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DESIGN OF WAVEGUIDE FILTERS WITHOUT TUNING ELEMENTS FOR PRODUCTION-EFFICIENT FABRICATION BY MILLING

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A filter design process is presented which allows the components to be readily manufactured by milling machines using relatively large cutters. This process makes the production more cost-effective and efficient. Several examples in the WR75 waveguide band demonstrate the feasibility of the design pocedure. Moreover, we address the differences in the manufacturing plane and the possibility of using different end-mill radii in different parts of a component. The design data are verified by comparing results of the mode-matching technique and those of the finite-element method (HFSS).

1 Introduction

A major drawback of waveguide filter design is the accuracy required in the manufacturing process. Of the many problems associated with this topic, the realization of sharp or slightly rounded corners has received special attention. It was found that a relatively small corner radius in the CNC fabrication has little influence on the performance of waveguide H-plane or E-plane filters, e.g. [1] - [2]. However, the manufacturing process still requires several stages with different cutters to implement a small corner radius. In other approaches, combinations of modal field solutions with different numerical techniques have been employed [2] - [5]. In this paper, we propose a filter design process which takes a relativeley large end-mill radius into account, thus permitting the filter to be fabricated without tuning elements and by using a single and relatively large cutter.

A second point of interest is the actual plane in which the filter is fabricated. For H-plane filters utilizing inductive irises, the obvious choice is to produce the components with radii in the H-plane. This is shown in Fig. 1a. However, 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. Since this transition occurs at locations of high current densities, the H-plane radius approch cannot be applied to high-power and/or satellite front-end components. In such applications, fabrication techniques producing E-plane radii are more appropriate. Two manufacturing examples for inductive irises with E-plane radii are shown in Figs. 1b and 1c. Since the two waveguide halves are joined in a plane of magnetic-wall symmetry, there will be no voltage difference across the small gap, thus no current is flowing between the two waveguide halves.

From the perspective of a fast computer-aided design procedure, which involve modal techniques, e.g., [6], the structure in Fig. 1b is at a disadvantage due to its nonstandard (cross-shaped) waveguide cross sections which are encountered when the filter is analyzed by utilizing building blocks in axial direction. While a process according to Fig. 1c maintains rectangular cross sections in all parts of the filter, this approach reduces the aperture area which can be tolerated only to a certain degree. This paper will present such a design in comparison with its H-plane-fabricated counterpart.

In other filter components such as those involving narrow stubs, it might be advantageous to use end-mill radii of different sizes: a large one for input and output transformers and a smaller one to mill the

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stubs. We also propose such a design in this paper.

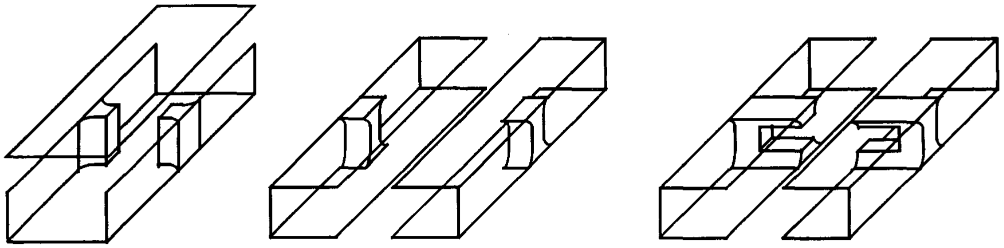

Fig. 1 Fabrication of inductive iris with H-plane radii (a) and E-plane radii (b, c).

2 Theory

For filters utilizing irises of Figs 1a and 1c, a modal expansion based on TE^x_{mn} modes, e.g. [6], is employed. This approach has been proven to be extremely efficient for certain classes of front-end diplexer designs [7]. (Note that the structure of Fig. 1b would require the full mode spectrum of the rectangular waveguide and, therefore, and in addition to the fact that cross-shaped cross-sections would need to be considered, requires more computing resources, both in terms of speed and memory allocation [8].) Special cases involve TE^x_{m0} modes for structures of Fig. 1a; E-plane components of constant width are based on a TE^x_{1n}-mode spectrum. Since all of these approaches are well documented, e.g. [6], we focus on the approximation of the radii.

