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RF field analysis and equivalent circuit analysis of conducting strips in rectangular waveguide

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Abstract Symmetric capacitive and inductive waveguide windows have been analysed using variational technique The normalised susceptance for those two types of windows have been found out both theoretically and experimentally Results obtained theoretically shows better agreement than standard results available with experimental results Using waveguide windows a waveguide filter has been designed and experimentally verified Finally, a switch has been designed using the filter which shows an isolation of over 40 dB.

Keywords Waveguide, conducting strips, RF field analysis

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1. Introduction

Waveguide structures are composite regions containing not only uniform or nonuniform waveguide regions but also discontinuity regions. The complete description of the fields within a discontinuity region generally requires in addition to the dominant mode, an infinity of nonpropagating modes A waveguide region can be represented by a single transmission line appropriate to the propagating modes. The discontinuity can be represented by means of lumped constant equivalent circuits together with the transmission line representative of the associated waveguide which serves to describe the fields almost everywhere within a general waveguide structure. The waveguide windows which are discontinuities are dealt here. The theoretical determination equivalent circuit parameters requires mathematical iods that do not properly lie within the realm of owave network engineering. Instead, such determination rally involve the so-called boundary value or field lems. Variational method has been used here to find out ormalised susceptance of capacitive or inductive window ch gives an approximation to the desired quantity. The nula is stationary about the correct solution which means the formula is relatively insensitive to variations in an ed field about the correct field.

2. Theoretical analysis and experimental verification for capacitive and inductive window

Let us consider the rectangular waveguide of Figure 1.

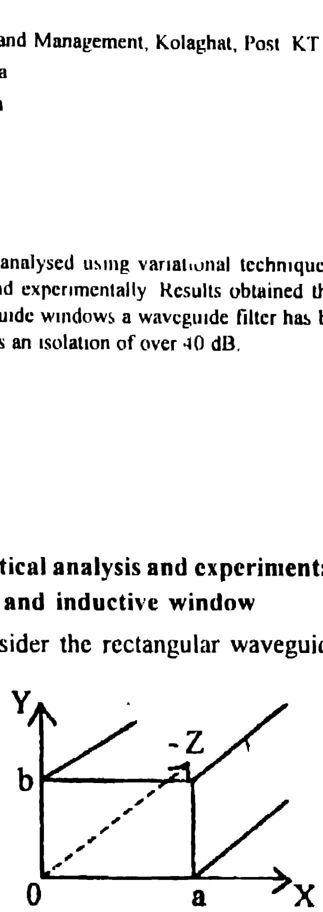

Figure 1. Rectangular waveguide

Let $E_x = 0$ and $E_y = f(x, y)$ be known over the $z = 0$ cross section. The TE_x modes have no E_x, so a superposition of these modes has been taken. The wavefunction can be written as

$$\psi = \sum_{m=1}^{\infty}\sum_{n=0}^{\infty} A_{mn}\sin(m\pi x/a)\cos(n\pi y/b)e^{-\gamma_{mn}z} \quad (1)$$

where A_{mn} are mode amplitudes and γ_{mn} are mode-propagation constants. E_y at $z = 0$ is given by [1]

$$E_y = \sum_{m=1}^{\infty}\sum_{n=0}^{\infty} \gamma_{mn} A_{mn}\sin(m\pi x/a)\cos(n\pi y/b) \quad (2)$$

For a capacitive waveguide junction as shown in Figure 2(a) the aperture admittance is given by

$$Y_a = (Y_0)_{10}\left[a/2b + j2a/\lambda_g \sum_{n=1}^{\infty} \sin^2(n\pi c/2b)\right.$$
$$\left.\cos(n\pi/2) \Big/ \left\{(n\pi c/2b)^2 \sqrt{\left(n^2-(2b/\lambda_g)^2\right)}\right\}\right] \tag{3}$$

Now, proceeding in the same way [1] in case of a capacitive diaphragm as shown in Figure 2(b, c) the normalised susceptance is obtained as

$$B/Y_0 = \frac{8b/\lambda_g \sum_{n=1}^{\infty}\left(1/\sqrt{\left(n^2-(2b/\lambda_g)^2\right)}\right)\left[\int_{b/2-c/2}^{b/2+c/2} f(y)\cos(n\pi y/b)dy\right]^2}{\int_{b/2-c/2}^{b/2+c/2} f(y)} \tag{4}$$

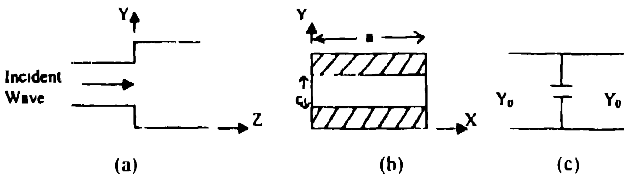

Figure 2. (a) Capacitive waveguide junction, (b) Capacitive diaphragm and (c) Equivalent circuit

