MMIC Active Bandpass Filter Using Negative Resistance Elements

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Abstract

This paper describes a monolithic bandpass filter using lumped L-C resonators with single transistor negative resistance elements. The measured response of the filter exhibits a 400 MHz 3dB-bandwidth centered on 4.7 GHz, and has 0 dB insertion loss with only ±0.1 dB ripple in the pass-band.

Introduction

For fully integrated microwave subsystems there is considerable interest in active filter techniques for MMIC realization. Conventional active filter techniques, widely used at low frequencies for integrated circuits, are not directly applicable to microwave filters because of the lack of suitable Op-amps at such high frequencies. A number of alternative techniques have been reported in the literature for microwave active filters [1-7].

Active resonators have obvious advantages of small size and high Q-factor for monolithic filters. However, active resonators previously reported for MMIC filters have tended to use fairly complex topologies which require many power supply lines for different settings of transistor and varactor bias voltages. For example, FET-based lossless active inductors require at least two FETs and may in practice need as many as four to achieve zero loss and good tunability [8]. In this paper, an active filter technique is described which is based on using an FET negative resistance element to increase the Q-factor of the resonators in an otherwise conventional L-C bandpass filter.

It has been shown before that MESFETs can also be used as negative resistance elements to compensate for losses in microwave active filters [9, 10]. It can be considered that the device is operating in a reflection-type amplifier mode in this case, amplifying the signal within the resonator. However, in this paper we use the FET negative resistance circuit as an integral part of a lumped L-C resonator, in a similar manner to the previous UHF filters employing bipolar transistors [11-13]. When comparing the use of bipolar and FET devices in this technique it is found that they must be used in a fundamentally different way, and whilst the negative resistance principle is similar the actual filter topology becomes quite distinct.

Filter Design

The negative resistance element uses an FET (MESFET or HEMT) in common-source configuration with a capacitive feedback element and the negative resistance is developed at the gate terminal [10]. In the ideal case, the FET negative resistance circuit has an input impedance given by:-

$$Z_{in} = -\frac{g_m}{\omega^2 C_{gs} C_{fb}} - j\left(\frac{1}{\omega C_{gs}} + \frac{1}{\omega C_{fb}}\right)$$

This input impedance comprises a negative resistance in series with C_{gs} and C_{fb}. By placing the negative resistance in parallel with an inductor-capacitor parallel resonator, the losses of the resonator can be compensated for. Fig. 1 shows the circuit diagram of a single unloaded resonator of this type: In practice a varactor diode is used instead of a MIM capacitor to facilitate a degree of tuning.

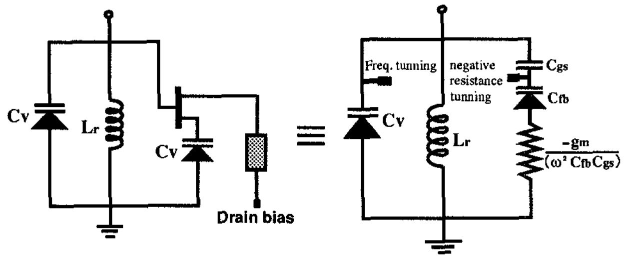

Fig.1 Resonator with negative resistance element

Fig. 2 shows a photograph of the MMIC implementation of this single resonator, and Fig. 3 shows the measured reflection gain of the solitary resonator. It can clearly be seen that the negative resistance is able to completely compensate for the losses of the passive lumped element resonator.