Within the modal analysis, we use a staircase approach to model the radii (Fig. 2). For a given radius r and number of steps n, the distances s and lengths l are given by

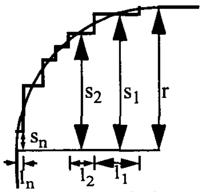

Fig. 2 Staircase approach for E-plane or H-plane radii.

$$\frac{s_i}{r} = \cos\left\{\left(i - \frac{1}{2}\right)\frac{\pi}{2n}\right\} \tag{1}$$

$$l_i = s_{n+1-i} - s_{n-i} \tag{2}$$

The filter design proceeds is as follows. First, the filter is designed without milling radii according, e.g., to [6] and fine optimized, e.g., using [9]. This specifies resonator lengths and aperture sizes. For a given end-mill radius and number of steps in the staircase approximation, the filter is analyzed again. The number of steps depends on the radius, but even for large radii, it was found that about nine steps are sufficient. In order to finalize the design, a two-step optimization procedure is applied. Since the corner radius mainly affects the effective resonator lengths, these parameters are adjusted first. A subsequent optimization fine tunes the aperture dimensions together with the resonator lengths for close to equiripple performance. Note that whether or not equiripple response is actually achieved depends on any specified manufacturing tolerances. For most satellite communication equipment in Ku-band, a tolerance of 1 mil (25.4 μm) is acceptable.

3 Results

Our first example is a five-pole inductive-iris filter fabricated according to Fig. 1a. Figs 3 show the results of the different design steps. Especially the frequency shift towards higher frequencies and the influence on the return loss, when incorporating a large radius of 0.18", is clearly visible (Fig.3, left).

Fig. 3 (right) shows the performance of the final optimizd design and a validation by the commercial software package HFSS.

The same filter was then reoptimized for fabrication with E-plane radii according to Fig. 1c.. In this case, a radius of 0.1" was used. As shown in Figs. 4 (left), the influence of this manufacturing technique on the filter performance is more severe. Therefore, it might be necessary at times to resynthesize the filter for a frequency range that offsets the expected shift produced by the cutter radius.

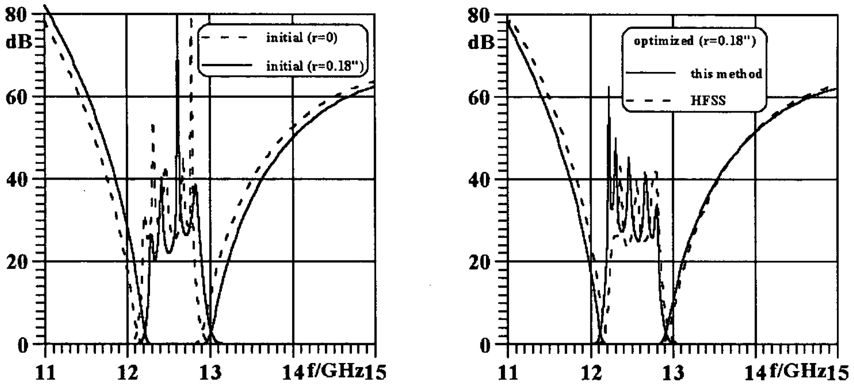

Fig. 3 Performances of the design steps of a five-pole filter fabricated with H-plane radii according to Fig. 1a.

