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Compact and Wide Stopband E-Plane Waveguide Diplexer Design

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Abstract—This paper presents the design of a compact E-plane waveguide diplexer with wide stopband characteristics of high rejection level. This is achieved by utilizing a unique E-plane waveguide filter comprising rectangular apertures located along the waveguide's E-plane. The upper and lower sections of the aperture in the septum insert have periodic comb-like ridges. The effect of the septum is (i) to slow the propagating wave that helps to reduce the filter's size, and (ii) widens its stopband property. Dimensions of the periodic ridges of the aperture enable the center frequency of the filter to be controlled without compromising its bandwidth. In addition, the proposed E-plane waveguide filter provides a high isolation between the two diplexer channels, which is necessary to prevent significant cross-talk between the channels. The performance of the proposed design was verified through measurements. There is excellent agreement between the simulated and experimental results.

1. INTRODUCTION

Design of E-plane diplexers has attracted much attention over recent years because this technology offers low-cost and mass producible characteristics. The design of E-plane filters essentially involves the mounting of metal inserts in the E-plane of a rectangular waveguide [1]. In this filter configuration, the impedance inverter constants of the half-wave prototype are synthesized through the thin metal septa inserted in the mid-plane of waveguide. E-plane filter has become one of the most popular technologies for waveguide filters implementation for transmitter/receiver front-end applications when low-loss and high power handling are required. However, the stopband attenuation of these filters is too low and too narrow for many applications such as multiplexers, where wide stopband and high stopband rejection are necessary in order to avoid cross-talk between the channels [1].

Diplexers with E-plane filters combined with an H-plane Y-junction splitter are reported in [2, 3] to improve the selectivity of the filters. Here the filter performance is optimized using mode matching technique.

In [4] the design of a higher order E-plane filter is reported to enhance the selectivity of the filter where the E-field is aligned parallel to the resonators, and the gaps between resonators are filled with thin metallic plates. The difference in power levels between transmitting and receiving bands in a diplexer can give rise to passive inter-modulation (PIM) products where the transmitting carriers fall within the receiving band at power levels of the same order as the receiving carriers. [5] shows the importance of maintaining cleanliness of the surfaces and the nature of metal contacts as well as micro-cracks in diplexer waveguides in order to minimize the generation of PIM products. In [6] it is found that the E-plane T-junction provides superior performance to H-plane T-junction for wideband applications.

In this paper, an E-plane waveguide diplexer design is presented for wide stopband and high rejection. This is achieved with a septum insert with rectangular apertures whose upper and lower

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sections have periodic comb-like ridges or fingers. The centre frequency of individual E-plane filters comprising the diplexer can be controlled by modifying dimensions of the aperture's ridges. The design was analyzed and optimized using CST Microwave Studio®, which is a 3D EM simulator. The diplexer was implemented using aluminium waveguide and silver E-plane insert metal septum.

2. DESIGN PROCEDURE AND PROPERTIES STUDY

The waveguide diplexer consists of two E-plane filters and one T-junction connecting the two channels. The standard T-junction includes a matching network to achieve good return-loss in a common port of diplexer.

2.1. E-Plane Waveguide Filter Structure

The configuration of the proposed E-plane septum inserted for the waveguide filter, shown in Fig. 1, is similar to a standard direct-coupled half-wavelength E-plane waveguide filter.

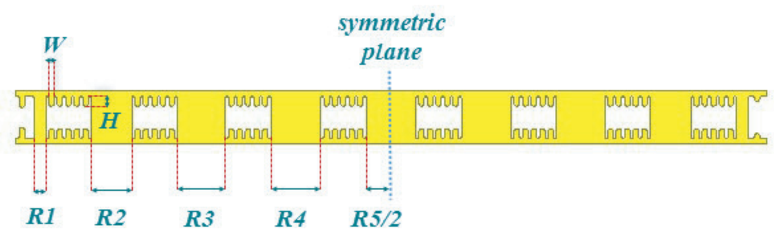

Figure 1. Geometry of proposed E-plane septum insert for the waveguide filter.

