Desclos, Terret, and Toutain were able to reduce the antenna size by 50% with 25 of transverse slits on the patch and without any slits on the ground plane [1]. In our case, we have achieved a 50% reduction in size with good VSWR by introducing only seven pairs of slits on the patch and three slits on the ground plane. It is expected that a much higher size reduction can be achieved by increasing the number of slits on the patch of proper length and width. The only minor drawback of this antenna is a back lobe.

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NOVEL DUAL-MODE RING RESONATORS WITH VERY LOW SENSITIVITY TO SUBSTRATE THICKNESS

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ABSTRACT: *This paper presents the design of two filters at a center frequency of 1 GHz using a novel type of ring resonator. Their advantage over conventional microstrip ring resonators lies on their lower-frequency sensitivity to substrate thickness due to the addition of interdigital capacitors that concentrate the electric field near the surface.*

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Key words: *ring resonators; closed-loop resonators; microstrip resonators; dual-mode resonators; sensitivity to substrate thickness*

INTRODUCTION

A dual-mode ring resonator consists of a 360° closed-loop transmission line. These resonators are attractive, as they are easily manufactured using planar technology and size miniaturization can be achieved by the excitation of two orthogonal modes [1–4]. Different methods to excite these two modes have been proposed. In [5], filters using ring resonators were presented with different corner perturbations that can add or eliminate transmission zeros in the frequency response. In [6], the two orthogonal modes were excited by the addition of stubs in the feed lines, without having to add perturbations to the resonator. In [7], a ring resonator with corner perturbations was meandered into a cross shape in order to achieve size miniaturization.

As the requirements for communications systems become more demanding, high-performance technologies such as high temperature superconductors (HTS) are playing an increasing role [8]; thus, having low-cost, rapid manufacturing processes where tuning filters are either eliminated or reduced is necessary. One of the main concerns when making planar filters is the lengthy task of tuning their response to the optimum. Hence, there some efforts have been carried out to design filters that will need little or nil tuning. Two main factors affect the frequency response of the resonators, which in turn detune the response of the filter. These are tolerances in the dielectric constant of the substrate, and differences in the substrate's thickness.

Several attempts have been made to achieve resonators with low sensitivity to substrate thickness. Coplanar filters are known to have lower sensitivity, as compared to filters in microstrip technology. However, for systems requiring many components mounted on the same chip, numerous manufacturing difficulties arise due to the need of wire-bonding the ground planes in order to balance the coplanar lines.

In [9], a novel HTS microstrip hairpin resonator with low sensitivity to substrate thickness was presented. The filter was made on MgO with a specified manufacturer's thickness of 500 μm at a center frequency f_o = 610 MHz. It is reported that a change of 10 μm in the substrate height shifts the center frequency by 33 kHz.

In this paper, a novel form of a planar dual-mode ring resonator with lower sensitivity to substrate thickness is presented. This novel resonator includes extra interdigital capacitances between the sides of the resonator that concentrate the electric fields near the surface of the substrate, thus making it less sensitive to substrate thickness tolerances. Using this novel resonator, two filters are designed and tested for demonstration. Simulated and experimental results are presented.

RESONATOR DESIGN

A ring resonator consists of a 360° closed-loop transmission line. By inserting one or several notches [5] in one or more corners of the resonator, two orthogonal modes can be excited. Figure 1 depicts these two modes.

The novel resonator proposed in this paper is shown in Figure 2(a). The addition of the interdigital capacitor to the resonator has the effect of concentrating the electric field on the surface of the substrate, hence making its resonant frequency less sensitive to variations in the substrate's thickness. By adding one or several notches, two orthogonal modes can be generated.

Firstly, a conventional ring resonator was folded into a cross-shape, as shown in Figure 2(b). This resonator was designed on

