Design of a Half-Mode SIW High-Pass Filter

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Abstract **─** A planar high-pass filter with simple topology, low insertion loss and high power handling is presented in this paper. It is based on the half-mode substrate-integrated waveguide (SIW) structure whose shorting wall is implemented with periodical via-holes. Meanwhile, bevel edges are embedded to achieve good impedance matching. Parameter studies are also performed to give design insights for practical applications. A planar waveguide filter with cutoff frequency of 10 GHz is designed and built. The measured data have a good agreement with the simulated responses, and demonstrate practical utility of the proposed topology.

Index Terms **─** Half-mode, high-pass filter, impedance matching, waveguide.

I. INTRODUCTION

Microwave filters, including low-pass, band-pass, band-stop and high-pass types, play a key role in modern wireless systems. Recent studies introduce some waveguide-based or other bandpass filter structures [1-6]. The design of high performance high-pass filters (HPFs) seems to be more challenging because the series connected capacitors from lumped prototype filters introduce extra loss by using distributed components. Waveguide-based structures characterize inherently high-pass responses [7], but its three dimensional (3-D) configuration is not easy to be integrated with planar circuits.

An HPF with planar structures based on an exponentially tapered nonuniform transmission line [8], but its size may be bulky. Using high performance inductors in advanced high resistivity SOI CMOS technology, [9] develops an ultra wideband HPF integrated into the silicon-based substrate. Based on complementary split ring resonators, HPFs can also obtain compact sizes, but the double-sided configuration leads to a relatively complicated circuit topology and assembly problems [10-11]. A filter in [12] based on modified double-sided parallel strip lines shows good electric performance, but it has a multilayer-based structure.

Using the conventional microstrip line with short-circuited edge for planar filter applications is an effective way to design HPFs since it is compatible with most of planar circuits with good performance [13-14]. By using an electric wall placed at the edge of wide microstrip line, the structure is analyzed and confirmed from measurements [13]. Further, it is incorporated with other circuits to demonstrate a practical application of a 20-40 GHz subharmonically pumped mixer [14]. A transmission line loaded at regular intervals with closely-spaced shorted stubs [15]. Such a periodic structure exhibits waveguide-like behavior with a first pass-band whose width is a function of the characteristic impedance and pitch of the stubs. It also shows that the structure degenerates into a planar waveguide whose cutoff frequency corresponds to a short-circuited stub length when the stub pitch vanishes. To achieve good impedance matching, on the other hand, the extra matching networks lead to a large circuit size.

In this paper, a planar HPF with simple topology, low insertion loss and high power handling is studied. It is a waveguide-based structure, specifically, a half-mode substrate-integrated waveguide (SIW) structure [16]. To obtain good impedance matching, a pair of bevel edges is adopted. Measurement results with cutoff

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frequency of 10 GHz agree well with simulated characteristics, and demonstrate practical utility of the developed planar HPF topology.

II. DESIGN OF THE SIW FILTER

Figure 1 shows the 3-D view of the proposed filter structure. Basically, it can be treated as a section of the main transmission line with width w_f loaded unsymmetrically with a stepped microstrip line. The length of the stepped transmission line is L, and far away from the main line, a series of metalized via-holes with radius r and periodicity p are parallelly etched on the stepped edge. The distance from the hole center to another edge of the line is denoted as w. Meanwhile, a pair of tilting edges with an angle α and a length a are etched on the corners. The structure is etched on the upper side of a Rogers RT/Duroid 5870 substrate that has a relative permittivity of 2.33 with a thickness of 31 mils.

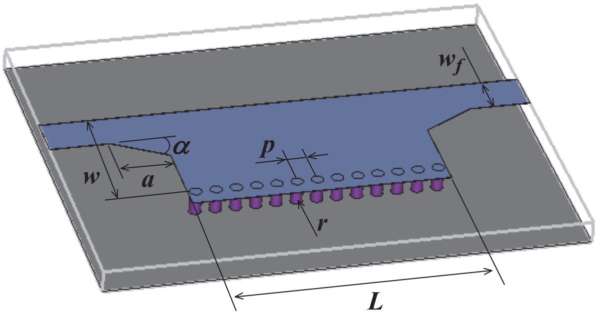


Fig. 1. 3-D view of the proposed filter.

Such a structure supports the microstrip higher-order field modes. The first HE_1 mode is similar to TE_{10} mode in a rectangular waveguide. Figure 2 illustrates the transition from a half-mode SIW mode to an equivalent TE_{10} mode. Fringe electric fields from the line to the ground plane are equivalent to a supplementary capacitor, which can be replaced with a slightly widened strip. Thus, the effective line width w_{eff} is observed with the needed line extension Δl for compensating the open-end effect. At the same time, the initial relative permittivity of the substrate is represented by an effective one ε_{eff} in this case. Finally, the equivalent result corresponding to TE_{10} mode of a rectangular waveguide is obtained by introducing a magnetic wall. Figure 3 shows that the electric field distribution in the proposed structure is similar to those in a rectangular waveguide.

