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ENGINEERING DESIGN AND FABRICATION OF X-BAND COMPONENTS

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Abstract

The CLIC RF frequency has been changed in 2008 from the initial 30 GHz to the European X-band 11.994 GHz permitting beam independent power production using klystrons for the accelerating structure testing. X-band klystron test facilities at 11.424 GHz are operated at SLAC and at KEK [1], and they are used by the CLIC study in the framework of the X-band structure collaboration for testing accelerating structures scaled to that frequency [2]. CERN is currently building a klystron test-stand operating at 11.994 GHz. In addition X-FEL projects at PSI and Sincrotrone Trieste operate at 11.4 GHz. Therefore several RF components accommodating frequencies from 11.424 to 11.994 GHz are required. The engineering design of these RF components (high power and compact loads, bi-directional couplers, X-band splitters, hybrids, phase shifters, variable power attenuators) and the main fabrication processes are presented here.

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INTRODUCTION

Generally RF components are used in the transmission and the transformation of radio frequency signals generated by the power source. Since CLIC frequency has been changed from 30 GHz to 11.994 GHz, there is a need to prepare various RF components which work at the new frequency for CLIC R&D studies. High power RF components at about 12 GHz are not easily available from the commercial suppliers. Many of 11.424 GHz components have been developed for the US high gradient research in 1990's. In many cases it is possible to scale the existing, successfully tested designs for 11.994 GHz and use them for CLIC study and other projects.

These devices should operate at power level of 100 MW and 300 ns pulse length. The technical requirements are also dictated by the necessity to operate in ultra-high vacuum (down to $5 \cdot 10^{-9}$ mbar). The helium leak tightness of the RF components should be better than $5 \cdot 10^{-10}$ mbar·l/s. These components had to be developed by CERN and used also in other laboratories, such as KEK, SLAC, PSI and Sincrotrone Trieste.

X-BAND HIGH POWER LOADS

The X-band high power load is one of the RF components specially developed for the CLIC study, and based previous developments of late 90ths. The whole structure of the load is made of magnetic stainless steel SS430. The BINP-based load has the grooved H-plane surface where the RF wall current is efficiently damped.

The design was dramatically improved with respect to RF matching and a vacuum port was added at the end of the load for better vacuum performance. A careful mathematical simulation was made to evaluate the temperature increase on the inner surface of the load due to RF pulse heating. RF and mechanical designs were made by CERN. The required cell shape accuracy and flatness are at a level of 0.01 mm. The cell surface roughness Ra required is lower than 0.4 µm.

The X-band load has a length of about 900 mm. It consists of few functional parts: the regular part with matching section, waveguide taper and the end-cap. The load is then equipped with standard WR90 flange. The length of the regular part was optimized so that the load can work at both frequencies, 11.994 GHz and 11.424 GHz. Several loads were successfully tested up to 60 MW peak power at 11.424 GHz [3] and they are used now in many test area worldwide.

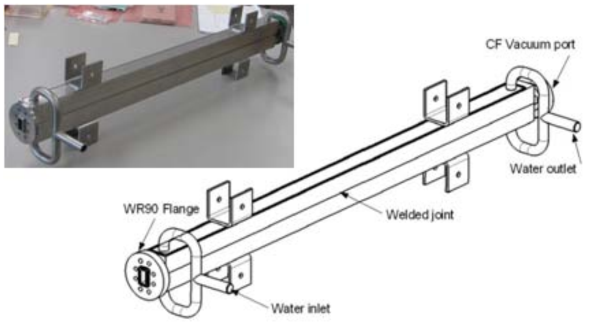

Figure 1: 3D model of X-band high power load

COMPACT LOADS

The compact load is a specially developed component for the CLIC Module RF network, where integration issues require compact elements. It will be the most common RF component in the RF waveguide system. Special attention was paid to provide a design with minimum fabrication cost, whilst keeping the required RF and high-power performance. The general view of the compact load is shown in Fig. 2.

