Rectangular Waveguide Dual-Mode Filters Without Discontinuities Inside the Resonators

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***Abstract*—A new configuration of rectangular waveguide dual-mode filters is presented where no discontinuity is present inside the cavities. It is based on the idea that coupling between the two diagonal modes in a square waveguide resonator can be obtained by deforming the square cross-section into a rectangular shape. Hence, no discontinuity is needed to couple the two diagonal polarizations. As a consequence, the input/output rectangular waveguide cross-sections are rotated by 45° with respect to those of the resonator. The advantages of this configuration are related to the fact that all the cross-sections (as well as the coupling apertures) are rectangular and no tuning is needed.**

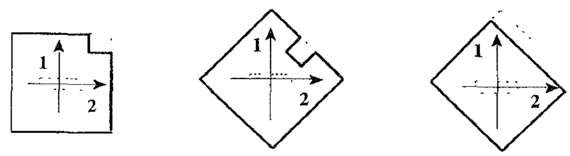

Fig. 1. Dual mode coupling configurations: (a) corner cut [1]; (b) an alternative; (c) new concept.

I. Introduction

In SATELLITE communication applications, dual-mode waveguide filters are more convenient than conventional single-mode ones because of their smaller size and reduced weight. The coupling between the modes is generally obtained by adding one or more suitably placed screws or, as shown in recent works, by means of a perturbation of the transversal waveguide section (*ridge*) [1], [2]. In the case of a rectangular waveguide, a suitable perturbation can be obtained by cutting one corner for the whole length of the resonator waveguide [1]. This proposal is very interesting since it removes all the disadvantages caused by the coupling screws and is easy to realize. However, particularly in the case of narrow band filters, an accurate design is very critical and cumbersome. In fact, not only do the first two propagating modes of each guide have to be determined in order to evaluate the dual-mode frequency splitting, but a large number of evanescent modes, which are necessary for the characterization of the intercavity discontinuities, must also be known. Even if several numerical methods (e.g. mode matching, method of moments, finite element method, etc.) can be used to obtain the modal characterization of a waveguide with arbitrary cross-section, this study, for the higher-modal orders, is generally CPU-time consuming and the accuracy may not be satisfactory. This aspect becomes more important in the case of narrow band characteristics where, as is well known, the coupling coefficients must be specified with high accuracy.

From this point of view it would be highly desirable to use waveguide cross-sections whose mode spectrum is known analytically. Still more desirable would be to obtain the required coupling maintaining the rectangular shape. In this letter we propose a new configuration that realizes this condition.

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II. Discussion

In order to better explain the genesis of the new resonator concept, it is beneficial to refer to the geometry proposed in [1], shown in Fig. 1(a), for convenience. In this configuration, the modes of the reference waveguide TE_{10} and TE_{01}, indicated as 1 and 2 for brevity, are coupled by the corner cut. For clarity, a coupling slot is also sketched. Since in a square waveguide the TE_{10} and TE_{01} modes are degenerate (i.e., have the same phase velocity) it is obvious that any linear combinations of them can be assumed as mode of the structure. In particular, if we choose the sum and difference of the previous two modes, we obtain fields polarized according to the square diagonals that hereinafter we call *diagonal modes*. Following the idea proposed in [1], these modes could be coupled, for instance, through a ridge as sketched in Fig. 1(b). Also this structure suffers from the same drawback of the previous one: the mode spectrum of the guide must be computed by numerical techniques. However, if we increase the width of the ridge up to the guide side length, the diagonal modes are still coupled as before, but the cross-section has become rectangular. This concept has allowed us to identify the usual TE_{10} and TE_{01} modes of the rectangular waveguide of Fig. 1(c) as the dual modes discussed in [1] and, clearly, the frequency splitting, generally used to compute the coupling coefficient c, is obtained in analytical form and can be controlled by varying the guide side ratio a/b. With the definition of (11) in [1], we may write rigorously

$$c = \frac{(a/b)^2 - 1}{1 + (a/b)^2 + 2(a/l)^2} \tag{1}$$

where l is the dual-mode cavity length. Obviously, in this configuration the input/output rectangular waveguide cross-

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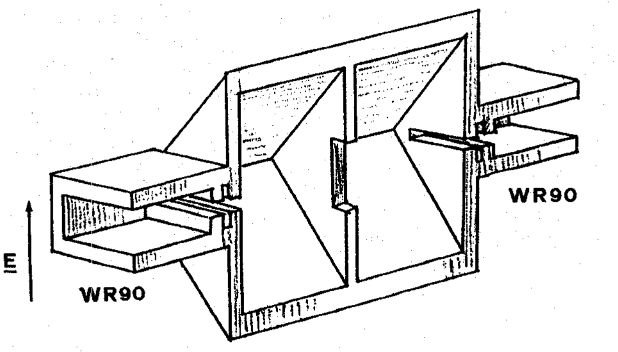

Fig. 2. Cutaway perspective of the filter waveguide structure.

