MMIC TUNABLE BANDPASS FILTER USING A RING RESONATOR WITH LOSS COMPENSATION

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Abstract

Ring resonators incorporating negative resistance circuits for loss compensation are studied for use as high Q tunable MMIC resonators. The design of a 13 GHz MMIC bandpass filter together with a background theoretical analysis, are presented. Simulation results indicate unloaded Q-factors of 1000 over 1 GHz tuning bandwidth.

Introduction

Microstrip ring resonators find applications in microwave filters and oscillators as well as in their original role as tools for dielectric material characterisation. They are particularly useful when a compact plain structure is more important than the very highest possible Q factor. Techniques for studying tunable rings and methods for suppressing unwanted modes have been reviewed in a previous paper [1] where an encouraging performance for a compact MIC oscillator has been demonstrated. These techniques are equally applicable to MMIC technology. However, when tunable ring resonators are implemented in MMIC form, they exhibit poor Q factors which makes them unsuitable for use in high selectivity filters and low phase noise oscillators. A means of compensating for losses in the ring is, thus, essential in order to enhance Q.

In this paper, monolithic tunable ring resonators with negative resistance circuits for loss compensation are studied including theoretical analysis and the derived S-parameters for the circuit. The design of a 13 GHz monolithic tunable filter employing a negative resistance circuit is presented. Analytical simulations predict an average increase of 20 in the Q factor, demonstrating the feasibility and advantage of the loss compensation technique.

Tunable Ring Resonators With Loss Compensation

A ring resonator consists of a closed loop transmission line which resonates when the mean circumference is a multiple of the guided wavelength. When gaps are incorporated at $\pm 90^0$ away from the input/output excitation points, tunable modes are introduced. These modes are made tunable if varactor diodes are inserted within the gaps [see Fig.1(a)], resulting in reduced Q. This problem is more acute in monolithic circuits where the diodes have higher series resistance than the discrete devices. The simulated response of a 13 GHz ring resonator implemented in the GEC-Marconi F20 process is shown in Fig.1(b) for a simple ring and a tunable ring with two varactors.

The MMIC ring alone, has a loaded Q factor of 38 while the use of varactors further reduces the Q to 21. A shunt negative resistance circuit was employed for loss compensation since incorporation of transmission amplifier stages within the ring would disturb the resonator's operation governed by a standing wave pattern. Furthermore, inclusion of a shunt negative resistance circuit, being reciprocal, would not affect the resonator's operation.

The negative resistance circuit is coupled to the ring at a voltage maximum of the resonant mode of interest. Fig.2(a) shows a ring resonator with the loss compensating circuit for the first mode of operation. Care must be taken to ensure that the negative resistance circuit is compensating for the ring losses only and does not introduce instability. Standard network analysis was applied to investigate the characteristics of the equivalent ring resonator circuit shown in Fig.2(b) and the derived S-parameters are as follows:

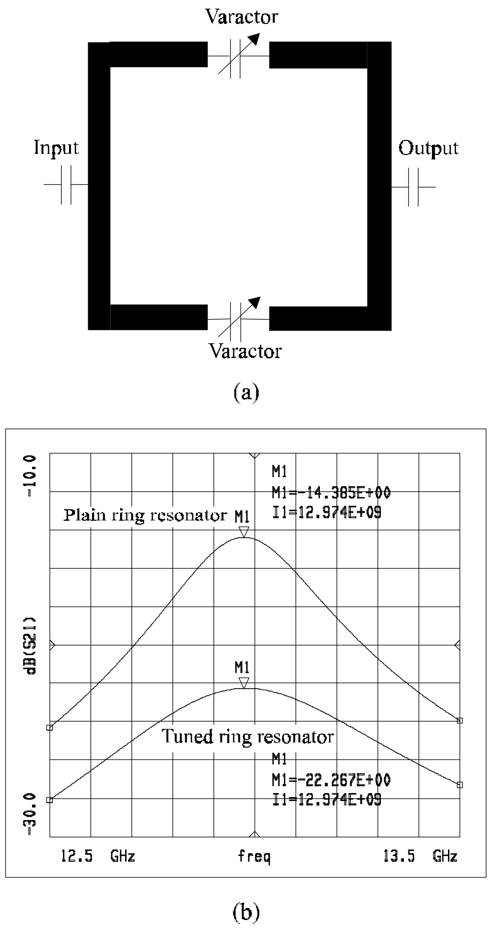

Fig.1 **(a)** Block diagram and **(b)** transmission response of the MMIC ring resonator with and without varactors

