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# Design and Development of High Power Broad Band Dry RF Load

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**ABSTRACT**

High power S-Band ferrite based RF load is designed and developed which is capable of handling 3 kW average power at operating frequency 2998±20 MHz. Electrical and thermal design is carried out using CST Studio Suite. Mechanical parts are fabricated according to the design. Water cooling is provided to the absorbing ferrites to support high power operation. Various RF load parts are fabricated, chemically cleaned and brazed. The experimental return loss better than 30 dB for a bandwidth of 250 MHz is achieved. The numerical and experimental results are discussed and presented in this paper.

**Keywords:** High power passive device; Microwave matched termination; Ferrite load; Microwave absorber

## 1. INTRODUCTION

RF load is a passive device which acts as a matched termination by absorbing microwave power incident on it. In microwave network, it is essential to terminate the unused ports with matched load to avoid undesired reflection and standing wave formation in the transmission line. The mismatch in the microwave circuit produces harmful effect like power loss, arcing, reduced efficiency which may even lead to total failure in the circuit. The sensitive components in the network may get damaged by strong reflection of RF signal. Therefore, RF load is an essential component to realise reflection free termination of a transmission line and smooth operation of the microwave network.

A number of geometries for waveguide microwave load/ absorber are proposed in the literature[1-2]. There are different types of microwave absorbing materials like dielectric absorber, ferroelectrics, ferrites, etc. used in waveguide based RF load. The developers need to judiciously select a particular absorbing material depending on the amount of attenuation, power handling capacity, and frequency of operation[3-6]. In the present work, Lithium ferrites having wide magnetic line width and high Curie temperature are used.

In the indigenous linac activity of SAMEER, the accelerating structure is powered by high power microwave source like magnetron/klystron via a circulator, wherein, the unused ports are terminated by matched RF load to protect the microwave source. SAMEER has already developed ceramic based RF load[7]. Ferrite load[8] is a dry load as the ferrites are not directly cooled by water. The absorbing ferrites are mounted on coper insert by using thermally conducting epoxy. Forced water cooling is provided to the copper insert which indirectly cools the ferrite. This type of RF load is relatively broad band and does not suffer from the water leakage. Therefore, ferrite based loads are widely used in high power microwave systems. In this paper, two different types of RF load models are discussed; (Model-A): straight rectangular waveguide coupled with tapered insert and (Model-B): tapered rectangular waveguide coupled with straight insert. The 3D views of both models are shown in Figs. 1 and 2 respectively. The present paper describes the design, electrical and thermal simulation, optimisation and experimental testing of a wideband ferrite based waveguide load in S-Band at operating frequency 2998 ±100 MHz.

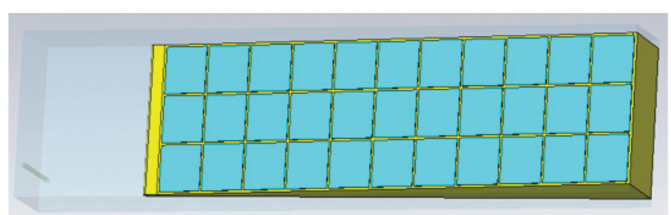

**Figure 1. 3D view of Model-A having straight rectangular waveguide coupled with tapered insert.**

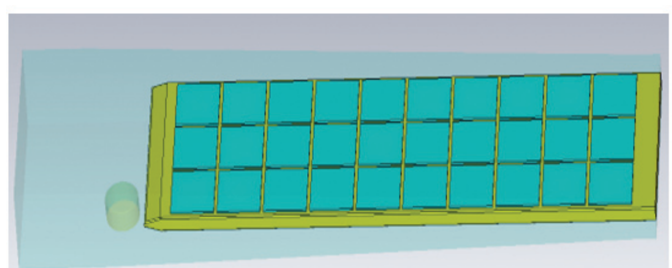

**Figure 2. 3D view of Model-B having tapered rectangular waveguide coupled with straight insert.**

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## 2. ELECTRICAL DESIGN OF FERRITE LOAD

The 3D model of both types of RF load is made in CST Studio Suite[9]. For each case, the device is comprised of three major components which are (1) outer waveguide with flange, (2) metal insert and (3) ferrites. An array (3X11) of square shaped ferrite slabs are fixed on both side of metal insert. The ferrite slabs are made thin for fast heat dissipation. Lithium ferrite is chosen for the present design. The device is simulated in CST frequency domain solver. A 60 dB coupling port, compatible with N-type connector is designed to couple a fraction of input power fed to the RF load. Parametric and optimisation analysis is done to converge on various variables like length of the wave guide section, length of the copper insert, tapering angles, dimension and quantity of ferrites, location and dimension of impedance matching post, etc. The simulated electric field pattern and return loss of Model-A are shown in Figs. 3 and 4 respectively. Figures 5 and 6, show the simulated electric field pattern and return loss for Model-B. The design specifications along with simulated results are given in Table 1.

