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ELECTRONICALLY TUNABLE AND SWITCHABLE FILTERS USING MICROSTRIP RING RESONATOR CIRCUITS

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ABSTRACT

A novel microstrip ring resonator loaded with two PIN diodes has been developed as a switchable filter. By replacing one PIN diode with a varactor diode, the switchable filter can be made electronically tunable. Over 20 dB isolation with 9 percent tuning bandwidth was demonstrated. The experimental results agree very well with the theoretical calculation.

INTRODUCTION

Microstrip ring resonators have been widely used for the measurements of dispersion, phase velocity and dielectric constant [1-4]. The ring resonator alone naturally acts as a bandpass filter. The frequencies that pass through the circuit are only those whose guided wavelength is an integral multiple of the mean circumference. If gaps are cut at 90 degrees radially from the feed point as shown in Figure 1, the odd numbered modes disappear and the new half-modes appear in order to satisfy the boundary conditions. Varactor-tuned ring resonators were recently demonstrated with up to 15 percent tuning range by mounting varactor diodes in the gaps [5].

This paper reports two novel ring circuits: an electronically switchable filter and a tunable switchable filter using PIN diodes. The PIN diode acts as an open circuit when reverse biased and a short circuit when forward biased. If the diodes are mounted across the gaps in a ring resonator shown in Figure 1, the odd modes can be switched on and off by varying the bias on the diode. When the diodes are forward biased it is as if there are no gaps in the ring and all integer numbered modes are passed. When the diodes are reverse biased, the boundary conditions will not allow the odd numbered modes to propagate and they will have a high attenuation. High isolation is thus achieved due to built-in mode rejection. A switchable ring filter was built with less than 2 dB insertion loss and over 20 db isolation.

If a varactor diode is used to replace one of the two PIN diodes, the switchable filter can be made tunable. This circuit would not only have an electronically tunable resonant frequency but also a resonant frequency that can be switched on and off. A tuning bandwidth of over 9 percent was demonstrated.

Equivalent circuits have been developed for both circuits. The analysis was based on the transmission line model including the effects of diode parasitics, coupling gaps, dispersion, and mounting gap capacitance. The experimental results agree very well with the theoretical calculation.

ELECTRONICALLY SWITCHABLE RING FILTER CIRCUIT

If two PIN diodes are used for the circuit shown in Figure 1, the resonant frequencies of the odd numbered modes can be switched on and off electronically. The odd modes exist when the diodes are forward biased and disappear when the diodes are reverse biased.

The equivalent circuit of the diode loaded ring can be represented by Figure 2. The transmission line is represented by a T-network and the coupling gaps are modelled by a gap series capacitance (C_2) together with two fringe capacitances (C_1). The impedance Z_{top} and Z_{bot} represent the impedance of the PIN diodes. The equivalent circuit used to calculate Z_{top} and Z_{bot} is given in Figure 3. R_f is the series resistance of the forward biased diode. When reverse biased C_j represents the junction capacitance and R_r is the series resistance. L_p is the lead inductance and C_p is packaged capacitance. L_s accounts for the inductance introduced by the bonding wire and C_2 is the capactance of the mounting gap.

The input impedance looking into the ring at the coupling gap can be calculated by solving the six loop equations. From the input impedance S_{12} can be calculated by

$$S_{12} = \frac{2\sqrt{Z_{in} Z_o}}{Z_{in} + Z_o}$$

where Z_o is the characteristic impedance.

If the forward bias condition is considered and an odd numbered mode is observed, S_{12} will reach a maximum at the resonant frequency. If the reverse bias condition is considered then the odd numbered modes will have a much higher attenuation and there will be no resonance. The isolation is given by the difference in S_{12} at the resonant frequency for the forward bias condition and S_{12} at the same frequency for the reverse bias condition.

A circuit was designed and fabricated based upon the analysis. Figure 4 shows a photo of the actual circuit. It was built on a RT/Duroid 5880 substrate with the following dimensions:

Substrate thickness= 0.762 mm
Line width= 2.310 mm
Coupling gap= 0.250 mm
Device mounting gap= 0.250 mm
Ring radius= 3.484 cm

The PIN diodes used were from MA/COM (Model 47047) with L_p=2.0 nH, C_p=0.1 pF, C_j=0.3 pF at -50 volts, R_f=1.3 ohms at 100 mA. R_r is estimated to be 2 ohms and L_s is about 0.2 nH.

