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SHORT COMMUNICATION
THE USE OF A 4-STUB-TUNER FOR IMPEDANCE MATCHING OF HIGHLY REACTIVE LOADS

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***RINGKASAN**: Kertas ini melaporkan penggunaan penala "4-stub" untuk di padankan dengan beban reaktif tinggi dan melibatkan satu model yang menggambarkan operasi penala "stub". Walaubagaimanapun, penala "4-stub" ini juga digunakan di dalam sistem gelombang-mikro plasma yang dibina di makmal. Kajian mendapati bahawa disamping beban yang terdiri daripada rongga (bekas plasma) dan plasma yang terlalu induktif dan faktor kualiti Q melebihi 2-3 aras magnitud, penala itu mampu untuk dipadankan dengan talian penghantaran "waveguide" kepada beban itu.*

ABSTRACT: This paper reports the usefulness of a 4-stub-tuner in a highly reactive load system and involves a model that demonstrates the operation of the stub-tuner. A 4-stub-tuner was also used in a microwave plasma system that was constructed in the laboratory. It was observed that in spite of its load, which comprises the cavity (plasma container) and the plasma, being highly inductive and the Q (quality factor) over 2-3 orders of magnitude, the tuner managed to match the line (waveguide) to the load.

KEYWORDS: Microwave plasma, 4-stub tuner, materials processing, quality factor

INTRODUCTION

There are various types of stub-tuners for microwave systems. The theory of operation and applications of the one, two and three stub-tuners (Wyslouzil *et al*, 1973) are very well established. They are all basically used in microwave systems for the purpose of maximum power transfer or perfect match. It is rather simple to match a load which is resistive and has lower values of Q. The lengths of the stubs of the tuners for matching are within the lengths of the narrow side for a rectangular waveguide. Hence it is easier and cheaper to design microwave systems having these load characteristics.

For highly reactive loads with Q of 2-3 or even higher orders of magnitude, then the application of the 4-stub-tuner is necessary. It can be easily shown that a typical plasma system operating using a 2.46 GHz power source is highly inductive. As the cavity and the plasma, being the lossy (resistive) dielectric medium, can be considered as part of a short-circuit transmission line of length less than $\frac{\lambda_g}{4}$, where λ_g is the guide wavelength, the reactance of the line is highly inductive. Hence the magnitude of the reflection coefficient is close to one. This explains the reason for the line to approach a short-circuit condition in spite of the presence of a plasma. As for the plasma, the typical non-electron cyclotron resonance (ECR) microwave plasma systems have plasma frequencies of several orders of magnitude lesser than the operating frequency which is often 2.46 GHz. This makes them highly penetrative to the incident electromagnetic fields, thus resulting in the dominance of reactance of the loads.

For matching, short or open circuit 4-stub-tuners can be used. The model explained in this paper uses a short-circuit 4-stub-tuner to match a load of $Z_L = 5 + j200\Omega$. The Z_L value was chosen for the various reasons stated in the above paragraph. The waveguide used in the model is type WR 284. Figure 1 shows the sketch of the short-circuit 4-stub-tuner. The Smith's chart shown in Figure 2 is used to find the length of all the stubs.

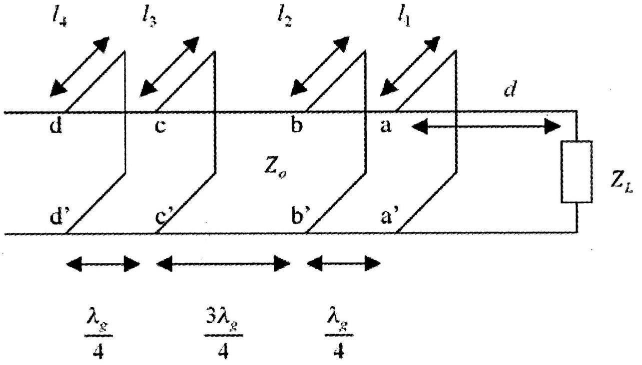

Figure 1. *The equivalent circuit of the 4-stub-tuner with load*

METHOD

Figure 1 shows the circuit diagram of the short circuit 4-stub-tuner connected to the load Z_L. The circuit is modeled using WR284 waveguide (Harsany, 1997). The propagation mode is TE_{10}. The characteristic impedance, Z_o of the waveguide is obtained from equation 1, where with the dimensions $a = 76.2$ mm and $b = 38.1$ mm, and neglecting power losses in walls of the waveguide, it is 314Ω. Z_L is normalised to Z_o and l_1, l_2, l_3 and l_4 are the lengths of the short circuit stubs at matching condition. These lengths must be less than the value of b for the stubs to be within normal operation. This condition is applied to any type of waveguide apart from the modeled waveguide. The length $d = 0.98\lambda_g$ is the distance of the load to stub l_1. This distance is the experimental value obtained from the home-built plasma system (Chakrabarty, 2002). The Smith's chart (Figure 2) is used to aid in the analysis. For the WR284 waveguide, the following equations are also relied upon to find the cut-off frequency f_c (maximum frequency at which no propagation is allowed) and guide wavelength λ_g (wavelength of the electromagnetic waves in a bounded-medium).

