VARACTOR-TUNED MICROSTRIP RING RESONATORS

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Abstract

Varactor-tuned microstrip ring resonators have been developed Up to 10 percent tuning bandwidth was achieved using a packaged varactor diode. The effects of the coupling gap on the ring resonant frequency were also investigated. The results should have many applications in electronically tunable stabilized oscillators and filters in both hybrid and monolithic integrated circuits.

Introduction

In many applications, it is desirable to have a highly stable oscillator which provides a fixed output frequency over a wide temperature range. Most frequency stabilized circuits use dielectric resonators or waveguide cavity circuits which are generally difficult to tune electronically [1-5]. This paper reports a ring resonator circuit which can be easily fabricated and electronically tuned over a wide range using a varactor diode. Unlike the dielectric resonators, the circuit is amenable to monolithic implementation. The circuit should have many applications for tunable filters and tunable oscillators that offer both electronic tunability and frequency stability.

Two types of varactor-loaded circuits were investigated: one with a varactor diode mounted inside the ring and the other with the diode mounted in the coupling gap. It was found that the ring varactor-loaded circuit gives much wider tuning range than the coupling gap varactor-loaded circuit.

Different tuning ranges were obtained with various varactor diodes. Up to 10 percent tuning bandwidth was achieved at X-band using a MA/COM packaged abrupt junction varactor diode. It is believed that a much wider tuning bandwidth could be achieved by the use of hyperabrupt junction beam-lead varactor diodes.

The effect of the coupling gap on the ring resonant frequency was also studied. It was concluded that the resonant frequency is slightly lower as the coupling gap becomes smaller. The effects are small and generally negligible unless a very small coupling gap is used.

Circuit Description and Modeling

The circuit with wide tuning range is shown in Figure 1 where the varactor is mounted inside the ring. Two small gaps were cut in the ring. The gap at the top of the ring is used for varactor mounting. The bottom gap can be used for mounting the varactor or a fixed value dc block capacitor. Bias and ground return are supplied through the bias lines. If a big fixed capacitor is mounted in the bottom gap, the equivalent circuit is shown in Figure 2. The transmission line is represented by a T-network and the coupling gap is modeled by a gap series capacitance (C2) together with two fringe capacitances (C1). C1 and C2 can be calculated from reference 6.

Z_c can be modelled by a varactor diode in parallel with a gap capacitance C2, as shown in Figure 3. For a packaged diode, the varactor can be represented by a variable junction capacitance $C_j(v)$ in series with a lead inductance L_s. The package capacitance is accounted for by C_p. The fringe capacitances (C1) are small and negligible. Without the consideration of coupling gap effect, the resonant frequency of a ring with a mean radius r can be calculated by [7]:

$$f = \frac{nc}{2\pi r\sqrt{\epsilon_{eff}}} \qquad (1)$$

where $n = 1, 2, 3$, etc. ϵ_{eff} is the effective dielectric constant and c is the speed of light. Here it is assumed that there is no gap inside the ring. With the varactor mounted across the gap inside the ring, the resonant frequency can be determined using the

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equivalent circuit given in Figure 2. The input impedance as a function of the varactor capacitance can be computed by solving the loop equations. Once the input impedance is calculated, the S-parameters can be found by:

$$S_{11} = \frac{Z_{in} - Z_o}{Z_{in} + Z_o} \qquad (2)$$

and

$$|S_{12}| = \sqrt{1 - |S_{11}|^2} \qquad (3)$$

where Z_o is the line impedance. The resonant frequency occurs when $X_{in} = 0$ or $|S_{12}| =$ maximum.

Results and Discussions

In the measurement of a ring with a gap in the middle of the top half of the ring, it was found that the odd number modes disappeared. This can be easily explained by examining the boundary conditions imposed on a ring that is broken at a certain point. Each point that has an open circuit will result in a maximum electric field. For the even modes the break occurs at the electric field maximum and thus the fields are virtually undisturbed. For odd modes the break occurs at what should be an electric field null point, the break point disturbs the field and the mode is therefore not present. The break in the ring also introduces the half-modes which have a positive maximum one side of the break point and a negative maximum at the other side. It is these modes that will be effectively tuned by the tuning varactor.

A resonant ring was fabricated on Duroid 6010 substrate with 0.635 mm thickness. The results displayed on the HP 8510 automatic network analyzer are shown in Figure 4 for various bias levels applied to the varactor. The resonant frequency was tuned from 7.38 to 8.06 GHz. The varactor used here is from MA/COM (Model 46600) with a capacitance varied from 0.5 to 2 PF. It is believed that a much wider tuning range can be achieved if a hyperabrupt junction varactor diode is used.

The loaded-Q was measured in the range of 100 to 200 which agrees with the theoretical calculation for a typical microstrip line [8].

