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HALF MODE SUBSTRATE INTEGRATED WAVEGUIDE BROADBAND BANDPASS FILTER

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Abstract—A planar half mode substrate integrated waveguide (HMSIW) broadband bandpass filter is proposed. It is realized by cascading a lowpass filter and a highpass filter. A transmission line with half mode substrate integrated waveguide (HMSIW) on the circuit board has the characteristic of highpass, while a periodic uniform photo band structure (PBG) array has the characteristic of bandstop. Combining these two structures, a novel compact broadband bandpass filter (BPF) is fabricated and measured. Measured results show that the proposed BPF has wide bandwidth from 11.8 GHz to 23.8 GHz, all the measured insert loss are less than 2.1 dB, return loss are less than 9 dB in the passband. The BPF achieves a wide stopband with 34 dB attenuation low to 5 GHz and 27 dB attenuation up to 35 GHz.

1. INTRODUCTION

Recently, broadband radio technology has attracted more and more attentions in academic and military electronic fields and been widely used in radio transceiver sets. In a broadband radio electronic system, a compact and low cost broadband bandpass filter plays an important pole. With a traditional parallel-coupled transmission line structure it is not easy to achieve an octave bandwidth filter. Some researchers have contributed greatly to the research, design and development of the broadband bandpass filter [1–3]. In [1], Kuo and Shin designed a wideband bandpass filter with threeline microstrip structures, this type of wide bandpass filter has the fractional bandwidth about 70%, but it has accessional passband. In [2], Gao, Zhu, and Menzel et al. designed a broadband bandpass filter with the short-circuited CPW multiple-mode resonator. This type of filter can cover the ultra width band (UWB) frequency band with low insertion loss and a very flat group delay variation in the passband. However, it has a relatively narrow stopband width at high frequency. In [3], Wang, Zhu, and Menzel utilized a hybrid microstrip-coplanar waveguide structure to design a broadband filter. The structure is very simple and it can achieve a wide passband from 3.1 GHz to 10.6 GHz with good frequency characteristics, but its out-band rejection bandwidth at high frequency is still relatively narrow. In [4], Yang and colleagues designed a planar microstrip ultra wide band (UWB) bandpass filter using U-shaped slot coupling structure. This type of filter has low insertion loss, a small group delay variation within the central passband and relatively small size. But its stopband rejection at low frequency is low. In [5], Wang, Hong and colleagues designed the HMSIW bandpass filter using I-shaped slot coupling resonant structure, but the passband width of the filter is narrow. In [6], Naghshvarian-Jahromi and Tayarani designed a miniature planar UWB bandpass filters with circular slots in ground and in [7] Shobeyri and Vadjed Samiei designed a compact ultra-wide band bandpass filter with defected ground structure, but stopband rejection is low in all these UWB filters simulational results.

In this paper, we present a new method to design a bandpass filter with performances such as broadband passband (bandwidth of 67%), compact structure, higher rejection of out-band and no accessional passband. This filter is realized by cascading a lowpass filter and a highpass filter. A transmission line with half mode substrate integrated waveguide (HMSIW) structure on the circuit board has the characteristic of highpass [5], while a periodic uniform photo band structure (PBG) array structure forms stopband of high frequency [8, 9]. We realized lowpass by upper frequency's stopband. Combining these two structures, a new broadband bandpass filter (BPF) is fabricated. Furthermore, the proposed filter has a relatively small size of 10 mm by 53 mm.

2. HMSIW FILTER ANALYSIS AND DESIGN

The proposed filter consists of a transmission line of HMSIW, a PBG array on HMSIW and a transition between microstrip and HMSIW as shown in Fig. 1. The three symmetrical I-shaped slots are etched on the circuit board. Each I-shaped slot is a PBG unit and three uniform I-slot-shaped PBG units form a PBG array. So this PBG array is periodic structure. We can analyze the characteristics of PBG structure's frequency response using periodic structure theory as following.

As shown in Fig. 2, the impedance of each resonator for the wave propagating in x direction, can be calculated considering the loading

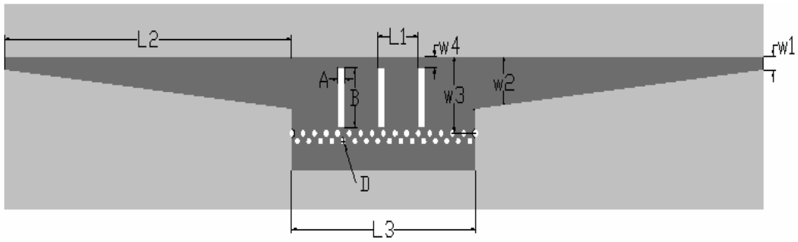

Figure 1. Circuit of broadband bandpass filter.

