CLIC crab cavity final report

Burt, G et al (ULAN-CI/STFC/CERN/SLAC)

19 June 2014

The research leading to these results has received funding from the European Commission under the FP7 Research Infrastructures project EuCARD, grant agreement no. 227579.

This work is part of EuCARD Work Package **10: SC RF technology for higher intensity proton accelerators and higher energy electron linacs**.

Grant Agreement No: 227579

EuCARD

European Coordination for Accelerator Research and Development

Seventh Framework Programme, Capacities Specific Programme, Research Infrastructures,
Combination of Collaborative Project and Coordination and Support Action

DELIVERABLE REPORT

CLIC CRAB CAVITIES

DELIVERABLE: D10.3.2

Document identifier:	EUCARD-Deliverable-D10 3 2.doc
Due date of deliverable:	End of Month 36 (March 2012)
Report release date:	07/03/2013
Work package:	WP10: SRF
Lead beneficiary:	ULAN
Document status:	FINAL

Abstract:

A high gradient 12 GHz, normal-conducting travelling-wave structure, with a high group-velocity to minimise the effects of beam loading, has been developed. Appropriate input coupler and wakefield damping processes have been incorporated and two ‘undamped’ structures have been fabricated, one in the UK by Shakespeare Engineering Ltd and the other by VDL at CERN. Systematic high gradient tests are planned at SLAC and CERN, to study breakdown differences between deflecting and accelerating structures.

The European Coordination for Accelerator Research and Development (EuCARD) is a project co-funded by the European Commission in its 7th Framework Programme under the Grant Agreement no 227579. EuCARD began in April 2009 and will run for 4 years.

Delivery Slip

	Name	Partner	Date
Authored by	G. Burt, P.K. Ambattu, A. C. Dexter, C. Lingwood, B. Wooley, P. Goudket, A. Grudiev, V. Dolgashev	[ULAN-CI] [STFC] [CERN] [SLAC]	01/10/12
Edited by	G. Burt, A. Grudiev	[ULAN-CI] [CERN]	01/10/12
Reviewed by	P. McIntosh	[STFC]	01/02/13
Approved by **Project Coord.**	Jean-Pierre Koutchouk	CERN	07/03/2013

Executive Summary

Crab cavities are required for all next generation colliders, including ILC, CLIC and LHC. Each of these machines has different beam properties and hence require different cavity solutions.

CLIC beam has 312 bunches spaced at 0.5 ns, thus forming a train of 156 ns. The short train has a peak current of 1.2 A and misalignments of the beam position relative to the cavity centre can cause dipole beamloading. As the nature of beamloading is random depending on the beam position on either horizontal offsets, it can randomly modify the deflecting fileds. Visible effect of beamloading is the change in deflecting field in the cavity which cause phase and amplitude instability resulting in luminosity loss. Phase stability of the order of 20 mdeg and amplitude stability of 2 % has been targeted for the CLIC crab cavity. Thus the primary RF requirement on the CLIC crab cavity is to minimise dipole beamloading. The proposed technology choice is a normal conducting, travelling wave structure. A high group velocity is required to have a high power flow to stored energy ratio helping fast field propagation. A frequency choice of 12 GHz allows the use of existing high power, X-band infrastructure. A conventional dual-feed coupler is proposed to transversely symmetrise the deflecting field, however single-feed couplers with beamloading compensation and those without any field asymmetry were also evaluated. Waveguide dampers are proposed to control the lower, same and higher order modes (LOM, SOM, HOM respectively) in the structure, with the most threatening SOM requiring a damping of the order of Q ~ 100. Two prototypes have been manufactured for high gradient testing, one by UK industry and the other by CERN using the same manufacturer as the main linac cavities. A third prototype to be manufactured with the waveguide damped cells is also designed and its performance is being evaluated.

1. CLIC Crab Cavity

1.1 Introduction

The 20 mrad crossing angle scheme of CLIC necessitates one crab cavity per beam to rotate electron / positron bunches at the interaction point for luminosity regain. Choice of the cavity frequency is based on using the existing RF sources and test facilities available at other laboratories. Higher the frequency, lower the required deflection voltage for a given rotation. As the bunch frequency is much higher and the beam is pulsed at 50 Hz, CLIC requires a very different technology solution compared to the LHC. As the crossing angle is much larger and the beam much thinner than the LHC, (45 nm x 1 nm), the phase stability requirement is much tighter for CLIC [1]. Also the fast timescales of the order of the bunch spacing make state of the art RF control very challenging.

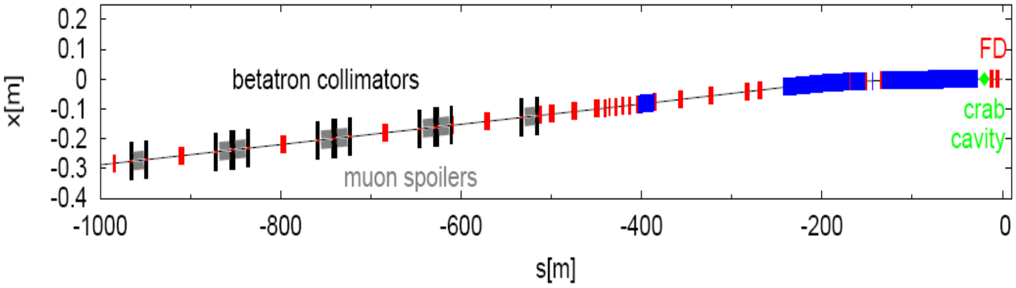
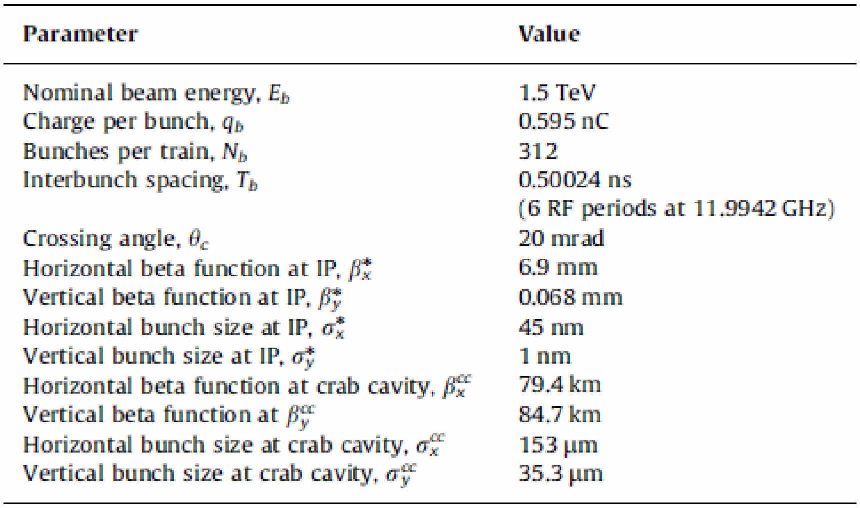


Figure 1: Location of crab cavity on the CLIC beam line

All of which has lead to the choice of the 6th bunch harmonic or 12 GHz as the RF frequency. With the high beta functions at the crab cavity location shown in Table 1, the above frequency gives a kick of 2.55 MV per beam for a crossing angle of 20 mrad. For the ease of stabilising the deflecting field against beamloading, a travelling wave structure with a group velocity of 3 % has been adopted as the baseline solution as detailed in [2].

