C-Band Negative Resistance Bandpass filter with HEMT Technology

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Abstract—In this paper, we especially analyze in detail the active capacitance circuit and its Negative resistance characteristic. We used ADS2009 to perform simulations. Through the simulated results, it is shown that the proposed RF active filter can be applicable to the narrow bandpass filter (BPF) design, which also is stable and possesses Low-noise characteristics. The frequency range in which the circuit has negative resistance is 3-8GHz. And center frequency is 5.5GHz. We have 1.2dB gain at the center frequency and quality factor (Q) is 32. The noise-figure of active filter is 1.7dB at the center frequency. In general, the K factor is larger than unity and the circuit absolutely stable at the frequency range.

Index Terms— bandpass filters (BPFs), active capacitance circuit, negative resistance and HEMT

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1 INTRODUCTION

Monolithic microwave integrated circuit (MMIC) RF integrated circuit (RFIC) technology becomes popular as GaAs-and Si-based processes mature today. Even though there has been much effort to integrate into a single chip with the whole system, one of the major difficulties to accomplish a fully integrated RF front-end is the integrated RF bandpass filters (BPFs).

When we shrink the volume of an integrated RF filter, it shows poor performances. It still requires more progress for commercial usage, whereas there have been several attempts to overcome this problem, such as active resonators, since the 1960s [1] [2] [3] [4] [5] [6] [7] [8] [9] and RF micro electromechanical systems (MEMS) filter designs [10] [11] [12] [13] [14]. On the other hand, the design of passive filters has been extensively studied over the last 50 years. The major interest in the design of miniaturized narrow BPFs is the low insertion loss, which requires resonators with a high-quality (Q) factor. It is well known that the smaller resonator, the smaller their Q values. Therefore, increasing Q with a smaller resonator size is the key for the integrated BPF design. During the past ten years, numerous researchers have published active filter design methods based on active resonators [1] [2] [3] [4] [5] [6] [7] [8] [9], active couplings [15] [16] [17], or other schemes [I18] [19] [20] [21] [22].

For active BPFs 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. Some of active BPFs, unfortunately, did not show good noise figures, and the other types are not applicable to the narrow BPF design. Also, it could be possible to face a problem that a negative resistance circuit becomes unstable because of an insufficient forecast for the negative resistance value as the frequency varies. Reference [25] shows the feasibility for an active filter using a negative resistance circuit to have a good noise performance. In this paper, we especially analyze in detail the new type of active resonator based on an active capacitance circuit. We also present its design method based on the conventional microwave passive BPF design using admittances inverter theory. We wish to discuss the frequency-response characteristic of equivalence resistance for the circuit, which has a series feedback circuit of a common-source structure, as depicted in Figure 1(a). Through the simulated and measured results, it is shown that the proposed RF active filter can be applicable to the narrow BPF design, which also possesses low-noise characteristics.

2 NEGATIVE-RESISTANCE THEORY

We Most of the negative resistance topologies are composed of common-source or common-gate series feedback structures. These feedback structures are usually used for oscillator design, and the noise performance of overall circuits is degraded by a series feedback structure. The proposed topology is common-source and an R–L–C series feedback structure. Figure 1(a) shows the structure and equivalent circuit of this topology. It is different from the conventional types in the oscillator design methods. It does not use a common-gate series feedback structure or any additional drain- or source-to-gate parallel feedback paths, which may decline the noise performance.

Therefore, the noise performance can be improved by the proposed topology. The active capacitor made of a field-effect transistor (FET) exhibits a negative resistance

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property, as well as capacitive property. This topology is simple in structure and could be conveniently applied to the narrow-band filter design. Figure 1(b) represents the equivalent circuit of Figure 1(a).

In Figure 1(b), the input admittance can be written as follows:

$$Yin = \frac{Z_1 + Z_2 + Z_d + gmZ_1Z_d}{Z_1(Z_2 + Z_d)} \qquad (1)$$

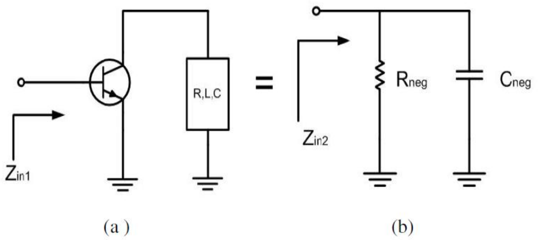

Fig. 1. (a) Proposed active capacitance circuit (b) its simple equivalent circuit

Where the parameters are:

$$Z_1 = \frac{1}{j\omega C_{gs}} = -jX_1 \quad , Z_2 = \frac{1}{j\omega C_{gd}} = -jX_2$$

$$Z_d = R_d + j(\omega L_d \frac{1}{j\omega C_d}) = R_d + jX_d$$

And $X_1, X_2 > 0$

These relationships can be summarized as follows in (2) as concerns all series feedback circuit elements:

$$Y_{in} = \frac{R_d}{\xi} + \frac{gm}{\xi}(R_d^2 + (X_d - X_2)X_d) + j\left(\frac{1}{X_1} - \frac{X_d - X_2}{\xi} + \frac{gmX_2R_d}{\xi}\right) = \frac{1}{R_{neg}} + j\omega C_{eq} \qquad (2)$$

$$\xi = R_d^2 + (X_d - X_2)^2 \qquad (3)$$

TABLE 1
PARAMETERS A SERIES FEEDBACK CIRCUIT FOR INSTANCE

g_m	R_d	L_d	C_d
60mS	15Ω	2nH	12pF

In the real part of (2), we can find the frequency range in which the circuit has negative resistance, as shown in (4) at the bottom of this page, where

$$f_{low} = \frac{1}{2\pi\sqrt{L_d C_{low}}} \qquad f_{up} = \frac{1}{2\pi\sqrt{L_d C_{up}}} \qquad (4)$$