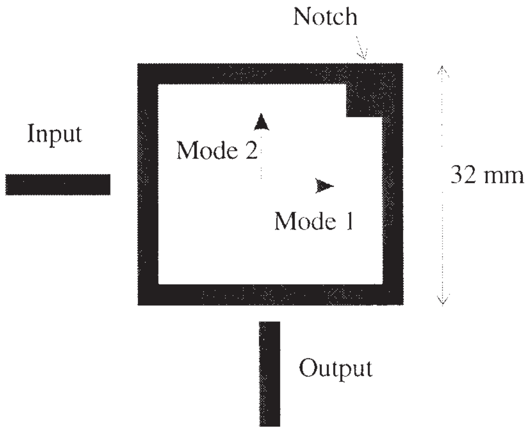

Figure 1 Conventional dual-mode ring-resonator at 1 GHz

Duroid ($\varepsilon_r = 10.2$ and $h = 1.27$ mm) at a center frequency of 1 GHz. Then interdigital capacitors were added with different number of fingers [from 2 to 10, as shown in Figure 2(a)]. All the resonators were tuned to resonate at the same frequency. The width of the fingers in the interdigital capacitors and the gaps between fingers is 0.3 mm. These structures were then simulated in a full wave electromagnetic simulator [10] at different substrate thickness.

Figure 3 shows the ratio of variation in the center frequency per millimeter of substrate variation (Δf) versus the number of fingers in the interdigital capacitor. Δf is given by

$$\Delta f = \frac{\Delta f_o}{\Delta h \times f_o} \times 100, \tag{1}$$

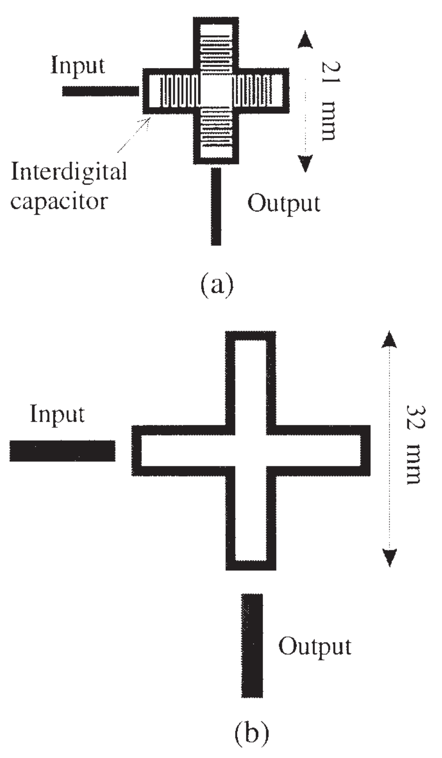

Figure 2 Layout of 1-GHz ring resonators: (a) proposed ring resonator with interdigital capacitors; (b) cross-shaped ring resonator. The resonators are to scale and show the reduction in size with the addition of interdigital capacitors

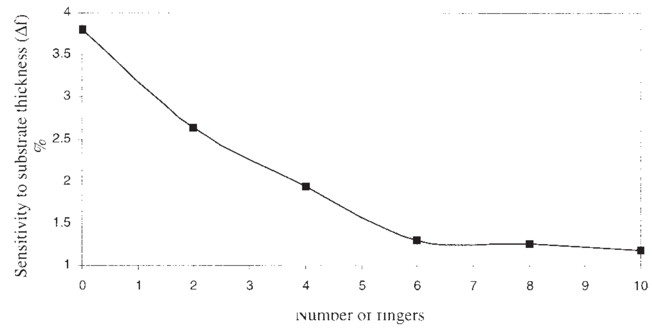

Figure 3 Sensitivity to substrate thickness of the ring resonator with 0.3-mm gaps between interdigital fingers

where Δf_o is the variation of the resonant frequency, Δh is the variation in substrate thickness, and f_o is given by

$$f_o = \frac{f_{o1} + f_{o2}}{2}, \tag{2}$$

where f_{o1} and f_{o2} are the resonant frequencies of the resonator with different substrate thicknesses.

The ring resonator without capacitor has a frequency change Δf of almost 3.9% for each millimeter of substrate-thickness variation, whereas the resonator with 10 fingers shifts its resonant frequency by only about 1.2% for each millimeter of substrate-thickness deviation. As can be seen in Figure 2, the proposed ring-resonator is almost two times smaller than the conventional one.

By reducing the width of the gaps of the interdigital capacitors, it is possible to decrease the frequency sensitivity (Δf) even further, as the electric field would be even more concentrated along the surface.

