A Dual-Mode Microstrip Ring Resonator Filter with Active Devices for Loss Compensation.

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ABSTRACT

A new bandpass filter design is presented which uses a dual-mode microstrip ring resonator with a pair of FETs which provide negative resistance to compensate for the losses in the ring. The measured results show excellent performance, with a 32 MHz 3-dB bandwidth centred at 1.48 GHz.The technique used in this paper is particularly attractive because of its ability to implement two transmission poles and two transmission zeros with only one ring if a suitable mode-coupling structure is designed. The advantage of the combined passive resonator and active device technique is that the poles and zeros of the filter are accurately defined by the ring dimensions, and the FETs only provide negative resistance to compensate for the ring losses. Hence, the filter is less sensitive to environmental changes than a filter based on entirely active techniques.

INTRODUCTION

High selectivity microwave active filters are highly desirable for the next generation of satellite and mobile communications systems. The principle advantages to be gained are small-size and light-weight compared to existing filters. In this paper a new technique has been demonstrated using a microstrip ring resonator and FETs to compensate for the ring losses. Microstrip rings were proposed as high Q resonators [1] and were used successfully for microstrip dispersion measurements [2]. Later, the field structure of the resonant modes of microstrip rings was studied and results were published by Wu and Rosenbaum [3]. This paper indicated the possibility that the TM_{110} resonance, using their mode definitions, could be excited twice on the same physical ring thereby creating a dual-mode microstrip ring resonator. This feature of the microstrip ring is similar to the dual-mode resonator in cylindrical waveguide, which is extensively used in filter design. In both cases the dual-mode behavior is simply obtained by exciting a specific resonant mode twice, with a rotation of 90 degrees in the respective field patterns to ensure the orthogonality of the two modes. Wolf [4] has presented experimental evidence of the excitation of the degenerate modes.

Microstrip ring resonators have been used to implement a large variety of devices . Tuneable resonators [5] , [6] and conventional bandpass filters [7] have already been reported. Recently [8], practical results for filter designs using dual-mode microstrip ring resonators have been presented for purely passive resonators. In this paper, the excellent performance of the ideal lossless dual-mode ring has been achieved using active devices to compensate for the ring losses.

THE DUAL-MODE RING RESONATOR

The basic geometry of the microstrip ring resonator being investigated in this paper is shown in figure 1. The total length of the ring is chosen to be equal to one wavelength at the resonance frequency. The field excited in the ring exhibits two maximum intensity points [3]. One in correspondence with the excitation point, and the other in the opposite location. These two maxima, however, have opposite phases so that between them there are two points where the field intensity is equal to zero. Two such resonances can be excited in the same physical microstrip ring at the same time and they will be electrically independent if the maxima of one resonance can be made to correspond to the nulls of the other. The two resonances will occur at the same frequency only if the ring resonator is perfectly symmetric.

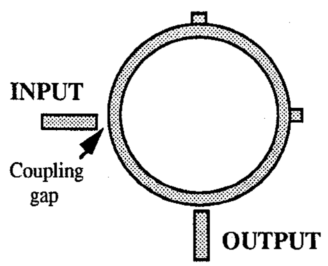

Figure 1. The Basic Dual-Mode Ring Resonator Structure

If we introduce a discontinuity that perturbs the field of the ring resonator, we will couple the two degenerate resonances. Although any discontinuity would in principle have the same effect, we have found that open-circuited stubs placed at 45 degrees from the location of maximum intensity of the degenerate modes is most suitable for this purpose. To better understand the effect of the coupling discontinuity, let us consider the circuit in figure 2. In this structure, the ring resonator is coupled directly to two lines are that are connected at 90 degrees from each other. In this configuration the structure exhibits a stopband at the first resonance of the ring. This represents the case where the two degenerate modes are not coupled to each other. By computing the transfer function of the structure, one can easily demonstrate that at resonance there is a second order zero.

