# A NEW C-BAND 50-MW CLASS SiC RF LOAD. II

S. S. Win, H. Matsumoto, KEK, Tsukuba, Japan
M. Yoshida, University of Tokyo, Tokyo, Japan
Z. Kabeya and S. Kakizaki, Mitsubishi Heavy Industries, Ltd., Nagoya Aerospace Systems

*Abstract*

A new type high power rf-load is being developed as a part of the R&D for an $e^+e^-$ linear collider. The main body of this rf-load is composed of a cylindrical chain of 10 $TM_{011}$ cavities; in each sintered ceramic Silicon Carbide (SiC) is used as the microwave absorbing material. A total of 40 SiC disks per rf-load can absorb enough microwave power to meet the requirements for vacuum operation in a system with 50-MW of peak rf power at a pulse width of 1-μsec and pulse repetition rate of 50-pps.

## INTRODUCTION

The first SiC type rf-load was developed for the KEK 2.5-GeV injector linac for S-band (2856-MHz) use in 1980. Although the direct water-cooling system was efficient, corrosion problems make the risk of water leaks into the vacuum inevitable. In 1995 a modified rf-load was developed which uses indirect water-cooling of SiC rods brazed to a wave-guide [1]. However, at the present there are no commercial off-the-shelf 50-MW class rf-loads for C-band (5712-MHz) frequencies, and so we have undertaken this as an R&D project.

The Linear Collider project (GLC-I, Japan) aims to build a new high energy $e^+e^-$ linear collider for the 300-500 GeV C.M. energy region. The GLC-I klystrons will be of the 50-100 MW class, and the accelerator will use more than 8,000 in total [2] and therefore more than 16,000 high power rf-loads will also be needed. This huge-scale machine requires an almost astronomical total component count; certainly no laboratory heretofore has any experience in fabricating, or operating such so many accelerator devices. Therefore, manufacturability, reliability and maintainability are all critical considerations.

Accordingly, we have developed the rf-load using SiC with indirect water-cooling for C-band operation. In this rf-load we use a very simple stack of cylindrical $TM_{011}$ cavities chained to form the main body so that it can be manufactured easily using a conventional turning lathe. Except for the first cell of the cavity-chain, each $TM_{011}$ cell is of the same physical dimension. Because of this design, we get the extra great advantage that it will allow us to eliminate 8,000 E-bend high power wave-guide components and thus contribute to the overall cost reduction and system simplification.

In this paper, we discuss the detailed design of the new type rf-load, and in particular the results of studies using the HFSS (High Frequency Structure Simulator) code, the frequency sensitivity of the $TM_{011}$ cavity and the thermal analysis of the SiC mounted cavity-chain.

## OVERVIEW

A cut-away view of the first prototype model of the 50-MW SiC C-band rf-load is shown in Figure 1. The rf-load mainly consists of four components: an impedance matching section which matches the impedance between rectangular wave-guide ($TE_{01}$) and the $TM_{011}$ mode cavity-chain, a mode filter which suppresses unwanted modes, a cavity-chain of 10 $TM_{011}$ mode cavities with SiC disks which absorb the rf-power and a cooling water jacket.

For impedance matching between the wave-guide and the cavity-chain of $TM_{011}$ mode cavities, we chose an inductive iris-type coupler, which is structurally simpler than the doorknob-type coupler. Further, the inductive iris-type coupler has advantages over the capacitive iris-type and doorknob-type couplers because of the reduction of the surface electric field at the coupling iris.

