The Coplanar Waveguide-Fed Electronically Tunable Slotline Ring Resonator

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Abstract

A coplanar waveguide(CPW)-fed slotline ring resonator has been developed and integrated with varactor diodes to create an electronically tunable planar resonator. The resonator can be electronically tuned over a 23% bandwidth from 3.03 to 3.83 GHz with a 4.5 ± 1.5 dB variation in insertion loss. The resonator is truly planar offering ground planes and center conductor on one side of the substrate which allows easy series or shunt insertion of devices. Monolithic implementation can be accomplished without via holes to ground devices which should reduce processing complexity and increase yields.

I. Introduction

In recent years, coplanar waveguide(CPW) has emerged as an alternative to microstrip in microwave and millimeter-wave integrated circuits(MIC). The fact that the center conductor and ground planes are on the same side of the substrate allows series and shunt connections of passive and active solid-state devices. Use of CPW also avoids the need for via holes to connect the center conductor to ground which should help to reduce processing complexity and increase yield in monolithic implementations.

Also of interest, is the search for new uniplanar MIC resonators. Microstrip ring resonators can be used for filters and allow easy series insertion of solid-state devices for tuning[1], switching[2], and RF power generation[3]. These rings have not been realized in truly planar transmission lines such as slotline or CPW to take advantage of easy shunt device hybrid integration[4]. These truly planar designs should also reduce processing complexity in monolithic applications.

In this paper, we report on a CPW-fed slotline ring resonator with over 23% varactor tuning range and 4.5 ± 1.5 dB of insertion loss. A wider tuning range can be obtained for a greater insertion loss variation. The tuning range is wider and the circuit has greater flexibility over the microstrip ring in [1]. For instance, the microstrip requires high impedance lines to apply DC biasing and the position of the varactor is fixed at a series gap. Shunt varactor placement on a microstrip ring requires drilling through the substrate. The slotline ring circuit, on the other hand, has inherent DC biasing pads and shunt placement of the varactor can be optimized on the ring. The configuration also lends itself to other device integration for filtering, switching, tuning and RF power generation.

II. Circuit Design and Model

The CPW-fed slotline ring and equivalent circuit are shown in Figure 1. A distributed model similar to that developed for a microstrip ring was used for modeling the slotline ring[5]. The 50 Ohm CPW is in shunt with the 85 Ohm slotline ring coupled via a series gap. The gap can be represented by a capacitor which controls the coupling efficiency into the slotline ring and is inversely proportional to the gap spacing. The effect of the size of the coupling gap is shown in Figure 2 for gaps(g) of 0.48 and 0.05 mm. It can be seen that the 0.05 mm gap reduces the loss by increasing the coupling into and out of the resonator. The ring with a mean radius of 11.26 mm, uses a 0.48 mm slotline on 0.63 mm RT-Duroid 6010 with a relative dielectric constant of 10.5. The ring will resonate when the ring circumference is a multiple of the guided wavelength:

$$2\pi R = n\lambda_g \qquad n = 1,2,3...$$

where R is the mean slotline radius, n is the mode number and λ_g is the slotline guided wavelength.

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Figures 3a and 3b show the theoretical and experimental results for a 0.05 mm gap. The theoretical results were obtained based on the equivalent circuit shown in Figure 1. The slotline ring is formed by cascading many small sections of slotlines together. The value used for the series coupling capacitance used in the circuit model is approximately 0.15 pF. The theoretical results agree fairly well even though the slotline dispersion model was only approximated over the frequency range.

Since the ring resonance sets up either an even or odd multiple-wavelength standing wave along the resonator, one can selectively choose to match, tune, or switch-off even or odd modes. By mounting varactors at 6 and 12 o'clock of the ring, we can electronically tune the even modes of the slotline ring resonator. The varactors have a C_{jo} of 1.6 pF and the overall capacitance behaves as:

$$C(V) = \frac{C_{J0}}{\left(1 + \frac{V}{\phi}\right)^{\gamma}}$$

where ϕ is the built-in potential of 1.3 volts for GaAs, γ is the capacitance-voltage slope exponent of 0.5 for abrupt-junctions and V is the applied reverse-bias varactor voltage.

III. Electronic Tuning Results

The varactors tune the even modes of the resonator and allow a second mode electronic tuning bandwidth of 930 MHz from 3.13 to 4.07 GHz for varactor voltages of 1.35 to 29.9 volts. Figures 4a shows the experimental results. The first peak is for the first mode which is stationary during the electronic tuning. Figure 4b shows a comparison between the theoretical and the actual tuning range with reasonable agreement. The increase in loss as the frequency is lowered is due, in part , to a reduction in input/output coupling. The loss increases linearly from 6 dB at 4.07 GHz to 11 dB at 3.13 GHz.