Using the above parameters, the analysis shows the resonant frequency for the third resonant mode is about 2.74 GHz when the diode is forward biased. The measured results shown in Figure 5 indicate a resonant frequency of 2.69 GHz. The resonant frequency was accurately predicted to within a respectable 2 percent. Using simply the approximation $2\pi r = n\lambda_g$, the resonant frequency is calculated to be 3 GHz which is off by 10 percent. The isolation is over 40 db. The high insertion loss is mainly due to the big coupling gap.

To reduce the insertion loss, a much smaller coupling gap is required. Since fabrication tolerance limits the gap size to a minimum of about 25 μm, an insulated copper tape was used to bridge the gap. The coupling capacitance is formed by the insulation material between the tape and the microstrip line. This capacitance is equivalent to a coupling gap size of less than 3μm. The circuit with insulated copper tape across the gap was tested and the results are shown in Figure 6. The loss has been reduced to less than 2dB in the "on" state with over 20 dB isolation in the "off" state. The resonant frequency was shifted from 2.74 GHz to 2.6 GHz as a result of the increased coupling capacitance [5].

ELECTRONICALLY TUNABLE AND SWITCHABLE RING FILTER CIRCUIT

By replacing one of the two PIN diodes with a varactor diode, the switchable ring filter can be made electronically tunable. The circuit would not only have an electronically tunable resonant frequency but also a resonant frequency that can be switched on and off. Using the same equivalent circuit shown in Figure 2 and replacing Z_{bot} by the varactor circuit, the analysis can be used to predict the tuning range. Only the half-modes can be effectively tuned [5]. The theoretical and experimental results for the tuning range are given in Figure 7 for comparison. The error is approximately 3 percent. The varactor (MA/COM model 46600) used has C_p=0.05 pF, L_s=1 nH, R_s=1 ohm and C_j(V) varied form 0.5 to 3.0 pF.

CONCLUSIONS

Two novel microstrip ring circuits have been developed. One uses two PIN diodes mounted inside the ring and works as a switchable filter. Another works as a tunable switchable filter using one PIN diode together with a varactor. An isolation of over 20 dB and a tuning bandwidth of 9 percent was achieved. The resonant frequency and tuning bandwidth agree very well with a theoretical analysis based on transmission line modelling. The results should have many system applications.

ACKNOWLEDGEMENTS

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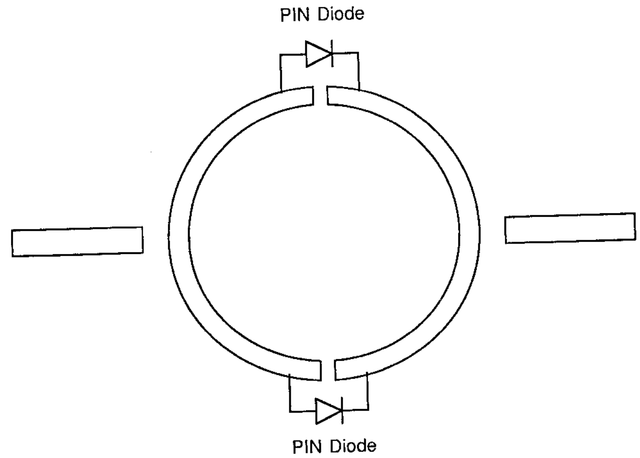