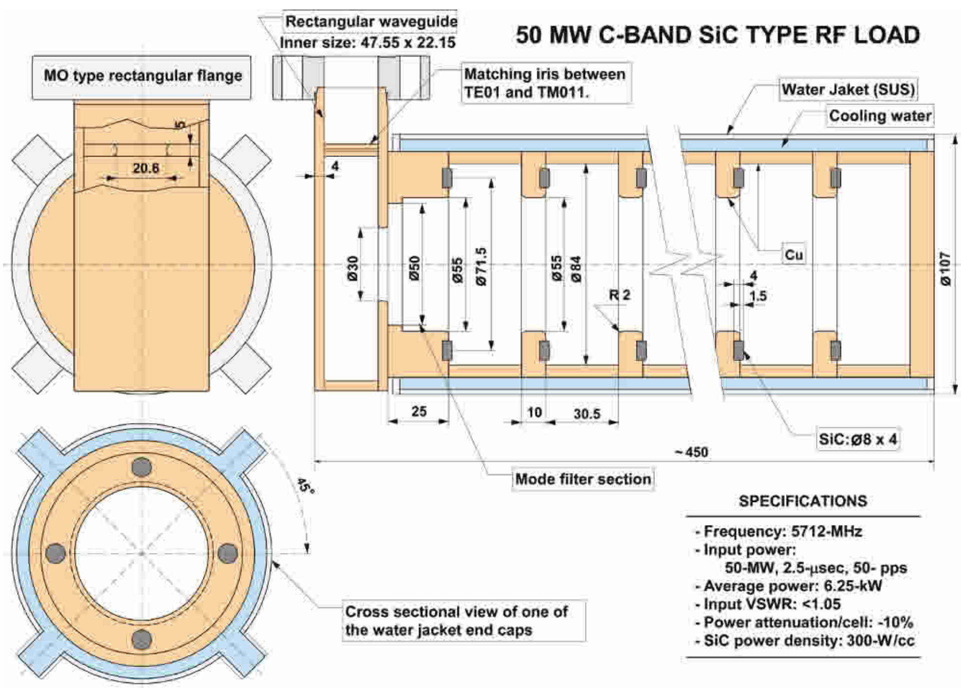


Figure 1: A conceptual drawing of 50-MW Class SiC rf-load.

E-mail: susuwin@post.kek.jp

The mode filter diameter is 50-mm, this was chosen to so that only the $TM_{011}$ mode would be excited into the cavity chain, and it can help suppress unwanted modes which might propagate in the 84-mm cavities such as the $TE_{11}$ (2116.6-MHz), $TM_{01}$ (2764.9-MHz), $TE_{21}$ (3511.3-MHz), $TM_{11}$ (4405.4-MHz), $TE_{01}$ (4405.7-MHz), and $TE_{31}$ (4830.0-MHz) modes.

The cavity-chain consists of 10 $TM_{011}$ mode cavities with 4 SiC disks per cavity, surrounded by a cooling water jacket. The cavities are separated by 10-mm thick loading-disks each with a 55-mm diameter coupling iris. The iris diameter is determined so as to keep the transmitted rf power safely below a 300-W per cc absorbed power density in each SiC disk. The loading disk thickness of 10-mm was chosen to provide good thermal conductivity for the SiC disks as well as to provide mechanical strength. Four SiC disks are brazed symmetrically about one side of each loading-disk; so there are 40 SiC disks in total which will absorb the rf power. We will use the same proven brazing method that was used for the KEKB injector linac rf-loads.

The water jacket includes 4 inlets and 4 outlets so as to maintain a uniform water flow from the inlets to the outlets. The temperature of the cooling water is 30°C at the inlet and the flow rate ranges between 10 and 20 L/min when running at the rf input power of 50-MW, 2.5-μsec and 50-pps (that is, 6.25-kW average power). In that case, the cooling water temperature rise at the outlet is only about 8°C. Therefore, we can use a very simple concentric pipe for the water jacket, and a uni-directional water flow.

## SIMULATION

We used the ANSOFT commercial FEM code HFSS™ ("High Frequency Structure Simulator"), for simulation studies in the design of the inductive iris type impedance matching section, the mode filter and the main body of the $TM_{011}$ cylindrical cavity.

The loaded cavity quality factor $Q_L$, which corresponds to the rf transmission loss was determined to find the optimum diameter for the coupling iris between the cavities. The four-fold symmetry of the structure allows the simulation of the $TM_{011}$ mode single cavity and the cavity-chain to be done on an idealized quarter-cavity and cavity-chain assuming perfect-H boundary conditions at the truncated surfaces as shown in Figure 2. This separates the $TM_{01}$ mode from other unwanted modes as well as reduces the calculation time.

The reflection and transmission S matrix characteristics of the $TM_{011}$ mode cavity are shown in Figure 3; $S_{11}$ (upper curve), corresponds to the reflection power, and $S_{21}$ (lower curve), corresponds to the transmission power. From measurements of the plot, $Q_L$ can be calculated by the equation $Q_L$=f/(2Δf) and the group velocity $v_g$ by the equation $v_g$=1/2 kωL where k is the coupling factor when the cavities are in series. The total cavity transmission loss, taking into account the coupling factor between the cavities, was calculated for a single cavity, a cavity-chain of 5 $TM_{011}$ cavities and a cavity-chain of 10 $TM_{011}$ cavities. The coupling iris diameter of each loading-disk was chosen to be 55-mm which results in a $Q_L$ value of 30. The simulation was then extended to determine the power loss in each cavity due to the insertion of the SiC disk on one side of the loading-disk between the cavities as can be seen in Figure 2.

