Short Papers

Design of Tolerance-Corrected Filters Employing Half-Cylinder Posts

R. Coccioli, A. Morini, G. Pelosi, and T. Rozzi

Abstract—**An alternative post geometry suitable for the realization of waveguide filters is investigated. The new post consists of half a cylinder. Due to its asymmetry it is possible to vary the electrical characteristics of such an element by means of a simple rotation. This permits us to compensate for fabrication tolerances of a filter without introducing additional screws.**

Index Terms— **Half-cylinder post, tolerance-corrected filters.**

I. Introduction

It is well known that mechanical tolerances render the realization of tuning-free filters quite a difficult task. For example, in the high-capacity radio links for civil applications operating at 38 GHz, the branching filters of 300-MHz bandwidth are conveniently realized by metal insert technology. However, in our experience it is extremely expensive to mill waveguide housings with a precision better than ± 50 μm, and such an error produces a frequency shift up to 150 MHz in the response. Mechanical tolerances on the length of the cavities produce an even worse deterioration. Moreover, since filter design is quite critical, numerical errors due to machine accuracy (truncation, roundoff, etc.) may produce additional deteriorations.

In order to compensate for such errors it is common practice either to broaden the filter bandwidth or to insert additional tuning elements—typically screws. The latter not only causes additional losses and costs, but also requires some design modifications. In fact, the cavities must be enlarged with respect to their nominal values since the insertion of screws can only reduce their electrical sizes (in E-plane technology, tuning screws are inserted in the narrow wall).

In this paper, we investigate the possibility of realizing filters employing directly tunable coupling elements capable of compensating mechanical errors. The basic idea consists of using asymmetrical posts as coupling elements in the form of half-cylinder screws whose rotation produces as a prime effect a variation of the cavity lengths, thus permitting some tuning. In particular, the properties of a half-cylinder inductive post [3], (as shown in Fig. 1) are analyzed by exploiting the flexibility of the FEM [1], [2] in modeling arbitrarily shaped geometries. The results of this numerical analysis show that by rotating such an element, its reflectivity varies somewhat depending upon the post-radius and off-axis displacement. On the basis of such numerically derived data, the filter being synthesized is designed by considering all the posts rotated by 45° with respect to the waveguide axis, so as to obtain maximum tunability. Furthermore, in order to reduce costs, the post diameter is the same for all the elements and depends only on the filter specifications. In practice, the reflection of the smallest k-inverter (maximum reflection) has to be that of the half-cylinder post when its axis is almost centered in the waveguide. Smaller reflections are then obtained by shifting the post with respect to the waveguide axis. Fig. 2 shows the top view of a nominal inductive waveguide filter. Once the filter is realized it is possible to adjust its frequency response by slightly rotating the posts. It is worth emphasizing that the design procedure proposed is accurate and, in principle, does not require any adjustment. These are effected for the purpose of compensating mechanical tolerances.

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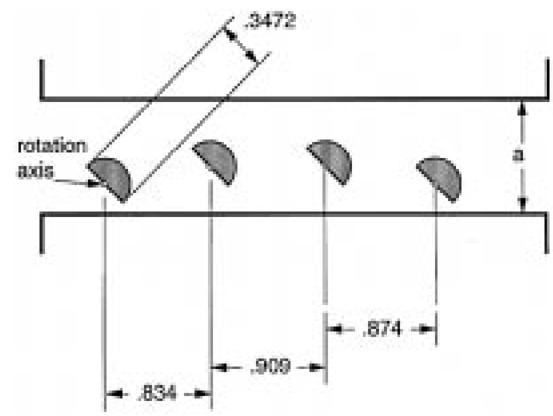

Fig. 1. H-plane section of a filter containing the proposed half-cylinder inductive posts. In particular, the picture shows the actual dimensions (scaled 0.6) of the three-pole WR90 filter analyzed. In the initial design, posts are rotated by 45°. Their centra are displaced by 0.216, 0.079, 0.079, and 0.216 with respect to the waveguide axis. All dimensions are expressed in inches.

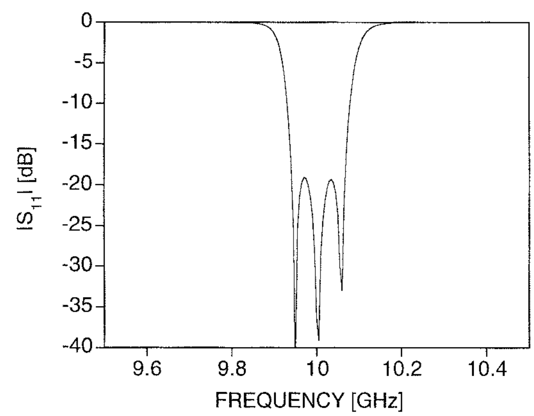

Fig. 2. Response of the filter prototype.

