H-PLANE WAVEGUIDE FILTERS WITH E-PLANE DISPERSIVE INVERTERS FOR HIGH-POWER APPLICATIONS

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Abstract **—** Conventional H-plane waveguide filters are supplemented with E-plane stubs which simultaneously act as impedance inverters and create transmission zeros (attenuation poles) at prescribed frequencies. Due to the utilization of E-plane stubs, the filter can be manufactured as two identical halves joined in the center plane of the components. Since current in the housing is minimal in this plane, E-plane fabrication facilitates high-power applications. The different steps in the design of such filters are outlined. It is concluded that E-plane stub inverters are not only more compact than H-plane stubs but also display better return-loss behaviour. The individual designs are verified by independently developed and/or commercially available software packages.

INTRODUCTION

H-plane inductive-iris waveguide filters are frequently employed in modern communication systems. Owing to their ease of fabrication and simplicity in numerical modeling, they have been proven especially useful in front ends and di/multiplexer applications, e.g. [1], [2]. Recent requirements in a densely populated frequency spectrum demand that many filter components be equipped with mechanisms to produce transmission zeros close to their passbands. Of course, this can be accomplished by utilizing cross-coupled dual/multi-mode filters, e.g. [3], but many of these designs are subject to post-assembly tuning which makes them unsuitable for high-power front-end operation.

Another method of producing transmission zeros in the filter response consists in using waveguide stubs in combination with standard direct-coupled filters. Such stubs can be implemented in addition to the filter component for the sole purpose of creating transmission zeros, e.g., [4], [5]. However, they can also be used as highly dispersive inverters, hence producing transmission zeros and acting as filter coupling elements at the same time [5], [6]. The latter approach is often confused with the extracted-pole synthesis technique [7], which extracts series or shunt resonators at each end of the filter. Dispersive inverters, however, need not necessarily be placed at each end of the filter [8].

Following simplified modeling capabilities using TE_{m0} modes and optimization, H-plane inductive-iris filters are preferably equipped with H-plane dispersive inverters to produce transmission zeros [5], [6]. For high-power applications, however, H-pane fabrication (milling) is not the appropriate choice of production. This is due to the fact that, together with the top plate required to complete the filter, the waveguide housing will exhibit small transition resistances between the milled component and the cover plate. This transition occurs at locations of high current densities and, therefore, might lead to non-linear effects when operated at high power levels [9]. In such cases, E-plane manufacturing technology, e.g. [4], [10], is used to place the joint of the two component halves at a position of (theoretically) vanishing current densities.

Therefore, this paper focuses on the design of H-plane waveguide filters with E-plane dispersive inverters. Starting with a standard H-plane filter design at 6.5 GHz, we demonstrate how transmission zeros can be implemented with E-plane dispersive inverters, which are more suitable for high-power applications and E-plane fabrication. Moreover, it will be demonstrated that E-plane inverters are not only shorter, i.e., more compact than H-plane inverters but are also superior with respect to overall return-loss performance.

DESIGN STRATEGY

In the first step, a regular H-plane iris filter is designed according to conventional practices, e.g. [2]. As an example, a five-pole component at 6.5 GHz and a bandwidth of 400 MHz is shown in Fig. 1.

The next step consists of replacing the outermost irises by dispersive stub inverters. As mentioned earlier, any other iris of the design of Fig.1 can be chosen as well. However, in many different designs of this kind, it turned out that dispersive inverters at the input and output of the filter are easier to match than those closer to the center. Fig. 2a compares the performance of the first iris of the design of Fig. 1 with those of H-pane and E-plane stub inverters. At the center frequency of 6.5 GHz, all three inverters show nearly identical results. But away from the center frequency, their behaviour is distinguishly different.

Whereas the inductive iris (dash-dotted lines) shows little frequency dependence over a wider frequency range, the H-plane (dashed lines) and E-plane (solid lines) stub inverters have been designed for an additional transmission zero (attenuation pole) at 5.5 GHz.