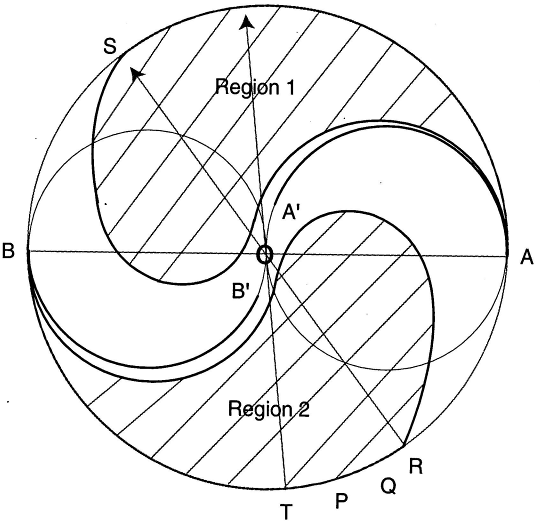

Figure 2. *The Smith's chart for the 4-stub-tuner*

$$Z_o = 377\left(\frac{b}{a}\right)\frac{1}{\sqrt{1-\left(\frac{f_c}{f}\right)^2}} \qquad (1)$$

$$f_c = \frac{u_p}{2}\sqrt{\frac{m^2}{a^2}+\frac{n^2}{b^2}} \qquad (2)$$

$$\lambda_g = \frac{\lambda}{\sqrt{1-\left(\frac{f_c}{f}\right)^2}} \tag{3}$$

The normalised admittance of the short circuit stub is

$$\overline{Y}_{SC} = -jCot\,(\beta l) \tag{4}$$

Since $0 \leq l \leq 38.1mm$, the range of the normalised short circuit admittance of the stub is $-j\infty < \overline{Y}_{SC} < -j0.42$. The normalised load is $\overline{Z}_L = 0.02 + j0.64$. At the plane dd' (as shown in Figure 1), the admittance when looking into the transmission line (TL) from the right of this plane is $1 + jB_4$, where $B_4 > 0.42$. This is represented in the Smith's chart as AA'. Moving the plane dd' by $\frac{\lambda_g}{4}$ towards the load until the left side of cc' is reached, the locus AA' is transformed to BB'. The admittance when looking into the TL from the right side cc' falls on shaded region 1. And from here, as the plane moves by $\frac{3}{4}\lambda_g$ to the left side of plane bb', the shaded region is thus rotated by 180° and falls on region 2.

The normalised load admittance is $\overline{Y}_L = \frac{1}{\overline{Z}_L} = 0.039 - j1.57$. This is represented by point P on the Smith's chart. This point is moved toward the generator along the constant standing wave ratio (SWR) circle of radius represented by the length of the line OP, $0.98\lambda_g$. This is the left-side of the plane aa'. The admittance $\overline{Y}_L(-0.98\lambda_g)$ from the Smith's chart is $0.059 - j2.05$ and is represented by Q.

The starting value of $l_1 = 38.1mm$ is chosen. Hence the $\overline{Y}_{sc1} = -j0.42$. Therefore the admittance as seen into the TL from the right-side of plane aa' is

$$\overline{Y}_L' = \overline{Y}_L(-0.98\lambda_g) + \overline{Y}_{sc1} \tag{5}$$

This is represented by R. Then by moving this point of admittance on its constant SWR circle towards the generator by $\frac{\lambda_g}{4}$, S is reached. In choosing $l_2 = 20.0mm$ which is equivalent to $\overline{Y}_{sc2} = -j1.41$, the total admittance is

$$\overline{Y}_L'' = \overline{Y}_L'\left(\frac{-\lambda_g}{4}\right) + \overline{Y}_{sc2} \tag{6}$$

and is represented by T in region 2. Hence the circuit is converted into a two-stub-tuner matching network and the usual method (Rao, 2000) for determining the stub lengths is used. From the analysis, $l_3 = 24.1mm$ and $l_4 = 2.9mm$, which are well within the limits of operation of the stubs, are obtained. The analysis can be repeated for different values of l_1 and l_2 and the admittance $\overline{Y}_L''$ will consistantly be in region 2 which is the acceptance load region for the remaining stubs or the two-stub-tuner to perform the match.

CONCLUSION

This paper has shown the usefulness of the 4-stub-tuner to perform impedance matching for very reactive loads. The analysis has also shown the region of acceptance of the equivalent load in the Smith's chart prior to matching. It has also reported the consistancy of this load to be in the region of acceptance, for the two-stub-tuner method to be applicable.

REFERENCES

Chakrabarty, C.K. (2002). The development of a low-cost microwave plasma system for materials processing. *Solid State Sci. and Tech.* **Vol (10), No. 1 & 2**, pp 167-172.

Harsany, S.C. (1997). Principles of Microwave Technology, Prentice Hall, pp 73 - 93.

Rao, N. (2000). Elements of Engineering Electromagnetics, Prentice Hall, pp 440 - 455.

Wyslouzil, W. and Vankaughnett, A.L. (1973). Automated matching of resonant microwave heating systems. *J. Microwave Power*, **8(1)**, pp 89 -100.