Quasi-Dual-Mode Resonators

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***Abstract*—This paper discusses the concept of using two single-mode resonators to construct a quasi-dual-mode resonator that has all the features of traditional dual-mode resonators. Two novel filter structures are presented in this paper that employ this concept; one employs planar-type resonators and the other employs dielectric resonators. A new configuration for a single-mode dielectric resonator is also proposed in this paper. The use of such a type of resonators makes it possible to construct dielectric-resonator filters that are much smaller in size than conventional TE_{01} single-mode resonators. Measured results are presented for four filters along with theoretical results to verify the novel concepts proposed in this paper.**

***Index Terms*—Dielectric resonators, filters.**

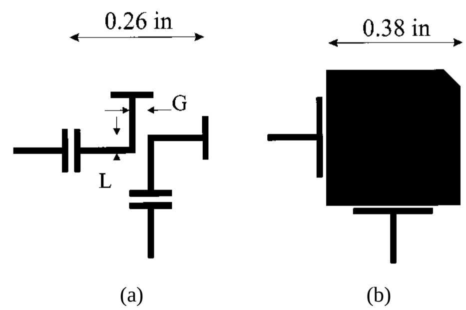

Fig. 1. Comparison between the proposed quasi-dual-mode resonator and traditional dual-mode resonators.

I. Introduction

The use of dual-mode resonators to realize microwave filters has been known for years [1]–[3]. The main advantages of such type of resonators are the ability to realize compact-size filters and ability to couple between nonadjacent modes, which, in turn, makes it easy to realize elliptic-function or self-equalized filters. In this paper, we present two novel filter configurations that use single-mode resonators configured in a certain way to resemble dual-mode resonators (i.e., quasi-dual-mode resonators).

The quasi-dual-mode resonator has the major advantages of the traditional dual-mode resonator. Additionally, it allows the realization of filters with an improved spurious performance. Another important feature of quasi-dual-mode resonators is in the number of degrees of freedom available to control the filter layout. The only limitation is the difficulty to realize extremely narrow-band filters of less than 0.02%. This is due to the fact that the two modes are not perfectly decoupled from each other and there be will always a finite small coupling between the two modes.

In this paper, we present measured results for two planar microstrip filters built using the novel quasi-dual-mode resonator configuration. One is a ten-pole self-equalized filter with 1% bandwidth, while the other is an eight-pole filter with 0.12% bandwidth. The results indicate the feasibility of building quasi-dual-mode filters that have superior performance in comparison with traditional dual-mode planar filters.

We also expand the concept of quasi-dual mode from planar microstrip technology to dielectric resonator technology. Several possible configurations for quasi-dual-mode dielectric resonators are proposed along with theoretical results for field distribution. Experimental results are presented for a four-pole filter quasi-elliptic filter built using one of the proposed quasi-dual-mode dielectric-resonator configurations.

Measured results are also given for a four-pole filter that employs a new single-mode dielectric-resonator configuration. Our original intention was to use this single-mode resonator as the basic building block for the quasi-dual-mode resonator. Nevertheless, it was found that the resonator itself could be used to construct compact-size single-mode dielectric-resonator filters. We illustrate how one can improve the spurious performance of the proposed single-mode resonators. We also present theoretical results for the coupling values between two resonators as well as a mode chart and Q values for the various dielectric resonators proposed in this paper.

II. Quasi-Dual-Mode Planar Resonators

Fig. 1(a) illustrates the proposed quasi-dual-mode planar resonator. The resonance frequency is controlled by either changing the capacitance portion or the inductive portion of the single-mode resonators. The coupling between the two modes is controlled by adjusting the lengths L and G shown in Fig. 1. This figure also presents a size comparison between the proposed resonator and a conventional dual-mode patch resonator [4], [5]. The two resonators are operating at 4 GHz and built on the same substrate with a dielectric constant of $\varepsilon_r = 24$. It can be seen that the proposed quasi-dual-mode resonator is considerably smaller in size.