An experiment was designed to validate the above results. Two of the previous resonators (with 0 and 10 fingers) were manufactured using two different Duroid substrates with substrate thicknesses of $h = 1.27$ mm and $h = 1.9$ mm. These resonators were weakly coupled to the feed line in order to avoid any effect of the external coupling. The results are shown in Figure 4. The resonant frequency of the resonator without fingers on Duroid ($h = 1.27$ mm) is $f = 968$ MHz, and the same resonator on Duroid ($h = 1.9$ mm) is $f = 992$ MHz. Similarly, the resonator with 10 fingers shows a resonant frequency $f = 1082$ MHz on Duroid ($h = 1.27$ mm) and $f = 1094$ MHz on Duroid ($h = 1.9$ mm). By using Eq.

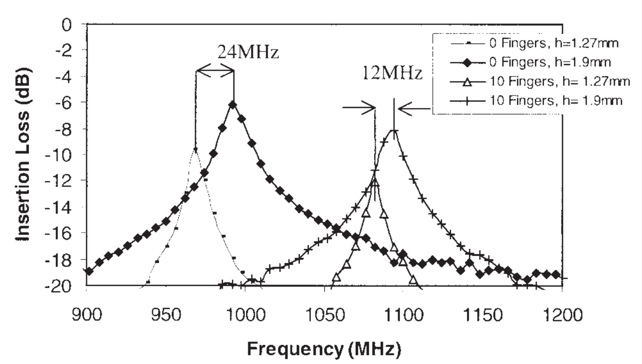

Figure 4 Resonant frequencies of two novel ring resonators (0 fingers and 10 fingers) manufactured on two different substrates: Duroid with thickness of $h = 1.27$ mm and $h = 1.9$ mm (permittivity is 10.2)

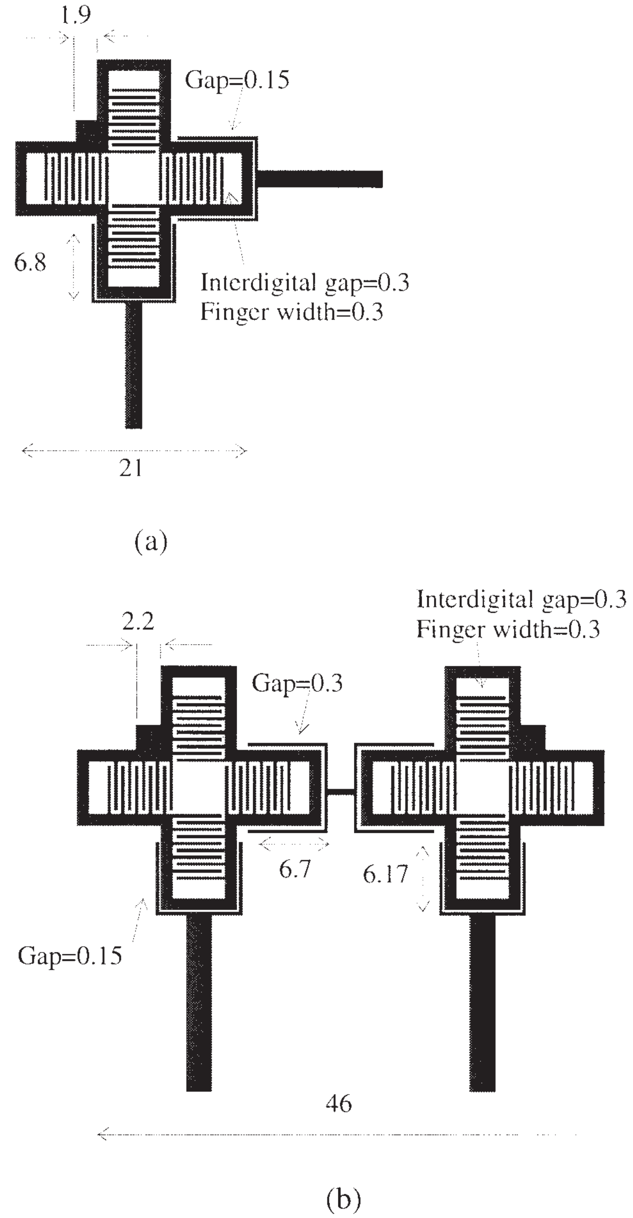

Figure 5 Layout of the (a) two-pole filter on Duroid ($\varepsilon_r = 10.2$ and $h = 1.27$ mm) and (b) four-pole filter on Duroid ($\varepsilon_r = 10.2$ and $h = 1.9$ mm) (all dimensions are in millimeters)

(1), the sensitivity for the 0-fingers case is $\Delta f = 3.85\%$ per millimeter, whereas for the 10-fingers case it is $\Delta f = 1.74\%$ per millimeter, which well in agreement with the simulated results of Figure 3. The small differences are believed to be due to permittivity tolerances in the substrate plus manufacturing tolerances.