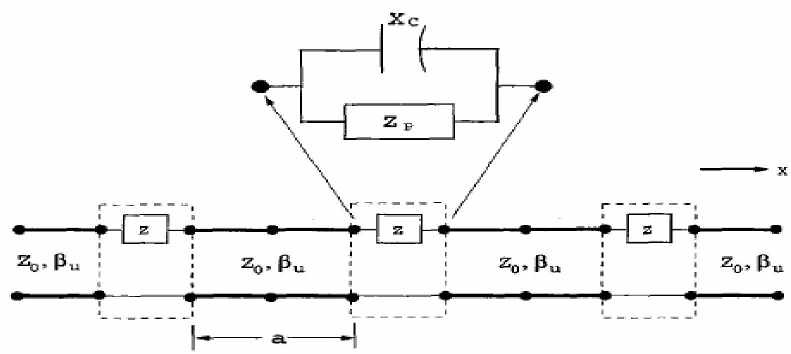

Figure 2. Equivalent circuit of periodic circuit representing PBG structure.

at the center and using the well known transmission line formula [9]:

$$Z_{in} = Z_0 \frac{Z_l + jZ_0 \tan(\beta_u l)}{Z_0 + Z_l \tan(\beta_u l)} \tag{1}$$

where Z_o is the characteristic impedance and β_u is the phase constant (losses of the transmission line are assumed to be zero) of the transmission line, Z_l is the loading impedance, and l is the line length. The transmission line is approximated either by microstrip line or other transmission line depending on the width-height ratio of the line and the dielectric material.

The propagation constant (γ) for the infinite periodic structure is [12]:

$$\cosh(\gamma a) = \cos(\beta_u a) + j\frac{Z}{2Z_0}\sin(\beta_u a) \tag{2}$$

The characteristic impedance (Z_0) and the phase constant γ, in Eq. (2) are the same as those of the resonators. With $\gamma = a + j\beta$, Eq. (2) can be rearranged as

$$\cosh(\alpha a)\cos(\beta a) + j\sin(\alpha a)\sin(\beta a) = \cos(\beta_u a) + j\frac{Z}{2Z_0}\sin(\beta_u \alpha) \quad (3)$$

Since the right hand side of Eq. (3) is real, as impedance is imaginary for loss less resonators (as assumed), either $\beta = 0$, or $\beta = n\pi/a$, where "a" is the structure period. Condition $\alpha = 0$ corresponds to a non-attenuated, propagating wave on the periodic structure, and defines the pass-band of the structure. Eq. (3) reduces to

$$\cos(\beta a) = \cos(\beta_u a) + j\frac{Z}{2Z_0}\sin(\beta_u \alpha) \quad (4)$$

which can be solved for β if the magnitude of the right hand side is less than or equal to unity. Condition $\beta = 0$, $n\pi/a$ in Eq. (3), gives

$$\cosh(\alpha a) = \cos(\beta_u a) + j\frac{Z}{Z_0}\sin(\beta_u \alpha) \quad (5)$$

which describes an attenuated wave along x direction, and this defines the stop-band of the structure.

According to above analysis, the HMSIW PBG array is basically a periodical structure that satisfies the following equation, and strongly shows band-stop filter characteristics as the number of cells is increased [8]:

$$k = \pi/L_1 \quad (6)$$

where k is the propagation constant. The cell distance (L_1) is equal to 1/2 guided wavelength (λ_g) if k is equal to $2\pi/\lambda_g$. The propagation constant is difficult to determine and full-wave analysis is necessary to calculate λ_g for the structure in Fig. 1. As a simple approximation, it is acceptable to set the propagation constant as approximately the same as an unperturbed transmission line, assuming that the perturbation of the PBG structure is very small [9–11]. The circuit length is dependent

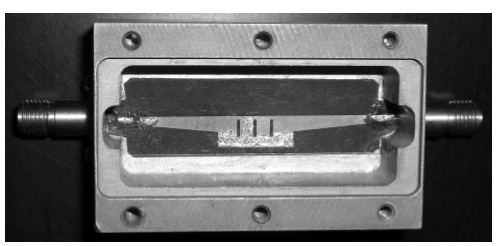

Figure 3. Fabricated broadband bandpass filter.

on the cell number, center frequency, and dielectric constant. In this study, the substrate used is a RT/Duroid 5880, with relative dielectric constant (ε_r) of 2.2, height (H) of 0.254 mm, and length of 33 mm. The stopband center or resonant frequency (f_o) is chosen near 35 GHz and, thus, the distance of adjacent cells is $L_1 = 2.8$ mm for about $\lambda_g/2$ and the number of cells is three.