For patch dual-mode resonators, the type of housing and its proximity to the substrate has a strong impact on the resonator Q

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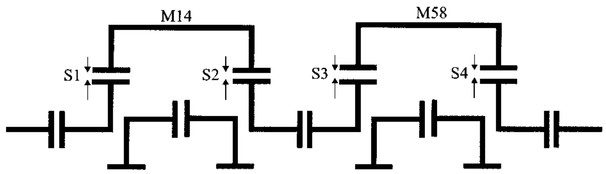

Fig. 2. Layout of an elliptic function eight-pole filter.

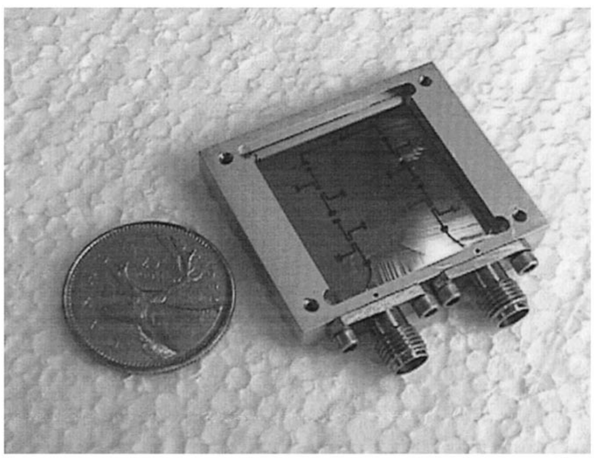

Fig. 3. Self-equalized ten-pole filter.

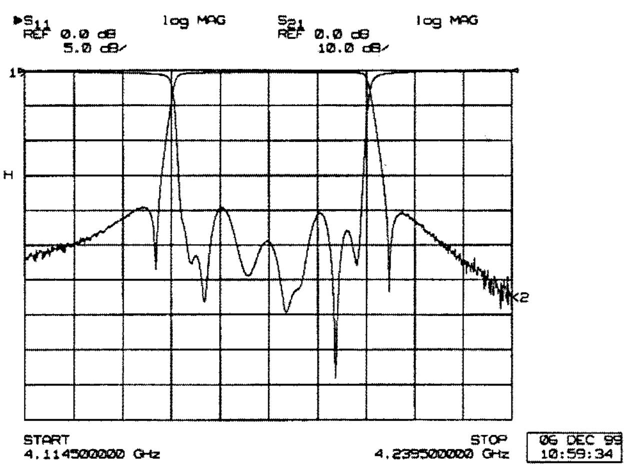

Fig. 4. Measured isolation of the self-equalized ten-pole HTS filter shown in Fig. 3.

factor. The proposed quasi-dual-mode resonator does not suffer from the same radiation problem, which patch resonators typically have. Even though it has a much smaller surface area, the effective loaded Q of the quasi-dual-mode resonator could reach that of the patch resonator for the same housing dimensions.

Fig. 2 illustrates the layout of an eight-pole elliptic function filter. The filter consists of four capacitively coupled quasi-dual-mode resonators. The filter layout permits ease of realizing the cross-coupling $M14$ and $M58$, allowing elliptic-function filters. The sign of coupling, positive or negative is selected by controlling the length of the coupling elements as well as the gaps $S1$, $S2$, $S3$, and $S4$.

We have successfully built several high-temperature-superconductive (HTS) filters of this type having different orders.

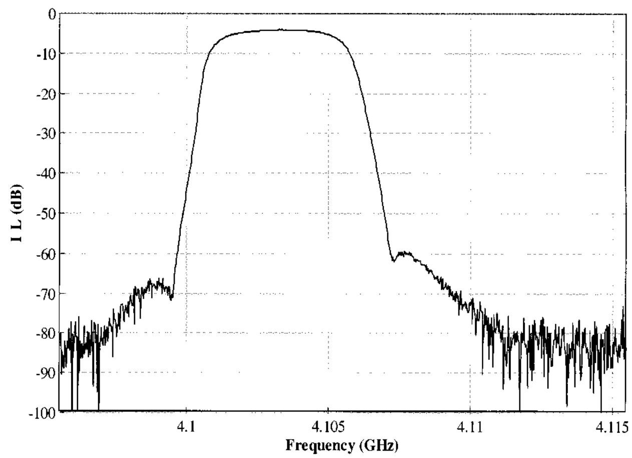

Fig. 5. Measured performance of a quasi-dual-mode resonator eight-pole filter with 0.125% bandwidth.