Varactor Mounted Across the Coupling Gap

A coupling gap varactor-loaded circuit shown in Figure 5 was also fabricated and tested. The resonant frequency varies with the varactor capacitance as shown in Figure 6. It can be seen that the resonant frequency decreases as the varactor capacitance increases. This circuit only works for a small value of capacitance since the big capacitance will bridge the coupling gap and the ring will no longer behave as a resonator.

Effects of Coupling Gap on Resonant Frequencies

Coupling gaps and feed lines are generally used to couple the ring resonator to the outside world. The size of the coupling gap determines the coupling between the microstrip line and the resonator. For better accuracy, it was recognized that excessive loading effects which would otherwise affect the measurements should be minimized by loosely coupling the resonator to external circuit. However, no quantitative analysis on the effects of coupling gaps has been reported in the literatures. A computer program has been developed to facilitate the calculation. The resonant frequency as a function of gap size is shown in Figure 7. It can be seen that the resonant frequency is almost constant until the gap becomes very small.

Experiments were carried out to verify the theoretical calculation. The ring was fabricated on Duroid 5870 substrate with 1.57 mm thickness. The experimental results for several gap sizes are shown in Figure 7 for comparison.

Conclusions

Two types of varactor-tuned microstrip ring resonator circuits were developed. Tuning range of up to 10 percent was achieved using a packaged commercially available varactor diode. The results should have many applications in electronically tunable oscillators and filters. The effects of coupling gaps on the resonant frequency were also studied.

Acknowldegments

The authors would like to thank Mr. James Klein for technical assistance. They would also like to thank Dr. Henry Taylor and Dr. Mark Weichold for many helpful suggestions and discussions. The work was partly supported by Office of Naval Research under contract No. N00014-86-K-0348.

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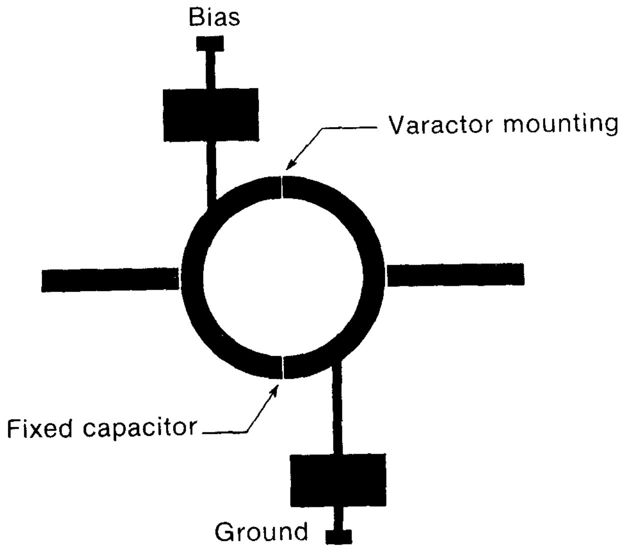