II. Building the Database by Means of Finite-Element Analysis

Filter design is based on the knowledge of the reflectivity of a single post for different values of its displacement with respect to the waveguide axis [3], [4]. With a view to speeding the design and optimization process, it is advisable to build a database containing the reflectivity for a set of displacement values from which all the needed data can be obtained by interpolation. The analysis of the post for each configuration may be carried out by resorting to a hybrid finite-element modal-expansion technique [5]. In order to outline this numerical procedure, let us consider the geometry of an arbitrary half-cylinder post shown in Fig. 1. The problem is formulated as follows. In the bounded domain delimited by ports one and two, and by the perfectly conducting waveguide wall in which the irregular post is contained (region Ω), the problem is modeled by the Helmholtz equation discretized by finite elements. The usual Galerkin procedure leads to the weak form of the Helmholtz equation

$$\iint_{\Omega_s} \nabla E_y \cdot \nabla W_m \, ds + k_0^2 \iint_{\Omega_s} E_y W_m \, ds + \int_{\Gamma_{1,2}} \frac{\partial E_y}{\partial n} W_m \, d\gamma_{1,2} = 0 \quad (1)$$

where W_m are weighting function

Assuming that the exciting mode is the fundamental TE_{10} mode due to the translational symmetry of the structure, the modes scattered by the half-cylinder post belong to the set TE_{n0} $(n = 1, 2, \cdots)$. Hence, a number M of members of this set of eigenfunctions is used to represent the field in each waveguide connected to the filter section. To solve the set of integro-differential equations (1), it is necessary to enforce the tangential-field continuity at ports one and two. Magnetic-field continuity can be enforced by introducing the derivative of the modal expansion of the field into the boundary integral at ports one and two of (1). Electric-field continuity must be explicitly enforced by means of a point-matching procedure [6] or by exploiting a projective approach [5].

This hybrid FEM/modal-expansion approach has also been employed in other works for the analysis of various homogeneous and inhomogeneous waveguide devices, providing accurate results [7], [8]. Following this procedure, the generalized scattering matrix for a single half-cylinder post can be computed for different values of the post axial displacement, as well as for different values of the rotation angle. Each configuration to be analyzed has been finely discretized using about 150 second-order isoparametric element corresponding to about 500 nodal unknowns. The reference planes has been placed at 5 mm from the post axis, and 30 modes have been used to represent the field into the waveguide.

III. Example Filter Design

As an example, we have designed a three-pole 20-dB minimum return loss (mrl) 130-MHz bandwidth cavity filter operating at X-band. The prototype response, centered at 10 GHz, is shown in Fig. 2.

In order to achieve the largest tunability, the design starts by considering half cylinders of radius 4 mm and is rotated by 45°. The filter was designed by standard techniques [3], considering a prototype consisting of k-inverters alternating to cavities. The value of the displacement of the post axis with respect to the waveguide sidewall has been interpolated from a previously built database containing the post reflectivity as a function of the displacement, calculated at the midband frequency. Note that 20–30 values are required in order to build a database suitable for interpolation. The design procedure outlined is now completed and, as usual, it neglects the frequency dependence of the post reflectivity. On the other hand, this is not a problem since the small discrepancies occurring in the physical structure due to the frequency dependence of the post, to higher order mode interaction, or to mechanical tolerances, can be corrected by rotating the posts. This will be shown in the following by introducing in the model all the above error sources and recovering the prototype filter response by simulating the effect of the rotation.

The "actual" filter response has then been calculated by a full-wave analysis based on the FEM method applied to the whole filter structure, as shown in Fig. 3. As can be observed, there is an evident deterioration between prototype and physical structure in the design process, having considered only the fundamental mode interaction and neglected the frequency dependence of the posts. Mechanical tolerances also affect the filter response. In particular, the prototype was actually housed in a waveguide 100-μm wider than the nominal one (22.96 mm instead of 22.86 mm). Fig. 4 shows the full-wave response of the same filter in the larger housing. A significant shift of the bandpass of the filter can be observed. A database relevant to the half-cylinder post in the wider waveguide has been built to show the possibility of recovering the prototype response. The database contains the scattering matrices of posts as function of the rotation angle calculated at N frequency spots corresponding to the reflection zeros and to the intervening maxima [9]. Of course, the computed scattering matrices refer to an appropriate number of accessible modes. The mode is considered "accessible" if its attenuation through a waveguide length equal to the minimum distance between two successive discontinuities is less than 20 dB. Typically, the first two waveguide modes are sufficient to properly simulate the filter, the length of the cavities being larger than $\lambda_g/4$. As in the design process, the values stored in the database are interpolated and exploited by an optimization routine until the prototype response is achieved. After optimization, the post rotations (from the left) are as follows:

$$\phi_1 = 40.3^\circ \quad \phi_2 = 48.1^\circ \quad \phi_3 = 47.5^\circ \quad \phi_3 = 51.5^\circ.$$

Finally, a full-wave FEM analysis of the entire filter was performed to check the effectiveness of the optimization, finding the response

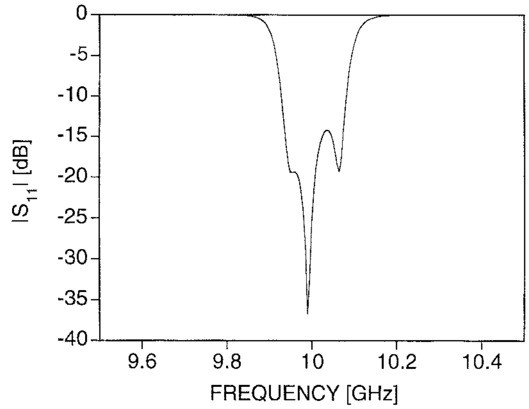

Fig. 3. Full-wave response of the nominal filter.