Table 1: CLIC beam parameters [2]



Parameter	**Value**
Nominal beam energy, E_b	1.5 TeV
Charge per bunch, q_b	0.595 nC
Bunches per train, N_b	312
Interbunch spacing, T_b	0.50024 ns (6 RF periods at 11.9942 GHz)
Crossing angle, θ_c	20 mrad
Horizontal beta function at IP, β_x^*	6.9 mm
Vertical beta function at IP, β_y^*	0.068 mm
Horizontal bunch size at IP, σ_x^*	45 nm
Vertical bunch size at IP, σ_y^*	1 nm
Horizontal beta function at crab cavity, β_x^{cc}	79.4 km
Vertical beta function at β_y^{cc}	84.7 km
Horizontal bunch size at crab cavity, σ_x^{cc}	153 μm
Vertical bunch size at crab cavity, σ_y^{cc}	35.3 μm

1.2 CLIC Crab Structure Design

As mentioned above, the fast timescales and tight tolerances required in CLIC make LLRF control very difficult. As a consequence the cavity must be designed to passively minimise the effects of beamloading on the cavity voltage. This can be done by reducing the efficiency of the structure thereby minimising the voltage variation per kW of beamloading. This can be done by either maximising the ohmic losses for a given stored energy or by increasing the group velocity. As ohmic losses add to the thermal contributions, it was decided to go with a high group velocity structure and hence a travelling wave solution. A high group velocity also means a large input power is required. The maximum klystron power available is 50 MW, however this has to be split to both cavities and transported via ~ 50 meters of waveguide, hence the maximum power available at each cavity is around 15 MW, which limits the group velocity to around 3 % the speed of light.

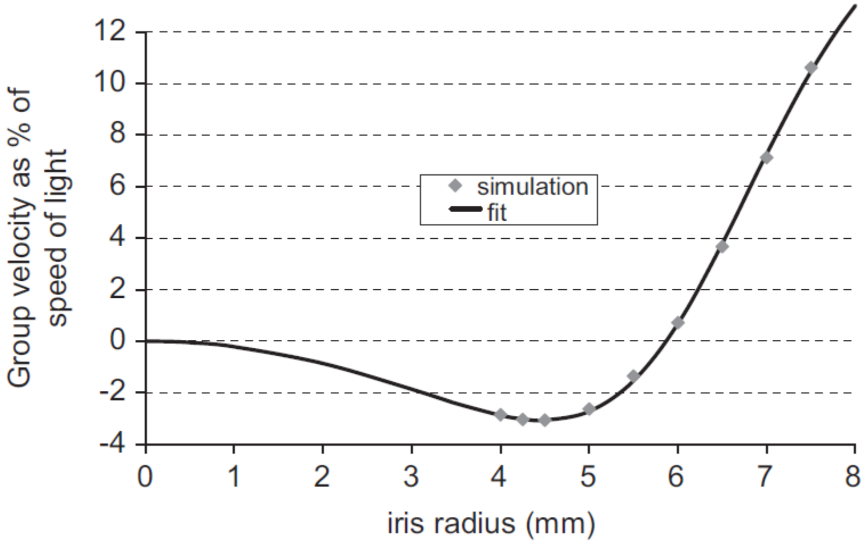


Figure 2: Group velocity vs iris radius for a single cell with periodic boundary at 11.9942 GHz

A $2\pi/3$ structure was chosen as it has the lowest surface fields at a 3 % group velocity. This allows an iris radius between 4 and 5 mm as shown in Figure 2. A study was performed considering all properties related to luminosity, including wakefields, and beamloading as well as the required power [3]. A single cell geometry with a periodic boundary $2\pi/3$ and the 1st dipole frequency at 12 GHz has been simulated in CST Microwave Studio to obtain the cavity wall Q, transverse R/Q, group velocity V_{gr} and surface fields to gradient ratio - E_{surf}/E_{trans}, H_{surf}/E_{trans}. All parameters for various iris radii in the range shown by the data points in Figure. 2 were obtained. Now assuming a structure containing a given number of cells, the power flow in each cell is calculated by the power diffusion equation as the input power minus the total losses per cell. The total loss includes the wall losses and the beamloading contribution. The beamloading assumes a constant offset from the beam axis in all cells, even though practically it can be variable cell-to-cell. The voltage per cell is then calculated from the losses and transverse R/Q. The input power can then be increased until the target deflection has been reached, provided the surface electric field is under 115 MV/m. The process is repeated for various numbers of cells, which finally gave the optimum cell shape with optimum number of cells. The basic cell shape is shown in Figure 3, in which L=8.332 mm, t=1 mm, a=5 mm and b=14.09 mm, and the structure consist of 12 cells for the required deflecting field.

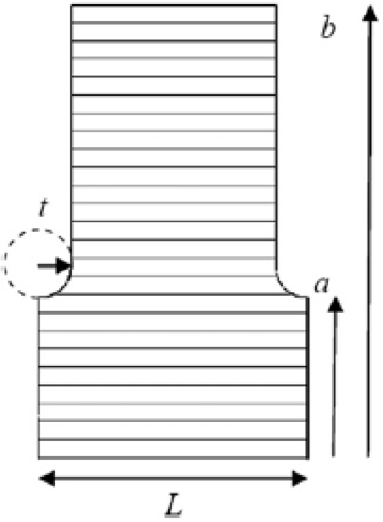


Figure 3: Single cell shape of the CLIC crab cavity

1.3 Input and Output Couplers

The addition of couplers to a cavity can break the transverse symmetry of the structure ends and add multipole components to the operating mode. For the CLIC crab cavity which is about 150 mm long, the couplers will add monopole components to the deflecting field.

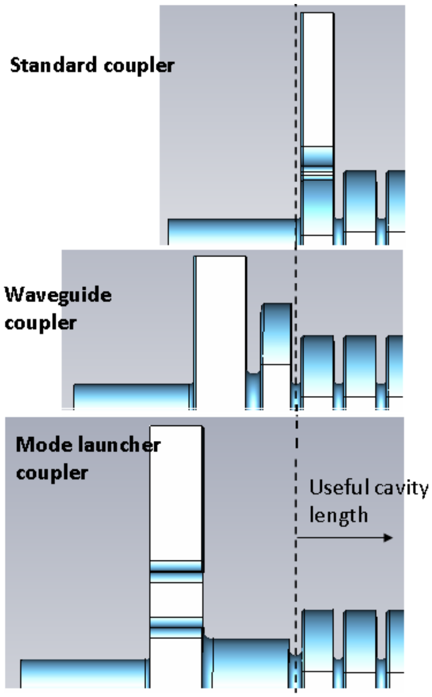


Figure 4: Three types of symmetric dual-feed couplers

This creates an additional component of beamloading which is present even when the beam is on-axis. Additionally, depending on the coupler shape, the monopole component need not be in phase with the dipole component, thereby adding a phase shift to the beamloading. To avoid these multipole fields in general and to reduce the coupler fields (which is a problem only in accelerating cavities) a symmetric dual-feed coupler is often used. To start with, three types of fundamental dual-feed couplers were investigated and are shown in Figure 4.

Standard Coupler

The standard coupler is similar to the "fat-lip" couplers used in accelerating cavities. This style of design is the most longitudinally compact of all three types. It couples inductively to the magnetic field of the end-cells through a slot or iris on the equator. The slot width, thickness and the matching cell diameter can be varied to get matching and tuning to the required mode. For the CLIC crab cavity, the deflecting electric (Ey) and magnetic (Hx) field patterns at 11.9942 GHz for such a structure are shown in Figure 5.