However, instead of using a standard homogeneous rectangular waveguide, the modified resonators have been used in an E-plane filter. The modified resonators have a septum with a rectangular aperture. These rectangular apertures have comb-like periodic ridges on upper and lower edges. The configuration of the septum insert creates necessary periodic boundary conditions required for slow wave propagation within the resonators [7–10], which results in a physically smaller waveguide but with improved stopband and rejection characteristics.

Generally, a waveguide filter should have characteristics of low passband ripple, low-loss, high return-loss, and wide stopband rejection. Generic steps to synthesize waveguide filters are:

- Determine the number of resonators required to achieve desired rejection in stopband.
- Determine filter equivalent circuit.
- Find the individual septum length and spacing.
- Realize the filter equivalent circuit in full wave software.

Simulate and optimize (if required for that) the full wave software.

In order to implement the filters, the specifications below should be satisfied:

Filter I: Center freq. $f_0 = 8.5$ GHz, bandwidth BW = 300 MHz, minimum rejection = 40 dB from $f = 8.35$ GHz to 8.65 GHz.

Filter II: Center freq. $f_0 = 7.9$ GHz, bandwidth BW = 200 MHz, minimum rejection = 100 dB from $f = 7.8$ GHz to 8 GHz.

Parameters of the proposed two filters are given in Table 1. The numbers of resonators required to implement Filters I and II are 5 and 9 resonators, respectively, for the above specifications. MATLAB software was utilized to design the two filters that were subsequently optimized using CST Microwave Studio®. Instead of performing the optimization on the complete diplexer unit, the model of the diplexer was divided into several subsections to reduce the numbers of mesh cells. This strategy significantly reduced the simulation runtime and allowed the mesh density of the sub-sections to be increased in order to achieve higher accuracy. Waveguide ports, considering dominated mode, were assigned at the intersections.

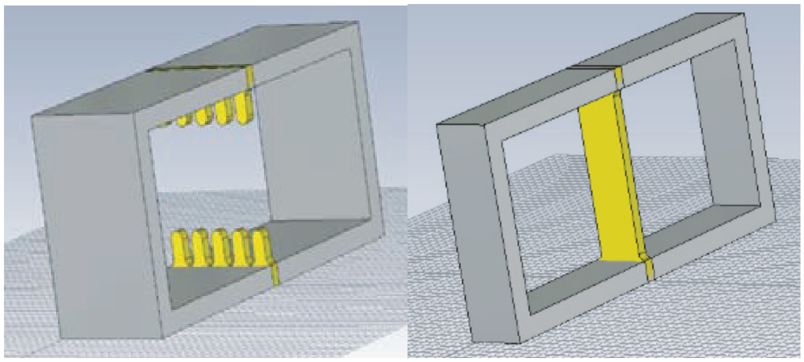

Figure 2. Sub-model of the E-plane waveguide filter.

Table 1. Design parameters of the proposed filter.

Parameter	Filter I	Filter II	Tee j.
w	1.32 mm	1.76 mm	
h	2.64 mm	3.38 mm	
R_1	2.64 mm	3.734 mm	
R_2	8.8 mm	11.68 mm	
R_3	13.2 mm	15.85 mm	
R_4	– – – –	16.29 mm	
R_5	– – – –	16.810 mm	– – – – – –
$L1$	– – – –	– – – – – –	0.88 mm
$L2$	– – – – – –	– – – – – –	12.76 mm
$L3$	– – – – – –	– – – – – –	7.08 mm
$S1$	– – – – – –	– – – – – –	10.12 mm
$S2$	– – – – – –	– – – – – –	13.37 mm
t	– – – – – –	– – – – – –	0.88 mm

Here a frequency domain solver and a model order reduction solver (MOR) were used with CST Microwave Studio® for analyzing the response below the cutoff frequency.