In order to reduce the insertion loss, a 3 x 3 x 0.3 mm capacitive overlay[6] over the input and output of the slotline ring was used to increase the coupling and reduce the discontinuity radiation. This overlay reduced the loss and slightly lowered the frequencies of operation. The tuning bandwidth becomes 3.03 to 3.83 GHz. The 800 MHz tuning range centered at 3.4 GHz is shown in Figure 5. As shown, the overlay helps to improve the insertion loss of the tunable resonator. The 23% tuning range from 3.03 to 3.83 GHz has an insertion loss of 4.5 dB $\pm$ 1.5 dB for varactor voltages of 1.50 to 29.9 volts. As shown in Figure 5, the varactors have no effect on the first mode of the slotline ring resonator while capacitively tuning the second mode. The 3 dB points on the pass band varies from 5.17% at 3.03 GHz to 4.85% at 3.83 GHz. The insertion loss $\pm$10% away from resonance is about 15 dB. The increase in insertion roll-off for the lower frequency end of the tuning range is due to the fact that the odd modes remain stationary. As the varactor bias level is lowered, the second mode continues to approach the stationary first mode.

IV. Conclusions

A planar slotline ring resonator has been developed and shown to provide a useful electronic tuning range. The configuration can be easily designed to match, switch, or tune modes electronically. The circuit is uniplanar and allows series and shunt connections of solid-state devices. It can be fabricated using monolithic techniques without the need for via holes which should reduce processing complexity and improve yields. The circuits should have many applications in filtering, switching, stabilizing and signal processing.

V. Acknowledgement

This work was supported in part by the Army Research Office and the Texas Higher Education Coordinating Board's Advanced Technology Program. We would also like to thank the Rogers Corporation for providing the substrate materials for this investigation.

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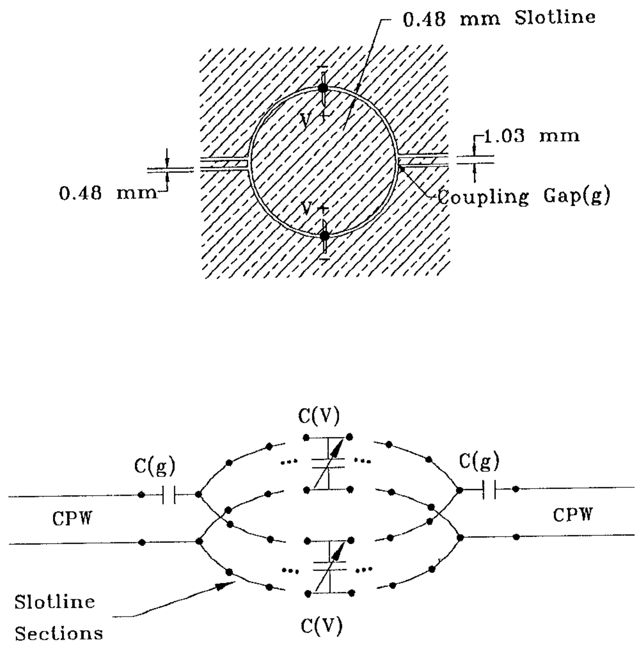


Figure 1. The CPW-fed Tunable Slotline Ring Configuration and Equivalent Circuit.

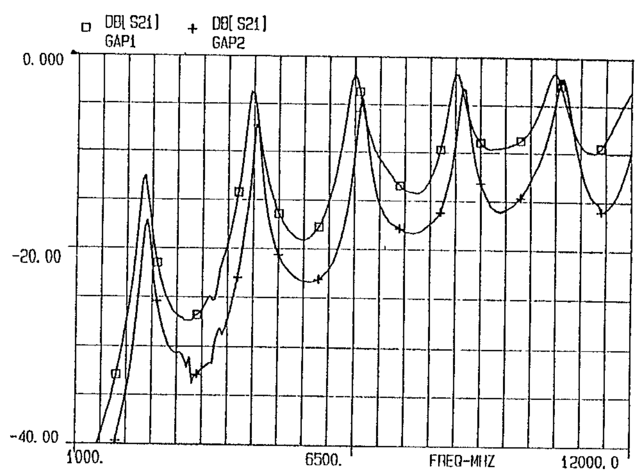


Figure 2. Effects on Insertion Loss due to different Coupling Gaps: Square-0.05 mm, Crosses-0.48 mm.

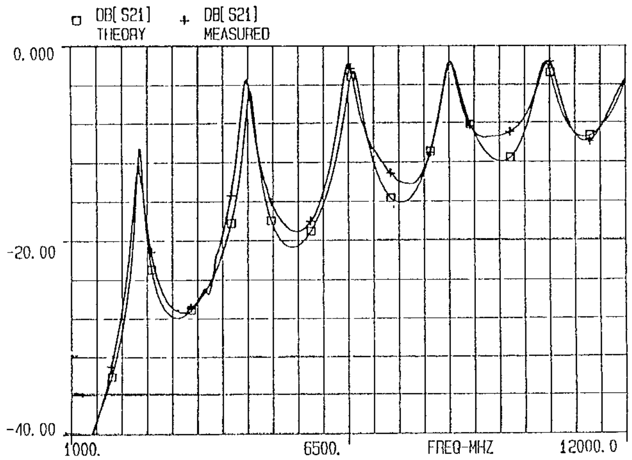


Figure 3a. Comparison of Theoretical and Experimental Insertion Loss Results vs. Frequency.