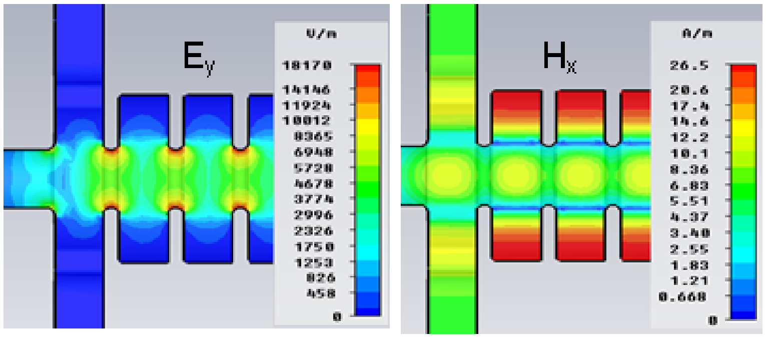


Figure 5: Deflecting fields for a structure with standard coupler

Waveguide coupler

The waveguide coupler is designed to have very low surface fields around the coupler. It has a waveguide that is inductively coupled to the TE111-mode of the matching cell which is then inductively coupled to the main TM110-mode cells of the cavity. The TE111-mode does not kick the beam as much as the TM110-mode, hence the structure is longer than a standard coupler. The fields are shown in Figure 6.

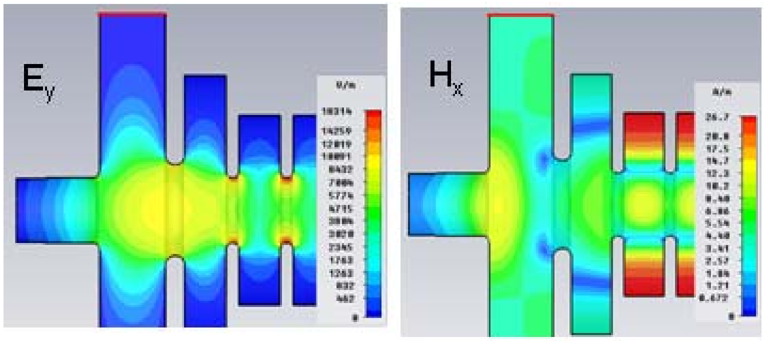


Figure 6: Deflecting fields for a structure with waveguide coupler

Mode launcher coupler

A mode launcher coupler is a mode converter that converts the TE10 mode in the coupling waveguide to a propagating TE11 mode in a circular waveguide, which is then coupled to the cavity through a matching cell as in the case of a standard coupler. This type of coupler is much longer than the other couplers and is primarily used to enable the testing of multiple cavities without having to remake couplers owing to the broad bandwidth of the large beampipe. As relatively few crab cavities are likely to be made, this coupler design is unlikely to be used. Figure 7 shows the electric and magnetic fields.

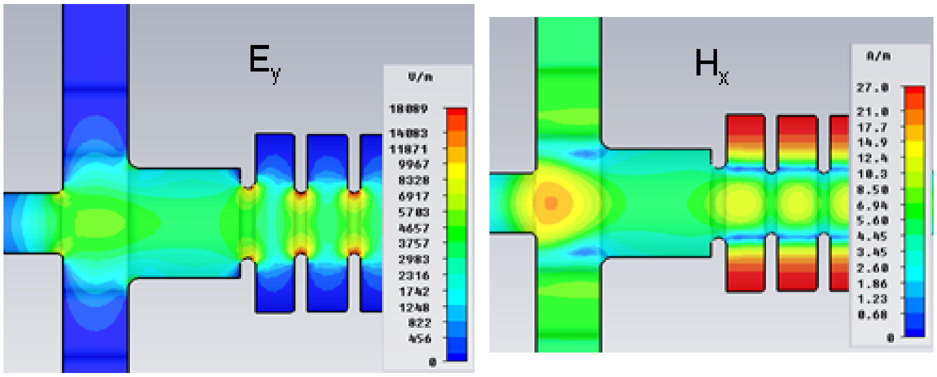


Figure 7: Deflecting fields for a structure with mode launcher coupler

As shown in Table 2, apart from geometrical size differences, all couplers behave identically at the desired CLIC frequency. This is an advantage of the deflecting cavity over the accelerating cavity. The reason lies in the differing field distribution of the TM110-like deflecting mode and TM10-like accelerating mode. The surface electric field of both deflecting and accelerating fields maximise on the irises. The surface magnetic field however peaks on the iris for the former, while on the equator for the latter. Hence the cavity performance is not limited by surface heating for the deflecting cavity in the presence of coupler interception. This allows the crab cavity to use any cell geometry and coupler option unlike the CLIC accelerating structure, provided space constraints are met. However the coupler specific multipole fields and wakefields are important for crab cavity as it is much shorter than accelerating structures.

Table 2: Surface fields for the three different coupler options for a kick of 2.55 MV

Coupler Type	E_{surf}, MV/m	H_{surf}, kA/m
Mode launcher	102	339
Waveguide	100	339
Standard	102	332

Coupler Solution Adopted

The waveguide coupler structure shown above may have the problem of higher multi-bunch wakefield contributions from the two extra TE matching cells compared to the standard coupler structure. At present the baseline design is to use a standard dual-feed coupler. This will require a splitter to feed the symmetric dual arms. The splitter design is shown in Figure 8 with the reflection better than -40 dB at 11.9942 GHz.

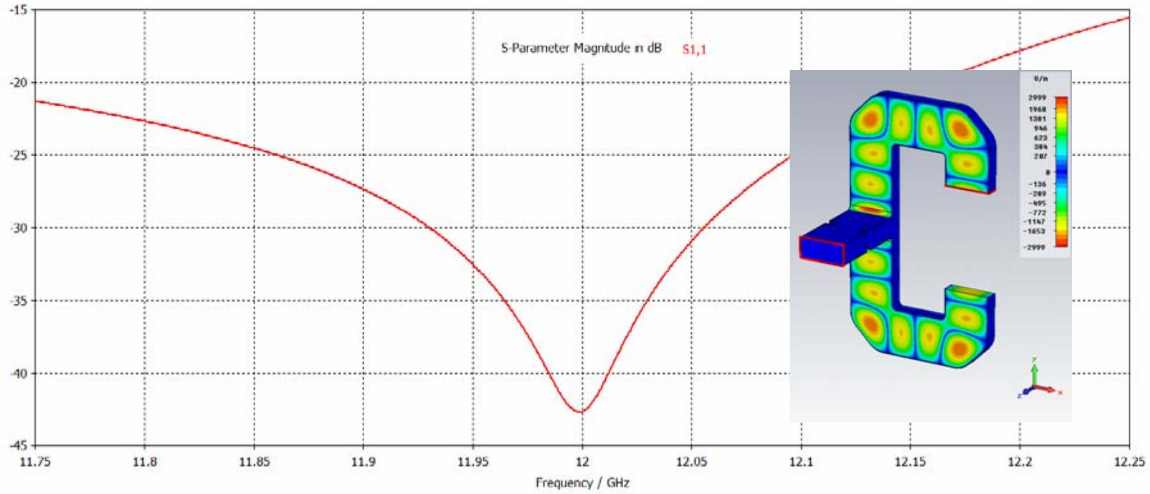


Figure 8: Dual-feed splitter design and reflection coefficient

With the splitter incorporated, the crab cavity and the matched electric field profile are shown in Figure 9.

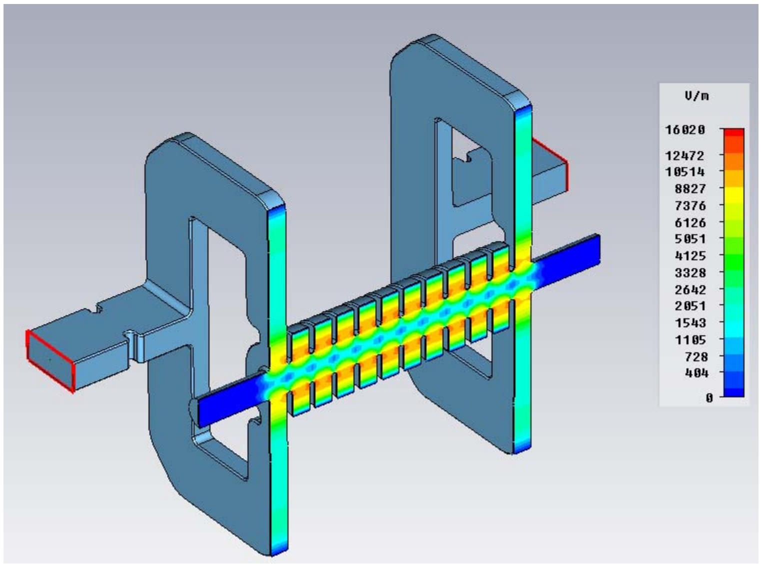


Figure 9: Dual-feed coupler for the crab cavity

The major advantage of the structure is that the symmetric feed ensures the geometrical centre and the dipole mode centre are coincident, leaving a pure dipole mode as shown by the longitudinal electric field along the radial direction in Figure 10.