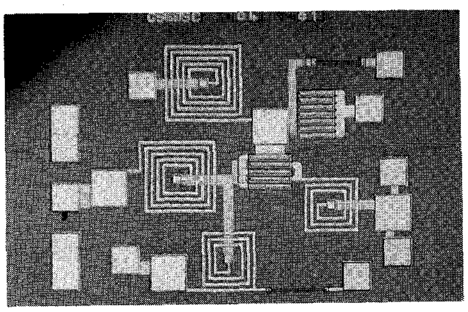

Fig.2 Photograph of the MMIC resonator

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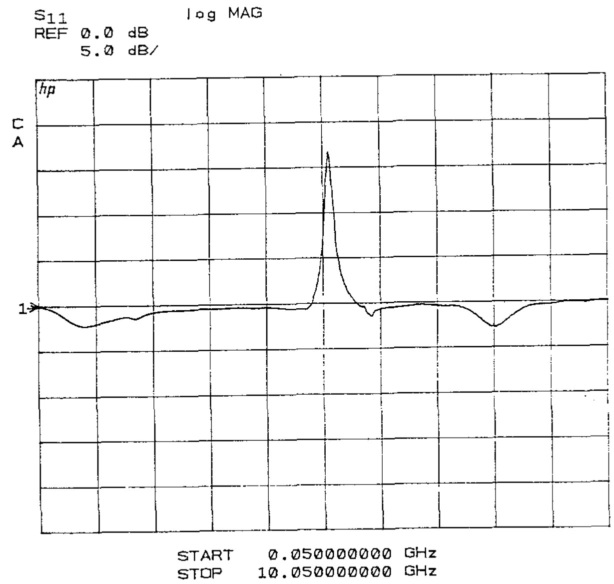

Fig.3 Measured reflection gain of solitary resonator

A two resonator filter was designed to demonstrate the new technique. The GEC Marconi Materials Technology Ltd (Caswell) F20 Foundry was used to fabricate the circuit. This process offers 0.5 µm gate-length ion-implanted MESFETs and through-substrate via-holes. Fig. 4 shows the circuit diagram of a two-resonator filter employing this new technique and Fig. 5 shows a photograph of the filter chip, which measures 2x2mm.

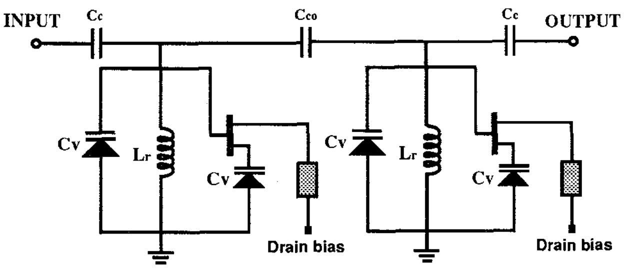

Fig.4 Filter circuit diagram

The extremely important function of the varactors in the FET sources is to accurately control the amount of negative resistance introduced by the FETs. Clearly, too little negative resistance would compromise the filter performance, but on the other hand too much negative resistance could lead to stability problems. The spiral inductor is the most lossy component and so one might expect that since a typical MMIC spiral inductor has, say, 4 Ω series resistance then the FET needs to provide only -4 Ω to make the resonator lossless. However, it is found that negative resistances as high as -1000 Ω are required once the resonator is coupled into the external circuit.