Fig. 3 shows the layout of a ten-pole self-equalized HTS filter built on a lanthium–aluminate substrate ($\varepsilon_r = 24$), while Fig. 4 illustrates its measured performance. The overall filter is built on a wafer size of 1.5 in $\times$ 1.5 in. The use of dual-mode patch resonators would require a much larger substrate area to fit a filter with similar characteristics.

One key problem with traditional dual-mode patch resonators is the difficulty in controlling the coupling between nonadjacent resonators. This coupling is mainly due to radiation and cannot be easily controlled or eliminated unless the filter circuits are integrated in separate housings. Such parasitic coupling makes it difficult to balance the notch level leading to nonsymmetry in the filter performance. For the quasi-dual-mode resonators, the radiation is small and its effect on the symmetry of the RF performance can be easily be circumvented, even for filters with 1% bandwidth, as demonstrated in Fig. 4.

The problem is even more pronounced for traditional patch-resonator filters with narrow bandwidth. In this case, the parasitic coupling is comparable with the coupling values between the various resonator elements, which makes it difficult to achieve a filter with a reasonable RF performance. Fig. 5 presents the measured results of a quasi-dual-mode eight-pole HTS planar filter designed with 5-MHz bandwidth at 4.1 GHz (i.e., 0.125% bandwidth). All resonators are placed in one single housing. To our knowledge, this is the first time a planar HTS filter with such narrow percentage bandwidth is ever demonstrated.

III. Quasi-Dual-Mode Dielectric Resonators

The same concept can be applied to realize quasi-dual-mode dielectric resonators. The mode distribution of the $\mathrm{HE}_{11\delta}$ mode in conventional dual-mode dielectric resonators [6], is given in Fig. 6(a). It is also well known [7] that with the use of a metallic plate (electric wall) as an image plate, half of the resonator can be made, as shown in Fig. 6(b), to resonate at the same resonance frequency of the original full-size resonator. The use of a perfect magnetic wall, as shown in Fig. 6(c), should also yield the same result leading to a resonator with the same resonance frequency f_o. The perfect magnetic wall could be approximated by an dielectric–air interface (nonperfect magnetic wall) leading

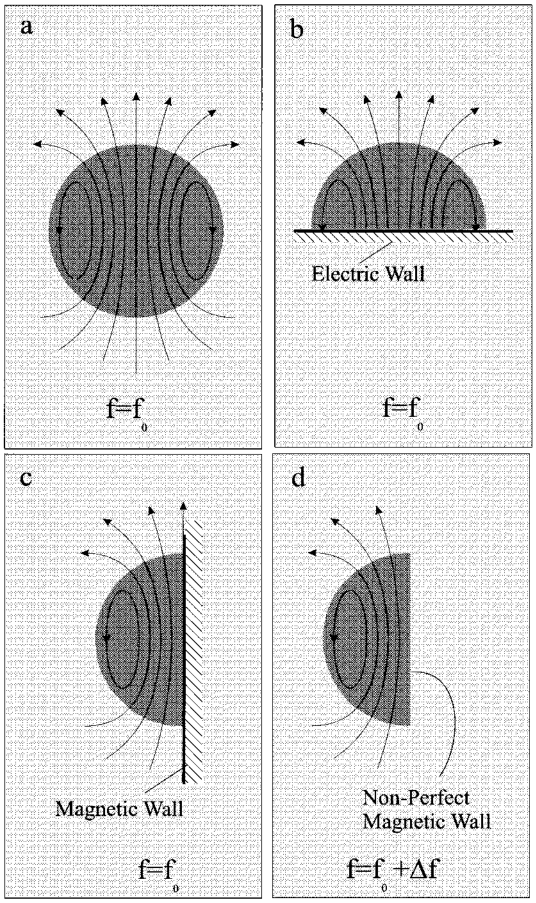

Fig. 6. Dielectric-resonator configurations.

