A Low-Power Monolithic GaAs FET Bandpass Filter Based on Negative Resistance Technique

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***Abstract*— This paper describes a monolithic GaAs FET active bandpass filter utilizing negative resistance elements. The negative resistance element was realized with a common-drain FET with series inductive feedback and the measured output impedance characteristics are given. The fabricated monolithic forth-order filter showed an insertion loss of 0.7 dB at 4.85 GHz and a 3-dB bandwidth of 50 MHz with a dc power consumption of 7.5 mW.**

***Index Terms*— Active filter, bandpass filter, microwave FET integrated circuits, negative resistance circuits.**

I. Introduction

In RECENT years, a number of researches on the monolithic GaAs bandpass filters for the integration with radio frequency (RF) front-end monolithic microwave integrated circuits (MMIC's) have been performed because of their potential of reducing the size in portable communication systems. These approaches are mostly based on the negative resistance techniques [1], [2] or the high-Q active inductors [3]–[6]. While those circuits exhibit good RF performance, it is necessary to reduce the dc power consumption for them to be monolithically integrated with receiver IC's in portable communication systems where battery life time is an important design factor.

The transistor-based active inductors, i.e., capacitor-terminated gyrators which are generally composed of a common-source FET [common-emitter bipolar junction transistor (BJT)] and a common-gate FET (common-base BJT) as an inverting and a noninverting transconductor, respectively, seem to be very attractive in realizing MMIC filters because we can achieve high-Q resonators using only transistors and capacitors without any spiral inductors. However, the active inductor has at least three series-connected transistors including a common-source transistor, a common-gate transistor, and a current source transistor, so that it is difficult to reduce bias voltage while providing acceptable RF performance. The performances are dependent on the transistor gm/gds ratio which is a function of drain-to-source voltage. On the other hand, active resonators using negative resistance technique result in simple circuit configurations composed of a single transistor and passive LC elements. Hence, they are more suitable for the realization of low-voltage and low-power MMIC filters.

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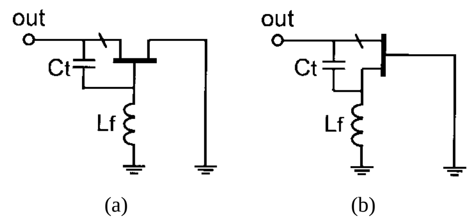


Fig. 1. Negative resistance circuits. (a) A common-gate FET with series inductive feedback. (b) A common-drain FET with series inductive feedback.

II. Design and Experimental Results

For the negative resistance circuits, two circuit configurations have generally been used, i.e., a common-gate FET with series inductive feedback [1] and a common-source FET with series capacitive feedback [2]. While the latter represents negative resistance and capacitance in the lower microwave frequency band, the former represents negative resistance and inductance in the higher microwave frequency band. The negative resistance is used for the compensation of filter loss. We also found that a common-drain FET with series inductive feedback shows a negative resistance. The common-drain FET circuit and the common-gate FET circuit are shown in Fig. 1. Capacitor C_t is required for negative resistance tuning. In this letter, the common-drain FET circuit [Fig. 1(b)], which has similar characteristics except for slightly larger inductance compared with the common-gate FET circuit, is used in realizing a monolithic active bandpass filter. If we consider transconductance gm and gate-to-source capacitance C_{gs} as equivalent circuit elements of FET, we can describe the output impedance Z_{out} as follows:

For the common-drain circuit

$$Z_{\text{out}} = \frac{1-\omega^2 L_f C_t}{g_m + j\omega(C_t + C_{gs} - \omega^2 L_f C_{gs} C_t)}$$

and for the common-gate circuit

$$Z_{\text{out}} = \frac{1-\omega^2 L_f (C_t + C_{gs})}{g_m + j\omega(C_t + C_{gs})}.$$

So, if we use a small-size FET for a low dc power operation, the difference in the Z_{out} is slight because C_{gs} is negligible compared with C_t.