Figure 1 Varactor diode mounted inside a ring resonator

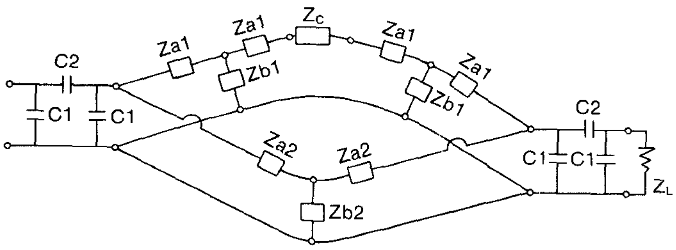

Figure 2 Equivalent circuit of varactor tuned ring

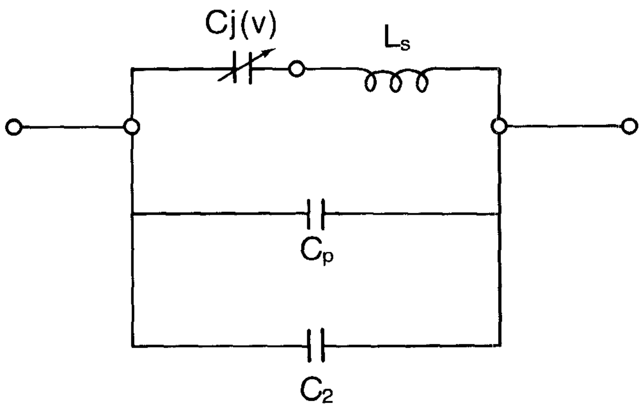

Figure 3 Equivalent circuit of varactor and mounting gap

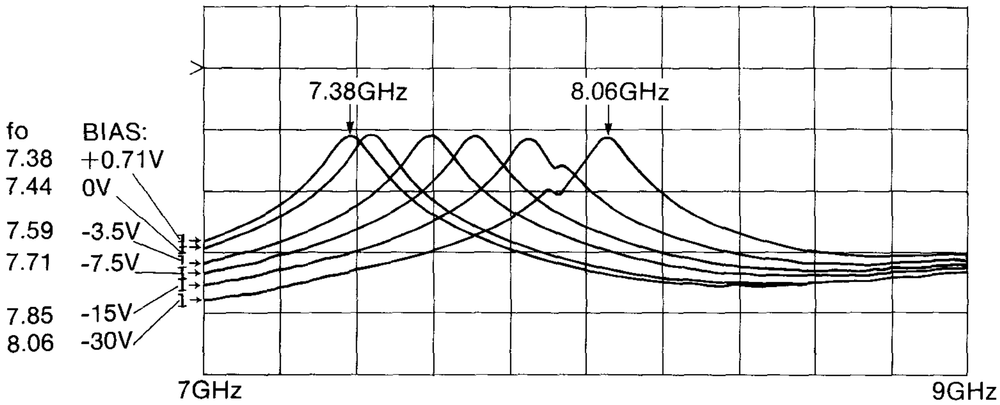

Figure 4 Resonant frequency of the varactor tuned ring as a function of bias voltage (Reference: 0dB, Vertical: 10 dB/scale)

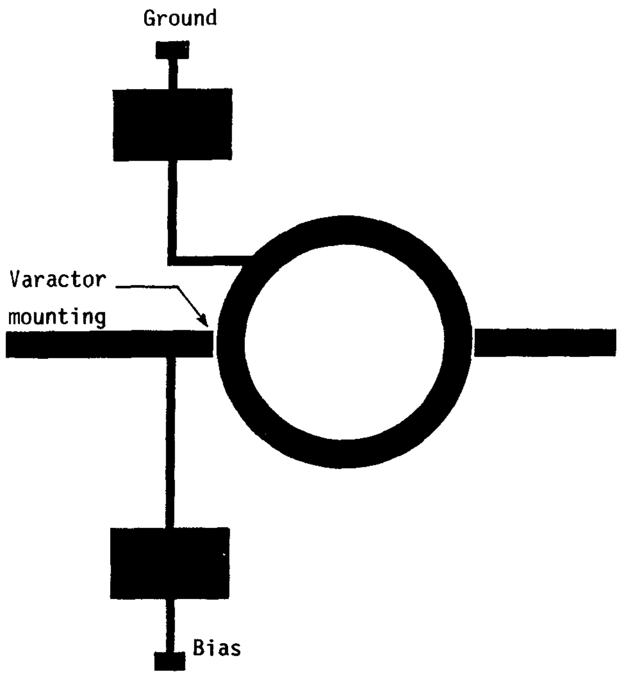

Figure 5 A varactor diode mounted across the coupling gap

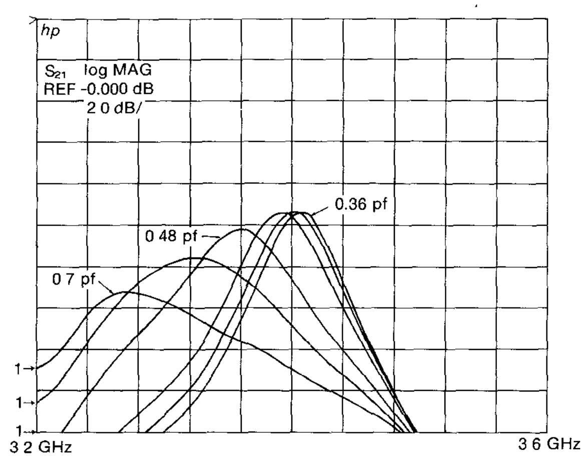

Figure 6 Resonant frequency of the varactor tuned ring as a function of varactor capacitance for a circuit with the varactor mounted across the coupling gap

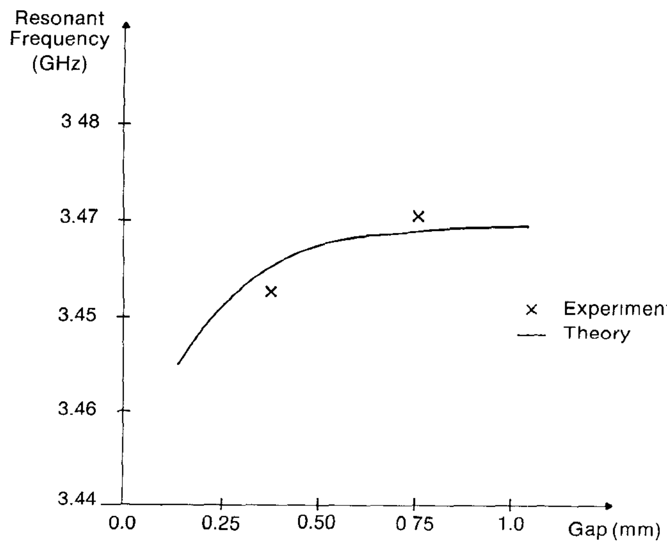

Figure 7 Resonant frequency as a function of gap dimensions