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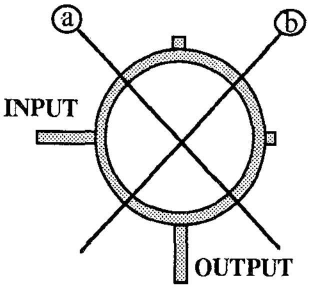


Figure 2. Ring Resonator Directly coupled to the input/output lines

The coupling discontinuity can be introduced at four different locations, namely along a line **a** or **b** in figure 2. Coupling of the two modes is obtained in all cases, but the two additional transmission zeros are generated only if the geometrical symmetry of the structure is preserved. These transmission zeros are located one on either side of the passband and their distance from the center frequency depends on the coupling introduced. Figure 3 shows the simulated performance of a filter using an ideal lossless ring with the discontinuities carefully designed to place the poles and zeros correctly, and an excellent filter response is achieved. Here we have used 25 thou alumina substrates (ε_r=9.8) and line-widths corresponding to a characteristic impedance of 50 ohms. When the normal ring losses are introduced into the simulation, the performance gets degraded very badly, as shown in figure 4. Hence, we turn our attention to ways of compensating for the ring losses with active devices.

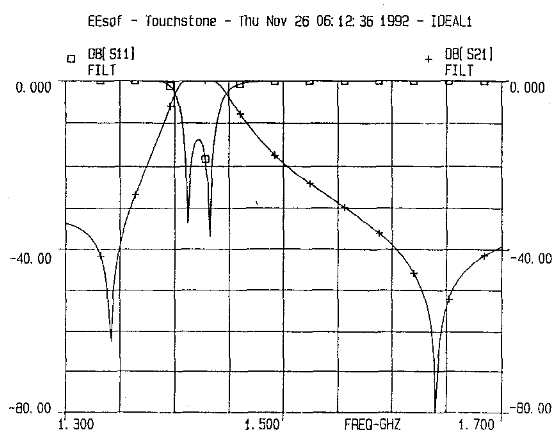


Figure 3. Simulated Ideal Lossless Dual-Mode Ring Filter

DUAL-MODE RING RESONATOR FILTER WITH ACTIVE DEVICES

From the nature of the ring resonant modes, it can be shown that the best position at which the active devices can be placed for loss compensation is as shown in figure 5. If the lossy ring is now simulated with an ideal negative resistance connected at these points, it is found that the ideal filter response can be re-gained if a large negative resistance value is used. This simulation is shown in figure 6. In order to realise the required high value of negative resistance, we use a GaAs FET and a topology drawn from oscillator design. Here, the FET source is connected to ground with a small capacitor, which enables the required feedback to be achieved. Figure 7 shows the simplified equivalent circuit of this arrangement, and the derivation of its input impedance. Looking into the FET gate one gets a very large negative resistance in series with a small capacitance. Figure 8 shows the simulated input impedance for this ideal model, compared with that achieved using the NE760 packaged device which was selected for the filter.

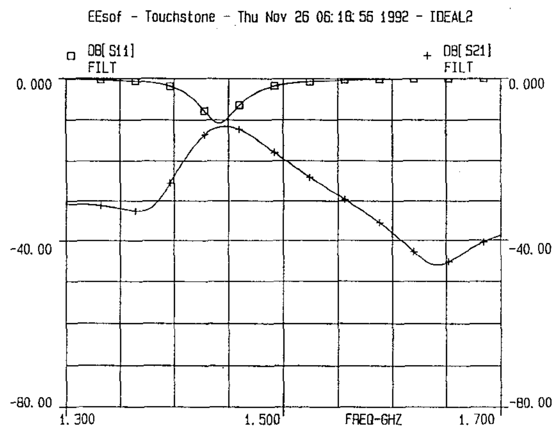


Figure 4. The Same Structure with Microstrip Losses Introduced

The complete filter using NE760 devices was simulated and it was found that a near ideal response could be achieved with some manual tuning of the ring stubs and optimisation of the FET source feedback capacitance, which was realised with short radial stubs. The photograph of the finished filter is shown in figure 9. The input and output connectors are on the left of the test fixture, and the other three connectors are for the DC bias to the FETs. The measured results of the filter are shown in figure 10. A small degree of tuning was employed via gold tuning discs. The transmission response

