THE DEVELOPMENT OF RECTANGULAR WAVEGUIDE BANDPASS FILTER

Badrul Hisham Ahmad, Noor Azwan Shairi,
Redzuan Abdul Manap, Mazran Esro

Faculty of Electronic and Computer Engineering, Universiti Teknikal Malaysia Melaka

badrulhisham@utem.edu.my, noorazwan@utem.edu.my, redzuan@utem.edu.my, mazran@utem.edu.my

Abstract

the design and development of rectangular waveguide bandpass filter is presented in this paper. The principle of operation of the filter is that the posts act as shunt inductive discontinuities and the sections of the waveguide between the posts are half waveguide resonators. The bandpass operated at X band frequencies with 1 GHz bandwidth. Pass band is from 8 GHz to 9 GHz. Insertion loss achieved is less than 0.3 dB and return loss of more than 15 dB. Lower cut off frequency at 8 GHz is more selective than the upper cut off frequency at 10.5 GHz, which is 40dB and 20dB respectively. 3D simulator was used to model the structure and simulation results showed very good response.

Keywords: *Rectangular Waveguide, Bandpass filter.*

I. INTRODUCTION

Rectangular waveguides were one of the earliest types of transmission lines used to transport microwave signals and are still being used today for many applications. A large variety of components such as couplers, detectors, isolators, attenuators and slotted lines are commercially available for various standard waveguide bands from 1 GHz to over 220 GHz. However due to recent trends toward miniaturization and integration, a lot of microwave circuitries are currently fabricated using planar transmission lines such as microstrip and stripline rather than waveguide. There is still a need for waveguides in many applications such as high power systems, millimeter wave systems and some precision test applications [1].

A waveguide can be formed into a resonant circuit by placing short circuited boundary conditions, one half guide wavelength apart, to form a box, as shown in Fig. 1. If the mode of propagation in the waveguide is the TE_{10} mode propagating along z, then the E field must be zero at $z = 0$ and $z = l$. Then l must be one half guide wavelength. Therefore;

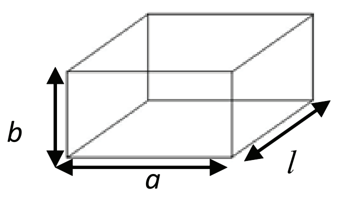

Fig. 1: Rectangular waveguide resonator

$$l = \frac{\lambda_g}{2} = \frac{\lambda_0}{2\left[1-(\omega_c/\omega)^2\right]^{1/2}} = \frac{\lambda_0}{2\left[1-(\lambda_0/2a)^2\right]^{1/2}} \qquad (1)$$

The resonant frequency is;

$$f_0 = \frac{c}{\lambda_0} = \frac{c\left(a^2+l^2\right)^{1/2}}{2a} \qquad (2)$$

This is independent of the height, b as there is no field variation along the y axis for TE_{m0} modes. This resonant mode is called the TE_{101} mode. The effect of finite losses in conducting walls determines the unloaded Q of the resonator. Q can be calculated by forming a volume integral of E_y to determine the stored energy and dividing it by the dissipated energy due to currents in the walls of the resonator [2];

$$Q = \frac{\lambda}{\delta}\frac{a \cdot b \cdot l}{2}\frac{\left(\frac{1}{a^2}+\frac{1}{l^2}\right)}{\frac{l}{a^2}(a+2\cdot b)+\frac{a}{l^2}(l+2\cdot b)} \quad (3)$$

where λ/δ is the ratio of free space wavelength to skin depth at the resonant frequency.

This paper demonstrates the principles behind the high performances and low loss characteristic of a rectangular waveguide bandpass filter.

II. DESIGN PROCEDURE FOR THE WAVEGUIDE BANDPASS FILTER

The principle of operation of the filter is that the posts act as shunt inductive discontinuities and the sections of the waveguide between the posts are half waveguide resonators [1]. It will be shown that an inductive post embedded in a waveguide can behave as an impedance inverter over relatively broad bandwidths. Thus, the physical structure has an equivalent circuit consisting of bandpass resonators separated by inverters, which is suitable for a bandpass filter. Series of discontinuities are difficult to produce, so in this work only parallel discontinuities will be considered [3]. As shown in Fig. 2.

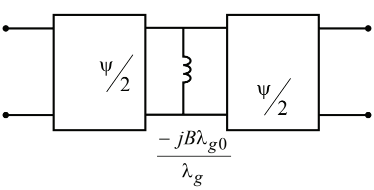

Fig.2: Shunt inductive iris embedded in a section of the waveguide [1].