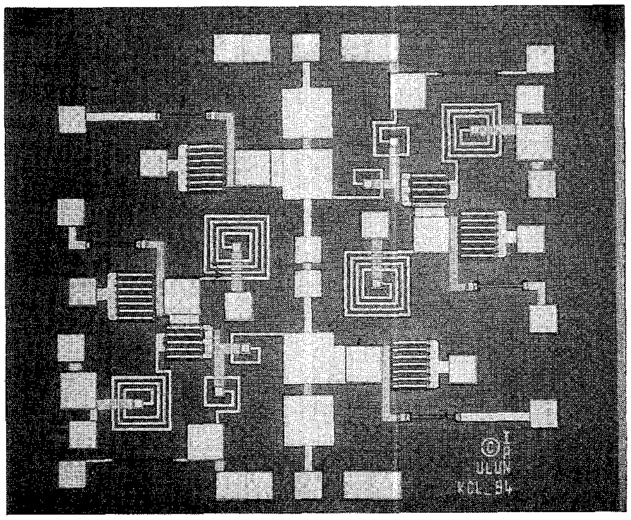

Fig.5 Photograph of the MMIC filter

Measurements

The filter chip was measured using an HP8510™ automatic network analyser and Cascade Microtech™ wafer prober. Fig. 6 shows the measured transmission and return loss response of the MMIC. The filter has a center frequency of 4.7 GHz with a 400 MHz 3 dB bandwidth. It has a measured insertion loss of 0 dB with only ±0.1 dB ripple in the passband. Fig. 7 shows how the feedback capacitance (the source varactor diodes) can be used to tune the response of the filter: Whilst insertion gain can be achieved, the return losses are degraded and the reflection coefficients may even become greater than unity. The out-of-band rejection is excellent, as shown in Fig. 8, with 70dB attenuation at low frequencies and 20-25 dB rejection up to 18 GHz.

Conclusions

The use of negative resistance transistor circuits to realize high performance monolithic microwave active filters has been described. This technique is ideal for MMIC applications, and a monolithic bandpass filter employing this technique has been demonstrated. The filter has a center frequency of 4.7 GHz with a 400 MHz 3 dB bandwidth. It has a measured insertion loss of 0 dB with only ±0.1 dB ripple in the passband. Furthermore, the out-of-band rejection is excellent with 70dB attenuation at low frequencies and over 25 dB rejection up to 18 GHz.

Acknowledgement

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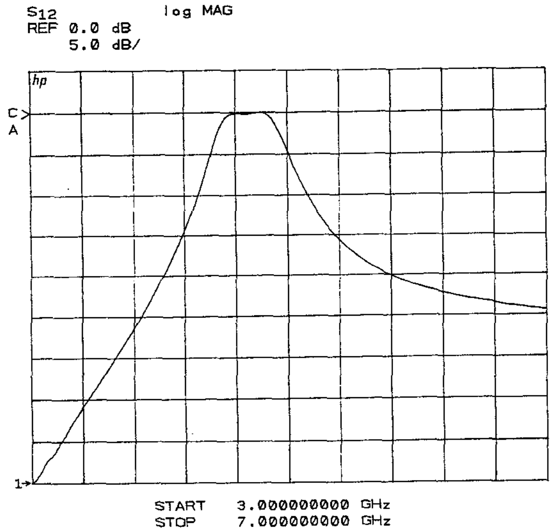

Fig.6(a) Measured transmission response

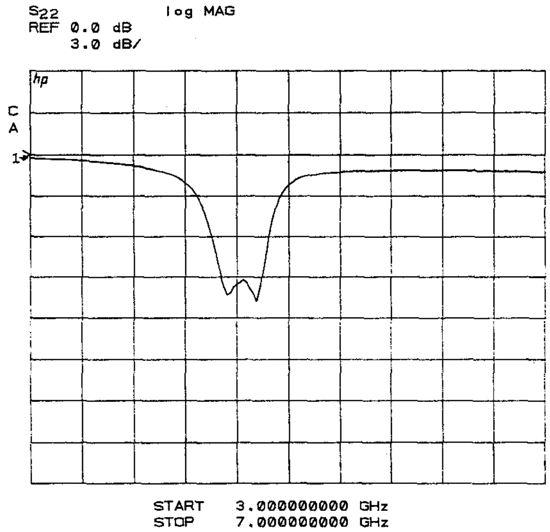

Fig.6(b) Measured return loss

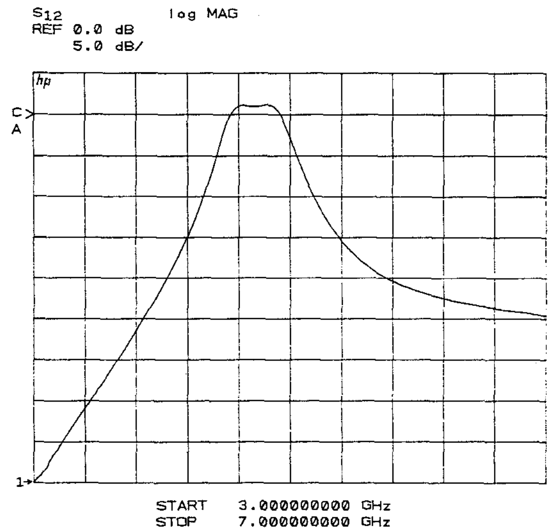

Fig.7(a) Measured transmission response (showing gain)