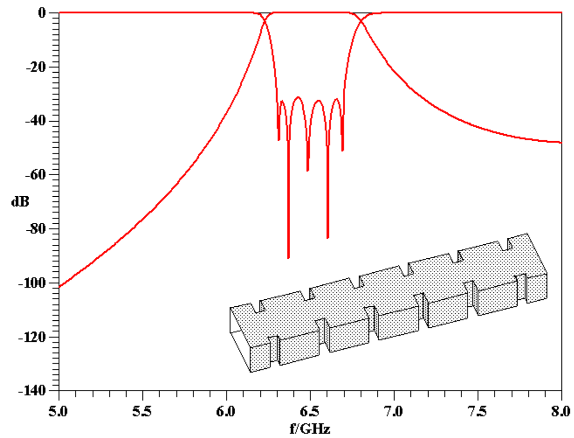
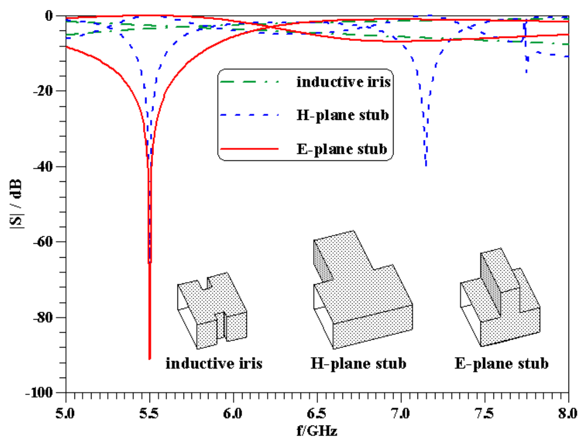
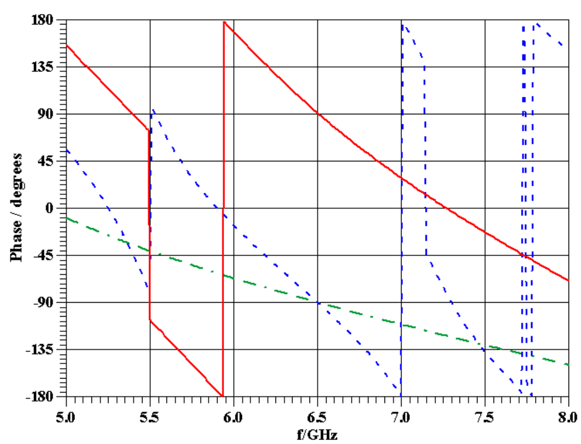


Fig 1. Initial design of five-pole inductive-iris filter.



(a)



(b)

Fig. 2 Comparison of inductive-iris, H-plane stub and E-plane stub inverters;
(a) S parameters in dB, (b) transmission phase.

Although the design/optimization of this process to produce the same inverter value and a transmission zero is described in [5], we like to point out that the location of the transmission zero is of fundamental importance in this step. The inverter value need not be completely identical to the one of the inductive iris as it will be modified in the following fine optimization of the entire filter. Fig. 2b depicts the transmission phase of the three inverters. The grid in the plot is introduced to demonstrate that all three inverters meet the ±90-degree phase requirement for an impedance inverter. As expected, the phase of the inductive iris is less frequency sensitive than those of the two stub inverters in the vicinity of the filter passband.

Comparing the plots for the H-plane and E-plane stubs in Fig. 2a, it is obvious that the H-plane stub is more dispersive than the E-plane inverter. It even produces a second transmission zero at 7.15 GHz and a dip at 7.74 GHz due to higher-order mode resonances in the stub. In direct comparison, the E-plane stub is less dispersive and more compact since its volume is less than one fourth of that of the H-plane stub.

In the last design step, the outermost irises in the initial design (Fig. 1) are replaced by the dispersive stub inverters shown in Fig. 2. A first optimization varies only the inductive irises next to the dispersive inverters and the lengths between them. This produces an appropriate tuning of the resonators next to the dispersive stubs. A final fine optimization includes the remaining parameters of the filter but excludes the stub dimensions to maintain the position of the transmission zeros.

RESULTS

Fig. 3 shows the performance – using the Coupled-Integral-Equations Technique (CIET) and the Mode-Matching Technique (MMT) – of the five-pole iris filter with two identical H-plane stub inverters according to Fig. 2a. The filter component is thus symmetric which reduces the computational effort. The desired transmission zero at 5.5 GHz is clearly observable and even more pronounced than in Fig 2a due to the fact that both stubs operate at the same frequency. Moreover, the spurious resonances due to the highly dispersive character of the H-plane stub (c.f. Fig. 2a) are also visible in Fig 3. This property of the H-plane stub makes it very difficult to obtain a good return loss over the entire passband of the filter. While the original design in Fig. 1 shows more than 30 dB return loss, the respective value in Fig. 3 is only 12 dB. It is obvious that this poor performance is predominantly caused by the spurious transmission zero at 7.15 GHz since it is closer to the passband, and the return loss deteriorates towards it. Note that the design can only be significantly improved by allowing the transmission zero at 5.5 GHz to move.

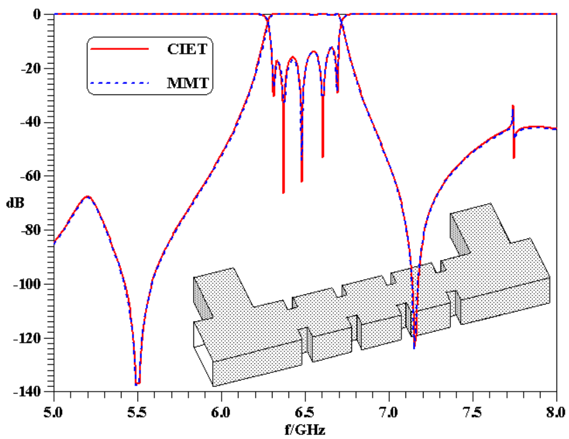


Fig. 3 Performance of symmetric five-pole H-plane filter with two H-plane dispersive stub inverters.