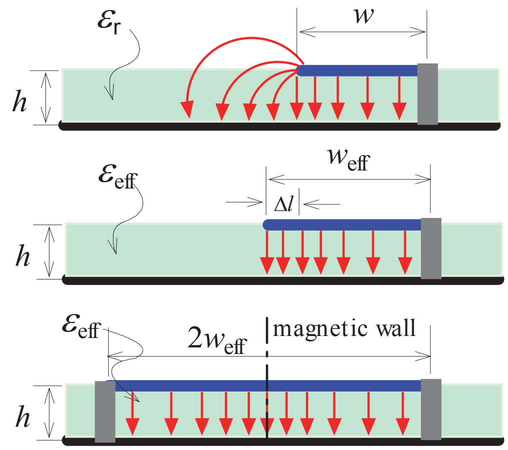


Fig. 2. Transition from the structure to an equivalent rectangular waveguide.

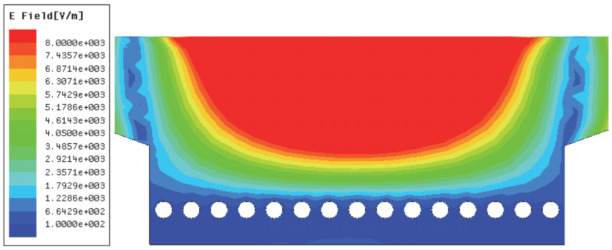


Fig. 3. Simulation results (by HFSS Software [17]) of electric field distribution in the structure.

Therefore, the half-mode SIW exhibits a cutoff frequency and high-pass filtering characteristic. It also exhibits low insertion loss and high power handling capacity like waveguides. Its cutoff frequency f_c can be evaluated from the equivalent rectangular waveguide model

$$f_c = \frac{c_0}{4w_{eff}\sqrt{\varepsilon_{eff}}}, \tag{1}$$

where c_0 is the light velocity in free space. The microstrip effective width w_{eff} is given by [18]

$$w_{eff} = w - \frac{r^2}{0.24p}. \tag{2}$$

The radius r and periodicity p of via-holes can be determined as follows [19]

$$\frac{p}{\lambda_g} \le 0.25, \tag{3}$$

and

$$\frac{r}{p} \le 0.5, \tag{4}$$

where λ_g is the guided wavelength at the cutoff frequency.

To simplify the design of an HPF with f_c=10GHz, $\varepsilon_{\mathrm{eff}}$ in (1) is approximated to ε_r. Therefore, w_{eff} should be 4.91 mm from (1). Via-holes with r=0.25mm and p=0.8mm, which satisfy design rules of (3) and (4), are adopted. Meanwhile, w is calculated from (2) to be 5.17 mm. After performing optimal electromagnetic design with junction discontinuities, the filter is designed with its physical parameters as: L=12mm, w=5mm, a=2.6 mm, α=30°, and w_f =2.2mm for a 50Ω microstrip line. Figure 4 shows the achieved performance of this filter.

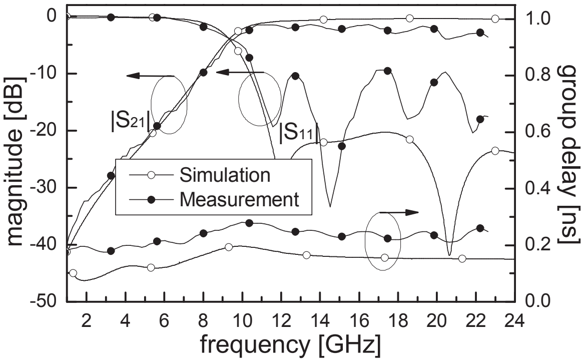


Fig. 4. Frequency responses of the filter.

To validate our design, a demonstrator filter shown in Fig. 5 is built. Measurements are performed by using a vector network analyzer [20]. The measured frequency responses are also recorded in Fig. 4, where the measured insertion loss involves the circuit loss and effects of SMA connectors (i.e., non-ideal coaxial/ microstrip-line transitions). Measurements indicate that the insertion loss is gradually increased with the increase of the operation frequency. This can be attributed to the following possible reasons: the substrate utilized in this demonstration generally works below 18GHz. Thus, its dielectric loss beyond this frequency may be relatively high. Another reason is due to the Ku-band SMA connectors employed in the measurement. A higher loss associated with the connectors is suffered from at the higher operation frequency band. It is found that the measured maximum insertion loss within the passband is approximately 3dB. Within the pass-band, the minimum return loss is better than 10dB. Figure 4 also plots the measured pass-band group delay variation of the fabricated circuit, and its value is less than 0.5ns. From these results, it is seen that the measured data reasonably match the predictions.