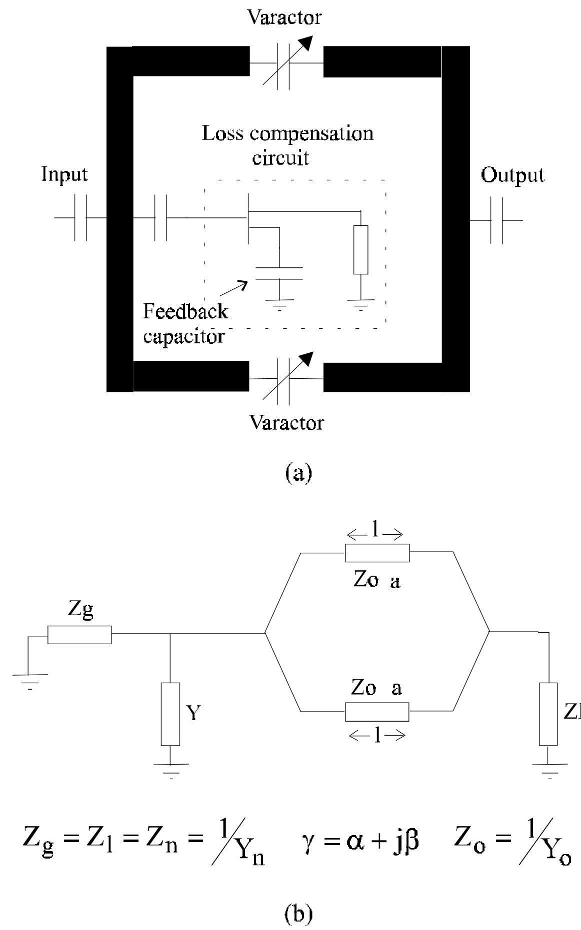

Fig.2 **(a)** Block diagram of tunable MMIC ring resonator with loss compensation and **(b)** equivalent transmission line circuit

$$S_{11} = \frac{-\frac{Y}{Y_n} + \left(\frac{Y_n}{2Y_o} - \frac{2Y_o}{Y_n} - \frac{Y}{2Y_o}\right)\tanh(\gamma l)}{\left(2 + \frac{Y}{Y_n}\right) + \left(\frac{Y_n}{2Y_o} + \frac{2Y_o}{Y_n} + \frac{Y}{2Y_o}\right)\tanh(\gamma l)} \qquad (1)$$

$$S_{22} = \frac{-\frac{Y}{Y_n} + \left(\frac{Y_n}{2Y_o} - \frac{2Y_o}{Y_n} + \frac{Y}{2Y_o}\right)\tanh(\gamma l)}{\left(2 + \frac{Y}{Y_n}\right) + \left(\frac{Y_n}{2Y_o} + \frac{2Y_o}{Y_n} + \frac{Y}{2Y_o}\right)\tanh(\gamma l)} \qquad (2)$$

$$S_{12} = S_{21} = \frac{2}{\left(2 + \frac{Y}{Y_n}\right)\cosh(\gamma l) + \left(\frac{Y_n}{2Y_o} + \frac{2Y_o}{Y_n} + \frac{Y}{2Y_o}\right)\sinh(\gamma l)} \qquad (3)$$

The above equations can be used to calculate the required negative resistance for low transmission loss, to identify regions of instability and to ensure stable operation.

High Q, MMIC Ring Resonator Design

Fig.3 shows the layout diagram of the designed and simulated MMIC ring resonator. The GEC-Marconi F20 process with 0.5 μm MESFETs is used with a chip size of 6.9 mm^2 of wafer area. Input and output RFOW pads are on the left and right side of the chip. Tuning of the resonator is achieved by the use of varactor diodes which are realised by the gate-to-source/drain capacitance of MESFETs. The resonator design enables the mounting of the loss compensation device inside the ring so that the wafer area is fully exploited. The simulated transmission response of the filter for a varactor bias voltage of 0 Volt is shown in Fig.4. The transmission response of a MMIC ring resonator with and without varactor diodes, is also plotted in order to demonstrate the benefits of the loss compensation circuit.