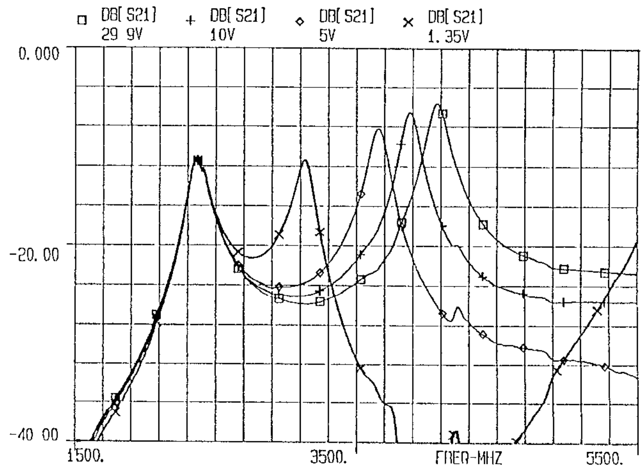


Figure 4a. Measured Electronic Tuning vs. Frequency for different Varactor Bias Voltages.

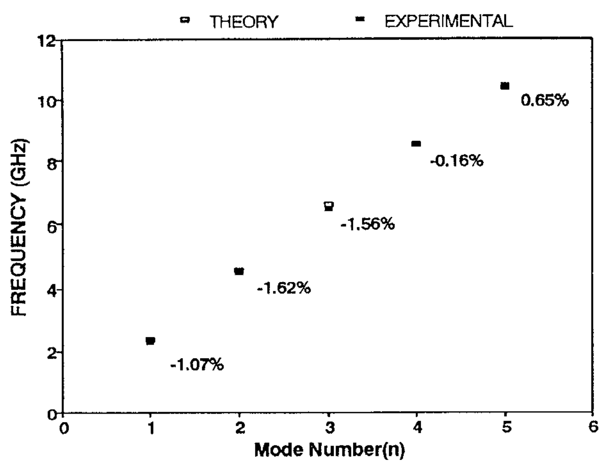


Figure 3b. Comparison of Theoretical and Experimental Resonant Frequencies for each mode.

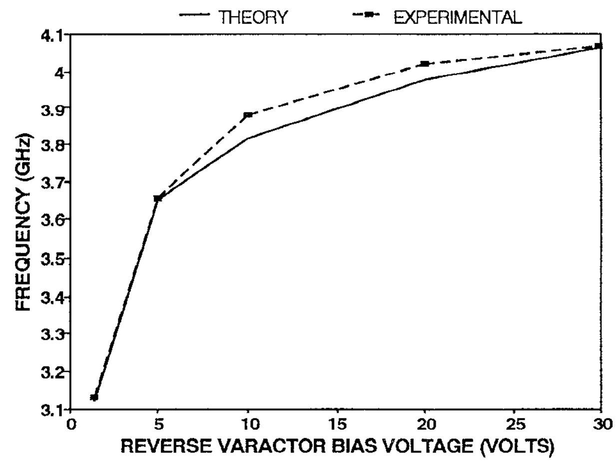
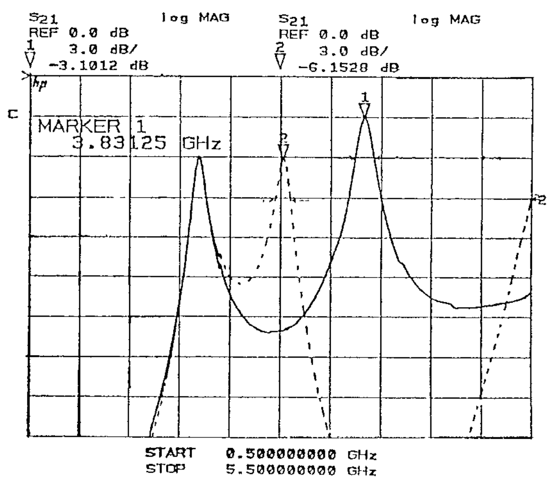


Figure 4b. Comparison of Theoretical and Experimental Second Mode Tuning vs. Varactor Bias Voltage.



Solid Line - 29.9 V
Dashed Line - 1.5 V
Marker 1 - 3.83 GHz
Marker 2 - 3.03 GHz

Figure 5. Experimental Electronic Tuning Range for the Varactor-tuned Slotline Ring with Capacitive Overlays.