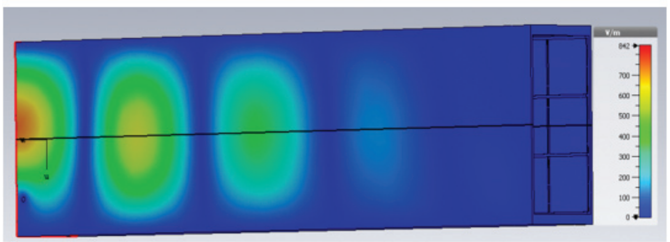


**Figure 3. Simulated E-Field Pattern for Model- A showing diminishing field strength as the wave travel towards the close end.**

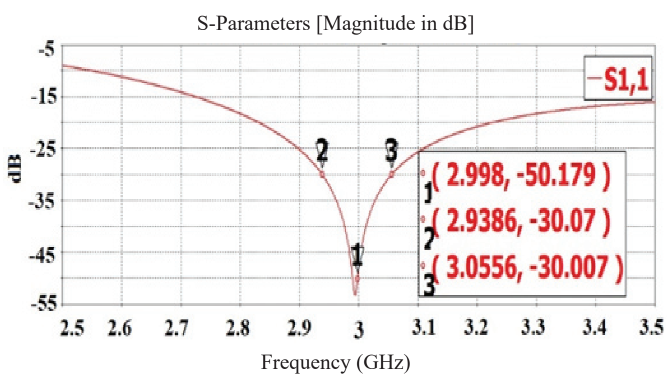



**Figure 4. Return loss for Model- A.**

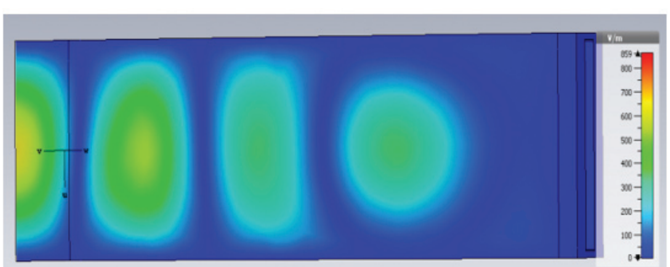


**Figure 5. Simulated E-Field Pattern for Model- B showing diminishing field strength as the wave travel towards the close end.**

**Table 1. Design specification vis-a-vis simulated results of RF load**

| Parameters | Specifications | Simulated results |
|---|---|---|
| Frequency | 2998±10 MHz | 2998±20 MHz |
| Average power | 3 kW | 3 kW |
| Return loss | ≥ 26 dB | ≥ 40 dB |
| Bandwidth | 20 MHz | 105 MHz approx. (30 dB) for Model-A. 151 MHz approx. (30 dB) for Model-B |
| Length of the wave guide section | 300 mm | 300 mm |
| Port | 60 dB coupling port | 60 dB coupling port |

