Available online www.ejaet.com

European Journal of Advances in Engineering and Technology, 2016, 3(6): 26-30

Research Article ISSN: 2394 - 658X

Design, Development and Testing of RF Window for C band 250 kW CW Power Klystron

OS Lamba, VK Saxena, LM Joshi, Meenu Kaushik, Debasish Pal, Deepender Kant and A Bandhopadhyay

Microwave Tubes Area, Central Electronics Engineering Research Institute, Pilani, India
Council of Scientific and Industrial Research, New Delhi
osl@ceeri.ernet.in

ABSTRACT

The paper presents the design fabrication and cold testing of vacuum RF window for C-band 250 kW CW power klystron. The electromagnetic simulation of the window has been carried out using the CST microwave studio software. The proposed window is designed for 5 GHz operating frequency for handling 250 kW of RF power. In the proposed window geometry, metalized alumina disc (99.5 % purity) of diameter 56 mm and thickness 1.5 mm is brazed in a cylindrical waveguide of diameter 56 mm. The cylindrical waveguide is terminated to WR 187 waveguide at its both ends. The return loss and insertion loss of the above mentioned window has been found to be –48 dB and 0.05 dB respectively which are well matched with experimental values. The bandwidth of 170 MHz was achieved. The thermal analysis is carried out using ANSYS code. Different temperature profiles are obtained for different values of dielectric loss. The temperature range on the alumina disc surface is found to be 33.7°C – 92.9°C for the dielectric loss of 30.95 watts in the window disc material. Cooling channel designed around the window outside surface for proper cooling of the window by flowing coolant in it. The coolant flow rate changed from 5 to 15 L/min to check the cooling effect with variation of flow rate and found that 5 L/min. flow rate is effective for the structure for cooling the required power dissipation. The window performance has been found satisfactory for microwave transmission.

Key words: RF Window, Klystron, pill-box type, alumina and S -parameters

INTRODUCTION

RF window is one of the important issues for developing the high power klystrons. RF window is a critical component of all microwave high power tubes and is used on the output section of the device for the transport of microwave power from vacuum to external pressurized atmosphere. RF window is a passive component [2] that must be transparent to microwaves and hold ultra high vacuum. The desired features of an ideal window are: minimum reflection, minimum insertion loss, high power handling capability, wide bandwidth, excellent mechanical strength, high thermal shock resistance and vacuum tightness. Pill-box type microwave windows are generally preferred for high power klystrons [1-5] due to their higher capacity for handling high peak and average rf power. The other functional advantages are broad bandwidth and easy impedance matching with the rest of the transmission line[4].The design studies on high power RF windows are motivated by the need for C band 250 kW CW power klystron which is under development at CEERI Pilani.

Specifications of C-band Klystron

Operating Frequency	5 GHz
Output Power	250 kW
Beam Voltage	60 KV
Beam Current	10 Amps
Focusing	Electromagnet
Efficiency	> 40 %
Gain	> 45 dB

WINDOW DESIGN

The electrical design parameters for the window are: thickness, diameter and dielectric constant of alumina disc, diameter and length of waveguide etc. The window performance is decided from the output results of the software in term of return loss, VSWR, insertion loss, bandwidth etc. Input parameters for the software are input frequency range, window dimensions and dielectric constant of the ceramic disc. To obtain the best results of scattering parameters, different combination of input parameters have been entered and corresponding outputs have been checked in terms of scattering parameters. The simulation has been carried out with CST microwave studio code. The disc thickness, diameter and W/G length are variable parameters to optimize return loss and insertion loss values.

The schematic view of pillbox type RF window is shown in Fig.1 in which ceramic disc is sandwiched in between circular W/G and other ends terminated in standard WR 187 wave guides.

Input Design Parameters:

Window Material Alumina
Loss Tangent of Disc 0.0002
Dielectric Constant 9.4
Disc diameter 56 mm;
Disc thickness 1.5 mm
Circular W/G diameter 56 mm;
Circular W/G length 25.01mm;
Rectangular W/G length 30 mm
Input and output W/G (WR187)
a= 47.55 mm, b=22.15 mm

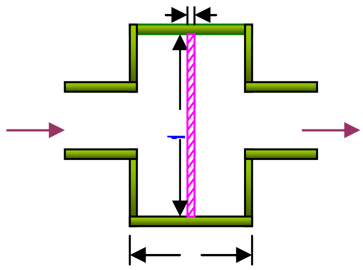

Fig. 1 Schematic view of pillbox type RF window

The electromagnetic simulation of RF windows carried out using CST Microwave Studio Code and HFSS code. We have optimized the return loss and insertion loss not only at the desired frequency but also in the entire range of desired bandwidths. The simulated return loss and insertion loss finally obtained at 5 GHz are –35.7 dB and 0.016 dB respectively. Fig.2 shows the plot of Return loss and Insertion Loss in the desired frequency range.