For an inductive junction as shown in Figure 3(a) the aperture susceptance is given by

$$B_a = -\frac{1}{2ab\eta}\sum_{m=2}\sqrt{\left((m\lambda/2a)^2-1\right)}\,\frac{(2\pi/c)^2}{\left[(m\pi/a)^2-(\pi/c)^2\right]^2}$$
$$\times\left\{\sin(m\pi/2 + m\pi c/2a)+\sin(m\pi/2 - m\pi c/2a)\right\}^2$$

For an inductive diaphragm as shown in Figure 3(b, c) the normalised susceptance is given by

$$\frac{B}{Y_0} \approx \frac{2B_a\lambda_g\eta}{\lambda} \Big/ 2ab \Big/ \left\{(2\pi/c)^2\Big/\left[(\pi/a)^2-(\pi/c)^2\right]^2\right\} \tag{5}$$

The values of normalised susceptance obtained for 0.9" × 0.2" capacitive window and 0.7" × 0.2" inductive window are

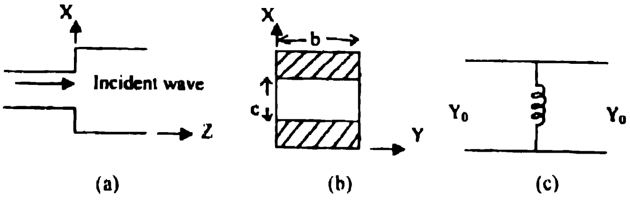

Figure 3. (a) Inductive junction, (b) Inductive diaphragm, (c) Equivalent circuit

compared with the corresponding values obtained from Marcuvitz's formulation [2]. Experimental values are obtained using slotted line technique and vector network analyser (HP 8410C). The results are shown in Figures 4 and 5

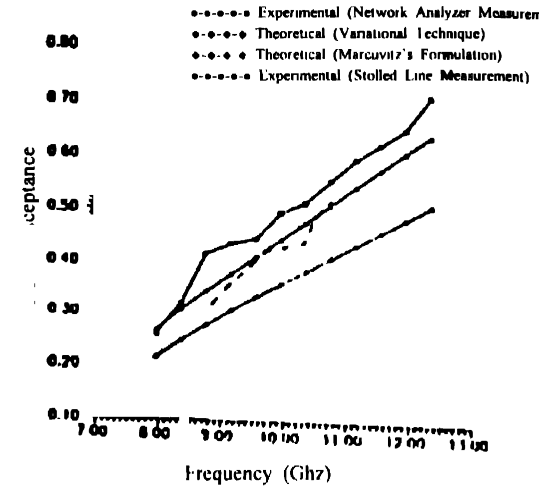

Figure 4. Normalised susceptance *vs* frequency for a capacitive window

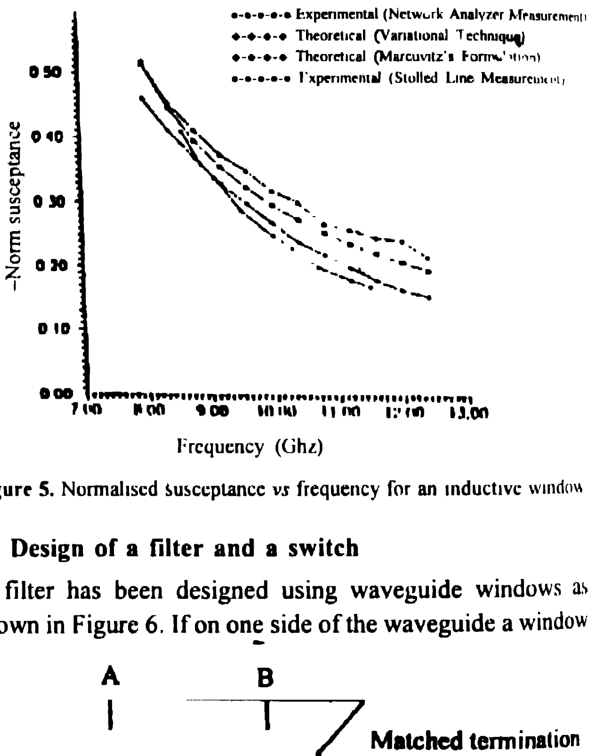

Figure 5. Normalised susceptance *vs* frequency for an inductive window

3. Design of a filter and a switch

A filter has been designed using waveguide windows as shown in Figure 6. If on one side of the waveguide a window

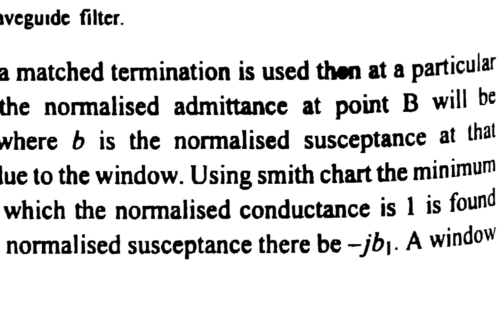

Figure 6. Waveguide filter.

