relative diameter. Though these components are improved, and in operation did not pose any significant issues, it became clear during the design work that further improvement in klystron output components, and high-power rf waveguide components in general, is possible. Testing of the tube ran from February to April 2010. The tube exhibits no gun or rf oscillations, and spurious modes within $\pm 1\text{GHz}$ from the 11.994GHz center frequency would appear to be at least -60dB . Both small signal and saturated bandwidths appear to be 50MHz . Gain curves (Fig. 4) at various voltages indicate consistent performance over a wide range. As can be seen, the 50MW operating point can be reached at $\sim 40\text{kV}$. The klystron meets all specifications at 40kV except the measured efficiency may be slightly low at 38% . The efficiency could be increased by a change in focusing though a thorough scan of magnet settings was not completed due to time constraints and issues with breakdown of external waveguide components.



Figure 3: The XL5-1 klystron ready to ship.

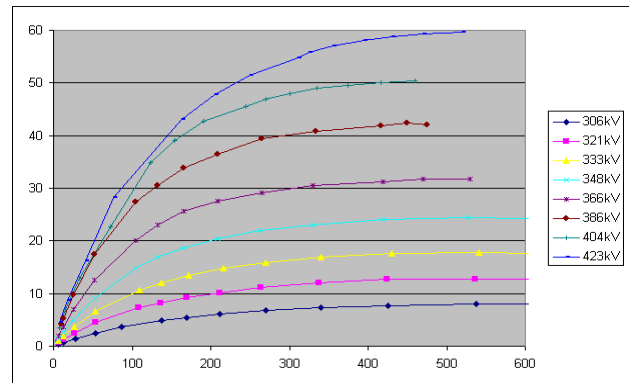


Figure 4: Gain curves at various voltages.

THE SOLID STATE MODULATOR

In the frame of the French special contribution to CERN, IRFU, CEA Saclay has purchased a modulator for the 12GHz klystron SLAC XL5, based on solid state technology. Its main components are two 1kV DC Power Supplies (DCPS), 10 High Power Switch Units (HPSU) and a High Voltage Pulse Transformer (HVPT), in addition to power supplies for the solenoid magnet of the klystron and control units. All parts of the modulator are located in a common enclosure. The 3-phase line voltage is applied to the DC Power Supplies. They charge up the 60 IGBT switches to a primary voltage of $\sim 1\text{kV}$. An external trigger pulse gates all the switches and discharges the stored energy to the pulse transformer. The pulse transformer steps up the voltage to the desired output high voltage. The main HV parameters were achieved during factory acceptance testing (FAT) with a dummy load. The flat top stability and ripple parameters have not been relevant because of the 1583 Ohms resistive load response. These additional tests will be done once the klystron mounted at CERN.

Table 1: HV Modulator FAT vs. Specs.

Parameters	Test	Specified
Peak voltage	450kV	450kV
Peak current	270A	335A
Pulse length (flat top)	~1.3 μ s	1.5 μ s
Pulse repetition rate	50pps	50pps
Max. Inverse voltage	25kV	100kV
Pulse voltage ripple	--	0.25%
Pulse to pulse stability	--	0.1%
Pulse width at 50 % (FWHM)	2.6 μ s	2.3 μ s

PULSE COMPRESSION

CLIC accelerating structures need RF pulses of ~230ns flat-top power up-to 2x60MW for testing two structures in parallel. This can be obtained with the XL5 klystron by any of the well established pulse compression schemes. Due to the space constraints and the varying temperature in the CTF3 klystron gallery, the most common SLEDII scheme [5] has not been retained for the test facility. A compact SLEDI type cavity compressor based on TE01-TE02 beating wave in high Q-factor compressor's cavities ($Q_1 \approx 25 \cdot 10^4$, $Q_0 \approx 1.5 \cdot 10^5$) has been designed and produced at IAP Nizhny Novgorod, Russia. It consists of a -3dB coupler, two mode launchers and the two high Q cavities equipped with pumping ports and plungers driven by stepping motors. The assembled compressor set-up for cold testing is shown in Fig. 5.



Figure 5: SLED-I type pulse compressor at cold testing

When driven by the 50 MW klystron power with a phase step after 1.2 μ s of 86 deg plus linear variation from 86 to 180 deg., 120 MW for 300 ns can be obtained as output assuming 15% losses in the RF network.

12 GHZ RF NETWORK

High power RF components at 12 GHz are not readily available at commercial suppliers. Many of such components have been developed at 11.4 GHz for the US high gradient research in 1990's [4] and it is straightforward in many cases to scale existing

successfully tested designs to the 11.998 GHz for CLIC and other projects.

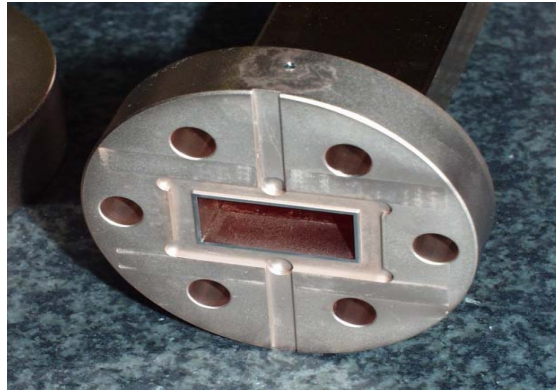


Figure 6: LIL type (unisex) RF flange

Unisex RF flanges (fig.6) of the LIL type have been scaled for the 12 GHz application, produced and successfully tested at SLAC. Most of the RF components for the 12 GHz test stand will be contributed by IRFU (CEA Saclay). Other components have been designed at CERN and built in industry.

Table 2: CEA components (* Simulated for 150 MW input power)

Components	E_{SurfMax} (MV/m)*
90° mode converter	52.5
Straight mode converter	37.2
RF Valve	0
36/50 mm circular taper	0
90° circ. waveguide bend	29
Double height hybrid splitter	In progress

CONCLUSION

The installation and the commissioning of the 12 GHz Stand-alone Test Stand at CERN is underway. The klystron and the modulator have passed the FAT and the modulator is now installed in the klystron gallery. All the newly designed RF components need to be qualified in dedicated tests and the final test stand RF network will be installed only in the last phase of commissioning. We expect to provide up to 120 MW pulses for 230 ns at 50 Hz at the level of the accelerating structure(s).

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