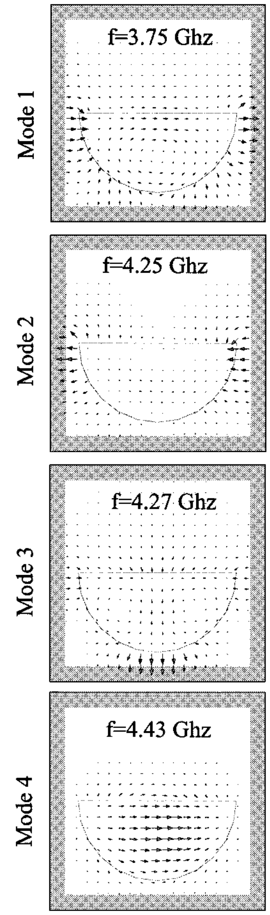

Fig. 7. E-field distribution of first four modes of the half-cut resonator.

to a half-cut resonator with a slightly higher resonant frequency $f_o + \Delta f$.

This resultant half-cut resonator was intended to be used as the basic building block for the quasi-dual-mode resonator, It was found, however, that this resonator could itself be used to build compact-size dielectric resonator filters. Fig. 7 illustrates the field distribution and resonance frequency of the first four modes of the half-cut resonator, as generated by MAFIA software.[1]

It can be seen that the field distribution of the dominant mode resembles half of that shown in Fig. 6(a) for the traditional dual-mode resonator. The mode chart for the half-cut resonator as generated by MAFIA is shown in Fig. 8. In this mode chart, we use the same dielectric resonator mode identification given in [6]. The term "1/2," shown in the mode chart, is used to distinguish the modes of the half-cut resonator from those of the traditional dual-mode dielectric resonators.

The spurious performance of the half-cut resonator can be improved by using a similar concept to that described in [8]. The resonator could be reshaped by removing dielectric materials from certain spots. Fig. 9 illustrates the modified half-cut resonator. The dielectric materials are machined out from the spots in the resonator where the second higher order has a high electric-field concentration, while the dominant mode has small electric-field concentration. A comparison between the spurious performances of the two resonators is given in Table I. The modified half-cut resonator has spurious-free window of more than 1 GHz.

[1]MAFIA software, release 4.0., CST, Darstadt, Germany, 1998. [Online]. Available: http://www.cst.de

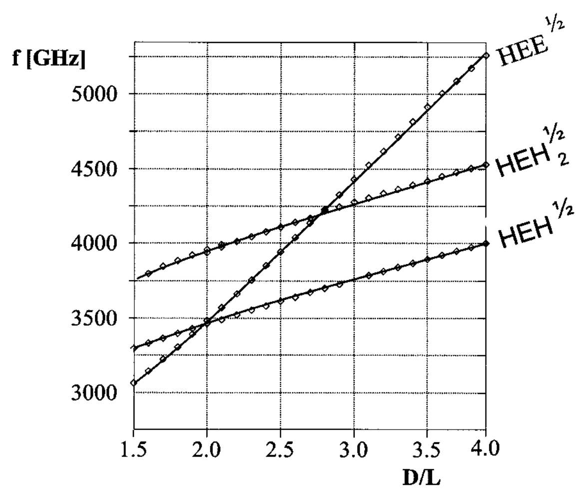

Fig. 8. Resonance frequencies for various modes with respect to D/L of the half-cut resonator.

