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FDTD STUDY OF RESONANCE PROCESSES IN MICROSTRIP RING RESONATORS WITH DIFFERENT EXCITATION GEOMETRIES

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ABSTRACT

The Finite Difference Time Domain (FDTD) method is employed in this paper to study resonance processes in microstrip ring resonators in both time and frequency domains. It is shown that the geometry of the excitation strongly affects wave propagation and standing wave formation in the structures; in particular, it causes resonance mode splitting in side-coupled ring resonators.

INTRODUCTION

Microstrip ring resonators are widely used in microwave applications [1], and the interest in these structures has recently increased because of availability of new materials, such as high temperature superconductors and ferroelectric thin films. In order to provide selective mode damping without an increase in the topological area, or to achieve frequency tunability, it is necessary to change the resonance properties of the ring resonators by modifying their design; hence, the understanding of resonance processes in ring resonators is very important. In the past, these resonators have been analyzed either by using the transmission line theory [2], or the magnetic-wall model [3]. These approaches are rather limited in scope and cannot adequately describe the influence of the excitation geometry on the resonance process.

In a previous work, we have applied the Finite Difference Time Domain (FDTD) algorithm to simulate the wave propagation and standing wave patterns in two basic types of ring resonators, *viz.*, the edge- and side-coupled varieties with microstrip feeds, and have shown [4] that the resonance phenomena in these two structures are significantly different from each other. The simulations were performed for ring resonators with thick rutile substrates (1.5 mm, K=98), and it was found that the excitation of surface waves strongly interfered with the signal propagation. In this work we present the results of simulations of ring resonators with thin alumina substrates (0.625 mm, K=9), whose dimensions are similar to the ones we investigated previously [4], *i.e.*, the outside diameter is 10 mm, the width of the ring and feed lines is 0.25 mm, and the coupling gaps are equal to 0.125 mm.

RESULTS AND DISCUSSION

Fig. 1 depicts the geometries of edge- and side-coupled ring resonators, as well as the Gaussian-shaped current pulse modulated by a sinusoidal wave used to excite the resonators.

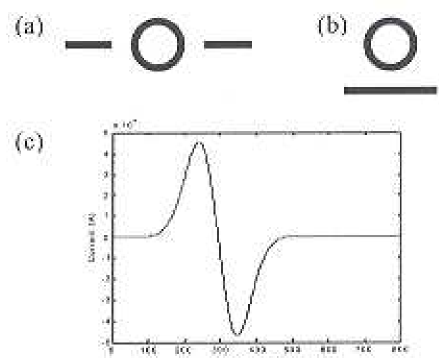

Fig. 1. Geometries of (a) edge- and (b) side-coupled ring resonators; (c) current pulse in the microstrip line with alumina substrate: time step equals to 0.24 ps.

We will begin by presenting the time-domain simulations and the frequency-domain results will follow thereafter.

A. Time-Domain Results

Figs. 2 and 3 plot the spatial distribution of the electric field component normal to the substrate surface in the edge- and side-coupled ring resonators with an alumina substate. The distribution is sampled in the plane located at a distance 0.25 mm below the metal ring inside the dielectric.

The magnetic-wall cavity model [3] predicts that the microstrip ring resonator would support two degenerate resonant modes that can be interpreted as two circulating waves, traveling clockwise and counterclockwise along the ring [1]. However, our simulations show that there exist two identical wave packets for the edge-coupled ring resonator, moving backward and forward between the two coupling gaps along the two halves of the ring, instead of two circulating wave packets predicted by the simplistic cavity model. When the wave packets arrive at the gaps, their movement is slowed down and here is a decrease in the magnitude of the superimposed wave. This phenomenon can only be interpreted correctly as being associated with the accumulation of the wave energy in the gap capacitance – one that could not possibly occur if the wave movement was of circulating type.

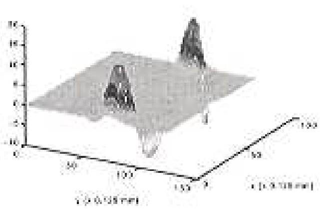

Fig. 2. Distribution of normal electric field component in the edge-coupled ring resonator at 1200 time steps. Time step is equal to 0.24 ps.

The presence of the gap discontinuities in the edge-coupled ring resonator make them behave as though the original ring resonator was replaced by two linear resonators connected in parallel. The standing waves in the ring resonator are formed as a result of superposition of the incident (forward) and reflected (backward) modes. It is worth mentioning that this contradicts the conventional point of view, which holds that it is preferable to use ring resonators over the linear ones because the former do not suffer from the reflections caused by the open ends [1].