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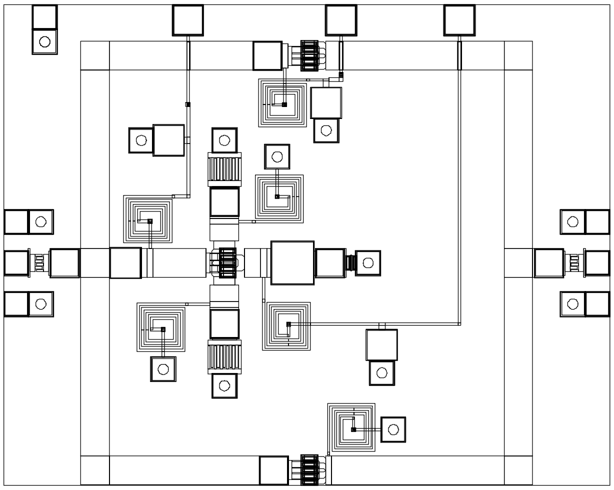

Fig.3 The Layout of the MMIC ring resonator filter

Analytical simulations made using the HP Microwave Design System (MDS) software package, show that the inductors exhibit a self resonance near the 13.7 GHz vicinity. Therefore, the tuning range of the filter is split into two bands with the first band offering higher loaded Q factors. Fig.5 shows the simulated transmission response of the filter for the first band.

The simulated resonant frequency and Quality factor against varactor bias voltage for the lower tuning range are shown in Fig.6. Fig.7 shows the equivalent results for the upper tuning range of the filter. The unloaded Q factor is given by [2]

$$\frac{Q_u}{Q_L} = \frac{1+\gamma_1+\gamma_2+\gamma_1\gamma_2}{\gamma_1\gamma_2-1} \tag{4}$$

where γ_1 is the VSWR of input coupling circuit with matched output load and γ_2 is the VSWR of output coupling circuit with matched input load. The results of Fig.6 show that unloaded Q factors of 1000 over 1 GHz tuning bandwidth can be achieved with this filter, and leads to a vast improvement in both bandwidth and Q factor over conventionally tuned MIC ring resonator filters reported so far in the open literature [3].

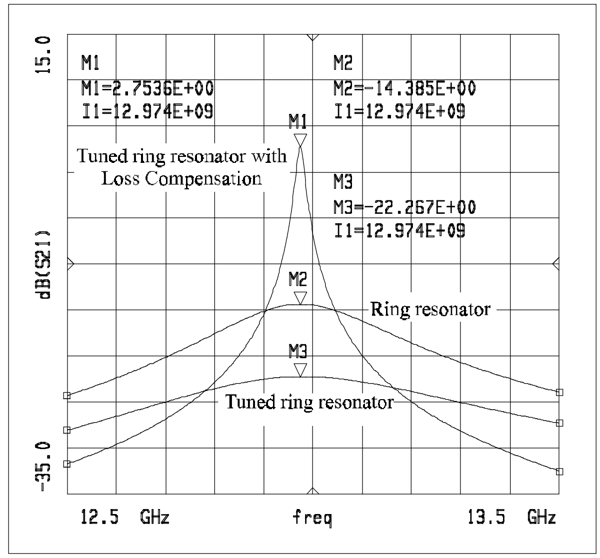

Fig.4 The effect of the loss compensation circuit on the losses in the ring

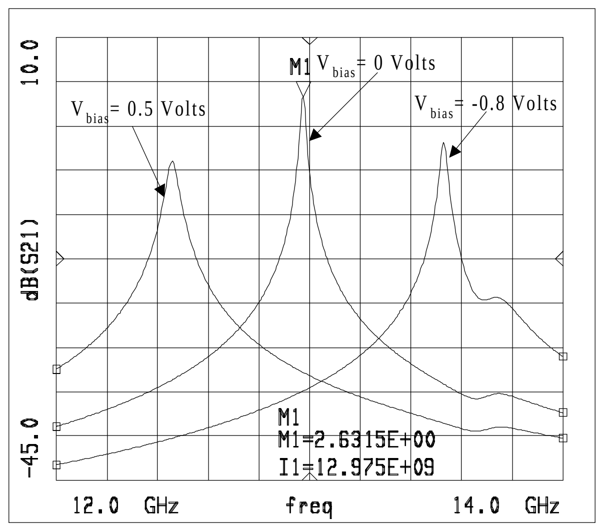

Fig.5 Lower band transmission response of the filter

Conclusions

A new approach to the design of tunable MMIC filters has been presented. With the incorporation of a loss compensation device, significantly higher Quality factors can be achieved over conventional ring resonator designs. The loss compensation technique is equally applicable for realisation of tunable MMIC ring resonator oscillators. The predicted high Q factors for the designed circuit, are comparable to other resonators, such as dielectric resonators commonly used for VCOs. With the size reduction resulting from MMIC technology, such monolithic components would have potential applications in communication systems as high selectivity filters and low phase noise sources. MMIC processes above 20 GHz would open further application areas such as personal communications, automotive radar and other microwave communication systems.

