DESIGN AND DEVELOPMENT OF DOUBLE RIDGED WAVEGUIDE FOR MICROWAVE ION SOURCE

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Abstract

This article describes analytical design, HFSS simulation optimization and experimental results of WR-284 double ridged waveguide used in the high current microwave ion source to efficiently couple the microwave power to the high density plasma.

INTRODUCTION

The microwave coupling to high current microwave ion source is very much vital since these ion sources operate in over dense regime and microwave energy can be coupled only at the plasma surface. For high current ion production it is necessary to design the coupling system to produce the electric field intensity maximum at the center of the plasma chamber. The earlier ridged waveguide, impedance transformer from WR284 to the plasma in the microwave ion source, did not work properly. There was lots of reflected power and heating in the ridged waveguide even at 200W and negligible coupling of power to plasma. We, therefore, decided to design new water cooled ridged guide. The initial design was done analytically and finally the ridge spacing and ridge lengths were optimized using computer code HFSS to maximize electric field in the centre of the plasma chamber. In order to transform 663.7 ohm (impedance of WR-284) to 110 ohm (typical plasma impedance) we have used an impedance transformation ratio of six which gives us the value of characteristic impedances of four quarter wave ridges. It has been designed for 25% bandwidth at a central frequency of 2.45 GHz and maximum reflection coefficient of 0.05. HFSS driven modal simulation of binomial transformer has been carried out for the optimization of ridge width and length to achieve minimum VSWR in the frequency band of 2.2-2.8 GHz. To study various coupling structures like waveguide, single ridge waveguide, feed horn and multi-section transformer, the HFSS eigen mode solver has been used.

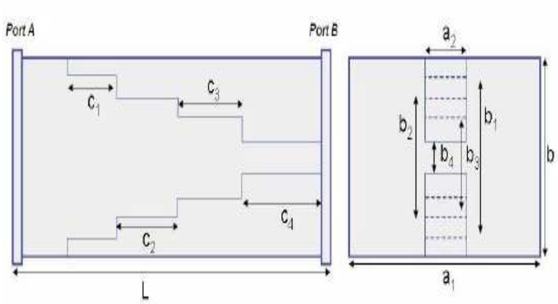

Figure 1: Sketch of four section matching transformer

ANALYTICAL DESIGN

Matching transformer was designed using theory of small reflections as outlined in ref. [1]. In our case Z_L= 663.7 Ω (impedance of WR-284 waveguide) and Z_0= 110Ω. This value Z_0 is chosen best on the experimental measurement of plasma impedance at different laboratories which is typically in the range of 100-150Ω. We have calculated characteristic impedance of four ridges using equation (1), where N and C are number of sections and binomial coefficients respectively. b_1, b_2, b_3, b_4 were calculated using equations (2) to (5) where, λ_{cr}=cut-off wavelength, *d*=spacing between the ridge and *s*=width of the ridge. *a* and *b* are the longer and smaller sides of the WR-284 waveguide

$$Z_{n+1} \sim Z_n \times e^{\left[2^{-N} \times \ln\left(\frac{Z_L}{Z_0}\right) \times C\right.} \quad (1)$$

$$\frac{1}{\lambda cr} = \frac{1}{2\times(a-s)}\left[1+\frac{4}{\pi}\left(1+0.2\sqrt{\frac{b}{a-s}}\right)\frac{b}{a-s}\ln\csc\frac{\pi}{2}\times\frac{d}{b}+\left(2.45+0.2\times\frac{s}{a}\right)\frac{sb}{d(a-s)}\right]^{-\frac{1}{2}} \quad (2)$$

$$\frac{B_0}{Y_0} = \frac{2b}{\lambda cr} \times \ln\csc\pi \quad (3)$$

$$Z_{0\infty} = \frac{120\times\pi^2\times\left(\frac{b}{\lambda cr}\right)}{\frac{b}{d}\sin\pi\frac{s}{b}\frac{c}{\lambda cr}+\left[\frac{B_0}{Y_0}+\tan\frac{\pi}{2}\frac{b}{\lambda cr}\left(\frac{a-s}{b}\right)\right]\cos\pi} \quad (4)$$

$$Z_0 = Z_{0\infty}\left[1-\left(\frac{\lambda}{\lambda cr}\right)^2\right] \quad (5)$$

Table 1: Calculated parameters of binomial transformer.

Section	Z_0 (Ω)	c (mm)	b (mm)
1	591.796	55.3	31
2	378.112	47.6	22.5
3	194.16	40.5	13.8
4	124.05	37.7	9.8

SIMULATION

The analytical parameter of binomial transformer had been used to develop a model in HFSS^{TM} [2] for the optimization of b_1-b_4, a_2 and c_1-c_4 for minimum VSWR and maximum electric field in the centre of the plasma chamber. HFSS driven modal and eigen mode solver with 20 adaptive passes has been used, optimization of ridges is done with the help of OPTIMETRICS module built in computer code HFSS.