For the side-coupled ring resonator, the movement of the wave packet was found to be different in nature. Our simulations show that the excitation pulse, which moves along the feed line, excites two wave packets circulating in opposite directions along the ring. The two packets have different shapes, and they continue to move forward without suffering any alterations, even as they encounter each other. In side-coupled resonators with rutile substrates, the packet with a clockwise movement had a much lower level than the other that propagated in the counterclockwise direction; for this reason it was omitted in previous paper [4]. The work by Taflove [5], which simulated side-coupled microcavity ring resonators designed for optical carrier pulse excitation, did not mention a clockwise-moving packet either.

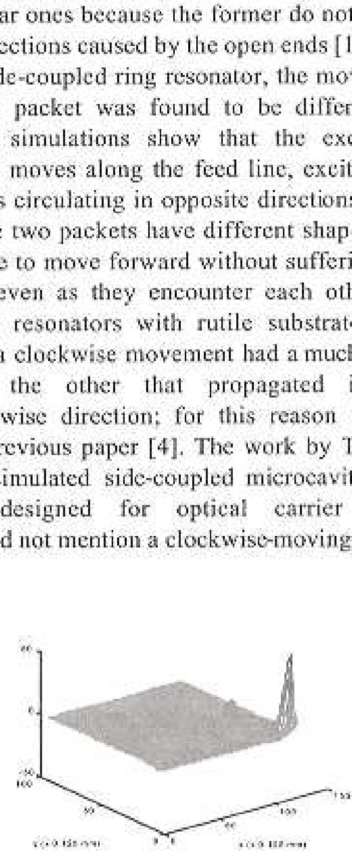

Fig. 3. Distribution of normal electric field component in the side-coupled ring resonator at 800 time steps. Time step is equal to 0.24 ps.

However, on the basis of our present simulations, we conclude that the two wave packets circulate along the side-coupled ring in opposite directions and, in contrast to the edge-coupled ring, they are not identical.

We conjecture that the asymmetry of the two packets in the side-coupled resonators is attributable to the enlarged region of coupling between the feed line and the ring. The excitation pulse is moving along this zone in one direction, and this direction should also be the preferable one for the pulses induced on the ring, *i.e.*, for packets moving counterclockwise.

On the basis of results presented above, we conclude that the standing waves in the side-coupled ring resonator appear as a result of the superposition of the resonant modes traveling clockwise and counterclockwise on the ring.

B. Frequency-Domain Results

In this section we move to the discussion of the frequency domain simulation results for standing wave patterns in ring resonators. Since the primary coupling mechanism in an edge-coupled ring resonator is via the electric field, we expect the maxima of its standing waves to be located just opposite the coupling gaps, regardless of the resonant frequency. Such locations of electric field maxima have also been predicted by Chang [1].

Figs. 4 depict the field distributions and the contour plots for the edge-coupled ring resonator at the first (a, b) and the second (c, d) resonant frequencies. The presented data together with the results for higher-order resonances show that the maxima of electric field standing waves are indeed located opposite the coupling gaps for all resonance frequencies, and that the standing wave patterns are symmetrical with respect to the axis of feed line.

The standing wave patterns observed in the side-coupled ring resonator are different from those in the edge-coupled one. Since the primary coupling mechanism in a side-coupled ring resonator is via the magnetic field, we expect the maxima of the currents, which coincide with the zeros of the electric field, to be located opposite to the coupling zone on the ring.

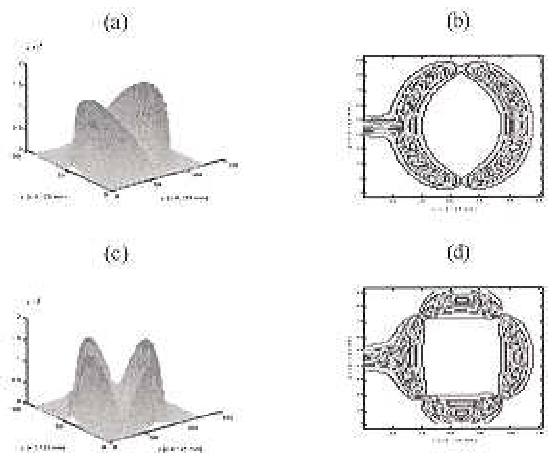

Fig. 4. (a, c) Distribution and (b, d) contour plots of normal electric field component in the edge-coupled ring resonator at resonant frequencies: (a, b) 3.9 GHz, (c, d) 7.6 GHz.

Figs. 5a and 5b show the contour plots of the fields for the first resonance mode in the side-coupled ring resonator. The two resonance patterns were observed for this mode at slightly different frequencies, which points to a splitting of the first resonance mode. The magnitudes of the field maxima were found to be the same for both standing waves.

The standing wave pattern for the higher frequency mode (see Fig. 5b) corresponds to what is expected for the magnetic field coupling, whereas the pattern for the lower frequency mode, shown in Fig. 5a, is rotated with respect to the previous one. The splitting of the first resonant mode has also been observed by Lu and Ferendeci [6], who have experimentally measured the S-parameter spectra of side-coupled ring resonators with alumina substrate.