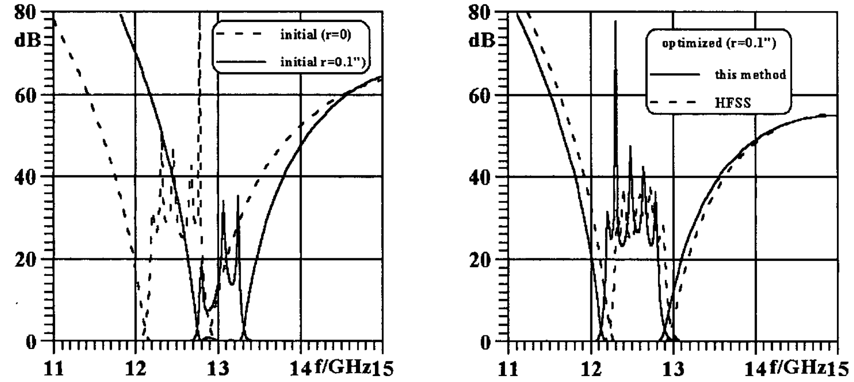

Fig. 4 Performances of the design steps of a five-pole filter fabricated with E-plane radii according to Fig. 1c.

The differences between the modal techniques and HFSS are attributed to the following facts. First of all, HFSS approximates the radii by a straight-line segmentation which, to a certain degree, reduces the cavity size and leads to a shift towards higher frequencies. The staircase function adopted in the modal technique (1), (2) is more likely to average out differences between the actual radius and the approximation. Due to the higher field concentration in the center of the waveguide, the structure with E-plane radii in Fig. 4 is more affected than the one with H-plane radii in Fig. 3, where the field concentration is much smaller.

The last example is an E-plane quasi highpass filter with stubs and waveguide transformers at both ends. As the layout in Fig. 5 (left) shows, two different end-mill radii have been used. The bulk of the structure, including the transformer sections, is fabricated with an E-plane radius of 0.1", while only stub 1, 2, 10 and 11, due to their smaller width, utilize a smaller radius of 0.025". The component is interfaced with standard WR75 waveguides. Excellent quasi-highpass performance is achieved (Fig. 5, right). The 30 dB return-loss passband is between 13.2 and 15 GHz; the 70 dB isolation stopband is between 10 and 12.75 GHz.

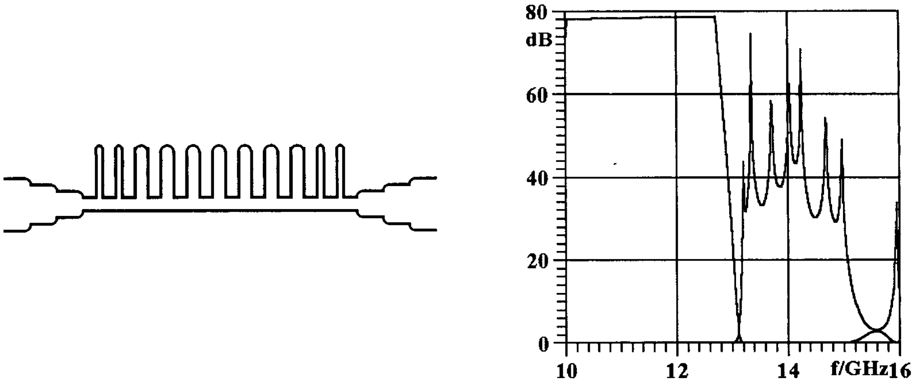

Fig. 5 E-plane stub filter with matching transformers fabricated two different cutters: r=0.025" (first and last pair of stubs only) and r=0.1" (all other parts of component).

4 Conclusions

The fabrication of waveguide filters is simplified by purposely using cutters of large radii in the milling process. The radii are fully accounted for in the design and modal-based analysis technique. Since components fabricated with E-plane rather than H-plane radii are advantageous in high-power satellite applications, an E-plane fabrication technique, which lends itself to a simplified numerical analysis, is developed. Several results in WR75 waveguide with cutter radii between 0.025" and 0.18" demonstrate the applicability of the design procedure.

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