along with a matched termination is used then at a particular frequency the normalised admittance at point B will be $y = 1 + jb$, where b is the normalised susceptance at that frequency due to the window. Using smith chart the minimum distance at which the normalised conductance is 1 is found out. Let the normalised susceptance there be $-jb_1$. A window which gives normalised susceptance of $+jb_1$ at the frequency concerned is used at point A so that the normalised admittance becomes simply 1 and hence the reflection coefficient is zero and the whole system acts as a narrowband filter. The design frequency is chosen to be 9.2 GHz. The normalised susceptance at that particular frequency is $b = B/Y_0 = 0.44$

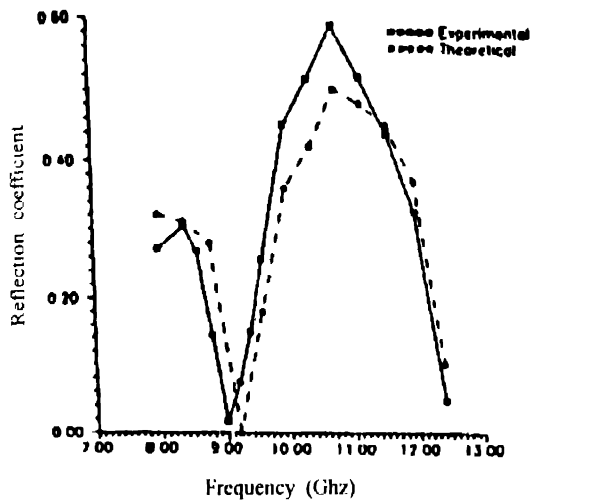

Figure 7. Reflection coefficient *vs* frequency for the designed microwave filter

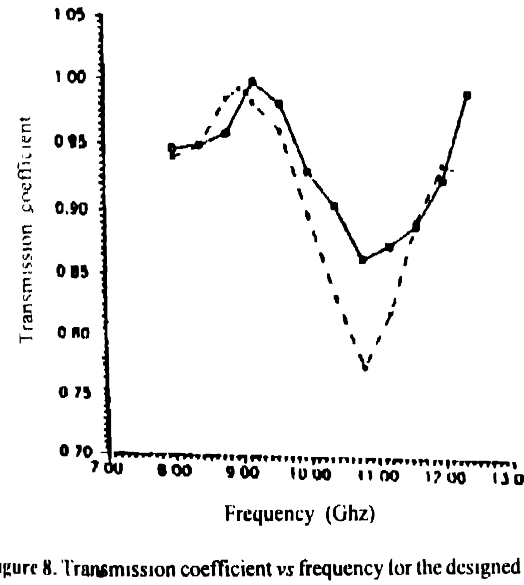

Figure 8. Transmission coefficient *vs* frequency for the designed microwave filter

as found from vector network analyser measurement for a capacitive window of size 0.9" × 0.2". From Smith Chart, it has been found that a same window which gives normalised susceptance of 0.44 is to be placed at a distance of 0 216 λ_g *i.e* 1.01 cm. Since the length is very small so it is placed at further a half wavelength distance apart. The reflection and transmission characteristics curves for the designed filter as obtained using HP 8757C Scalar Network Analyser are shown in Figures 7 and 8. The filter may be used as a switch by using PIN diodes across the windows.

Here copper strips have been utilised across both windows. Number of strips were increased step by step. Ultimately using seven strips an isolation of over 40 dB has been achieved which is shown in Figure 9

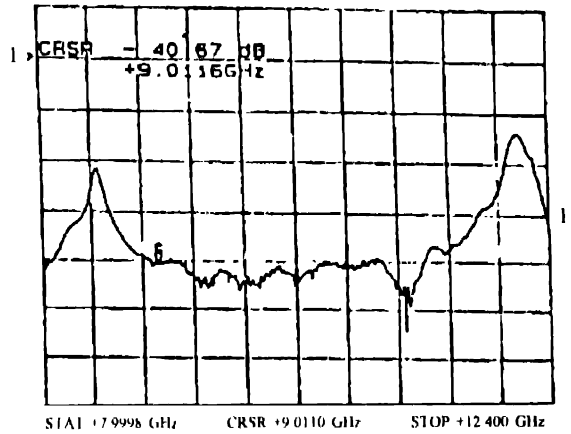

Figure 9. Transmission coefficient curve of the switch

4. Conclusions

The results obtained using variational method shows better agreement with experimental data than using Marcuvitz's formulation. The switch does not show narrowband response. The author suggests that analysis may be done using method of moments (MOM).

References

[1] R F Harrington *Time Harmonic Electromagnetic Fields* (New York McGraw-Hill) (1961)

[2] N Marcuvitz *Waveguide Handbook* (New York McGraw-Hill) (1986)