The software package MAFIA can also be utilized to calculate the coupling value between two identical half-cut resonators. With the proper choice of iris shape and dimensions,

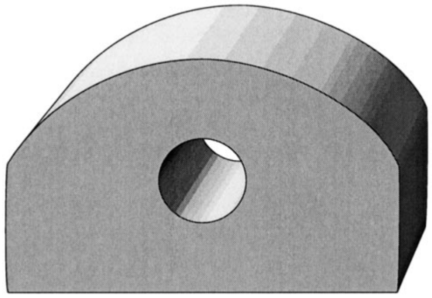

Fig. 9. Modified half-cut resonator with improved spurious performance.

TABLE I
COMPARISON BETWEEN THE SPURIOUS PERFORMANCES OF THE HALF-CUT AND MODIFIED HALF-CUT RESONATOR

Resonator	Mode 1	Mode 2	Mode 3	Mode 4
Half-Cut	3.75 GHz	4.25 GHz	4.27 GHz	4.43 GHz
Modified Half–Cut	4.02 GHz	5.13 GHz	5.20 GHz	5.45 GHz

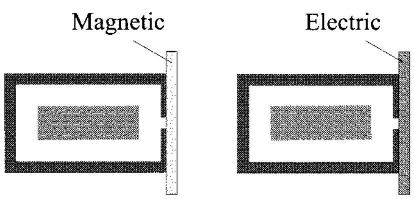

Fig. 10. Half-cut resonator cavity with electric and magnetic walls at the plane of symmetry.

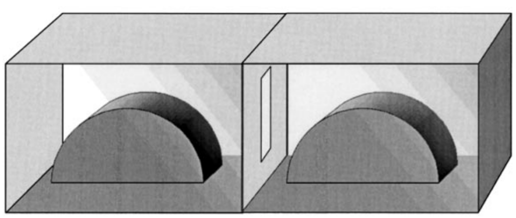

Fig. 11. Schematic presentation of the end-side coupling between two half-cut resonators.

the two resonators can be coupled in two different ways: either through end-side coupling or broadside coupling. The coupling value is determined by calculating the resonant frequencies associated with a single cavity terminated by an electric wall and a magnetic wall at the symmetry plane, as shown in Fig. 10.

Assuming that the two resonators are identical, the coupling value k can be written as

$$k = \frac{f_e^2 - f_m^2}{f_e^2 + f_m^2}$$

where f_e and f_m are, respectively, the resonant frequencies of the two structures shown Fig. 10 with electric- and magnetic-wall symmetry. A vertical iris can be chosen to provide end-side coupling, as shown in Fig. 11. The coupling can be controlled by either varying the slot width or the slot length. The variation of the coupling value k versus slot width is illustrated in Fig. 12.

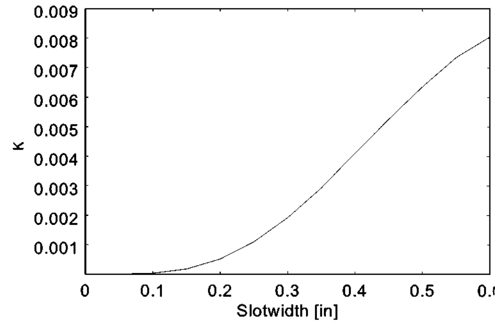

Fig. 12. Coupling value k of two loaded end-side coupled cavities. Cavity size 0.7 in × 0.6 in × 1.0, dielectric half-cut dimensions are: $\text{radius} = 0.427$ in, $d = 0.280$ in, $\varepsilon_r = 38$, $\text{wall thickness} = 0.100$ in, the slot extends the whole cavity height.