The window performance was evaluated by variation of dielectric constant of disc and length of wave guides. The variation results are shown in Table 1.

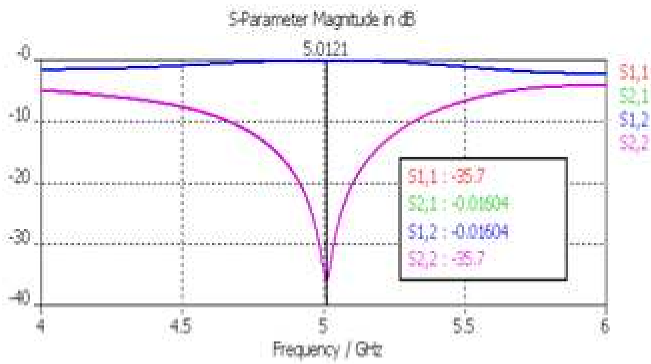

Fig. 2 Plot of Return Loss & Insertion Loss

Table -1 Window Performance with Dielectric Constant Variation

Dielectric constant	Frequency (GHz)	Return Loss(dB)	Insertion Loss(dB)
9.2	5.079	-69.77	-0.0022
9.3	5.0395	-71.96	-0.0021
9.4	4.999	-71.47	-0.0022
9.5	4.962	66.828	-0.0022
9.6	4.9226	-70.75	-0.0022

Thermal Analysis using ANSYS

Since this window is to be used for 250kW CW power klystron so, thermal analysis of this window is also necessary. This thermal analysis has been done using ANSYS code. The main approach of this software is the Finite Element Method. A steady state thermal analysis calculates the effects of steady thermal loads on a system or component. You can use steady state thermal analysis to determine temperatures, thermal gradients, heat flow rates and heat fluxes in an object that are caused by thermal loads that do not vary over time. Such loads include the following

- Convection
- Radiation
- Heat flow rates
- Heat fluxes (heat flow per unit area)
- Heat generation rates (heat flow per unit volume)
- Constant temperature boundaries

The desired features of microwave window vary with the types of their application. Nevertheless, a window ought to be almost loss less and reflection less. It must withstand high power, thermal and mechanical stresses and pressure gradient. Therefore care must be taken in selecting the power window material with low loss tangent, high thermal conductivity and mechanical strength. The thermal simulation of different parameters for window such as window dielectric materials, variable loss tangent, coolant flow rate, transmitted power v/s temperature rise for symmetric window geometry are presented.

The following conclusion has been drawn through the detailed simulated thermal analysis of the window:
In case of low power RF windows dielectric materials having loss tangents in the order of 10^{-3} are acceptable but for high power windows the loss tangent of the material must be of the order of 10^{-4}. Otherwise the high thermal stress due to the large temperature gradients may damage the window.

The analysis of single disc RF window is done using the material Alumina. The thermal design parameters are:
Window geometry, Window material, total heat dissipation in disc and Water flow rate.

Input parameters used in simulation are:
Material property, Coolant property, Heat flux, Film coefficient and Bulk temperature.

Output parameters are the temperature profile of RF window.

The values of input parameters involved in window design are:

Loss tangent	0.0002
Bulk temperature	25°C
Water flow rate	5 L/min.
Film Coefficient	8184 W/m²K
Input power	250kW

The table -2 shows the temperature profile obtained at different dielectric loss.

Table -2 Temperature versus Dielectric Loss

Dielectric loss (W)	Heat flux (W/m^2)	Temperature (°C)
30.95	2572.30	33.7 – 92.9
46.42	8856.42	48.1 – 136.9
57.49	23331.98	26.1 – 149

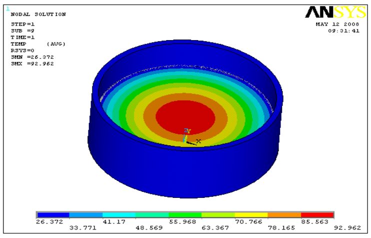

Fig. 3 Temperature profile for loss 30.95 W

WINDOW BRAZING

The RF window is an integral part of high power klystron tube. In order to maintain ultra high vacuum the window should be capable of holding vacuum of the order of 10^{-9} torr. The alumina disc is metallised [8] and brazed on the circumference with OFHC copper waveguide, with cylindrical part made extra thin at the joint area, and the disc is pushed to be fitted in it. A molybdenum wire clamp is placed on the outside of the waveguide in this region to keep the copper from expanding away from the ceramic during brazing. Palladium brazing alloy with MP 850 ^{0}C has been used to make the vacuum tight joint. The copper part has been made thin to make it ductile so that the seal may remain intact instead of mismatching of thermal expansion of both materials. The brazed window is leak checked on helium leak detector of sensitivity of $1x10^{-10}$ torr lit/sec. The window parts are shown below in Fig. 4.