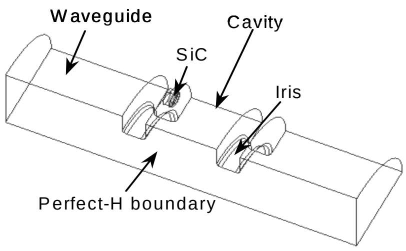


Figure 2: The drawing of single cavity for HFSS simulation

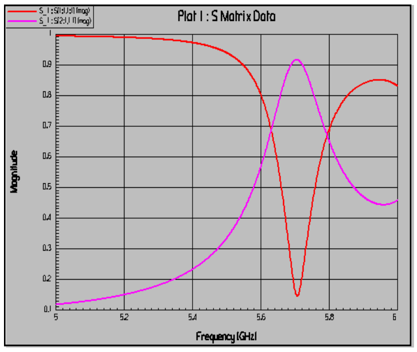


Figure 3: Typical S Matrix plot for $S_{11}$ and $S_{21}$ from HFSS.

For this rf-load, we chose SiC with β-form crystal structure; this provides a good uniformity of powder size so that the variation in the microwave loss-tangent of the SiC is very low. The major physical characteristics of SiC are listed in table 1. The power loss per cavity was calculated as a function of varying SiC dimensions. We chose the SiC size to be 8-mm in diameter and 4-mm in height (of which 1.5-mm projects into the rf field of the cavity), which can provide a 10% power loss per cavity. Each SiC button is inserted into an 8.25-mm diameter, 2.5-mm deep hole in the loading-disk so that the brazing material would be masked from the electrical field.

For practical manufacturing and fabrication, the allowable variation in physical dimensions of the cavity and SiC must be studied to verify the tolerances are acceptable. Therefore, we determined frequency sensitivity to the dimensions of the $TM_{011}$ cavity and the SiC disks; the results are shown in Figure 4. Of the cavity parameters we found the maximum frequency shift is due to variations in the length of the cavity and is 86-kHz/μm while the frequency shift due to changes in overall total length of the cavity-chain is only 8-kHz/μm. Comparing the two SiC disk parameters, the frequency shift is more sensivitive to the height than to the diameter. The frequency shift due to the height of the SiC disk is 65-kHz/μm. Since we have previously determined that the allowable resonant frequency error budget of the $TM_{011}$

Table 1: Major characteristics of the SiC-ceramic.

| | | |
|---|---|---|
| Thermal conductivity<br>(cal/cm·sec·°C) | 0.19<br>0.14 | at RT[1)]<br>at 600 °C |
| Thermal expansion coeff. ($°C^{-1}$) | $4.6 \times 10^{-6}$ | RT[1)] to 1200 °C |
| Dielectric constant | 30~35 | 0.5 to 20 GHz[2)] |
| Loss tangent | 0.3~0.5 | 0.5 to 20 GHz[2)] |

1) Ambient Room Temperature, 2) The measured frequency range is limited by the network analyzer available.

cavity can be 10-MHz, this confirms that the load requirements can be achieved through standard mechanical machining practices.

The MSC.Software FEM program, "NASTRAN V70™", was used for thermal analysis of the $TM_{011}$ cavity-chain including the SiC buttons, Figure 5-a) shows the FEM model geometry and typical temperature distribution data results are shown in Figures 5-b) and 5-c), where the cooling water flow speed is 0.5-m/s (equivalent to a volume flow rate of 17-L/min). As can be seen in the figure the periphery of the SiC on the top surface has the highest temperature and is about 151°C under these conditions. The temperature difference between the periphery and the centre on the top surface of the SiC is about 10°C. The highest temperature of the cavity body is about 70°C at the part, which is just below the SiC.