Figure 1 Circuit configuration

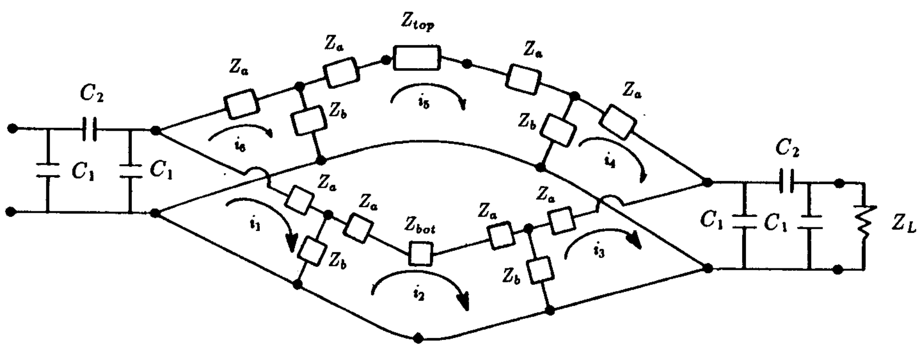

Figure 2 Eqivalent circuit of a diode loaded ring

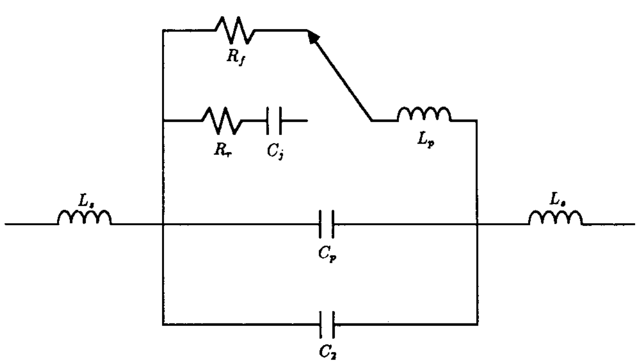

Figure 3 Equivalent circuit of a PIN diode

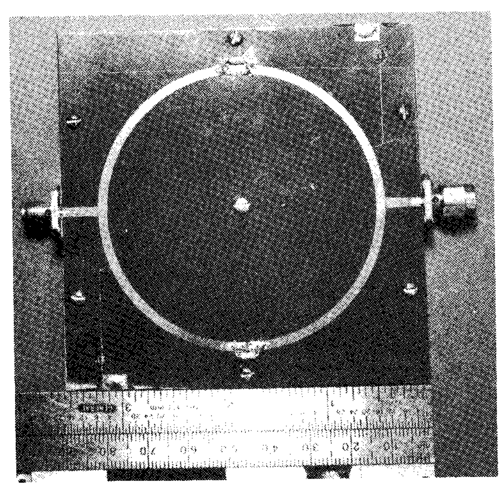

Figure 4 A photo of the actual circuit

Figure 5 Measured response of a switchable ring resonator

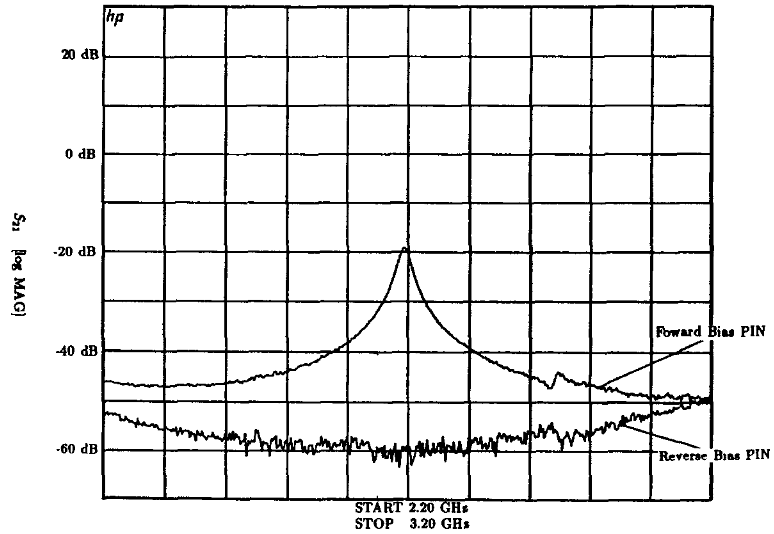

Figure 6 Measured response of a switchable ring resonator with lower loss

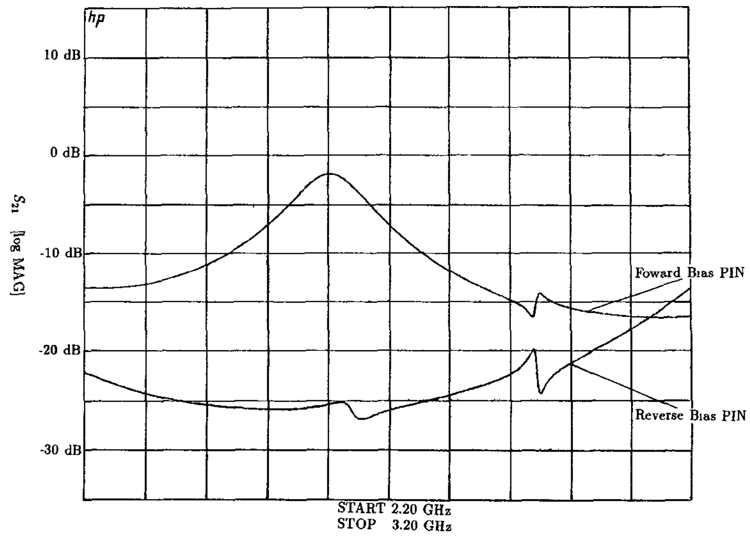

Figure 7 Tuning range for a tunable and switchable ring resonator