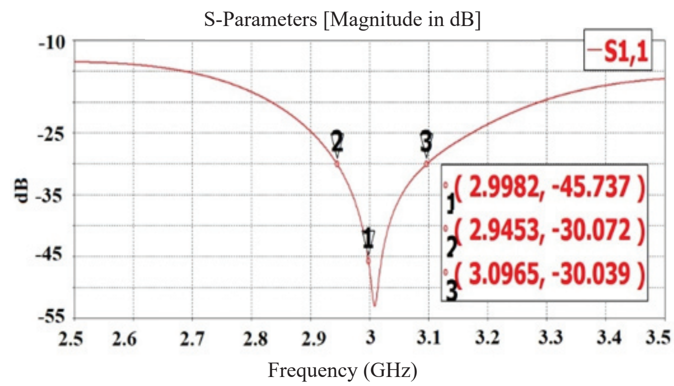



**Figure 6. Return loss for Model- B.**

## 3. THERMAL DESIGN OF FERRITE BASED RF LOAD

Thermal design is very essential for high power microwave devices because the operating power is often limited by the cooling efficiency of the device. In order to achieve reliable performance of the high power RF load, thermal design is the first and foremost requirement. In ferrite based matched load, ferrite material absorbs all the input RF power. Magnetic loss in ferrite produces volumetric heat generation depending on the distribution of RF field. Heat dissipation becomes a problem due to poor thermal conductivity of the ferrite. Therefore, the ferrite slabs are intentionally made as thin as possible to make it conducive for fast heat dissipation. However, ferrite thickness cannot be reduced beyond a certain limit because it will make the component very fragile. In thermal analysis, volume loss density from electrical simulation in CST microwave studio is directly imported to CST M Physics studio to provide thermal load. Heat dissipation in the form of convection heat loss of 10000 W/m$^2$K is applied inside the cooling duct fabricated inside the copper insert. Thermal contact surface is modelled at the ferrite-metal interface. Thermal conductivity and thickness of epoxy are considered to be 1 W/m.k and 50 µm respectively based on the data sheet. Steady state temperature distribution is obtained for 3 kW CW power input. Analogous temperature distributions are observed for Models A and B are displayed in Figs. 7 and 8, respectively. The middle ferrite located at the tip of the insert experiences intense electric field due to the dominant $TE_{10}$ mode input and consequently, hot

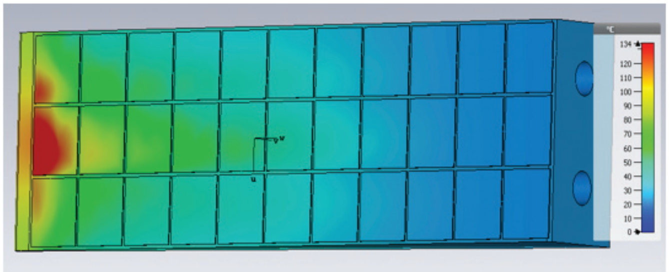


**Figure 7. Temperature distribution on the ferrite mounted copper insert for Model-A.**

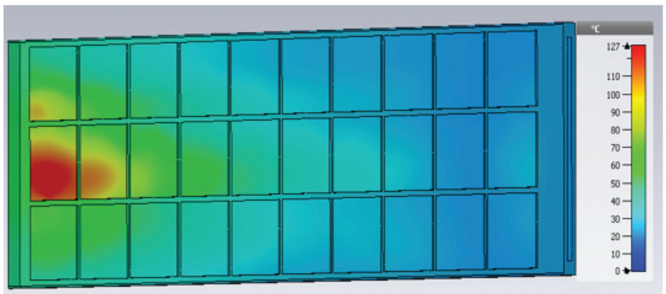


**Figure 8. Temperature distribution on the ferrite mounted copper insert for Model-B.**

spot formation is observed in this location. However, as the wave travels, the E-field intensity as well as heating potential weakens which is reflected in the temperature distribution plot. The epoxy material under consideration can sustain up to 200 °C temperature and the ferrites have 550 °C Curie temperature. Hence, the RF load should well withstand up to 3 kW CW power.

## 4. FABRICATION AND PROCESSING OF RF LOAD

On the basis of electrical design, mechanical part drawings of RF load Model-A are made in solid works. Suitable forced convection is provided to the metal insert by making internal cooling channels in the ferrite insert. Intense forced cooling is provided to the tip of the insert where heat dissipation is more. The cooling channels are shown in Fig. 9. The fabricated parts are chemically cleaned and brazed. Ferrites are mounted by using epoxy on the copper insert at regular interval. The unmounted and ferrite mounted copper inserts are shown is Figs. 10(a) and 10(b), respectively. The assembled RF load with 60 dB coupling port is shown in Fig. 11.