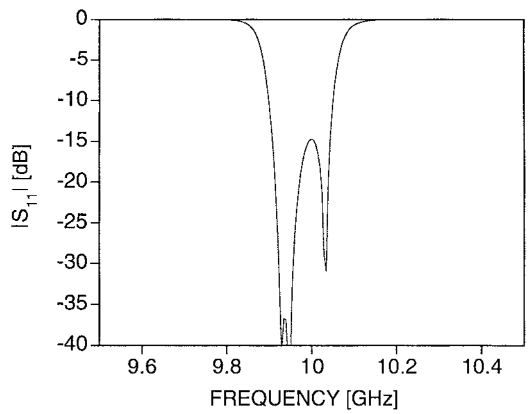

Fig. 4. Full-wave response of the filter of Fig. 3 when placed in a larger housing.

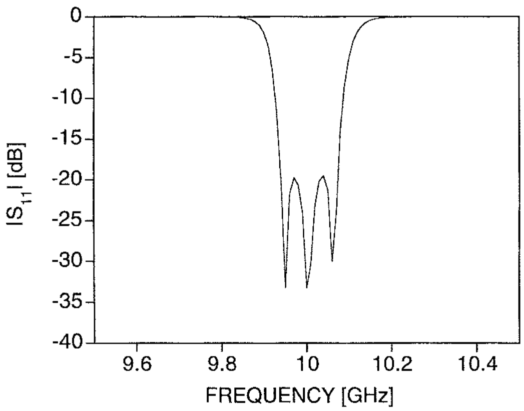

Fig. 5. Full-wave response of the filter after the optimization.

shown in Fig. 5. It can be observed that the original prototype response of the prototype was recovered.

IV. Conclusions

The half-cylinder post geometry is employed in order to realize direct coupled-cavity filters in waveguide.

Such an arrangement permits one to correct the deterioration due to mechanical tolerances by a slight rotation of posts whose main effect is a variation of the adjacent cavities.

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Cross-Coupled Microstrip Hairpin-Resonator Filters

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***Abstract*—A new class of cross-coupled planar microwave filters using microstrip hairpin resonators is introduced. The realization of both the canonical and the cascaded quadruplet (CQ) filters is feasible. Coupling characteristics of four basic coupling structures encountered in this class of filters are investigated in the light of full-wave electromagnetic (EM) simulations. A four-pole cross-coupled filter of this type is designed and fabricated. Both the theoretical and experimental performance is presented.**

***Index Terms*—Cross coupling, hairpin resonator, microstrip filter.**

I. Introduction

Miniaturized microwave bandpass filters are always in demand for systems requiring small size and light weight. Conventional hairpin line filters, introduced by Cristal and Frankel [1] in the early 1970's, were developed to meet this demand, and have become popular. Further miniaturized hairpin-resonator filters were reported by Sagawa and his colleagues [2] in the late 1980's for application to receiver front-end microwave integrated circuits (MIC's). Recently expanding mobile communications systems, together with advances in MIC's and high-temperature superconducting circuits, have further stimulated the development. Hong and Lancaster reported pseudo-interdigital filters which might be seen as a combination of hairpin and interdigital line resonators [3], while Matthaei and his co-workers developed narrow-band hairpin-comb filters, which use the hairpin resonators in such a way that their filtering properties are similar to those of comb-line filters [4].

In this paper, we present new applications of microstrip hairpin resonators which lead to a new class of cross-coupled microstrip bandpass filters. The cross-coupled filters are so attractive because they exhibit ripples in both passband and stopband, which according to the early work on filter synthesis [5] can improve both frequency selectivity and bandpass loss. For instance, they are able to place transmission zeros near cutoff frequencies of a passband so that higher selectivity with less resonators can be obtained. This property is of much interest in narrow-band filters where the passband insertion loss is strongly related to the number of resonators. The cross-coupled filters, depending on the phasing of cross-coupled signals, may also flatten the group delay. Owing to the difficulty in arranging and controlling the cross couplings in planar transmission-line resonators, only a few types of cross-coupled planar filters have been developed [6]–[8]. The new cross-coupled microstrip hairpin-resonator filters offer alternative designs. They are not only simple and compact in configurations, but also have great flexibility to shape filters into different sizes. The latter is mainly due to the great freedom in choosing hairpin-resonator shapes.

II. Cross-Coupled Filters

Fig. 1 shows two typical microstrip cross-coupled bandpass filters comprised of coupled hairpin resonators. The dielectric substrate with

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