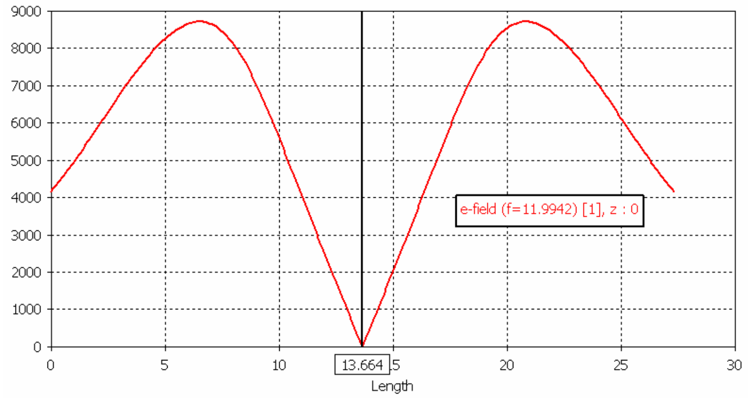


Figure 10: Dipole field symmetry in the coupler cell with a symmetric dual-feed.

However the dual-feed increases the transverse size of the structure, it complicates the end cell tuning using simpler means especially in the presence of damping waveguides, it needs perfect 180^0 phase stability between the arms and the dual-waveguides are likely to reduce the accuracy of the interferometer phase measurement envisaged for CLIC crab cavity [4]. Hence it was also investigated if the couplers could be simplified by designing a single-feed coupler with no monopole component in the deflecting field. If the input and output couplers are fed from the same side of the structure, then the monopole component will be in phase with the dipole (hence the beam) and will be added between the coupler cell. Alternatively, if the two couplers are fed from opposing sides, the monopole component will be shifted by 180^0, between the coupler cells, which will be subtracted. By adjusting the length of the cell, the phase between the beam and the monopole can be finely adjusted to achieve a zero monopole component. The scheme is shown in Figure 11 and the monopole component along the structure is shown in Figure 12. The beam will see the integrated monopole field which is zero in the above figure.

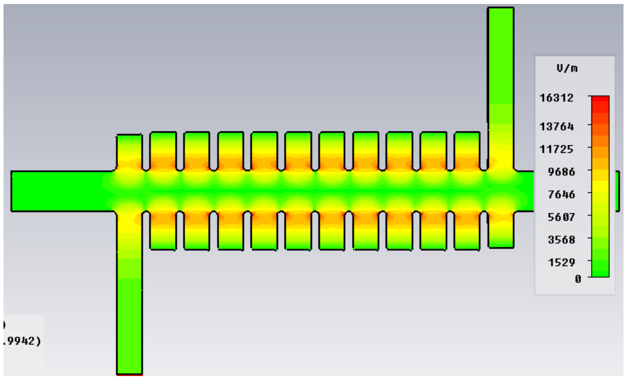


Figure 11: Couplers feeding from opposing sides of the structure

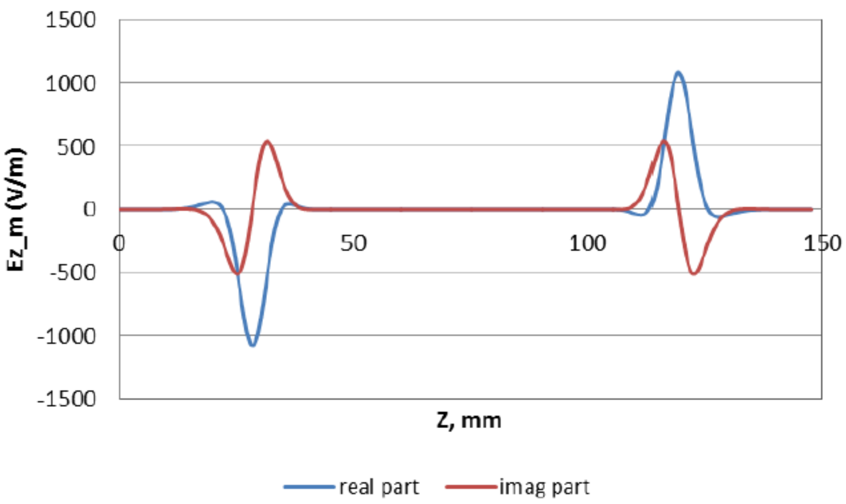


Figure 12: Monopole component of Ez along the beam axis of the structure in Figure 11

However this is not sufficient for a travelling wave structure as the reduction/increase of power in the input cell will propagate through the structure, which will alter the amplitude and phase of the kick. It is hence necessary to cancel the monopole component in each cell rather than just throughout the structure. Several methods have been investigated for absolute cancellation of the monopole component; initially using a dummy waveguide added to the opposing side of the cavity to symmetrise the geometry. This however didn't cancel the power flow or poynting vector across the cavity centre between the coupler and the dummy waveguide Py, it therefore left a monopole electric field Ez due to the dipole magnetc field Bx. This implies that it is extremely difficult to completely cancel the monopole term, unless the power flow is eliminated as done in a symmetric dual-feed coupler. The possibility of an identical effect was investigated with a TE20 mode coupler feeding from the side 90 degrees in azimuth to that of a TE10 mode coupler. The structures with the TE10 mode and TE20 mode couplers are compared in Figure 13, which shows that the monopole components for the dual-feed TE10 and the single-feed TE20 structures are respectively $1.32\times10^{-5}+3.02\times10^{-5}i$ V and $-2.52\times10^{-5}+1.63\times10^{-5}i$ V for a peak deflecting voltage of 1 V. This solution allows a single feed whilst preserving the symmetry of the input feed, which does however require a TE10 to TE20 mode converter whose TE10 mode rejection is critical in order to avoid any monopole component excitation. Although this is much more compact than the dual-feed option, it is potentially as complex as the dual-feed splitter. As a result the dual-feed coupler is considered the baseline for CLIC, with the TE20 mode coupler as an alternative.