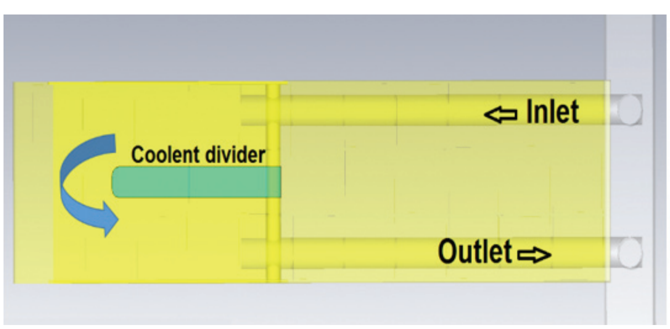
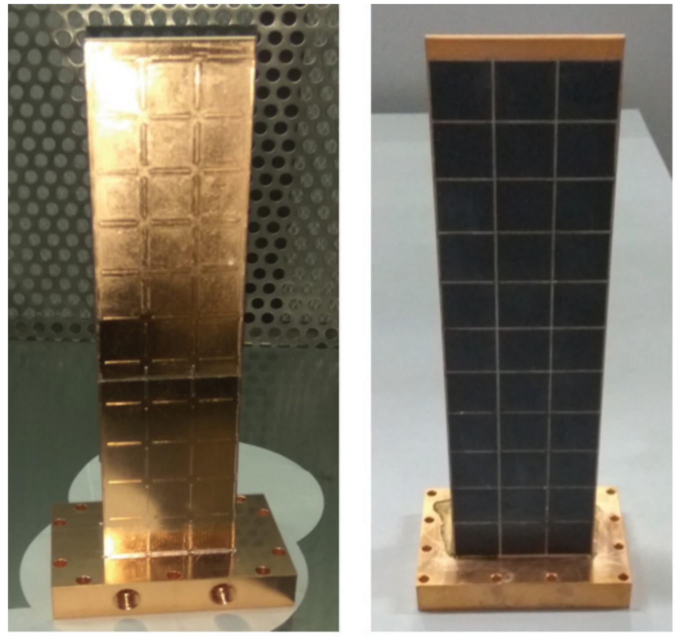



**Figure 9. View of coolant duct inside the metal insert.**



**(a)** **(b)**

**Figure 10. (a) Brazed copper insert, (b) Ferrite mounted insert.**

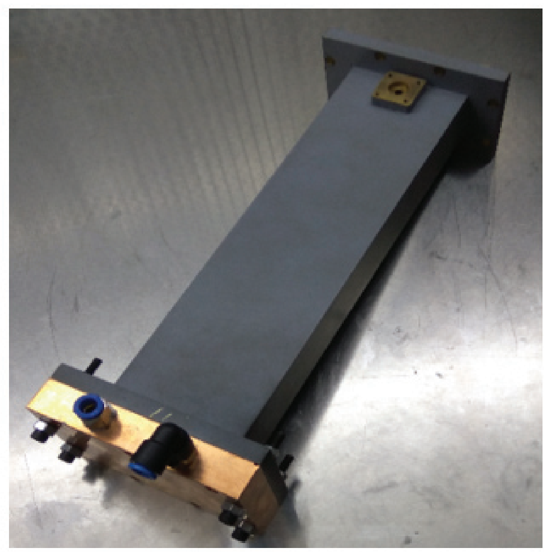


**Figure 11. Assembled RF load showing 60 dB coupling port and coolant ports.**

## 5. EXPERIMENTAL TESTING

Low power testing is performed by using VNA. Metal post is placed at waveguide wall for impedance matching and to optimise the return loss. The position of the post is varied manually to identify the best position where it is fixed with epoxy. The experimental setup and optimised $S_{11}$ is shown in Figs. 12 and 13 respectively. Leak testing is done by filling coolant in the coolant duct and then pressurising the same by nitrogen gas up to 40 PSI. The experimental setup is shown in Fig. 14. RF load operates under pressurised atmosphere to prevent electrical break down at peak RF power. Hence, pressurisation testing is also done up to 50 PSI pressure to check gas leakage.