The circuit was designed using HP-EEsof LIBRA. An 1 μm $\times$ 50 μm FET was used and the feedback inductance L_f and the tuning capacitance C_t were determined to exhibit lossless or negative resistance around the frequency of 5 GHz. The circuits, which were fabricated in the author's

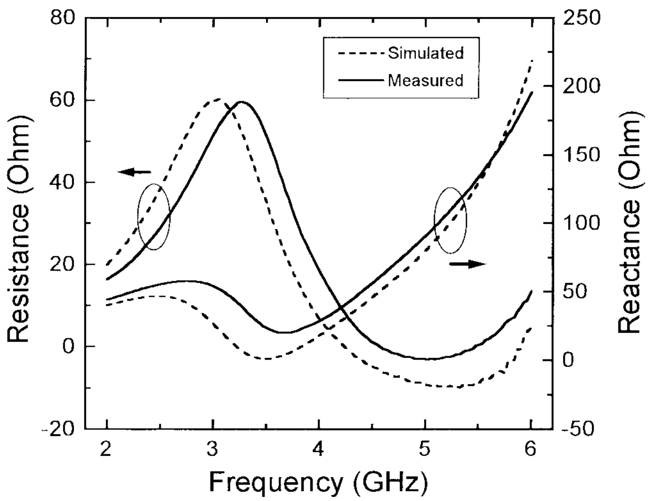


Fig. 2. Measured and simulated output impedance of the common-drain FET with series inductive feedback.

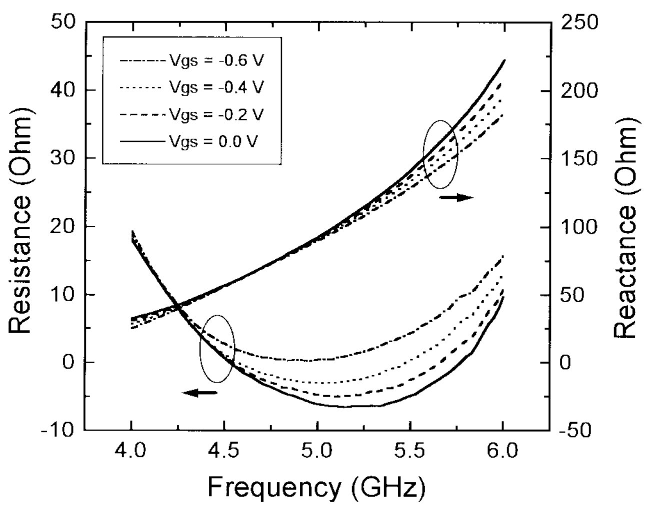
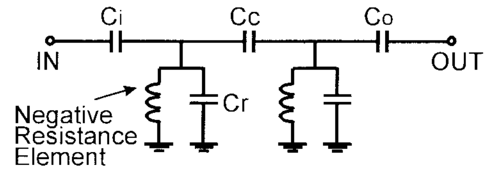


Fig. 3. Measured output impedance characteristics with the gate voltage (V_{gs}) change.

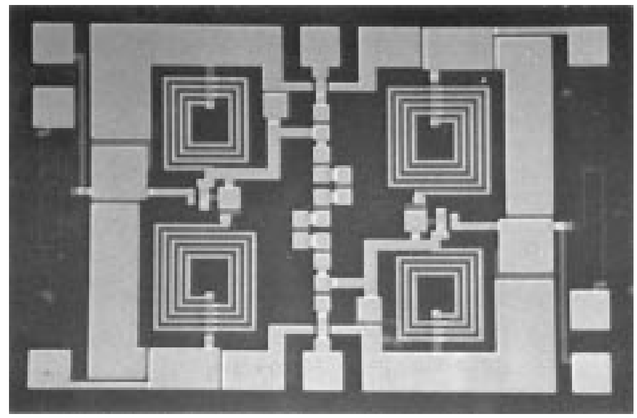
laboratory, include 1-μm gate-length FET's, mesa resistors, metal–insulator–metal (MIM) capacitors, spiral inductors, and gold-plated interconnections.