From the standard size available for waveguides, a suitable waveguide will be a standard hollow waveguide WG16, with internal dimensions of 22.86mm x 10.16mm [4]. The dominant mode is the TE_{10} mode and the cut-off frequency 6.56 GHz. The cut-off frequency λ_{g1}, λ_{g2} and λ_{g0} of waveguides can be obtained from the following equation (4),

$$\lambda_g = \frac{\lambda_0}{\left[1-(\omega_c/\omega)^2\right]^{1/2}} \quad (4)$$

$$L = 10\log_{10}\left\{1+\varepsilon^2 T_N{}^2\left[\alpha\frac{\lambda_g}{\lambda_{g0}}\sin\left(\pi\frac{\lambda_{g0}}{\lambda_g}\right)\right]\right\} \quad (5)$$

By using (5) the required degree will be determined from various values for *N*. For $N=5$, the insertion loss at λ_{g1} will be $43.5dB$, which fulfills the design specification. The values for the unit elements can be calculated [1],

$$B_{01} = B_{56} = 1.0402,\ B_{12} = B_{23} = 2.7404,\ B_{23} = B_{34} = 3.7714 \quad (6)$$

The phase length separating the posts can be calculated,

$$\psi_r = \pi - \frac{1}{2}\left[\cot^{-1}\left(\frac{B_{r-1,r}}{2}\right)+\cot^{-1}\left(\frac{B_{r,r+1}}{2}\right)\right] \quad (7)$$

giving,

$$\psi_1 = \psi_5 = 2.2807,\ \psi_2 = \psi_4 = 2.5825,\ \psi_3 = 2.654$$

The phase lengths are in radians and the physical length is given by the formula,

$$l_r = \frac{\psi_r}{\pi}\frac{\lambda_{g0}}{2} \quad (8)$$

giving,

$$l_1 = l_5 = 18.01mm,\quad l_2 = l_4 = 20.39mm,\quad l_3 = 20.96mm$$

The calculation of each of the susceptances is based on the formula for insertion loss for reciprocal and lossless networks,

$$L_A = 10\log_{10}\left\{1+\frac{1}{4}\left[(A-D)^2+(B'-C')^2\right]\right\}dB \quad (9)$$

From equation (9), the values of the respective A, B, C and D transfer matrices are put in the insertion loss formulae, which can then be simplified into,

$$L_A = 10\log_{10}\left\{1+\frac{1}{4}\left[\frac{B\lambda_g}{\lambda_{g0}}\left(\sin^2(\psi/2)+\cos^2(\psi/2)\right)^2\right]\right\}dB \quad (10)$$

Hence,

$$L_A = 10\log_{10}\left\{1+\frac{1}{4}\left[\frac{B\lambda_g}{\lambda_{g0}}(1)^2\right]\right\}dB \quad (11)$$

Rearranging equation (11) gives,

$$B = \frac{2\lambda_{g0}}{\lambda_g}\sqrt{\left(0^{L_A/10}-1\right)} \quad (12)$$

From equstion (12) the relationship between inductance and insertion loss is established. Therefore, the simulation for a single cavity (single post) has to be done first, in order to get the reference point for the first post. From the specific position, the equivalent insertion loss can be obtained. With this insertion loss value, from equation (12) the susceptance value can be obtained by obtaining the same value of susceptance as in equation (6). Then, the process is the same for the second and the third post. After that, it is just the mirror of each post, for example, the sixth post is equivalent to the first post, the second post is equivalent to the fifth post, and the third post is equivalent to the fourth post.

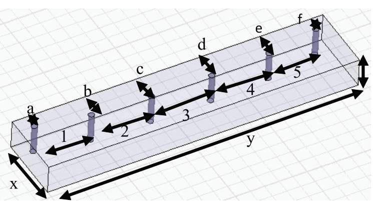

Fig. 3: Waveguide bandpass filter with cylindrical posts.

The first simulation is carried out based on a single post with fixed diameter configurations. It is desirable to have a radius that is feasible to manufacture in a normal workshop without the use of advanced machinery as this will lower the overall cost of manufacturing this filter. This design is a filter using a single post size with a constant diameter. The offset distance between the y axes of the posts is varied in order to get the desired susceptance. The structure is shown in Fig. 3. Table 1 shows a complete dimension of the proposed rectangular waveguide bandpass filter.

Table 1: Dimension of rectangular waveguide bandpass filter.

1	2	3	4	5	
18.01 mm	20.39 mm	20.96 mm	20.39 mm	18.01 mm	
a	b	c	d	e	f
4.73 mm	7.96 mm	8.87 mm	8.87 mm	7.96 mm	4.73 mm
x	y	z			
22.86 mm	106.56 mm	10.16 mm			
Radius of post	0.93mm				

III. RESULTS AND DISCUSSION

Fig. 4 shows the simulation result that was done using 3D simulator. At the pass band the return loss achieved is below 20dB and it showed that the signal is perfectly matched between the input port and the output port and for the insertion loss at the pass band it shows very low loss and satisfy one of the characteristics of the waveguide which is low loss. The frequency response of the filter is more selective on the low frequency side of the pass band. This is due to the transmission zero introduced by the finite cut-off frequency of the waveguide and also by the relatively wide pass band bandwidth.

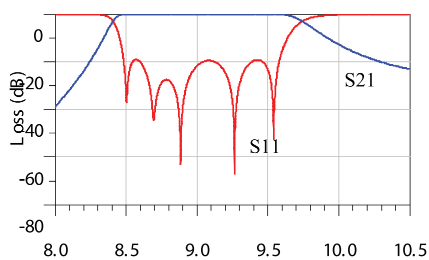

Fig. 4: Simulated result of the rectangular waveguide bandpass filter.

IV. CONCLUSION

This paper presented an approach to the design of rectangular waveguide bandpass filter. The simulation result shows a very low insertion loss at the pass band and also high return loss at the pass band. The filter will be fabricated in the near future and analysis will be made between the simulated and measured results.

V. ACKNOWLEDGMENT

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