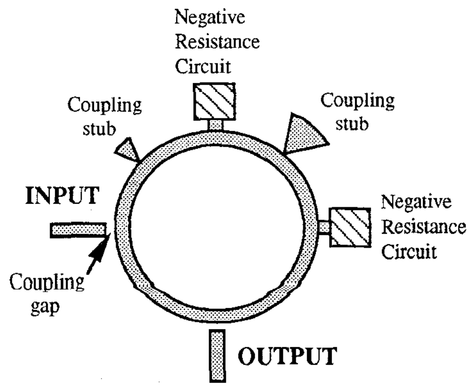


Figure 5. Schematic of the Dual-Mode Ring Resonator Filter With Active Devices for Loss Compensation

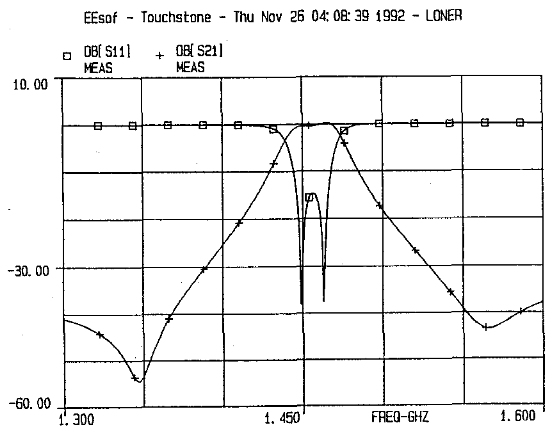
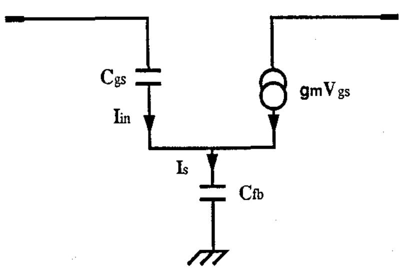


Figure 6. Simulated Lossy Ring with Negative Resistance Elements Introduced



$$I_{in} = I_s - gmV_{gs}$$

$$V_{in} = V_{gs} + V_s$$

$$V_s = I_s \cdot 1/j\omega C_{fb}$$

$$V_{in} = I_{in}/j\omega C_{gs} + I_s/j\omega C_{fb}$$

$$I_{in} = I_s - gm\, I_{in}/j\omega C_{gs}$$

$$I_s = I_{in}\,(1 + gm/j\omega C_{gs})$$

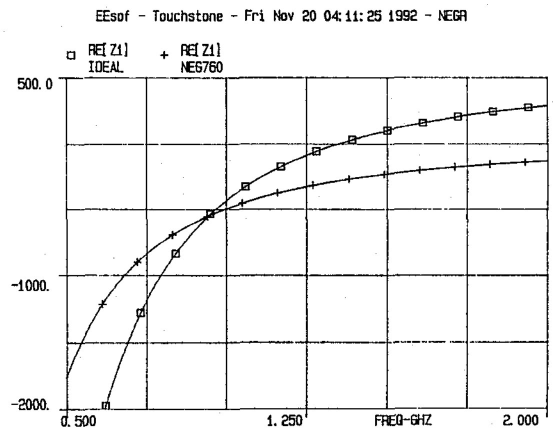
$$V_{in} = I_{in}/j\omega C_{gs} + I_{in}/j\omega C_{fb}\,(1 + gm/j\omega C_{gs})$$