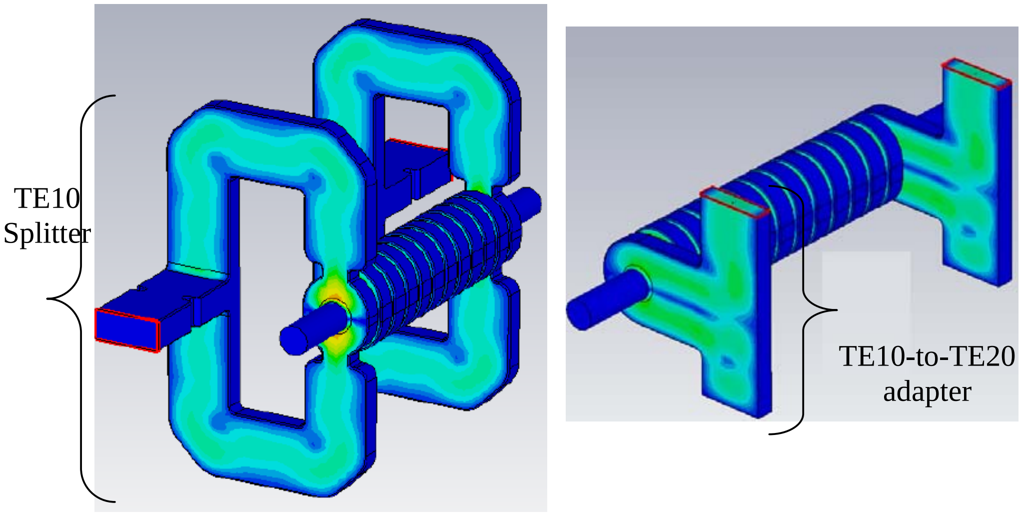


Figure 13: (a) TE10 mode (b) TE20 mode coupled to the crab cavity

1.4 HOMS and Dampers

In order to obtain a high bunch rotation for a given kick, the crab cavity should be located in a location with a high horizontal beta function, whilst keeping the cavities as close as possible to the IP to aid synchronisation. The only suitable location is immediately upstream of the final focus as shown in Figure 1, however this location also has a high vertical beta function making the beam sensitive to vertical kicks in the crab cavity. Any vertical kick will result in a large vertical beam offset between the bunches at the IP which reduces luminosity. Such kicks are likely to be created by vertical multi-bunch wakefields in the cavity hence significant attention has been paid to study their contribution and the level of control required.

The classification of the mode spectrum in a crab cavity is very different to that of an accelerating cavity as the crabbing mode is degenerate and is not the lowest frequency mode in the cavity. This means we have a vertical polarisation of the crabbing mode (Same Order Mode) and a fundamental monopole mode in the cavity (Lower Order Mode). As CLIC has such a high beam energy the LOM does not have much effect on the beam and does not require significant damping beyond that of ohmic losses in the copper. The SOM, and vertical HOMs to a lesser degree, however have a very strong effect on the beam and must be strongly damped to Q ~ 100.

As the vertical long-range wake is dominated by the SOM it is sensible to focus attention to the effect of this mode. By giving the cavity an elliptical cross section we can alter the frequency of the SOM without affecting the frequency of the crabbing mode. This allows us to place the frequency of this mode at a frequency that isn't resonant with the beam. The sum wake as a function of SOM frequency is shown in Fig 14, and shows that the minimum wake occurs at 11 or 13 GHz. Since it is easier to damp at higher frequencies the SOM is chosen to be at 13 GHz. Such a method has been tried before for accelerating cavity HOMs known as zero crossing [5]. This method however has not been successful due to the large number of HOMs involved and sensitivity to mechanical tolerances, however as the crab cavity wake is dominated by a single HOM contribution and computational studies [3] show it is quite insensitive to mechanical tolerances owing to the choice of 13 GHz.

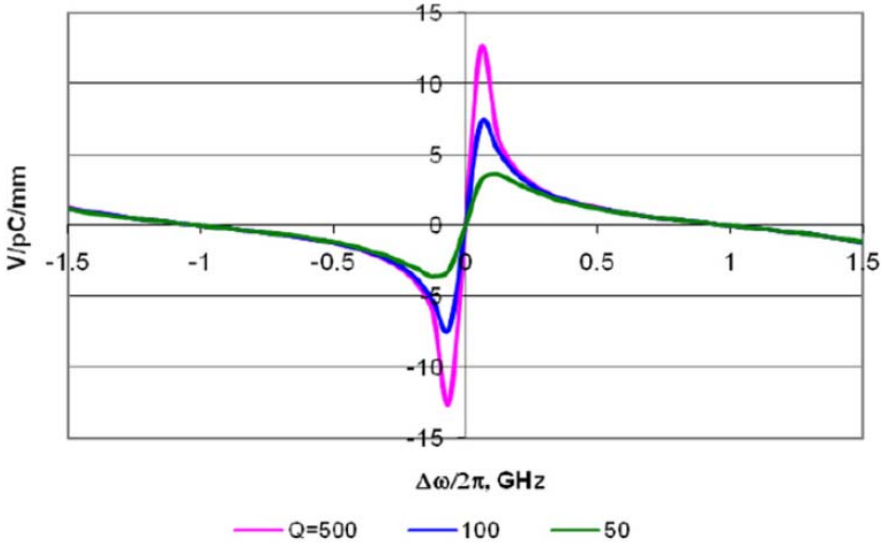


Figure 14: Single mode SOM sum wakefield for various Qs

Simulations have been performed to find the frequency and impedance of every HOM in the cavity up to 50 GHz. These were then used to calculate the wakefield in the cavity for arbitrary Q factors and hence the expected luminosity loss [6]. It was assumed that the frequencies calculated would vary due to mechanical tolerance by up to 1%. The Q factors of the modes were then modified until the luminosity loss was reduced to below 2%, shown in Figure 15. The Q required depends on the predicted maximum beam offset at the crab cavity which is 35.3 μm in the vertical plane [6].

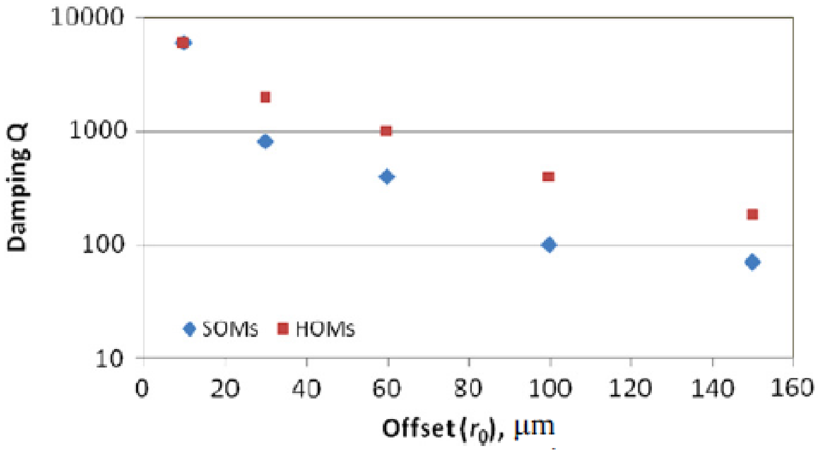


Figure 15: Vertical offset and the requited damping Q for luminosity loss of 10 %

In case of structure misalignments, the anticipated vertical offset is not likely to be larger than 100 μm hence a Q of 100 is required for the SOM and a Q of 800 is required for the HOMs as shown in Figure 15. The typical method for damping uses waveguides which are high pass filters. Damping the LOM and SOM is difficult as they are below or close in frequency to the crabbing mode. In order to do so the electromagnetic polarisation of the crabbing mode needs to be considered. As the mode is highly polarised, waveguide couplers operating in the TE10 mode will not couple to the crabbing mode in the opposite polarisation (however the TE20 mode will). Alternatively, asymmetric choke-mode couplers can be utilised. [6]

A choke mode coupler can be made asymmetric in three ways

- Elliptical cavity
- Elliptical choke
- Slotted choke

The best damping performance was achieved with the slotted choke, however the SOM frequency was not pushed as high as 13 GHz. The elliptical choke was able to damp the SOM whilst pushing it to 13 GHz however it also damped the crabbing mode slightly which could cause thermal problems. It was hence decided to use a waveguide damper as in Figure 16. Table 3 shows a comparison of the choke-mode and waveguide damped cavities.