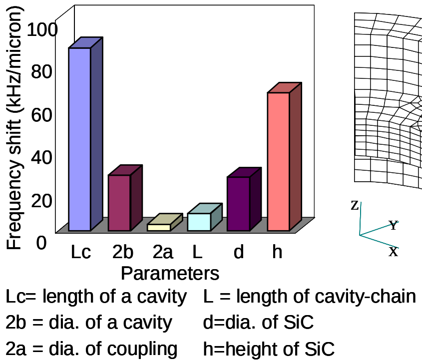


Figure 4: Frequency sensitivity of the $TM_{011}$ cavity

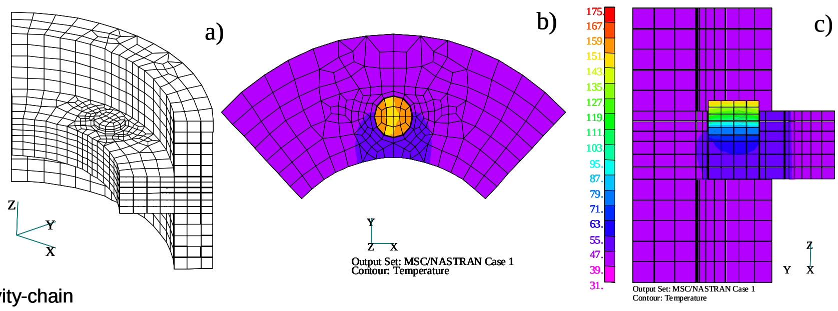


Figure 5: Thermal analysis of the $TM_{011}$ main body using NASTRAN V70;

Figure 6-a) shows the mode converter between the $TE_{10}$ rectangular wave-guide and the cylindrical $TM_{01}$ mode cavity. The mode converter not only provides impedance matching but also purifies the $TM_{01}$ mode. By adjusting the inductive coupling hole on the rectangular wave-guide the mode filter can match the impedance while by adjusting position of the short plane it can provide separation of the cylindrical $TM_{01}$ mode from the cylindrical $TE_{11}$ mode. Figure 6-b) shows the model used for the simulation of the mode filter section to the $TM_{011}$ cavity-chain. We used a quarter-wave impedance matching method to minimize the reflection coefficient ($S_{11}$) between the mode filter and the $TM_{011}$ cavity-chain. From analytical calculation we decided to initiate the simulation of the mode filter section beginning with a 50-mm diameter for the mode-filter and a 55-mm diameter for the quarter-wave section. Further fine modification is still needed in order to obtain $S_{11}$=0 at the resonant frequency of 5.712-GHz.

## SUMMARY

We have designed a new type 50-MW rf-load using a β-crystal structure SiC ceramic absorber. We used HFSS for design studies and found that the use of the cylindrical $TM_{011}$ mode cavity loaded with SiC disks provides great advantages over existing rf-loads. As the main parts of the rf-load are axially symmetric and can be manufactured by using conventional turning lathe, the result is much better manufacturability in mass production due to the ease of machining. In addition, it allows elimination 8,000 E-bend high power wave-guide components; that will also contribute to overall cost reduction and system simplicity for the linear collider. For the impedance matching section we will also use an inductive iris-type coupler, which has a simple structure instead of door-knob type impedance matching. Moreover, a very simple jacket type water cooling system can be used as the cooling water temperature rise at outlet is only ~8°C for an average power dissiapated of 6.24-kW.

We intend to develop an integral rf-load for the accelerating structure as the next step so as to eliminate all 8,000 output couplers and thus reduce the cost enormously. That should also increase the system reliability especially in high gradient operation.

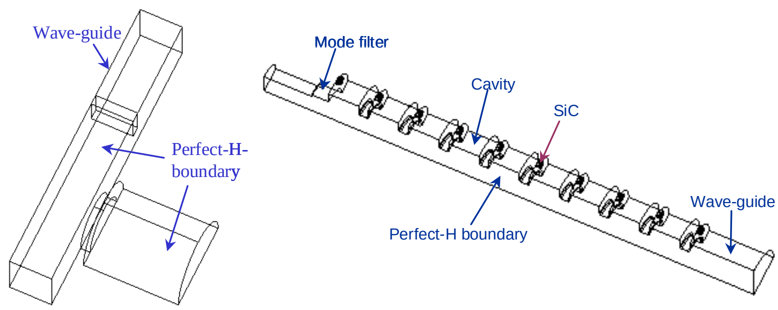


Figure 6: Drawing of impedance matching model for HFSS simulation; a) between rectangular wave-guide and mode filter and b) between the mode filter and the cavity-chain.

## REFERENCES

[1] H. Matsumoto et. al., "Experience on the High-Power SiC Microwave Dummy load using SiC Absorber", PAC99, March 29-April 2, 1999, New York City, U.S.A.

[2] S. S. Win et. al., "A new C-Band 50 MW Class SiC RF load", Proc. of 28th LINAC Meeting, July 30-August 1, 2003, Tokai, J-PARK.