Local sub-model parameters were accessible for assignment to global CST Design Studio™parameters. These parameters were used in an optimization process. An interpolation scheme was utilized in order to avoid numerous re-computations of S-parameters for individual setups that are required by the optimizer. Fig. 2 shows the two sub-models required to describe the complete E-plane waveguide filter.

Design parameters of the proposed waveguide filter are shown in Fig. 1. Seven main parameters are: w, R_1, R_2, R_3, R_4, R_5 and h, which are listed in Table 1.

2.2. T-Junction and Matching Section

The next stage is to design the T-junction and matching section. The purpose of the T-junction, shown in Fig. 3, is to connect the two waveguide filters and improve the return-loss property in the common port of diplexer. The construction of the T-junction and matching section was optimized by CST Microwave Studio®.

2.3. Diplexer Simulation

Finally, the last stage of the diplexer design requires the two waveguide filters connected with the T-junction. It was necessary to optimize the overall diplexer.

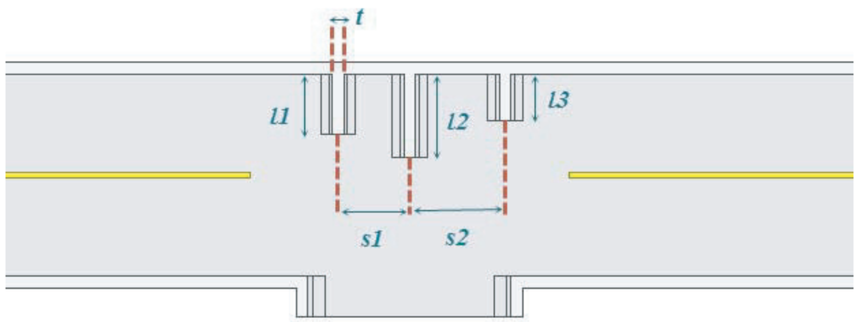

Figure 3. T-junction waveguide structure and the matching section.

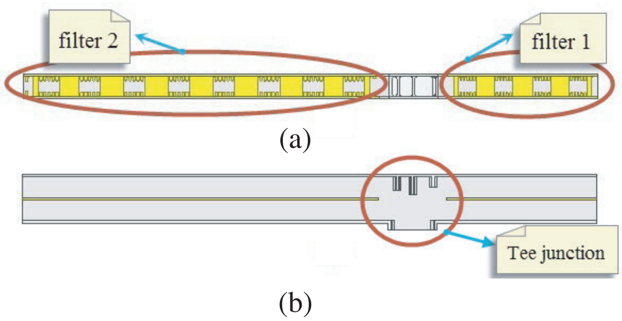

Figure 4. Complete diplexer structure. (a) Front view and (b) side view.

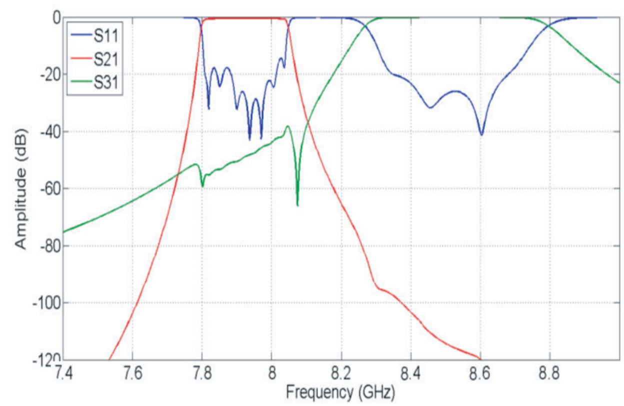

Figure 5. Simulation results of the diplexer's S-parameters in CST Microwave Studio®.

Figure 6. Fabricated E-plane waveguide diplexer.