Table 3: Performance of the single cell choke-mode and waveguide damped cavities

Shape	Dipole, R/Q (Ω)	Dipole, R_{sh} (MΩ/m)	Q_{ext} $\times 10^4$	Group velocity (%c)	E_{max}/E_{tran}	H_{max}/E_{tran}
Undamped cavity	53.92	41.20	Inf	−2.93	3.57	0.012
Symmetric choke-mode	48.5	28.01	1.865	−2.87	3.77	0.019
Elliptical cavity	44.74	21.95	1.394	−2.60	3.65	0.013
Elliptical choke-mode	45.52	21.75	1.466	−2.60	3.64	0.013
Slotted choke-mode	46.8	23.85	1.40	−2.64	3.61	0.013

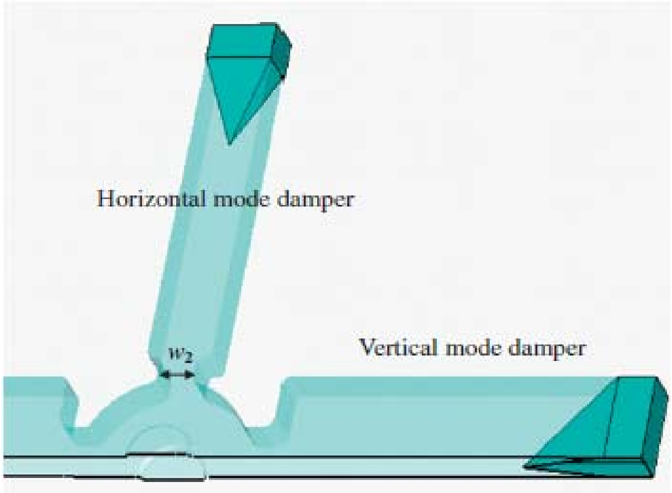


Figure 16: Horizontal and vertical waveguide damped cell with integrated SiC dielectric loads

For evaluating the high power performance of the damped prototype, the methodology expected to follow is to leave the damping ports shorted instead of using a SiC ceramic load. Such a structure has been designed and is shown in Figure 17. As explained before, the elliptical cell shape has been chosen to set the horizontal dipole or the operating mode at 12 GHz and the vertical dipole or the SOM at 13 GHz. WR112 waveguide has been chosen as the vertical mode coupler which has a cut-off at 5 GHz. The coupling slot has been adjusted to give a SOM Q ~ 100, corresponding to a -3dB bandwidth of 129 MHz from the resonance curve of the vertical coupler.

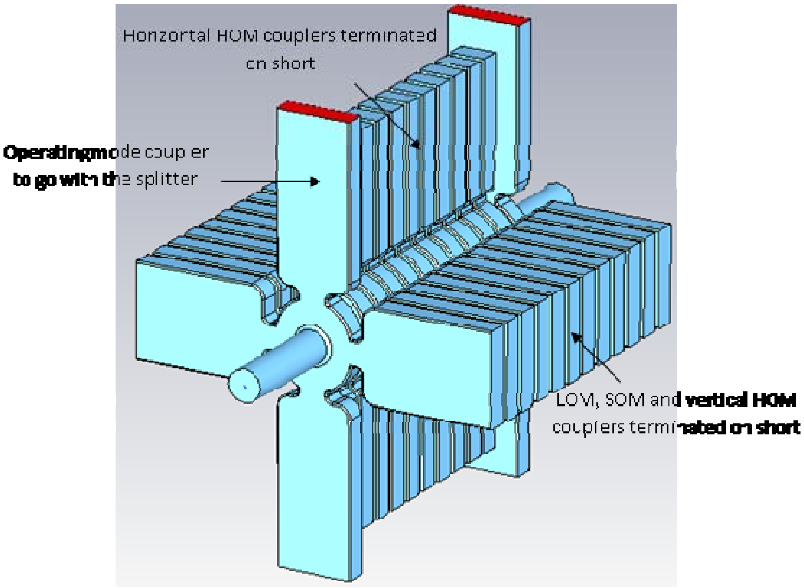


Figure 17. Shorted damping port crab structure

Figure 17 shows the 12 cell waveguide damped structure with all damping ports shorted. Figure 18 shows the longitudinal electric field in the matched structure. In order not to couple to the operating mode, the horizontal mode coupler has been chosen as WR 42 with a cut-off frequency of 14 GHz. From the RF-only point of view, shorting the ports is no different from having a matched load as firstly the RF power is being coupled vertically, which therefore won’t couple to the horizontal dipole mode and secondly, the vertical damping waveguide is cut-off to the operating mode.

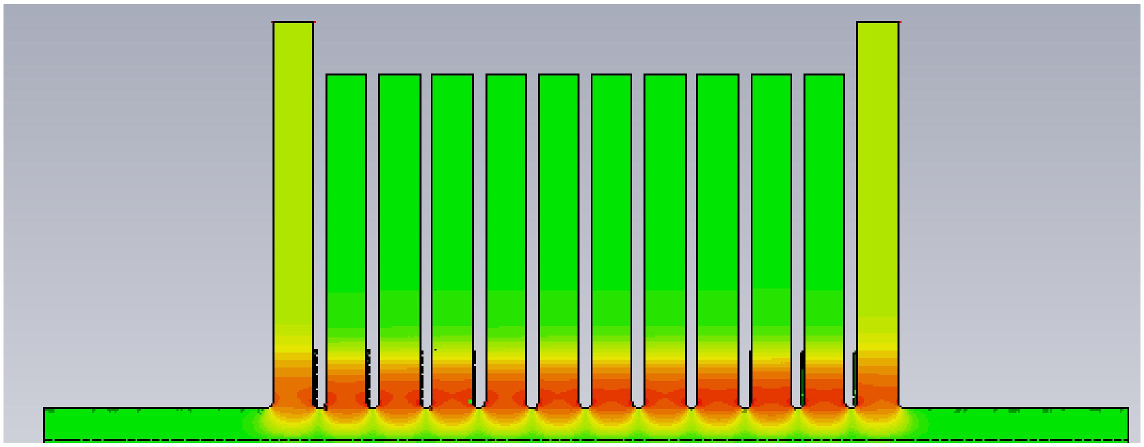


Figure 18: Damped CLIC crab cavity (a) structure shape (b) Electric field when matched at 11.9942 GHz

Avoiding the dielectric load also reduces the complexity and ensures a good vacuum seal and less chance of the dielectric material being exposed to high fields. If needed one or more ports can be used for diagnostic purposes.

The frequency spectrum of the reflection and transmission coefficients (S11 and S21 respectively) is shown in Figure 19, with a reflection better than -40 dB at 11.9942 GHz. The reflection also shows 12 resonances which is expected for the 12 cell structure. The electric field pattern in one of the the midcells for the operating mode at 11.9942 GHz and SOM at 12.996 GHz are shown in Figure 20. It shows the operating mode confinement in the cell and the SOM propagation in the waveguide.