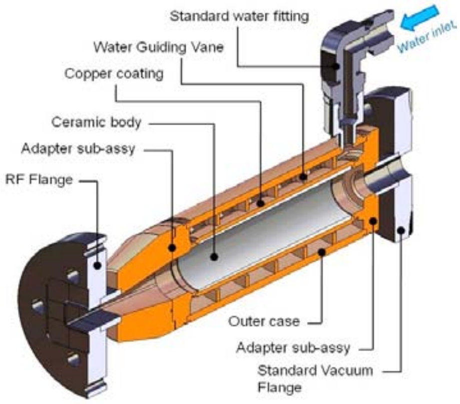

Figure 2: 3D model of X-band compact high power load

The most essential and challenging part of the compact load design is its ceramic body which performs the damping. The body is a thin-walled tube of 100 mm length, cone shaped outside and cylindrical inside. It is made of SiC which is currently the most appropriate material for CLIC RF high-power application. On both extremities, the ceramic body is joined to copper adapters. There is a need to provide not only high-quality thermal and electrical contacts between all the parts, but also to ensure a perfect isolation of the cooling channels from ultra-high vacuum. So initially the ceramic part is coated with a copper layer (2-3 mm) by electro deposition. After final machining of the deposited copper layer, it is possible to either braze or weld the components together. The difference in thermal expansion coefficient between copper and ceramic part makes the heat treatment application a rather delicate task. The use of low temperature brazing technique or EBW technologies could solve this issue. The final step of the assembly sequence is closing the middle section of the load by the outer case made of two half-shells. Thus the cooling circuit of the compact load is being formed. The water circulates through a pair of standard connectors, brazed to the outer case, spiralling around the load body by guiding vanes. This provides an efficient removal of the dissipated heat.

Recently the production of two prototype loads was launched. In parallel to that, qualification tests on brazing and welding solutions are being carried out.

BI-DIRECTIONAL COUPLERS

There is a great variety of ways for constructing the directional couplers. For the CLIC study, CERN invited few companies to develop the compact design of the bi-directional coupler with a coupling factor of -45÷50 dB and directivity lower than -20 dB.

The design shown in Fig. 3 was developed by GYCOM Ltd (RU) in 2006 and 10 units were successfully produced by the same company in 2009. The RF windows contain Al_2O_3 ceramic disk as a barrier window.

Figure 3: Bi-directional coupler by GYCOM Ltd

The disadvantage of this device is that it is not compact and relatively heavy. The final coupler weight is about 8.5 kg. The length between the two RF flanges is about 250 mm.

Currently CERN is collaborating with several companies and institutes for the development of more compact directional couplers. Recent tests on first produced units demonstrated a satisfactory performance at 12 GHz.

The bi-directional coupler of Nihon Koshuha (JP) consists of one main and two diagnostic waveguides crossing the main one. The RF windows originally foreseen in the supply were replaced by RF pick-ups integrating SMA connectors in two coupling holes. The SMA connectors are bolted to the coupler body. The principle is shown in Fig. 4.

Figure 4: Assembly of the bi-directional coupler by Nihon Koshuha

Nihon Koshuha has taken the appropriate steps to insure no scratches or other internal surface defects. All brazing is done in an appropriate dry hydrogen atmosphere. The final coupler weight is about 1.74 kg. The length between the two RF flanges is shorter by 50 mm when compared to the GYCOM design.

Another design with RF pick-ups was developed by Cobham Microwave (GB). The bi-directional coupler (see Fig. 5) contains one main and one diagnostic waveguide, which are parallel to each other. The SMA connectors must comply with UHV requirements. It has been suggested to use the market available stainless steel feed-through by Meggitt Safety Systems Inc (USA). Two feed-throughs are brazed directly to the coupler body.

Figure 5: Bi-directional coupler by Cobham Microwave

X-BAND SPLITTER AND HYBRID

Both, the X-band splitter and -3 dB hybrid were developed at CERN in 2008 [4]. Few tens of splitters were fabricated by VDL (NL). Fig. 6 shows the X-band splitter. Fig. 7 shows the X-band -3dB H-plane hybrid. These components were produced by IHEP (JP) and Cinel (IT).

VARIABLE POWER ATTENUATOR AND PHASE SHIFTER

The high power variable RF attenuator and RF phase shifter (see Fig.8 and Fig. 9) build by GYCOM Ltd is another example, when entire development, starting from the concept is done in collaboration with laboratories.