3. EXPERIMENTAL RESULT

The dimensions of the microstrip transition sect are $W_1 = 0.76$ mm and $W_2 = 2.76$ mm, and its length is $L_2 = 20$ mm respectively. The dimensions of the I-shaped PBG unit are $A = 0.5$ mm and $B = 3.1$ mm. The distance between two adjacent PBG units is $L_1 = 2.8$ mm, the width of the HMSIW structure is $W_3 = 4$ mm, and the length of the HMSIW is $L_3 = 12.8$ mm. The distance between the PBG unit and the open circuit side of the HMSIW structure is $W_4 = 0.66$ mm. The numerical simulation was performed with electromagnetic simulator software — CST.

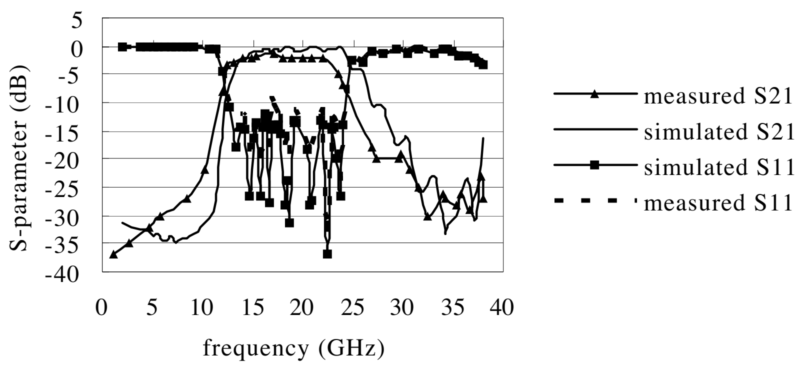

Figure 4. Measured (at normal temperature) and simulated S-parameters.

The simulated and measured results are shown in Fig. 4. Measured and simulated results agree approximately, except that the resonant frequency (f_o) is shifted by ± 1.4 GHz or $\pm 7\%$. Measured inserted loss about is 2.8 dB. This difference is mainly caused by nonsimulated effects of test fixture parasitic, copper thickness, and etching tolerance.

It has been found that by changing the parameters of the I shaped PBG unit "A" and "B", a different frequency resonator can be selected. In addition, by changing the distance "L_1" of the two PBG unit, the attenuation pole location can be adjusted. If we adjust the sizes of "A",

"B" and "W_3", we can improve upper cutoff frequency and decrease low cutoff frequency, then we can extend the bandwidth of bandpass filter more broadly. We fabricated a broadband bandpass filter to verify the above analysis and simulation. Fig. 3 shows the top view of the fabricated filter, which includes two SMA connectors at both the filter terminations.

As shown in Fig. 3, the designed broadband filter was fabricated on a RT/Duroid 5880 substrate, with a thickness of 0.254 mm, dielectric constant of 2.2. The filter was measured with an Agilent E8247C and an HP 8757D network analyzer (NA). The measured results are shown in Fig. 4, and S_{21}'s group delay of this filter is as Fig. 5. The full frequency passband is from 11.8 to 23.8 GHz, the bandwidth is about 67%. All the return loss are less than 9 dB, insert loss are less than 2.1 dB in the passband and it achieves a wide stopband with 18 dB attenuation up to 30 GHz in simulation. Respectively, the simulated results of the filter are also given in both figures for comparison.

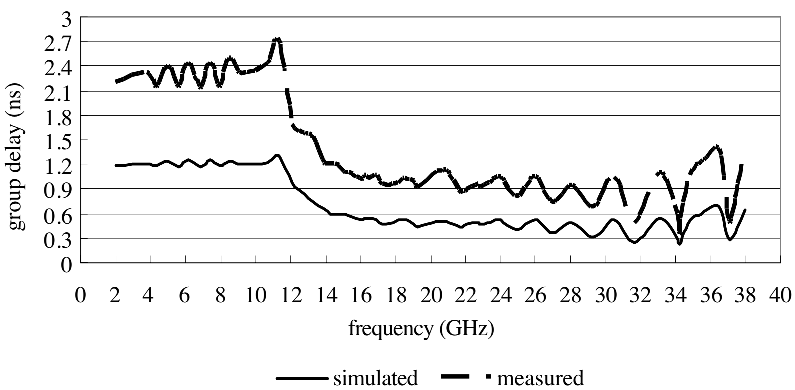

Figure 5. Measured and simulated S'_{21} group delay (at normal temperature).

4. CONCLUSION

A new structure of broadband bandpass filter is proposed. It is realized by cascading a lowpass filter and a highpass filter. The lowpass characteristic is realized mainly based on the PBG array on the circuit board, and the highpass characteristic mainly depends on the HMSIW. The novel broadband bandpass filter has a frequency passband from 11.8 GHz to 23.8 GHz and exhibits better performances. It has compact structure, low insertion loss and a flat group delay variation within the central passband.

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