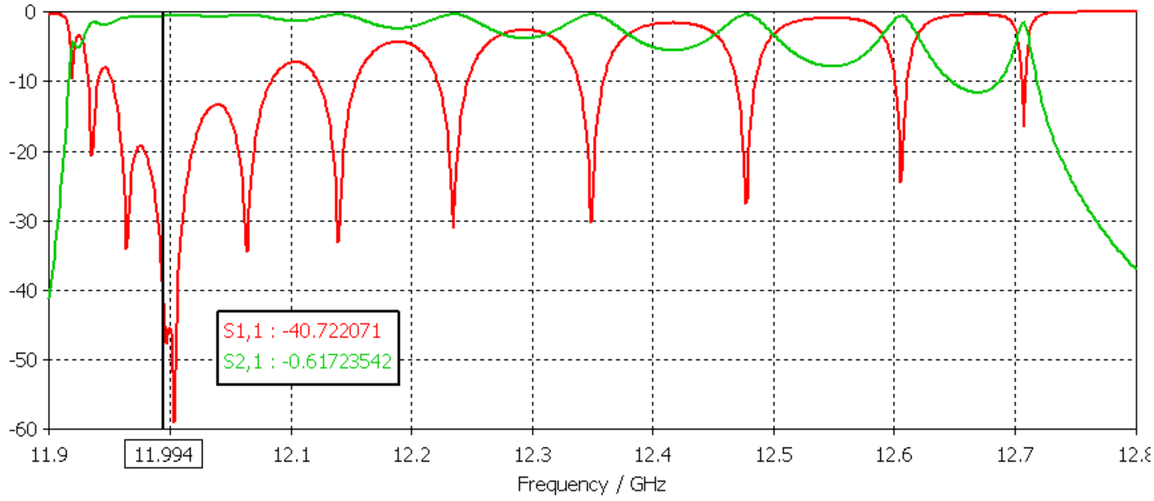


Figure 19. S-parameters of the 12 cell, damped Crab cavity

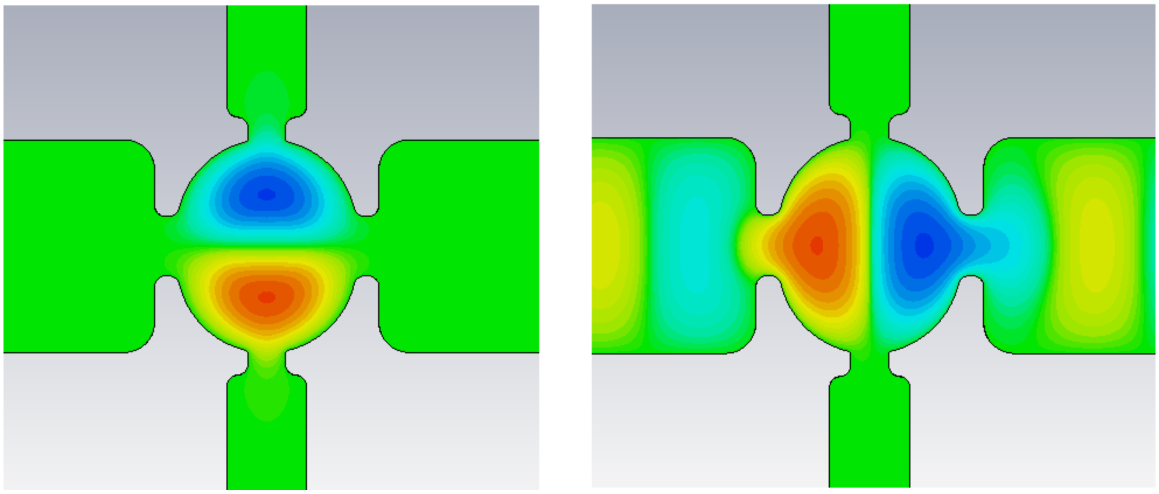


Figure 20: Horizontal (11.9942 GHz) and vertical (12.996 GHz) dipole modes in the midcell of the damped structure

The midcell of the structure was chosen to operate at a horizontal or operating mode frequency of 11.9942 GHz and a vertical mode or SOM frequency of 12.996 GHz. The slot width slot_a controls the damping Q and for a given slot_a, the cavity vertical diameter can be adjusted to set the SOM frequency to 13 GHz. The dependence of loaded Q of the SOM on the slot width of the vertical coupling waveguide is shown in Figures 21 and 22. The SOM coupler also couples to the LOM with Q ~ 600. I

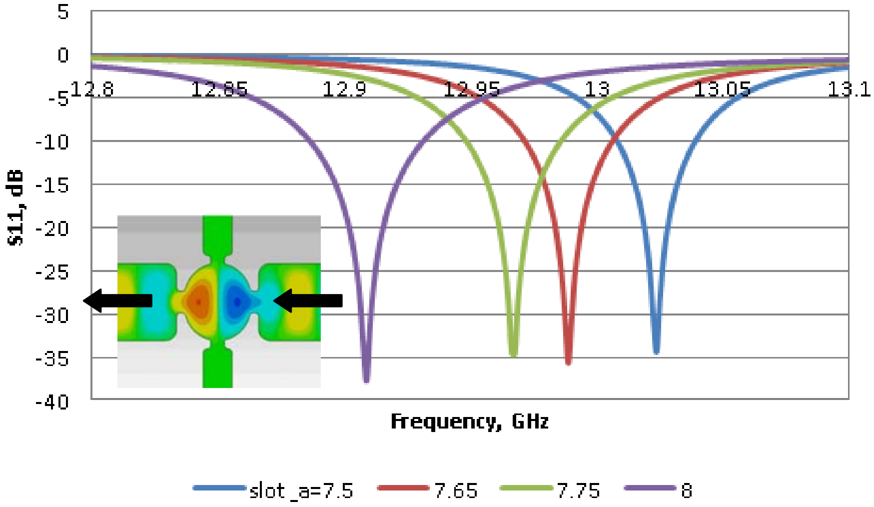


Figure 21: S-parameters of the symmetric vertical mode coupler around the SOM frequency for varying slot width

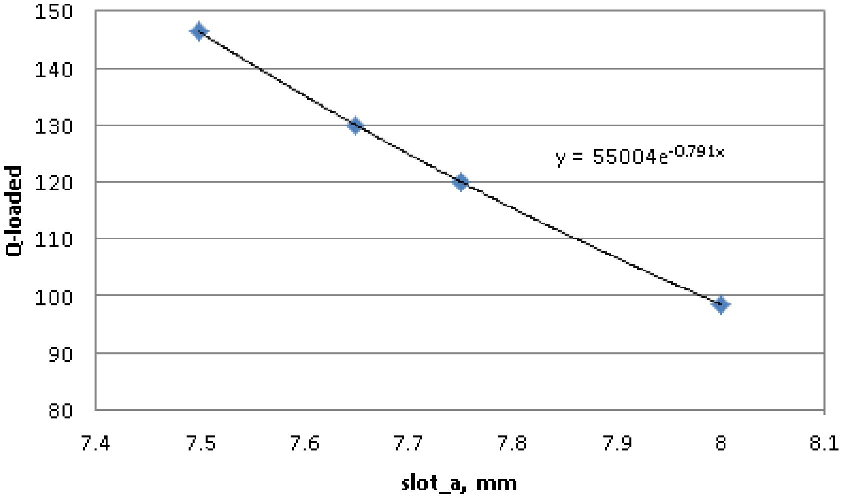


Figure 22. Q vs slot width calculated from the resonance curve in Figure 20

1.5 Prototype Measurements

Two prototype cavities have been produced, the first has been manufactured in the UK by Shakespeare Engineering and has specially designed couplers to minimise the field around the coupling iris by coupling through a special TE111 mode cavity. Shakespeare initially had difficulty in achieving the required machining tolerances for the cavity cells, requiring higher precision machining infrastructure to be implemented. These problems have subsequently delayed the delivery of the undamped cavity structure by approximately 12 months. Such investment by Shakespeare has provided them with a new fabrication capability which was not demonstrated prior to the EUCARD programme and as a consequence of which have enabled Shakespeare to secure contracts for other conventional X-band accelerating structures. The fabricated crab cavity is shown in Figure 23. A second cavity is also being manufactured by VDL through CERN, shown in Figure 24. This ensures the same manufacturing standards as the main linac and allows understanding of the differences between breakdown in accelerating and deflecting cavities [7].