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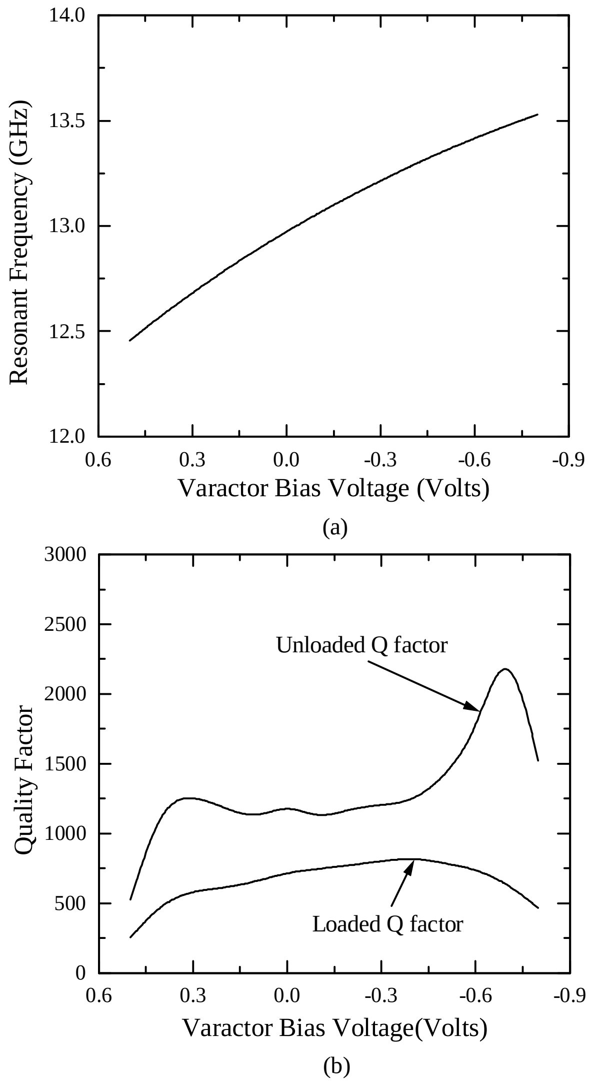

Fig.6 **(a)** Simulated resonant frequency and **(b)** quality factor for the lower tuning range

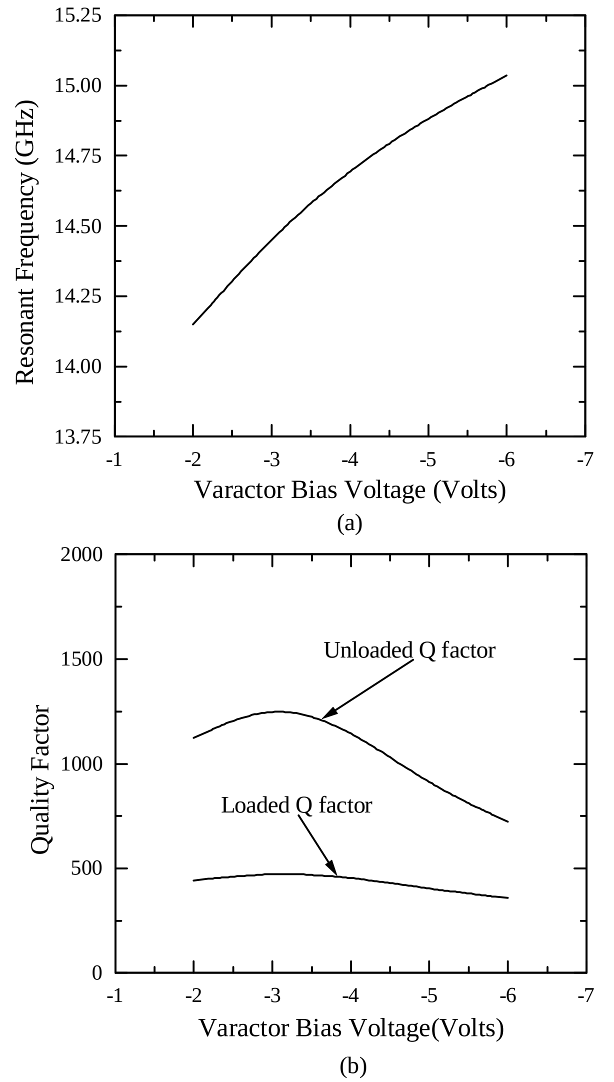

Fig.7 **(a)** Simulated resonant frequency and **(b)** quality factor for the upper tuning range

Acknowledgements

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