FILTER DESIGN

A two-pole filter was designed on Duroid ($\varepsilon_r = 10.2$ and $h = 1.27$ mm) with 1% frequency bandwidth. The element values were taken from [11] for a Chebyshev response with an insertion-loss ripple of 0.01 dB. Then, the coupling coefficients were calculated using the method given in [12]. The external coupling factor is $Q_e = 44.8$ and the coupling factor between the two orthogonal modes is $k_{1-2} = 0.023$. To relate these coupling coefficients to the coupling gaps and the size of the notch, the procedure given in [12] was followed.

A second four-pole filter was designed on Duroid ($\varepsilon_r = 10.2$ and $h = 1.9$ mm) with 2.2% frequency bandwidth. The coupling coefficient values are $Q_e = 32$, $k_{1-2} = 0.023$, and $k_{2-3} = 0.018$. Where Q_e refers to the external coupling, k_{1-2} is the coupling between the two orthogonal modes and k_{2-3} is the coupling between adjacent resonators.

Both filters were simulated and optimized using a full-wave simulator [10]. The final dimensions of the circuits are outlined in Figure 5.

SIMULATION AND MEASUREMENTS

The simulated and measured responses of the two-pole filter are shown in Figure 6. Losses were considered in the simulation. The insertion loss of the measured response is about −3.8 dB, whereas the return loss peaks at −30 dB at the center of the band. The measured center frequency is 1068 GHz. The response shows two attenuation zeros at 1013 and 1036 GHz for the measured filter and 985 and 1115 GHz for the simulated response. These attenuation zeros are present due to the shape of the notch, as explained in [5].

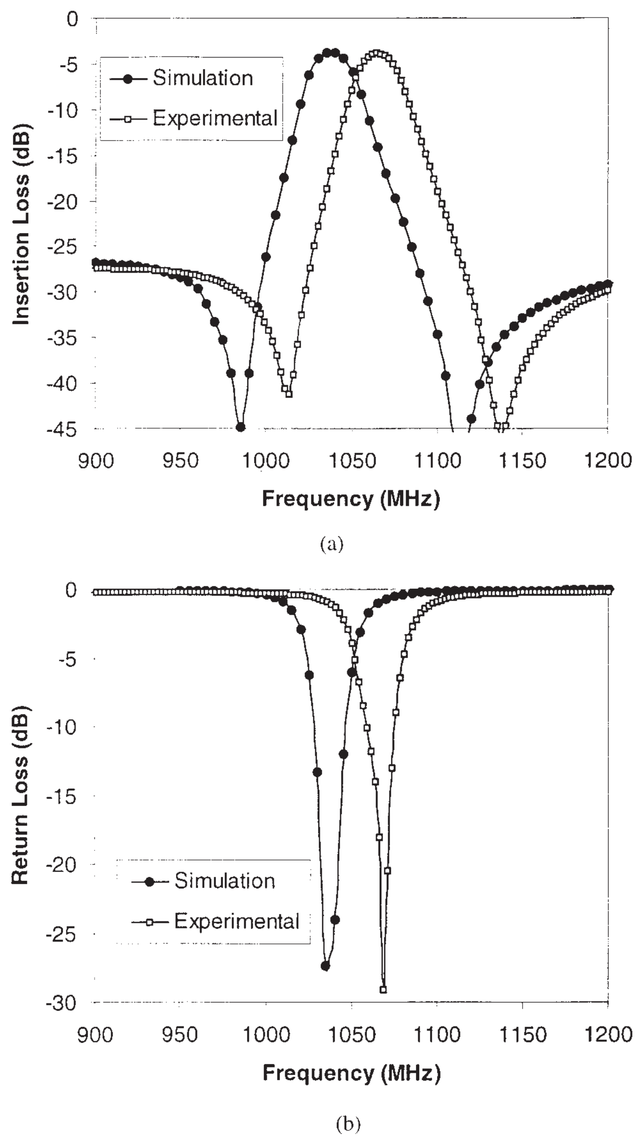

Figure 6 Simulated and experimental results of the two-pole filter: (a) insertion loss; (b) return loss

