A Novel Bandpass Filter Using Active Capacitance

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Abstract — **In this paper a novel RF active bandpass filter is proposed. In the proposed design the resonator is made of active capacitor together with the conventional inductor. The active capacitor made of FET exhibits a negative resistance property as well as capacitive property, and it compensates the resistance from the inductor which consists of the resonant circuit. The conventional active filters usually have high noise figure, while in the proposed design a good noise characteristics can be accomplished. So, the proposed active filter can be applicable in the RF font-end design as RFIC or MMIC. The measured 2-stage active bandpass filter shows bandwidth of 52.5 MHz, 0.3 dB insertion loss, 0.3 dB ripple, noise figure of 2.7 dB and OIP3 of 8 dBm at 1.9 GHz band, which agree well with the simulated results.**

I. Introduction

The MMIC/RFIC technology is in mature as GaAs, CMOS as well as HBT processes are commercially available nowadays. However, one of the major difficulties accomplishing SoC (System on Chip) has been the RF bandpass filters because the development of RF active filter design technology has not been very popular among RF engineers. On the other hand, the design of passive filters has been extensively studied throughout the world over 50 years. The major interest in the design of miniaturized narrow bandpass filter is the low insertion loss, which requires resonators with high quality factor (Q). It is well known the smaller the resonator, the smaller their Q values. Therefore, increasing Q with smaller resonator size is the key in the bandpass filter design. During the past ten years many researchers published active filter design methods based on active resonators[1-4], active couplings[5-7] or other schemes[8-10].

For active bandpass filters to provide useful alternatives of their passive counterparts in many applications such as receivers, their corresponding noise figures should be comparable with those of the competing passive filters. But unfortunately, some of active bandpass filters does not show a good noise figure performance, and some of those are not possible for narrow-band filter design.

We present a new type of active resonator based on active capacitor scheme and design method based on the conventional passive bandpass filters. Through the simulated and measured results it is shown that the proposed RF active filter can have a narrow-band property and low noise characteristics, which is essential to front-end application.

II. The Negative Resistance Theory

In the conventional topologies, the negative resistance topology composed of common-source or common-gate series feedback structure. This feedback structure usually is used for oscillator design. Therefore, the noise performance of transistor is increased by series feedback structure. The proposed topology is common-source, and common-drain inductive and capacitive series feedback structure. Fig. 1 shows the structure and the equivalent circuit of this topology. It is different from the conventional type by the oscillator design method. This topology doesn't use the common-source or common-gate series feedback structure with a major noise performance increment cause. Therefore, the noise performance can be improved by the proposed topology. The active capacitor made of FET exhibits a negative resistance property as well as capacitive property. This topology is simple in structure and could be conveniently applied to the narrow-band filter design.

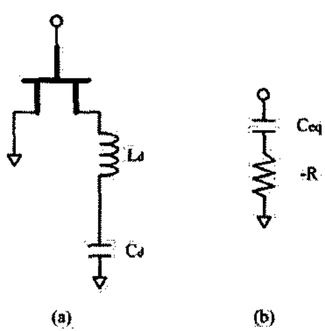

Fig. 1. Proposed circuit (a) and its simple equivalent circuit (b)

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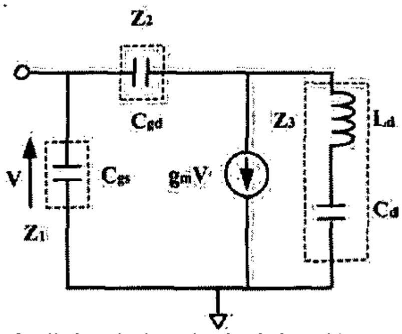

Fig. 2. The detailed equivalent circuit of Fig. 1 (a)