Fig. 4 RF window parts

Fig. 5 Measurement setup of VNA

COLD TESTING RESULTS

These measurements are carried out by the measurement setup named as 'Vector Network Analyser'. This type of network analyzer consists of a sweep oscillator (almost always a synthesizer so that measurements will be repeatable), a test set which includes two ports, a control panel, an information display, and an RF cable or two to hook up your DUT. Each port of the test set includes dual directional couplers and a complex ratio measuring device. Other options include a means for bias voltage/current injection, and a computer controller to manipulate and store data. This analyzer can make measurements from 45 MHz to 110 GHz.

Before doing measurements, we have to calibrate the network analyzer. There are many types of calibration techniques, and even more types of calibration standards. A typical calibration will move the measurement reference planes to the very ends of the test cables. We will have the choice of calibrating for reflection or transmission only, using either of the two ports or both of them together. For most tasks we will probably calibrate both test ports for reflection and transmission, which will allow us to measure full two-port scattering matrices (S-parameters for our device under test (DUT). The reflection calibration for each port requires three standards, typically: an open circuit, a short circuit, and a matched 50-ohm load (for waveguide calibration, a pair of offset shorts and a load are used. An open in waveguide usually acts closer to a load due to radiation).

The simulation results of alumina window of 56 mm disc diameter, 1.5 mm disc thickness are tabulated in Table 1. The plots of Return Loss, Insertion Loss v/s frequency have been obtained through the software as well as experiments which are shown in figure 2 and Table1. The nominal length of window has been optimized to 25.55 mm and corresponding return loss –44.4 dB and insertion loss –0.059dB at 5 GHz frequency. Cold test measurements were carried out on two fabricated window of length 24.55 mm and 24.40 mm. The measured return loss and insertion loss finally obtained at 5.022 GHz are –50.36 dB and 0.038 dB respectively. The measured results are shown in table 3.

Table -3 Cold Test Results

	Window1 Diameter : 56mm Length : 24.55mm Disc thickness : 1.50 mm Material : Alumina	**Window 2** Diameter : 56mm Length : 24.40mm Disc thickness : 1.50mm Material : Alumina
Measured Return loss(dB)	-44.4 dB	-48.6 dB
Measured Insertion loss(dB	-0.059	-0.0679

Fig. 5 Measured Return Loss & Insertion Loss of the window

CONCLUSION

Electromagnetic design of pillbox-type RF window for high power C-band klystron has been carried out using 'CST Microwave Studio' and 'Ansoft HFSS' software. The simulated results have been validated through experimental fabrication of window and their cold testing. The variation of dielectric constant, window length, diameter and disc thickness parameters are experimented to achieve the desired window performance. The thermal analysis of the window is successfully carried out using ANSYS code. The window designed using alumina disc material having proper cooling arrangements. It is concluded that the alumina material is best suitable for low power klystrons.

RF window for C band 250 kW CW Klystron alumina disc of 56 mm diameter and 1.5 mm thickness and 24.55 mm length has been designed, fabricated and cold testing is carried out. The performance of window found satisfactorily for using at 5 GHz operating frequency.

Acknowledgment

The authors are thankful to Dr. SN Joshi, Emeritus Scientist for his encouragement and guidance and Dr. Chandra Shekhar, Director, CEERI for allowing us to publish this paper.

REFERENCES

[1] WR Fowkes, High power RF Window and Waveguide Component Development and Testing above 100MW at X-band, *Linear Accelerator Conference (LINAC 92)*, Ottawa, Canada, SLAC preprint SLAC-PUB-5877, **1992**.
[2] G Caryotakisl, Development of Multimegawatt Klystrons for Linear Colliders, *Particle Accelerator Conference (PAC 93)*, Washington, DC, SLAC-PUB-6168, **1993**.
[3] Stevan H Gold and Gregory S Nusinovich, Review of High Power Microwave Source Research, *Review of Scientific* Instruments, **year of publication**, 68(2), 3945-3974.
[4] T Kageyama, A Large-Signal Analysis of Broad-band Klystrons with Design Applications, *IEEE Transactions on Electron Devices*, **1977**, 24, 3-12.
[5] GT Konard, High Efficiency, CW, High Power Klystrons for Storage Ring Applications, *IEEE Transactions on Nucteoa Science*, **1975**, 22, 1249-1252.
[6] H Matsumoto, Development of High Power RF Windows at S Band, *Energy Accelerator Research Organization*, Japan, **1993**, 1124- 1126.
[7] OS Lamba, Electromagnetic Simulation of RF Window for 2856 MHz High Pulse Power Klystron, *Asia Pacific Microwave Conference (APMC' 04)*, New Delhi, India, **2004,** 145- 150
[8] PA Rizzi, *Microwave Engineering* (Passive Circuits), Prentice Hall International, Inc, USA, **1988**.