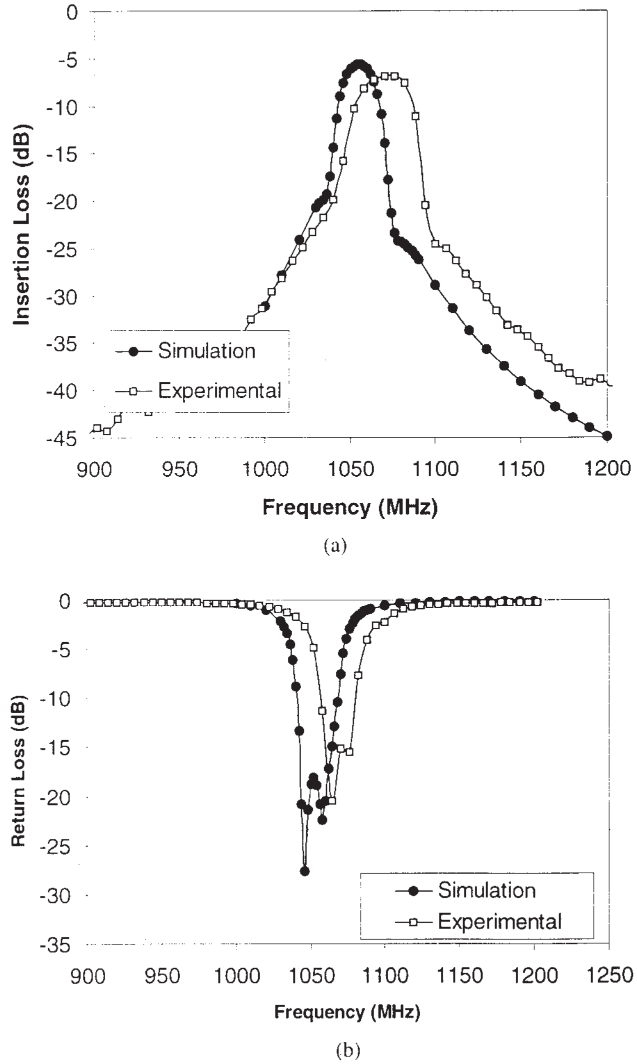

Figure 7 Simulated and experimental results of the four-pole filter: (a) insertion loss; (b) return loss

As can be seen, there is good agreement between the simulated and experimental results.

Figure 7 shows the experimental and the simulated responses for the four-pole filter. From the figure, it can be seen that also very good agreement was achieved between simulated and measured results. The measured insertion loss is -6 dB, and the return loss is better than -16 dB throughout the band. The center frequency was measured to be 1.07 GHz.

CONCLUSION

A miniature novel dual-mode resonator with low sensitivity to substrate thickness has been demonstrated. This resonator adds interdigital capacitors to the conventional ring resonator, thus achieving lower sensitivity to substrate thickness and reduction of size. Two filters, a two-pole filter and a four-pole filter, with respective 1% and 2.2% frequency bandwidths were successfully built and tested using this resonator. Good agreement between the simulated results and the experimental results was obtained.

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FINITE-DIFFERENCE TIME-DOMAIN MODELING OF A CORRUGATED HORN ANTENNA AS A RADAR SYSTEM FEED

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ABSTRACT: *The design of a reflector-antenna feed for monopulse tracking-radar application is presented. The feed consists of a rectangular-circular mode coupler to isolate the sum and difference channels required for monopulse tracking, and a corrugated horn for a symmetric radiation pattern with low cross polarization. The modeling is carried out using the finite-difference time-domain (FDTD) method, which is well suited for field visualization. The measurements show that the feed performance meets the design requirements and is in close agreement with the FDTD prediction.* © 2005 Wiley Periodicals, Inc. Microwave Opt Technol Lett 47: 384–387, 2005; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.21176

Key words: *finite-difference time-domain method; body of revolution; corrugated horn; reflector antenna feed; monopulse tracking radar*

INTRODUCTION

Although there exist many different types of tracking-radar systems, all of them are based on sensing the pointing-angle error, which is defined as the angle between the boresight and target