Fig. 2 represents the equivalent circuit of Fig. 1 (a). In the representation of Fig. 2, the input impedance can be written:

$$Z_{in} = \frac{Z_1(Z_2+Z_3)}{Z_1+Z_2+Z_3+g_m Z_1 Z_3} \tag{1}$$

where, the parameters are

$$Z_1 = \frac{1}{j\omega C_{gs}} = -jX_1$$

$$Z_2 = \frac{1}{j\omega C_{gd}} = -jX_2$$

$$Z_3 = j(\omega L_d - \frac{1}{\omega C_d}) = jX_3$$

and $X_1, X_2, X_3 > 0$

The expression (1) is

$$Z_{in} = \frac{g_m X_1^2 (X_3^2 - X_2 X_3)}{(g_m X_1 X_3)^2 + (X_3 - X_2)^2} - j\frac{X_1(X_3 - X_2)(X_3 - X_2 - X_1)}{(g_m X_1 X_3)^2 + (X_3 - X_2)^2}$$

$$= R_{neg} + \frac{1}{j\omega C_{eq}} \tag{2}$$

Therefore, the condition of negative resistance (R_{neg}) is

$$\frac{1}{\sqrt{L_d C_d}} \langle\ \omega\ \langle \sqrt{\frac{1}{L_d\left(\frac{C_d C_{gd}}{C_d + C_{gd}}\right)}} \tag{3}$$

The proposed topology can be made negative resistance by the feedback L_d, C_d and gate-to-drain capacitor C_{gd}. Also, the negative resistance, R_{neg}, is dependent on the frequency. The connecting by shunt inductor L_r at the proposed negative resistance circuit can make the resonator. The resonance frequency is

$$\omega_0 = \frac{1}{\sqrt{L_r C_{eq}}} \tag{4}$$

III. Design of Bandpass Filters

From the above analysis, it can be possible to design a new RF active bandpass filter. The resonance structure is composed of a feedback capacitor C_d, inductor L_d at drain, an external shunt inductor L_r and series capacitor C_g at gate. The parallel resonance circuit can be made by using the proposed negative resistance topology. Fig. 3 shows the parallel resonator circuit. The capacitance of resonator is $C_g // C_{eq}$. The resonance frequency is

$$\omega_0 = \frac{1}{\sqrt{L_r C_{eq} // C_g}} \tag{5}$$

The quality factor Q of inductor is controlled by negative resistance, therefore, the losses of the resonator can be compensated for. Also, in the structure of the resonator, it can be connected by parallel capacitor in order to increase capacitance of the resonator. Here, R_d has no need of use in the circuit. The reason is that it is used for fine controlling of negative resistance.

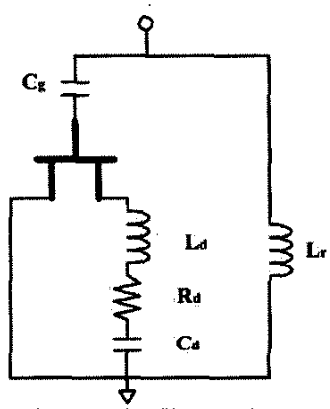

Fig. 3. The second-order active filter circuit

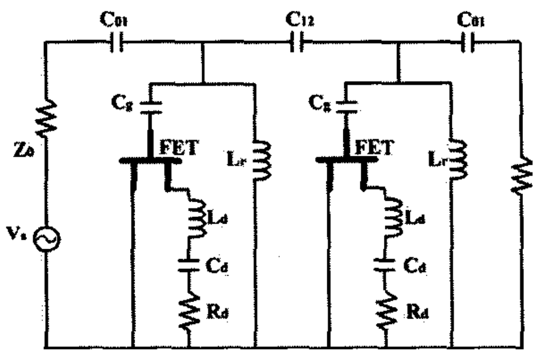

Fig. 4. The second-order active filter circuit

Fig. 4 shows the second-order active bandpass filter using the J-inverter. In the experiments, the second-order active bandpass filter was designed at 1.9GHz band. The used active element is an Agilent GaAs FET, ATF-21186. The bias of GaAs FET is V_{ds}= 2 V and I_{ds}= 15 mA. The external lumped capacitor C_g is 0.5 pF. Fig. 5 shows the measured frequency response with almost zero insertion loss at center frequency. Its 3 dB bandwidth is about 52.5 MHz. Fig. 6 shows the wide frequency responses of the second-order active bandpass filter. Fig. 7 shows the measured noise figure of the fabricated active bandpass filter. The noise figure is about 2.6 dB at center frequency. Fig. 8 shows the measured intermodulation distortion of the fabricated active bandpass filter. The OIP3 of active bandpass filter is 8 dBm. Table I shows the comparison data of the measured and simulated active bandpass filter performances.