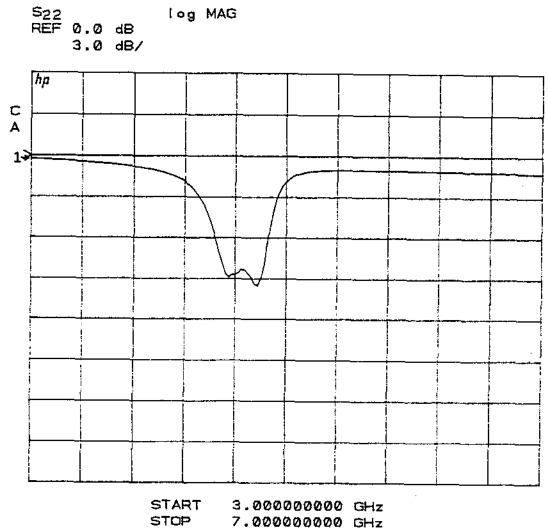

Fig.7(b) Measured return loss

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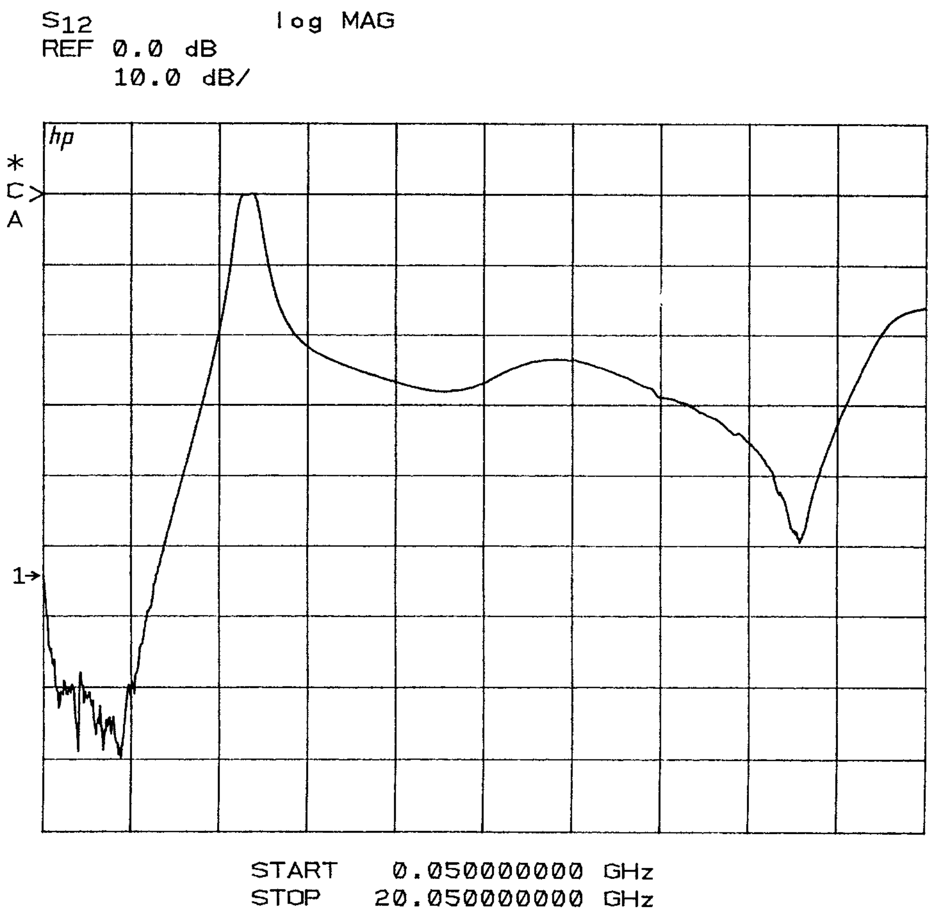

Fig.8 Broad band measured transmission response