TABLE II
COMPARISON OF Q-VALUES OF VARIOUS DIELECTRIC RESONATORS

Resonator	Conventional single-mode TE_{01} DR resonator	Half-cut DR resonator	Half-cut DR resonator
Cavity Size	1”x1”x1”	1“x1“x1“	1“x0.7“x0.6“
Q	10900	9700	7350

The information provided about the field distribution inside the cavity can be also used to calculate the losses in the cavity wall and dielectric materials, as well as the stored energy inside the resonator. The quality factor Q is given by

$$Q = 2\pi f \frac{\sum \Delta W_{\text{stored}}}{\sum \Delta P_{\text{loss,wall}} + \sum \Delta P_{\text{loss,diel}}}$$

where ΔW_{stored} is the stored energy in each element, while $\Delta P_{\text{loss,wall}}$ and $\Delta P_{\text{loss,diel}}$ are the losses in the wall and dielectric, respectively. Table II provides a comparison between the Q factor of traditional single-mode TE_{01} resonators and the half-cut resonators proposed in this paper. Since the half-cut resonator can be fit in a smaller cavity, we also include in Table II, the Q-value results for the half-cut resonator in cavity, which is approximately 40% smaller in volume. It can be seen that, in the large cavity, the half-cut resonator has a Q value, which is comparable to that of the traditional single-mode resonators. However, the half-cut resonator exhibits about 25% reduction in Q when it is placed in the smaller cavity.

Fig. 13 illustrates the RF performance of a four-pole filter built using the modified half-cut resonator shown in Fig. 9. A comparison between a four-pole filter of this type and a four-pole filter built using conventional cylindrical TE_01 single-mode resonator is given in Fig. 14. It can be seen that the half-cut resonator filter yields a 40% reduction in size. The measured loaded Q is 7000.

Two of the half-cut resonators can be combined in different ways, as shown in Fig. 15, to form a quasi-dual-mode resonator. Fig. 16 illustrates the field distribution as generated by MAFIA for a quasi-dual-mode resonator arranged in the configuration given in Fig. 15(c). It can be seen that even though the two half-cut resonators are brought closer to each other, the field distribution inside each half-cut resonator closely resembles that of the ideal half-cut resonator given in Fig. 7.

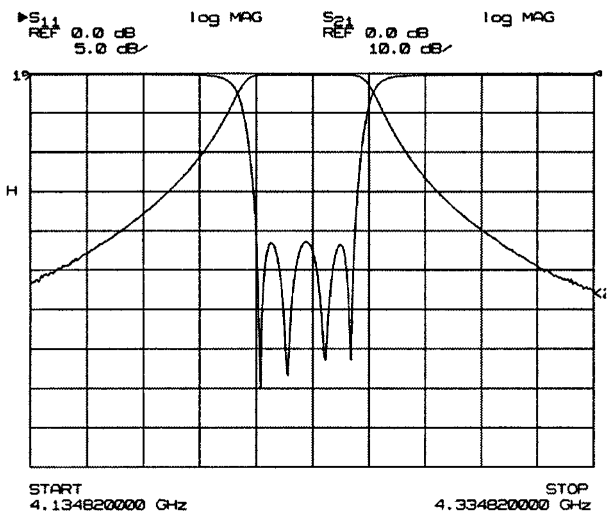

Fig. 13. Measured performance of four-pole filter built using the modified half-cut resonator.

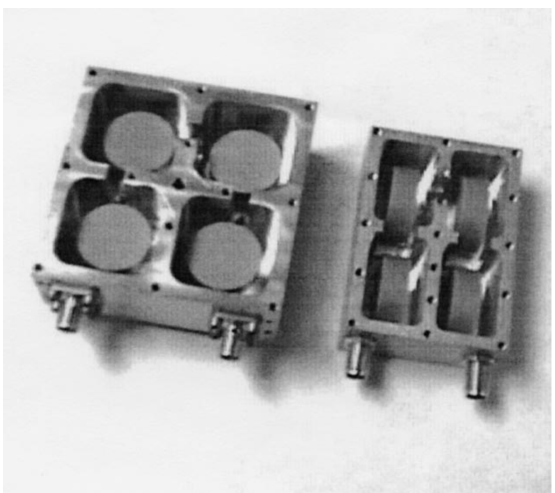

Fig. 14. Comparison between single-mode resonator traditional filters and single-mode half-cut resonator filters.