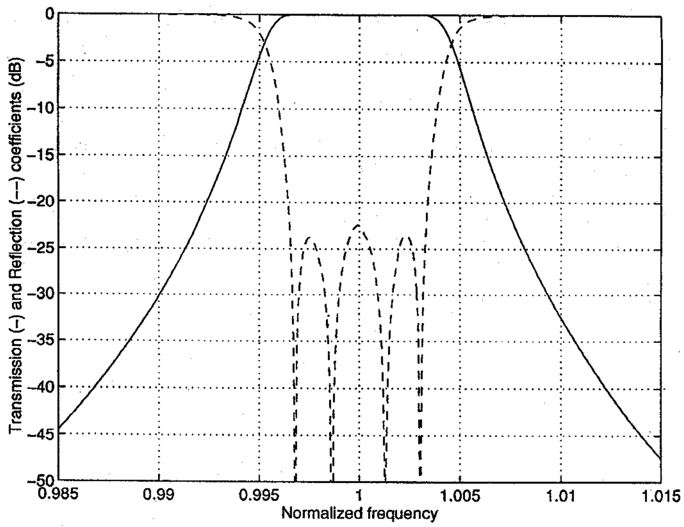

Fig. 3. Transmission and reflection response of the waveguide filter sketched in Fig. 2 (full-wave analysis).

sections are rotated by 45° with respect to those of the resonators. This occurs also in the case of the coupling apertures between the resonators.

As well known, the critical point in the design of a narrow band filter is the realization of the desired couplings. As for the coupling between the two modes of the same cavity, the problem is solved by (1), whereas for the other couplings, thick, iris-type discontinuities with rectangular apertures are used. To this end, the analysis of junctions between rectangular waveguides with rotated cross-sections is required. The solution of this problem can be obtained, for example, by the method presented in [3].

III. RESULTS

In order to show the usefulness of this new concept of dual-mode cavity, we have designed a four-pole dual-mode filter in rectangular waveguide. The filter structure is sketched in Fig. 2. The design specifications were: central frequency $f_0 =$ 11 GHz; bandwidth 72 MHz; passband ripple level 0.03 dB; WR90 input/output waveguides. For this example we have chosen a symmetrical configuration in which the resonators were realized starting from a reference square waveguide with side length $a_s = 18$ mm.

Even if it is possible to determine the various geometrical dimensions of the coupling discontinuities in such a way that the filter natural frequencies coincide with a set of values established on the basis of a lumped network (see for instance [1]), we have designed the filter following a new procedure based on a scattering approach that directly yields the scattering parameters of all the coupling discontinuities. Details on this procedure will be given in a separate paper.

From this synthesis procedure we have obtained the magnitudes of the transmission coefficients of the coupling discontinuities, relative to the diagonal modes: in particular, -9.35 dB for the external ones and -28.56 dB for the central one. Moreover, the resonator guide side lengths turn out to be $a = a_s + \Delta a/2$ and $b = a_s - \Delta a/2$ with $\Delta a = 0.213$ mm. With the help of design charts that we have developed for this purpose, the geometrical dimensions of the central 2-mm-thick iris-type discontinuity have been determined. As it is well known [4], each coupling discontinuity introduces a phase shift that must be taken into account in the determination of the cavity length. This problem is generally solved by introducing further tuning screws (see for example [4]) or, in the case of the configuration presented in [1], by changing the ratio a/b of the waveguide. This operation can be seen as the enforcement of a phase matching condition. In our configuration the ratio a/b controls the coupling inside the cavity, and it cannot be used for this purpose. The goal has been reached by designing two external coupling discontinuities of composite type. As it can be seen in Fig. 2, they are constituted by two 2-mm-thick capacitive irises separated by a waveguide section. The dimensions of this configuration have been selected in order to obtain both the desidered coupling level and the satisfaction of the phase condition, which, in this case, requires the equality between the phases of the S_{11} relative to the diagonal modes, of the external and central discontinuities.

Finally, we have analyzed the whole structure by using the mode-matching technique to characterize each discontinuity and by evaluating their interactions also through the evanescent modes (full-wave analysis). The frequency response is shown in Fig. 3. The slight degradation of the equi-ripple condition is due to the dispersion of the resonator waveguides and of the discontinuities. Even if only an experimental result can be considered conclusive, it is our opinion that a full-wave analysis is a sufficient proof of the feasibility of this new resonator concept.

IV. CONCLUSION

The results presented in this letter show the possibility to realize a dual-mode rectangular waveguide filter where all the cross-sections have a rectangular shape (this concept is the object of the italian patent no. TO95A000033). This fact offers obvious advantages in the design, construction, and operation of the filter.

The configuration discussed in this letter can be used also for dual-mode four-pole elliptic function filters. It is well known that in this case a negative feedback between the two dual-mode cavities has to be introduced [5]. This can be done without using a cross-iris [6], but simply by increasing the height of the rectangular central aperture [5] and rotating one of the two resonators by 90°.

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