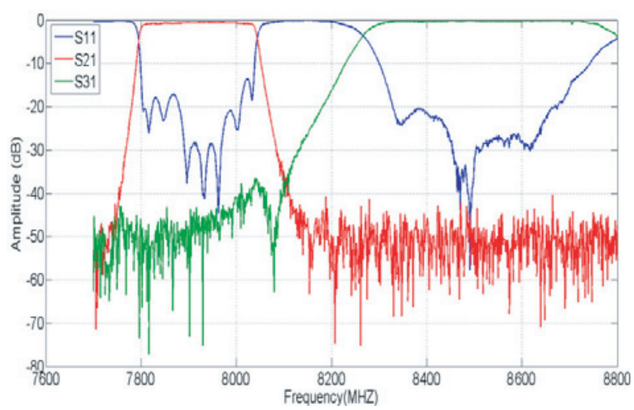

Figure 7. Measured S-parameters results of diplexer in common port.

The final structure of E-plane waveguide diplexer is shown in Fig. 4. The simulation results of S_{11}, S_{21} and S_{31} are shown in Fig. 5. Filter I has a center frequency of 8.5 GHz, bandwidth of 300 MHz, and minimum rejection of 40 dB. Filter II has a center frequency of 7.9 GHz, 200 MHz, and minimum rejection of 100 dB.

3. EXPERIMENTAL RESULTS

The prototype of the fabricated E-plane waveguide diplexer and its T-junction are shown in Fig. 6. The diplexer consists of the two waveguide filters with a 2 mm thick septum insert and T-junction with matching. The diplexer has a length of 47.5 cm. The diplexer was manufactured from aluminum and the insert plate from silver in order to minimize the insertion-loss in pass band. The fabricated diplexer was characterized using an HP 8510 network analyzer. The measured insertion-loss and return-loss performance in common port is shown in Fig. 7. Excellent agreement is observed at low frequency band with return loss below -19 dB, and at high frequency band with return loss below -20 dB. Although the simulation results show excellent isolation of 100 dB between the two channels, the measured isolation is better than 40 dB. This large discrepancy is due to the limited dynamic range of the network analyzer used.