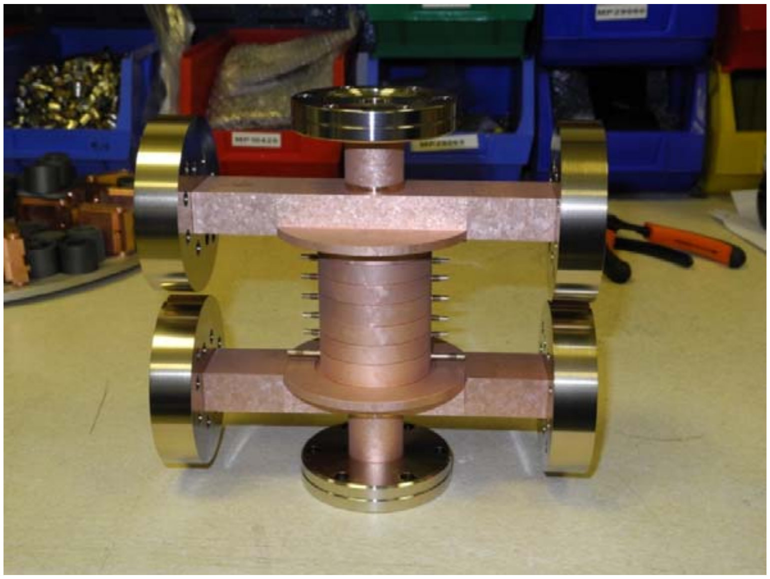


Figure 23. The UK built CLIC crab Cavity

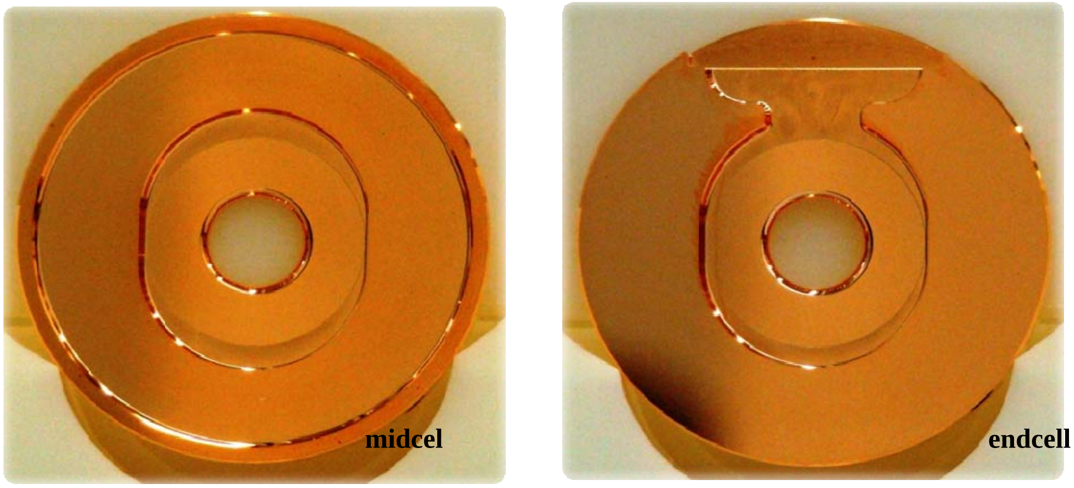


Figure 24: UK-CERN crab cavity mid and endcells

The UK cavity is designed to an operating frequency of 11.424 GHz in order to enable high power testing at the SLAC RF test laboratory, as this was the only envisaged high power testing infrastructure available during the EUCARD programme timescales. The cavity utilises a dual feed coupler with each feed being 180 degrees in phase from each other, shown in Figure 23. In order to measure the properties of the structure the S-parameters are characterised individually at each port and combined to produce F-parameters for the structure when correctly fed. The measurements were compared to CST, the reflection measurements are shown in Figure 23. The measurements show roughly the same frequencies as CST, although there is some shift in the 3rd and 4th modes. The structure has still to be bead-pulled and tuned which is anticipated to improve the agreement.

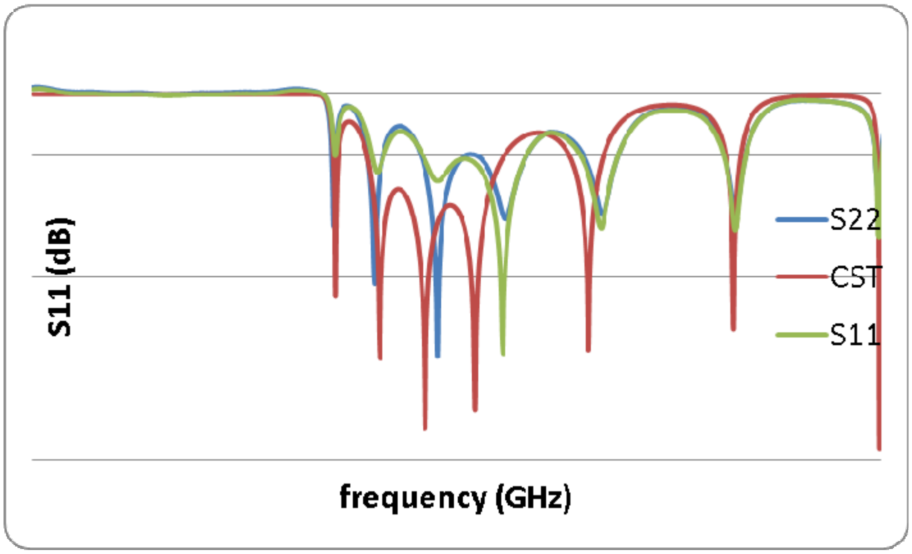


Fig. 25: Simulated and measured reflection of the UK cavity

The VDL cavity, which has been designed to an operating frequency of 12 GHz, has had all of its cells machined and has been inspected at CERN. The cells will be sent out for brazing soon. The testing of this cavity will be very interesting as deflecting structures have very different field patterns than accelerating modes. Whilst the peak electric and magnetic fields both occur at the same place in the iris of accelerating cavities they are located in perpendicular polarisations in deflecting cavities. By inspecting damage on deflecting cavities we will be able to evaluate the role magnetic field plays in breakdown. In fact the best theory for breakdown at present suggests the breakdown should be related to the maxima in the modified poynting vector [4] and for deflecting cavities this occurs at 45 degrees to both peak electric and magnetic fields.

1.6 Conclusions

The CLIC structure is a X-band travelling wave structure. It has a high group velocity to minimise the effect of beamloading. The power coupler is proposed to be a dual feed to minimise the monopole component of the field introduced by asymmetric coupler. Single feed couplers have also been investigated and are also being considered. SOM and HOM damping will be performed by waveguide dampers which are capable of damping the SOM and most of the HOMs to Q's below 100.

A prototype cavity has been manufactured by UK industry, which achieved machining tolerances of 1-2 microns. This is the first demonstrated X-band deflecting structure to have been fabricated in the UK. However, due to the challenges faced and the fabrication delays incurred, the performance evaluation tests to be undertaken at SLAC have been postponed to April 2013. The 2nd VDL structure is being manufactured for breakdown testing using the same manufacturing process as for the CLIC main linac accelerators. The anticipated test of this second prototype is expected to take place at CERN in late 2013.

1.7 References

[1] I.R.R. Shinton, G. Burt, et al Beam dynamics simulations of the CLIC crab cavity and implications on the BDS, NIM-A (2011)

[2] CLIC parametertable,Availableat: /http://clic-meeting.web.cern.ch/clic-meeting/

[3] A.C . Dexter, G. Burt, P.K. Ambattu et al, CLIC Crab cavity Design optimisation for Maximum Luminosity, NIM-A (2011).

[4] A. Dexter et.al, Synchronisation system for CLIC crab cavities, International workshop on future linear colliders, LCWS 2012, Texas

[5] R.M. Jones, Wake field Suppression in High Gradient Linacs for Lepton Linear Colliders, Phys. Rev. ST Accel. Beams 12 (2009)

[6] P.K. Ambattu, G. Burt et al, Analysis and Control of Wakefields in X-Band Crab Cavities for Compact Linear Collider, NIM-A (2011)

[7] A. Grudiev et.al, New local field quantity describing the high gradient limit of accelerating structures, Phys. Rev. ST Accel. Beams 12, 102001 (2009)

1.8 Acknowledgements

This work has been funded by the UK research council STFC as part of the Cockcroft Institute Core Grant number ST/G008248/1 and by the European Union under the FP7 EuCARD IA Project Grant agreement. 227579.