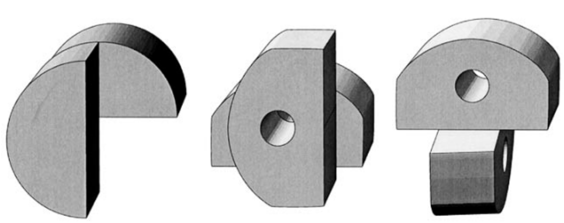

Fig. 15. Quasi-dual-mode configurations.

A four-pole filter was built and tested using the quasi-dual-mode resonator shown in Fig. 15(a). The filter has a similar size to that of a traditional 4-GHz dual-mode dielectric-resonator filter. The RF performance of this filter is given in Fig. 17. With a proper choice of the dimensions and shape of the coupling irises, filters with much more complicated response functions can be built using the quasi-dual-mode DR resonators.

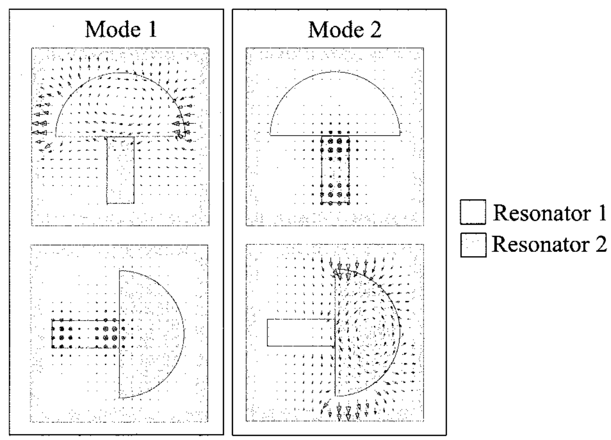

Fig. 16. Field distribution of a quasi-dual-mode DR resonator arranged in the configuration given in Fig. 15(c).

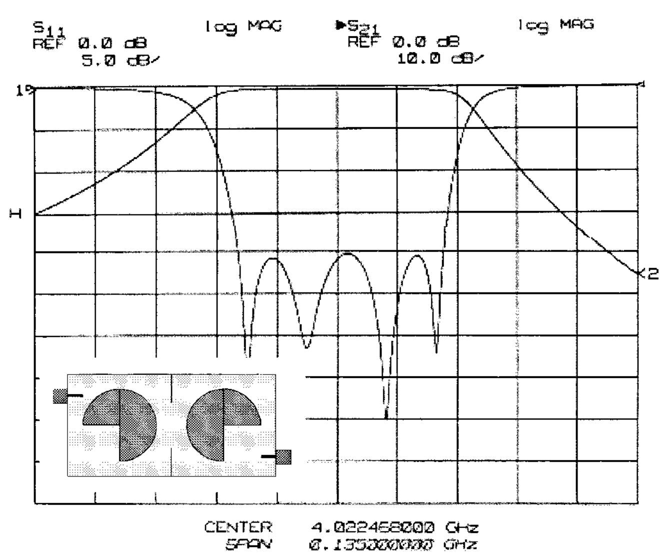

Fig. 17. Response of quasi-dual-mode dielectric filter.

IV. Conclusions

This paper has demonstrated the feasibility of using single-mode resonators to construct quasi-dual-mode resonators that have the majority of the features of traditional dual-mode resonators.

Experimental results are presented for two novel filter structures that use the concept of quasi-dual-mode resonators. A novel single-mode dielectric resonator has been also proposed in this paper. Although the filter has a slightly less Q than that achieved by traditional TE_{01} dielectric resonators, the proposed filter is much smaller in size and has much better spurious performance.

The use of quasi-dual-mode planar resonators has shown clear advantages over the use of traditional planar dual-mode patch resonators in all areas, i.e., size, spurious performance, and Q. However, the conclusion is different for the quasi-dual-mode dielectric resonator. In comparison with traditional dual-mode filters, the quasi-dual-mode filters can only match the size and spurious performance, but not the Q.

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