Using HFSS we have optimized the S11 parameter of two different matching transformers with a_2 =12 and 24 mm .The S11 plot for s=24 mm transformer (optimized) is shown in Fig. 3, it is evident from Fig. 3 that reflection coefficient is -30 dB in the frequency band of 2.4-2.5 GHz which is much better than our design goal. The second part of the simulation deals with the optimization of binomial transformer to get maximum electric field in the centre of plasma chamber at 2.45 GHz, the maximum electric field of $9*10^4$ V/m was obtained with a_2 =24 mm and its double to that of simple WR-284 waveguide and 10% higher as compared to a_2 = 12mm design. The comparison of electric field obtained in the simulation for various ridged width is as shown in Fig. 4.

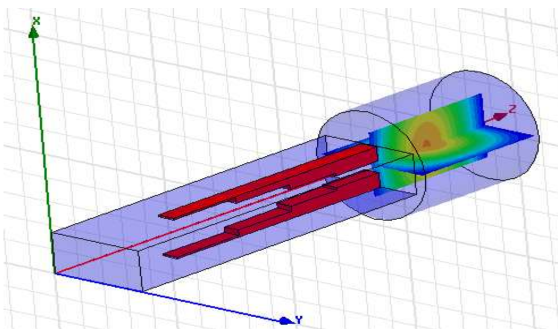

Figure 2: HFSS model of binomial transformer.

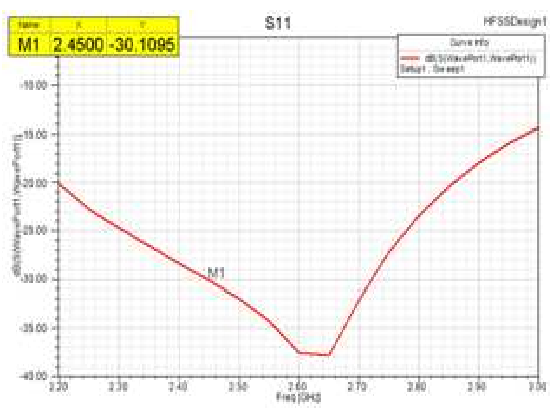

Figure 3: Variation of the reflection coefficient with frequency for the ridged waveguide.

EXPERIMENTAL RESULTS

During the operation of ion source we observed lots of reflected power and heating in the ridged waveguide even at 200W and negligible coupling of power to plasma. The beam current extracted was much below the expectation (~ 200 µA). We, therefore, designed a new water cooled ridged guide. It was fabricated in-house and installed in the microwave ion source as shown in Fig 5. During the operation of the source we found that maximum reflection is within 5% under different operating conditions. This is very close to the results of simulation, indicating a good matching of the waveguide impedance to plasma impedance.

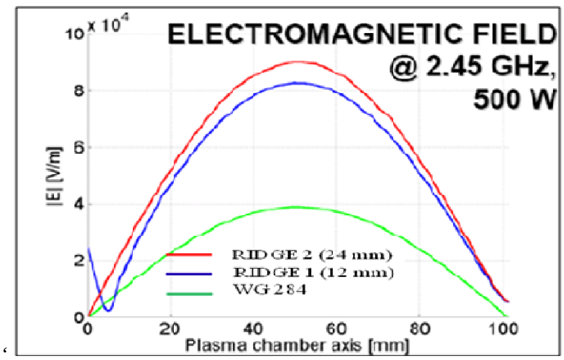

Figure 4: Electric Field in the centre of plasma chamber of different designs.

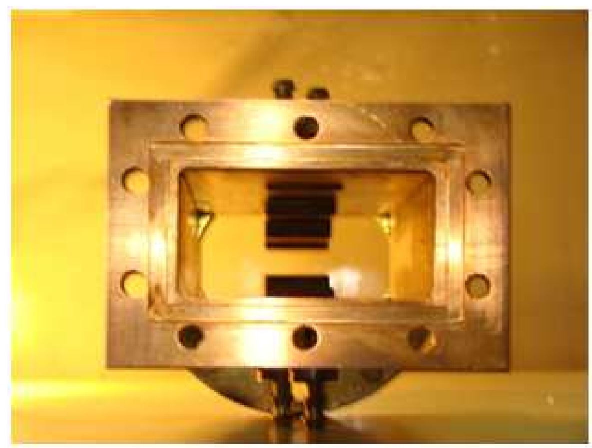

Figure 5: Installed ridged waveguide in microwave ion source.

CONCLUSIONS

The four section ridged waveguide has improved the efficiency of microwave ion source significantly and we are able to produce ~8.4mA beam current as measure by DCCT , 60cm away from the extraction electrode with 400W of microwave power. The analytical and simulated values of transfer impedance are 124 and 145 Ω respectively, which are in close agreement to the typical plasma impedance of 100-150Ω.

REFERENCES

[1] D. M. Pozar, "Microwave Engineering", John Wiley and Sons Inc.
[2] Ansoft HFSS website, http://www.ansoft.com