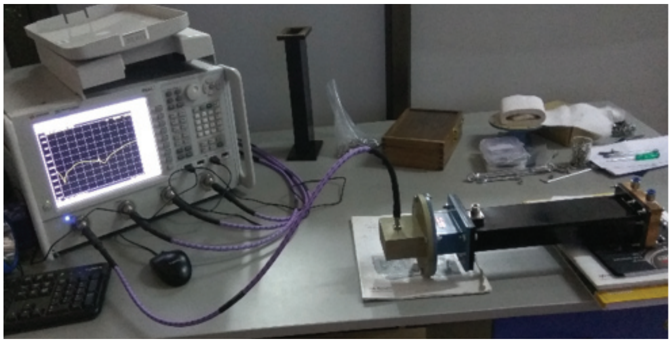


**Figure 12. Experimental set up for RF load.**

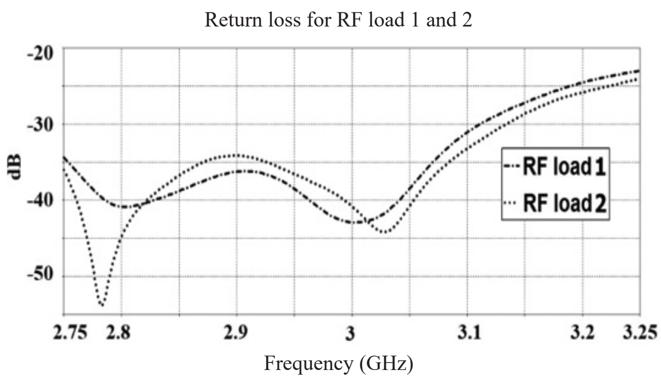



**Figure 13. Experimental return loss for RF load 1 and 2. The patterns are mutually agreed which reveals repeatability of the response.**

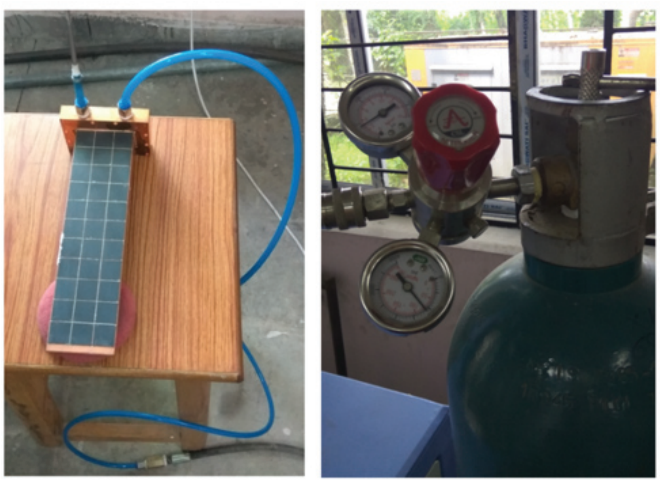


**Figure 14. Leak testing set up for coolant.**

## 6. CONCLUSIONS

Two different configurations of ferrite based high power microwave matched load are designed. Lithium ferrite is chosen for its wide magnetic line-width and high curie temperature. Electrical design is carried out to estimate and optimise the return loss. The load exhibits excellent matching for a bandwidth of 105 MHz for Model-A and 151 MHz for Model-B at center frequency 2998 MHz. Thermal analysis is performed to monitor temperature distribution and to finalise the cooling requirement. On the basis of design, various parts of the RF load Model-A are fabricated, chemically cleaned and brazed. Ferrites are mounted on the copper insert with the help of thermally conducting epoxy. Low power characterisation is done by using VNA. The results are improved experimentally by fixing metal post on the waveguide wall. Pressurisation and leak testing is carried out. The low power test results are found to be in good agreement with the design specifications.

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## CONTRIBUTORS

**Mr Narugopal Nayek** joined SAMEER, after receiving MTech in Electronics and Communication (Microwave) from Burdwan University, West Bengal, India in 2006. His research area includes active as well as passavle microwave, millimeter wave and sub THz vacuum electron devices and components.
In the present paper, he has performed the electrical design, conceptualisation of cooling mechanism, assemby, brazing and low power characterisation of the RF load.

**Mr Arvind Naik** received his Diploma in Mechanical Engineering in 1996. He joined SAMEER, Mumbai in 2008. His research area includes mechanical modelling of vacuum electron devices and components, design of jigs fixture, fabrication etc.
In the present paper, he has performed the mechanical design. He was also involved in fabrications of parts and high power testing of the RF load.

**Mr Manoj Phatangare** joined SAMEER after receiving MSc in Electronics from Pune University in 2008. His current research area is design and development of high voltage pulsed modulator.
In the present paper, he was involved in assemby, brazing and low power characterisation of the RF load.

**Dr T. Tiwari** received his PhD in the area of microwave tube technology from Center of Research in Microwave Tube (CRMT), Department of Electronics Engineering, IIT BHU, Varanasi. Currently, he is the Program Director In-charge of Society for Applied Microwave Electronics Engineering & Research (SAMEER), IIT Guwahati. His area of interest includes dielectric antenna, linear accelerator system, and slow wave and fast wave microwave tube.
In the present paper, he was involved in assemby, brazing and low power characterisation of the RF load and editing work of this paper.