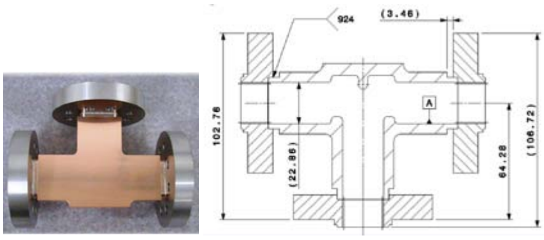

Figure 6: X-band splitter

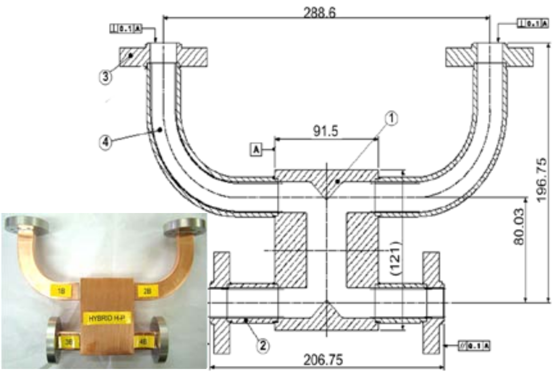

Figure 7: X-band hybrid H-plane

These devices were successfully used in a special experiment with beam power production [5]. They have been installed in TBTS/CTF3 experiment as a part of RF recirculation loop. They were ultimately tested up to 250 MW, 240 ns pulses and now routinely used in operation.

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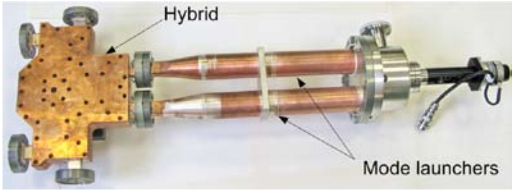

Figure 8: Variable power attenuator

Figure 9: Phase shifter

DOUBLE-SECTOR CHOKE MODE FLANGE

In CLIC the important requirement is the need for independent transverse alignment (of about ±0.1 mm) of the two linacs during machine operation. To avoid the mechanical stresses in a waveguide network we suggested using the double-sector choke-mode flange, as shown in Fig. 10. This device allows for the electrically contact-free connection between the waveguides and possibility to misaligned transversely the two waveguides without introducing any RF phase errors. This permitted to avoid the resonance condition for the trapped symmetrical mode in the case of significant transverse offsets. In this configuration, even for the relative shear shift of the waveguides by ±0.5 mm in both directions, the good matching (below -40 dB) can be obtained. The 1.0° twist and 3.0° tilt can be tolerated as well. The prototype of such a device is now under engineering design.

Figure 10: 3D model of the double-sector choke flange.

CONCLUSIONS

Recently, the X-band activities in Europe have significantly increased. Several laboratories have expressed their interests in using the X-band technology for their needs. In the framework of worldwide collaborations CERN developed a series of RF components successfully tested at high power. We are welcoming any requests to share our experience in terms of development and fabrication of these devices, even with customized specification. Also the design of the new types of the RF components can be done on collaborative bases.

AKNOWLEDGEMENTS

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REFERENCES

[1] S. Matsumoto et al., “Nextef: The 100 MW X-band Test Facility in KEK”; EPAC08, Genova, June 2008, WEPP096, p. 2740 (2008)
[2] F. Peauger et al., “A 12 GHz RF Power source for the CLIC study”; IPAC10, Kyoto, May 2010, THPEB053, pp. 3990-3992 (2010)
[3] S. Matsumoto et al., “High Power Evaluation of X-band High Power Loads”; LINAC10, Tsukuba, September 2010, MOP074, p. 226 (2010)
[4] I. Syratchev, “Variable high power RF splitter and RF phase shifter for CLIC”, CLIC-Note-552, Geneva, January 2003, CERN-OPEN-2003-005, pp. 4-6 (2003)
[5] E. Adli, “Analysis of the first 12 GHz PETS tests with beam using a constant parameter re-circulation model”, CTF3-Note 096, Geneva, CERN (2009)