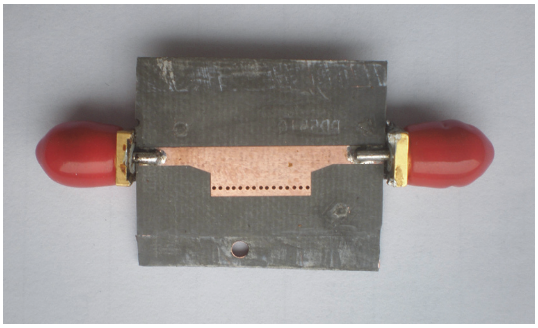


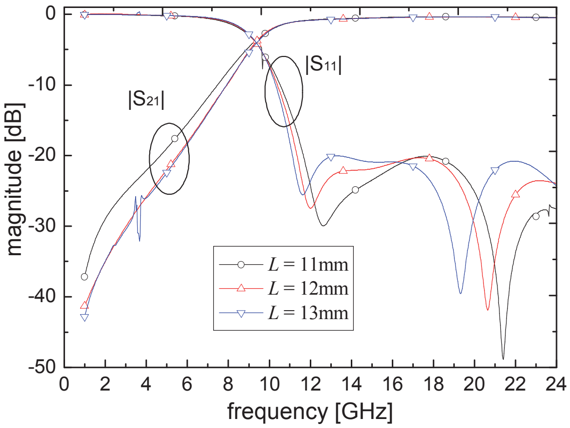
Fig. 5. Photograph of the fabricated circuit.

III. PARAMETER STUDIES

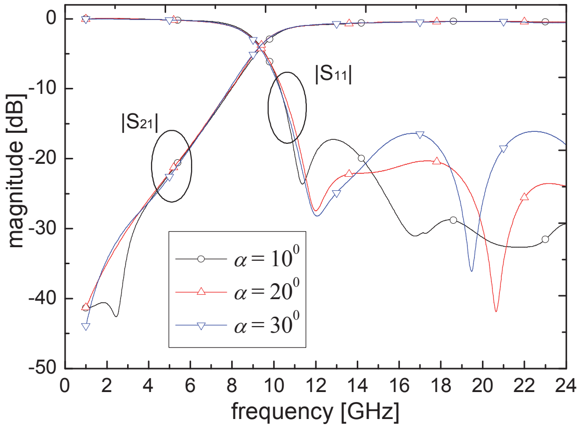
Purposes of parameter studies in this section are to provide some design insights for practical applications. It can be seen from above presentations that the metalized via-holes (r and p) are empirically predetermined based on (3) and (4). Although the parameter w needs fine tuning from optimal EM simulations, it is basically determined from (1) and (2). Hence, the first key parameter that needs studying is the length L of the short-circuited planar waveguide. By sweeping L (other parameters a, α, w, r, p, and w_f keep constant as mentioned before), it is interesting to find that L primarily affects the roll-off of the filter, as illustrated in Fig. 6(a). A shorter L corresponds to a more compact design at the cost of slightly poor roll-off or filter selectivity. Hence, L=12mm is utilized in this design for compactness considerations.

Results from sweeping simulations with the angle α indicate that α is not sensitive to filter selectivity or stop-band roll-off, but α primarily affects the pass-band return loss. A smaller angle cannot improve the lower pass-band return loss, while a larger α deteriorates the whole pass-band return loss, as shown in Fig. 6(b). Therefore, α=20° is adopted to obtain good return-loss performance.

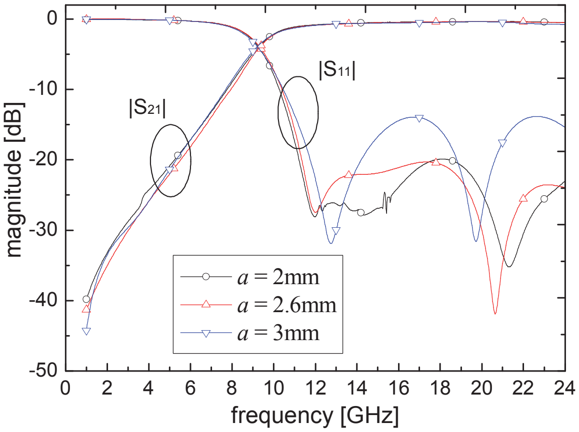
Figure 6(c) shows that the bevel length a also influences the pass-band return loss. The lower pass-band return loss can achieve good performance under a small value of a. On the other hand, a larger bevel length a can worsen the whole pass-band performance when referring to a 20dB return loss. Consequently, a=2.6mm is selected from optimal simulations in our design.



(a) Sweeping parameter *L*.



(b) Sweeping angle *α*.



(c) Sweeping parameter *a*.

Fig. 6. Sweeping responses of the studied filter.

VI. CONCLUSION

By replacing electric walls in a rectangular waveguide with metalized via-holes, a planar waveguide-based HPF has been developed in this paper. Further, based on the symmetry of mode-field distribution, a half-mode structure is employed to get a compact circuit topology. A pair of bevel edges is embedded into the planar waveguide to obtain good impedance matching. Parameter studies have been performed to give more insights to design such a kind of filters. An example filter with cutoff frequency of 10 GHz has been designed, built, and experimentally examined, and results validate the predications well.

ACKNOWLEDGMENT

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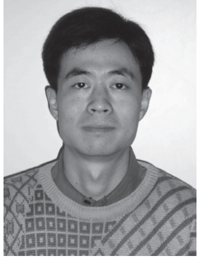

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