In direct comparison with Fig. 3, a symmetric filter with E-plane dispersive stub inverters is shown in Fig. 4. The transmission zero is located at 5.5 GHz, and the return loss is better than 34 dB, which is an improvement over the original design (Fig. 1) at the expense of a very slight reduction in attenuation in the 7-8 GHz range. Small differences in the passband return loss can be observed between the CIET and MMT computations. This also applies to the designs in the following figures and is due to the fact that the CIET allows the design to be carried out with many more spectral terms (modes).

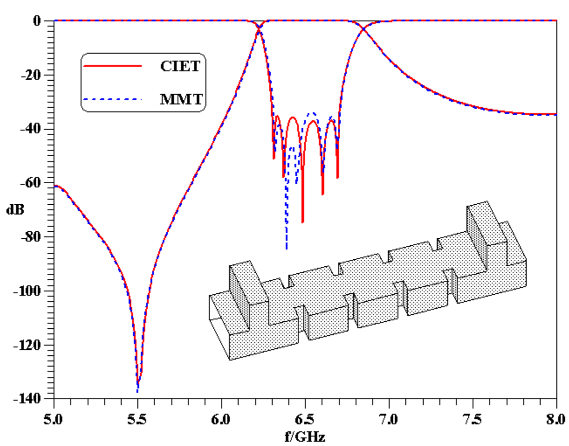


Fig. 4 Performance of symmetric five-pole E-plane filter with two E-plane dispersive stub inverters.

The advantage of the E-plane stub design of Fig. 4 over the H-plane stubs of Fig. 3 is threefold: First, a better return loss is achieved; secondly, E-plane fabrication of two identical halves allows for high-power application; and thirdly, the overall (inner) volume is reduced by almost 40 percent.

In order to demonstrate the flexibility of this design approach, Fig. 5 shows a symmetric filter with E-plane stub inverters, which produces a transmission zero above the passband. The transmission zero is designed for 7.3 GHz, and the return loss is better than 30 dB. The attenuation in the lower stopband, however, is slightly reduced compared to the original design in Fig. 1.

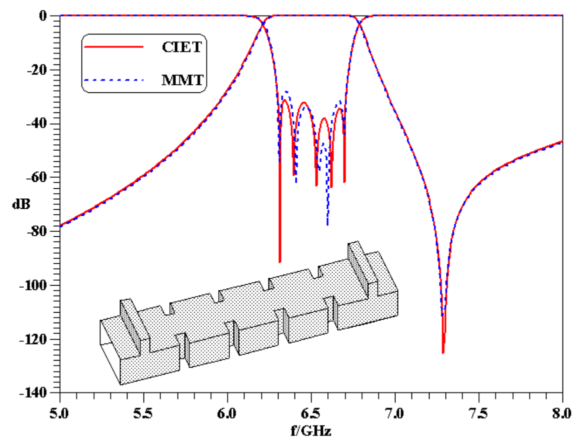


Fig. 5 Performance of a symmetric five-pole filter with two E-plane stub inverters which produce a transmission zero above the passband.

Finally, Fig. 6 presents an asymmetric filter with transmission zeros on both sides of the passband. To obtain a more symmetric response, the E-plane stub responsible for the lower transmission zero was redesigned for 5.7 GHz. The other stub, operating at 7.3 GHz, was taken from the design in Fig. 5. The return loss calculated with the CIET is better than 30 dB. Excellent agreement is not only achieved with results from the MMT but also with those of MiCIAN's commercial software package µWave Wizard©.

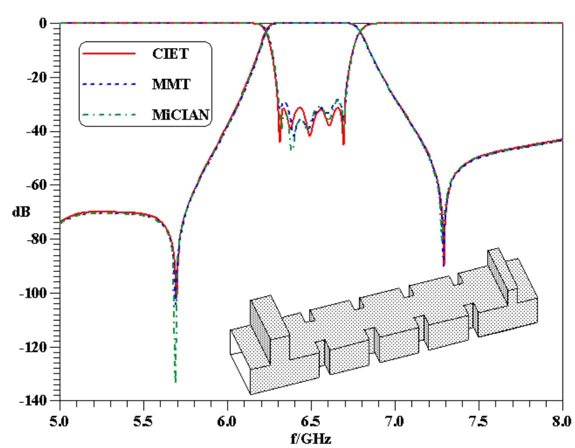


Fig. 6 Asymmetric five-pole filter with transmission zeros at both sides of the passband.

CONCLUSIONS

H-plane filters with E-plane dispersive inverters present a viable option to produce transmission zeros in rectangular waveguide filters for high-power applications. Since the component can be fabricated in E-plane technology, the two component halves can be joined at a location of minimum housing current. It is demonstrated that E-plane stub inverters are superior to H-plane ones, both in terms of matching capability and overall component volume. Principle design strategies are discussed which enable the microwave filter engineer to produce similar filter components. Computed performances are validated by independently developed codes and a commercially available software package.

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