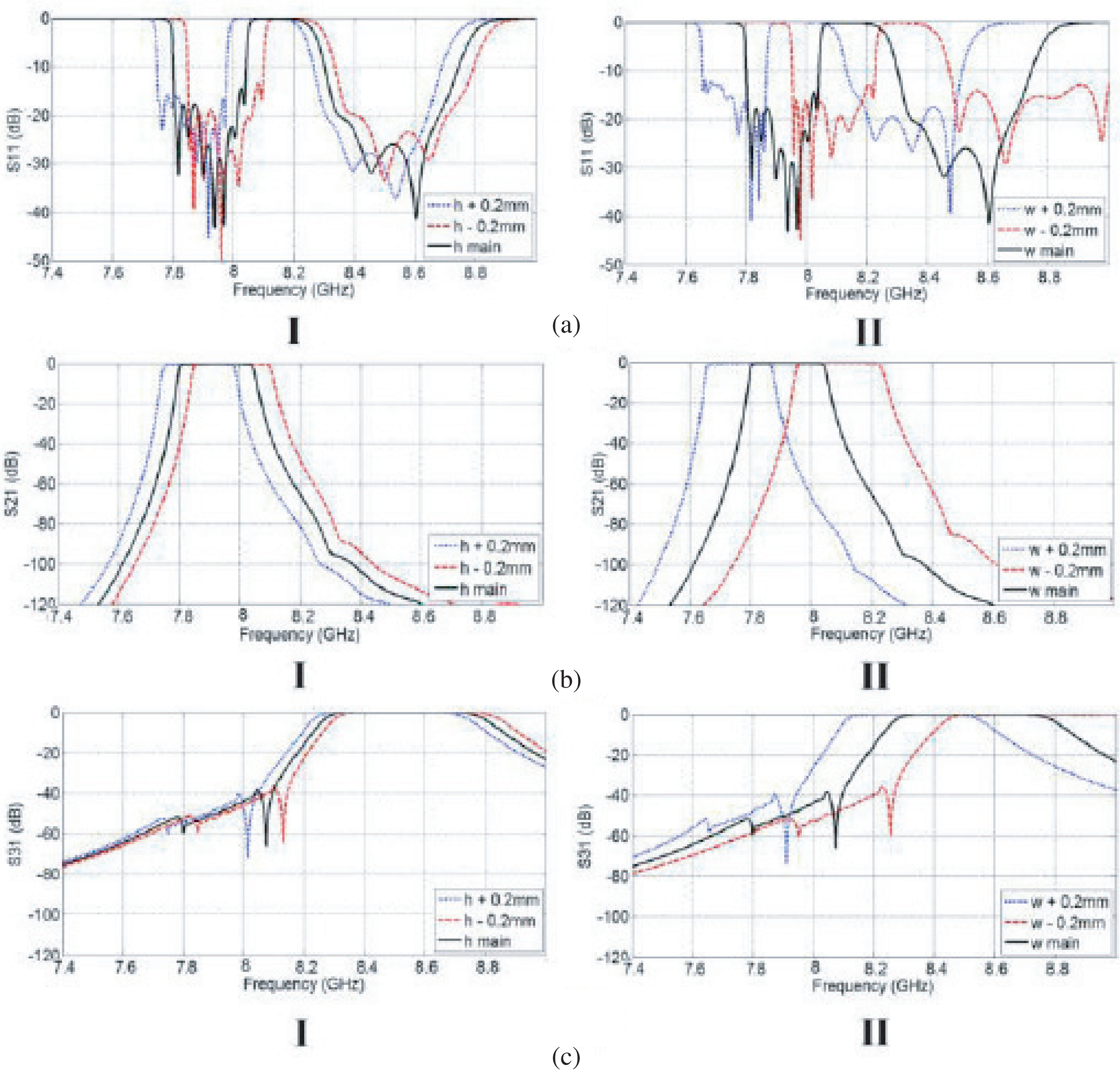

Figure 8. Simulation results of diplexer's S-parameters as a function of septum height h (I) and width w (II), (a) S_{11}, (b) S_{21}, and (c) S_{31}.

4. PARAMETRIC STUDY

The diplexer S-parameters (S_{11}, S_{21} and S_{31}) as a function of septum parameters h and w are shown in Fig. 8. Return loss (S_{11}), in Fig. 8(a), shows that increasing the height (h) of the periodic comb-like finger can shift the filter's center frequency downwards; and decreasing the width (w) of the finger increases the filter's center frequency. In both cases, no change in bandwidth is observed. The S_{21} and S_{31} results, in Figs. 8(b) and (c), show that by increasing h the filter's center frequency is shifted downwards, and by decreasing h the filter's center frequency moves upward. Effect of w on the frequency variations is the same as that for h. In the case of Filter I, by changing h by ± 0.2 mm the center frequency changes by ± 49 MHz. By changing w by ± 0.2 mm the center frequency changes by ± 147 MHz. In the case of Filter II, by changing h by ± 0.2 mm the center frequency changes by ± 30 MHz. By changing w by ± 0.2 mm the center frequency changes by ± 157 MHz. This shows that the filters response can be controlled by septum parameters h and w.

5. CONCLUSIONS

A waveguide diplexer design at C-band is shown to exhibit a wide stopband with high rejection level. This is achieved using an E-plane filter constructed from a metal septum with rectangular apertures, but the upper and lower sections of the apertures are configured into a periodic comb-like structure that slows propagating waves. The resulting waveguide filter is smaller in size and possesses a wider stopband with high rejection level. In addition, the proposed E-plane filter's center frequency can be modified without affecting its bandwidth by simply changing the dimensions of the periodic fingers of the comb-like structure. The diplexer's performance was verified practically.

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