$$Z_{in} = 1/j\omega C_{gs} + 1/j\omega C_{fb}\,(1 + gm/j\omega C_{gs})$$

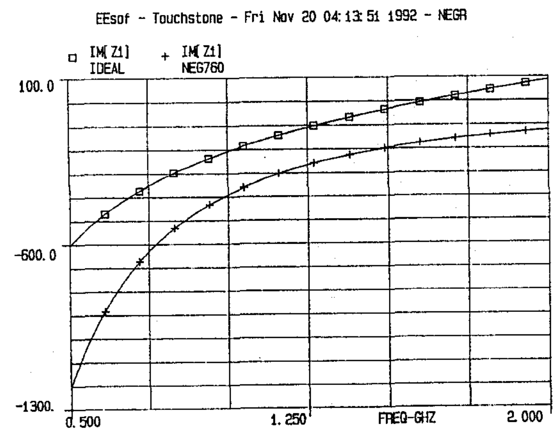
$$Z_{in} = 1/j\omega C_{gs} + 1/j\omega C_{fb} - gm/\omega^2 C_{gs} C_{fb}$$

Two capacitors in series , and -ve R component.

Figure 7. The Simplified Equivalent Circuit of the Negative Resistance Circuit, and Derivation of the input impedance



a) Resistance



b) Reactance

Figure 8. The simulated ideal negative resistance performance, compared with that achieved with the NE760 device

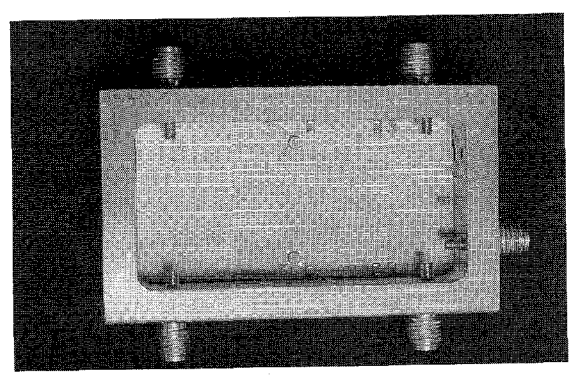
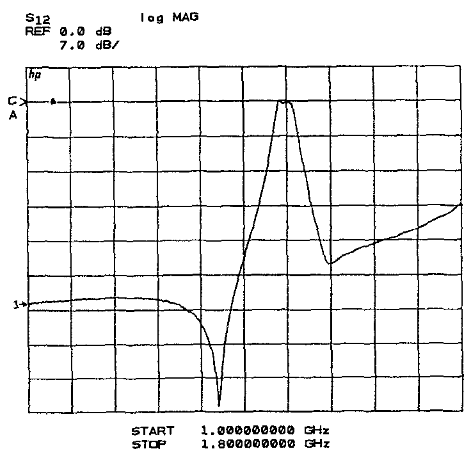


Figure 9. A Photograph of the Complete Filter

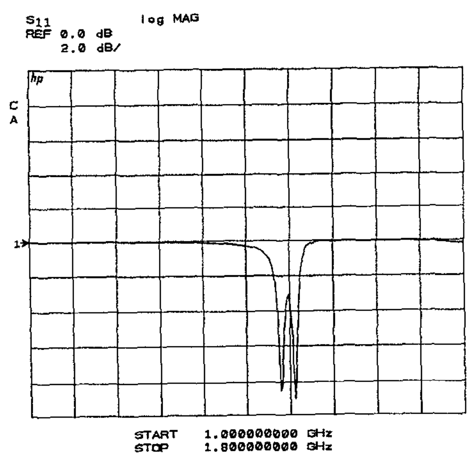
shows an excellent shape with a 32 MHz 3-dB bandwidth and very steep skirts provided by the transmission zeros. The return loss response shows the positions of the two poles very clearly. The actual return loss value is slightly poor because we were forced to use a chip capacitor standard value (non-optimum for the filter) in the circuit, and it could easily be improved if interdigitated capacitors were used.

CONCLUSIONS

A new technique has been demonstrated for realising high selectivity filters. It is based on a dual-mode microstrip ring resonator with active devices to compensate for the losses in the ring. An L-band filter prototype has been designed and constructed and gives a nearly ideal response. The measured results show a 3-dB bandwidth of 32 MHz centered on 1.48 GHz, which represents just over 2% relative bandwidth, and the filter has steep skirts as a result of the transmission zeros given by the dual-mode ring.



a) Transmission



b) Return Loss

Figure 10. The Measured Responses of the Filter

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