The fabricated circuits were measured using an HP8720 network analyzer and a microwave on-wafer probe. Fig. 2 shows the measured and simulated output impedance characteristics of the common-drain FET with series inductive feedback. Negative resistance is obtained from 4.6 to 5.5 GHz with a maximum negative value of $-3.1\ \Omega$ at a 3-V drain bias voltage with a drain current of 1.2 mA. Inductance is 2.9 nH at 5 GHz. For the comparison of the results, a postcircuit simulation was performed based on the measured process control monitor (PCM) data. There is a good agreement between the measured and simulated frequency response patterns of the output impedance.

The measured output impedance for several gate bias voltages (V_{gs}) at a 3-V drain bias voltage is shown in Fig. 3. The series resistance changes from 0.52 to $-6.2\ \Omega$ at 5 GHz with an inductance variation less than 3% as the V_{gs} varies from -0.6 to 0.0 V. However, the inductance variation is about 10% at 5.5 GHz. This resistance tunability makes it possible to control the Q-factor of resonator.



(a)



(b)

Fig. 4. The forth-order bandpass filter. (a) Circuit schematic. (b) Microphotograph.

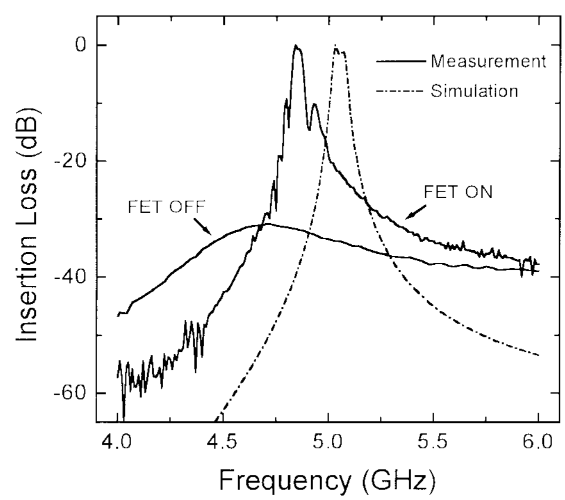


Fig. 5. Measured insertion loss of the fabricated filter with FET on and off.

A forth-order Chebyshev bandpass filter was realized by capacitively coupling two resonators as shown in Fig. 4(a). The resonators consist of negative resistance circuits and MIM capacitors. The coupling capacitor C_c should have very small capacitance and it is realized by the series connection of capacitors. The capacitors C_i and C_o are required for input and output impedance transformations. The microphotograph of the fabricated circuit is shown in Fig. 4(b). The chip size is 0.9 mm $\times$ 1.4 mm.

The measured and simulated performances of the bandpass filter are shown in Fig. 5. The measured results clearly show the loss compensation effect of the negative resistance technique with FET's on. The filter shows an insertion loss of 0.7

dB at 4.85 GHz and a 3-dB bandwith of 50 MHz. The center frequency shift in the measured result seems to be mainly due to the parasitics which are not considered in the circuit simulation. The supply current is 2.5 mA from a 3-V supply. The resulting dc power consumption is only 7.5 mW, which is the smallest value in the microwave active filters reported until now.

In the large-signal simulation, the filter shows a $P_{1\ \mathrm{dB}}$ of -22 dBm, which is much smaller than that of the negative resistance circuit. A solution for increasing $P_{1\ \mathrm{dB}}$ is to reduce the inductance of the resonator. This will reduce the loading resistance in a constant-Q resonator. So, resonator terminal voltages will be lowered at the same input power.

III. Conclusion

A new negative resistance circuit topology of a common-drain FET with series inductive feedback was reported and the output impedance characteristics were experimentally investigated. It was also shown that the negative resistance was easily controlled by the gate voltage with negligible inductance changes. Utilizing this negative resistance element, an MMIC active bandpass filter was demonstrated. The filter showed an insertion loss of 0.7 dB at 4.85 GHz and the 3-dB bandwidth of 50 MHz. The dc power consumption was as small as 7.5 mW from a 3-V supply.

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