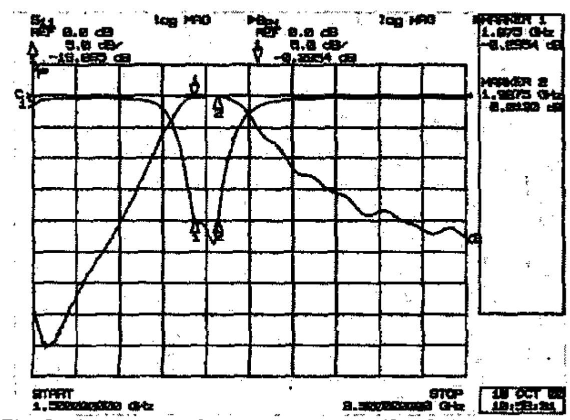
Fig. 5. The measured frequency responses (S_{21}, S_{11})

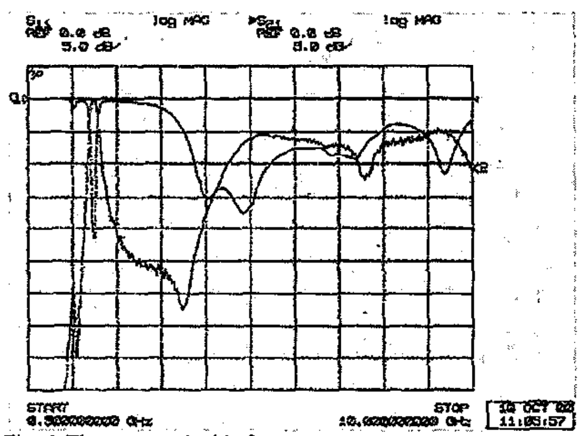
Fig. 6. The measured wide frequency responses

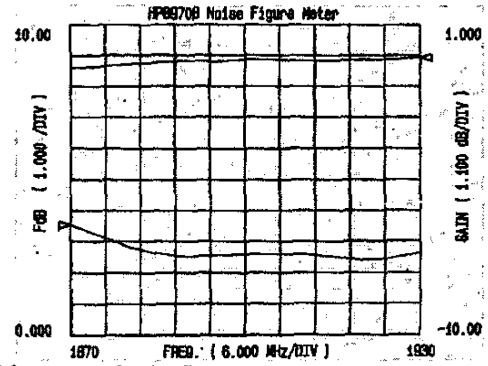

Fig. 7. The measured noise figure

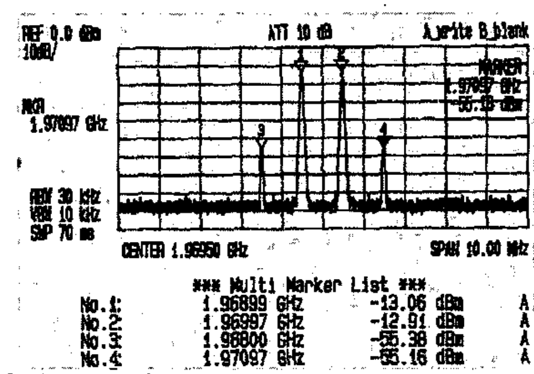

Fig. 8. The measured IM

TABLE I.
THE COMPARISON DATA OF THE SIMULATED AND MEASURED PERFORMANCES

	Simulated	Measured
C.F (GHz)	1.884	1.9
BW (MHz)	63	52.5
I.L (dB)	-0.3	-0.3
Ripple (dB)	0.35	0.3
N.F (dB)	2.53	2.7

IV. CONCLUSION

In this paper active bandpass filters using a new type of active resonators have been presented. The active resonator is made of active device such as BJT and HEMT, and its equivalent circuit is derived as an active capacitor consisting of a resistor having negative value and a conventional capacitor. From the theoretical analysis it is found that the active capacitor provides a negative resistance to compensate for the loss introduced by inductor when used as a resonator.

The proposed active bandpass filter is compatible with IC technology and the low noise performance of the active bandpass filters is also essential in the design of receiver RF front-end chip. The disadvantages of such active filters are that the active element must consume the DC power and its nonlinear characteristics may introduce distortion. However, it is believed that active devices working at low operating current are continuously developed and their nonlinear characteristics are also being improved. The possibility of the integration of all RF components onto a single chip can override such disadvantages.

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