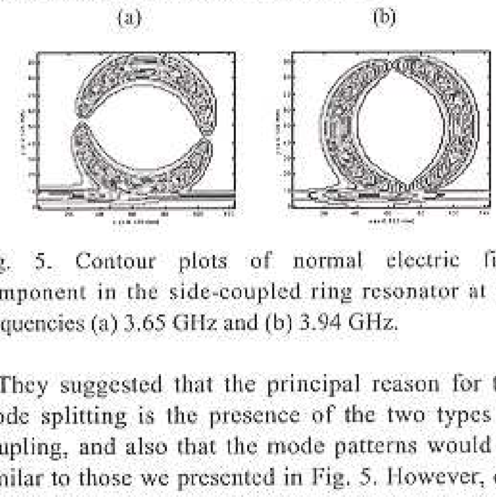

Fig. 5. Contour plots of normal electric field component in the side-coupled ring resonator at the frequencies (a) 3.65 GHz and (b) 3.94 GHz.

They suggested that the principal reason for the mode splitting is the presence of the two types of coupling, and also that the mode patterns would be similar to those we presented in Fig. 5. However, our simulation results for the second resonance in side-coupled ring resonator show that the splitting mechanism is more complex than they have conjectured.

For the second resonance mode we observe five patterns, which are rotated with respect to each other, and correspond to five frequencies with a slight shift one from the other (Figs. 6 a through 6e). The magnitude of the field maxima increases from the first to the third pattern, and then decreases from there onwards as we move to the fifth one. In addition, a clockwise rotation of the resonance pattern by 90 degrees was observed from the second to the forth resonances (see Figs. 6b through 6d). The positions

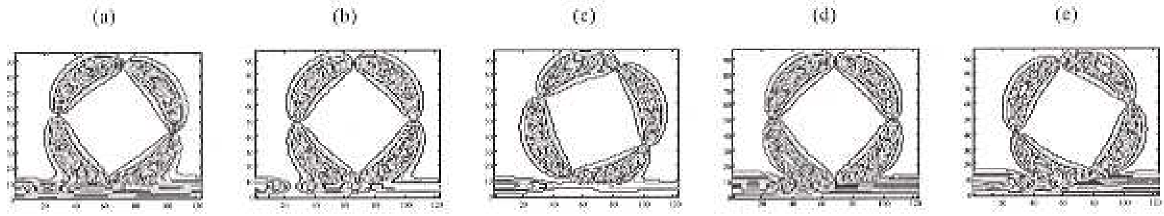

Fig. 6. Contour plots of the electric field component normal to the substrate surface in the plane located 0.25 mm below the ring in the side-coupled ring resonator at different frequencies: (a) 7.44 GHz, (b) 7.50 GHz, (c) 7.54 GHz, (d) 7.64 GHz, (e) 7.70 GHz.

of the zeros of the standing waves for the second and the fourth modes correspond to magnetic field coupling, while the other modes cannot be related exactly to either of the two coupling mechanisms. These data lead us to conclude that the type of coupling is not the only factor that defines the splitting of the resonance modes in the side-coupled ring resonator. It is worthwhile to note at this point that our simulations of the side-coupled ring resonators with thick rutile substrates have also revealed a splitting of the resonance modes, though the shift in the frequencies and the rotation of the modes were found to be significantly less than in the resonators with thin alumina substrates.

We propose that the splitting of the resonance modes in the side-coupled ring resonator is a consequence of the distortion suffered by the wave packets propagating through the extended coupling zone. It was previously shown [1] that, in the edge-coupled ring resonators, the splitting of resonance modes occurred when notches, patches or stepped impedance sections were inserted into the ring. In view of the observed circulatory movement of the wave packets in the side-coupled ring resonators, we suggest that the presence of the extended coupling zone can change the local impedance of the ring in the vicinity of the feed line and cause the resonance mode to split. It may be interesting to note that this effect may be useful for designing broadband antennas based on side-coupled rings. However, for designing microwave filters, where achieving a high Q-factor is of great importance, the edge-coupled ring resonators would be preferable.

CONCLUSION

We have used the FDTD algorithm to simulate wave propagation and standing wave patterns in alumina-based microstrip ring resonators with different excitation geometries. The wave processes, which determine the resonance formation in edge- and side-coupled resonators, were found to be significantly different. The standing wave patterns in edge-coupled resonators were observed at well-defined and isolated frequencies and were symmetrical with respect to the axis of the feed line; in contrast, the resonance mode splitting occurred in the side-coupled resonators. This makes the former a preferred candidate for filter design, while the latter more desirable for broadband antenna design. Finally, it was found that the character of resonance mode splitting in side-coupled ring resonators depended on the thickness and the permittivity of the substrate.

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