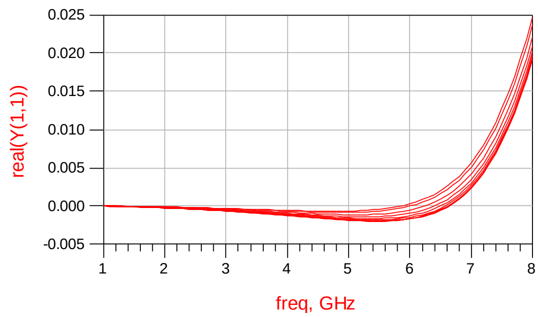

Fig. 2. Frequency responses as the feedback resistance (Rd) vary.

3 DESIGN OF THE BPF

It is possible to design a low-noise active microwave filter through the above analysis. The basic filter design procedure follows Cohn's for the design of direct-coupled resonator filters [24]. We have adopted the shunt resonator coactively coupled configuration. This configuration was also considered when it was analyzed above. The value of inductors was determined by the availability of commercial chip inductors. At first, we considered the simple active capacitance circuit, as shown Figure 1, for convenience.

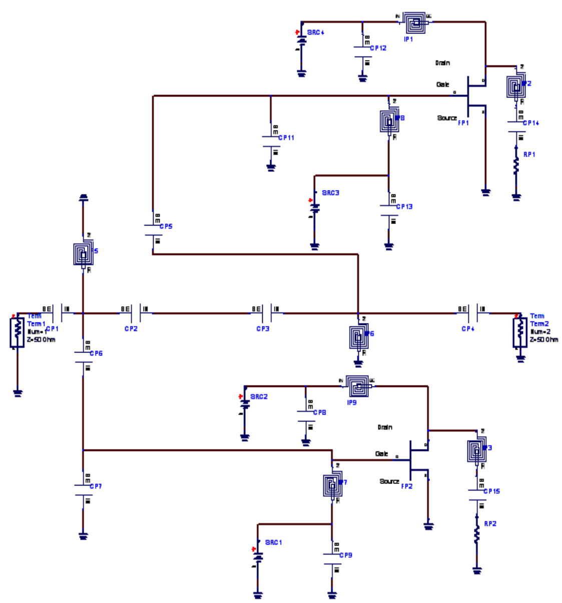

Fig. 3. Block diagram for the designed two-pole active BPF.

Using the small-signal equivalent-circuit parameters of an HEMT, we can calculate the equivalent admittance of an active capacitance, as shown in (1) and (2). For convenience, we have determined the initial values of series feedback parameters and under the condition of. These values can be calculated using (4) when the frequency range at which an active capacitance circuit should have negative resistance is defined. For the stability and low-noise property, we should adjust the value of. Increasing makes an active capacitor have low negative resistance and shrink the frequency range with negative resistance, as shown in Figure 2. We decided the initial values of and with the consideration of these characteristics. After we designed a series feedback network, we should tune the resonance frequency by adding and. Even though it influences the negative-resistance value, its variation is limited. We can substitute a passive resonator with a novel active resonator through the above procedure.

4 Experimental Results

Figure 3 shows the schematic of a second-order active BPF using an active capacitance circuit. It has a center frequency of 5.5 GHz and a bandwidth of 150 MHz. The resonance circuit is composed of an active capacitance circuit and a shunt inductor Lr of which value was decided by the convenience of obtaining. At this example, we have an inductance of 2nH. The active capacitance circuit is composed of an HEMT-ED02AH Technology, and commercially available lumped elements.

The bias condition for the Transistor, Vds=3V و Vgs=-.5V و Ids=22mA .Under this bias condition, it has low noise property and a stable operation can be obtained. The quality factor (Q) of an inductor can be enhanced by the negative resistance circuit, which can compensate the losses of the resonator. Using its equivalent-circuit model, we can perform simulations to estimate the equivalent admittance. We at first chose the feedback elements Ld and Cd under the condition of Rd=15Ohm. In this example, the frequency range with negative resistance is limited from 3 to 8 GHz. We can determine the values for Ld and Cd . If Cgd=1.5pF, the initial value can be Cd=15pF and Ld=2nH. They should be adjusted when we consider the situation that is not Zero and the parasitic from microstrip lines used for the soldering and interconnections. The growing forces to have lower value because larger reduce, as discussed in Section II. Also, we should use larger capacitance for and lower inductance for when we insert microstrip lines. Also, adding and could adjust the capacitance of an active capacitor for an active resonator to have its resonance frequency of 5.5 GHz. We can optimize the feedback parameters and external capacitors using commercial simulators.

TABLE 2
Feedback Circuit Parameters for a Comparison

	R_d	L_d	C_d
I	15	2nH	15pF
II	20	3nH	30pF

In order to get equal insertion loss in the passband and good stability, we designed series feedback circuits (Zd) so that an active resonator takes adequate negative resistance values and an overall stability factor (K) of an active filter is large enough. For the purpose of demonstrating the dependency between Zd and the flatness at the passband, and the stability of an active BPF, two types of active resonator, which have the same topology with different values of series feedback circuits, are chosen. The detailed circuit parameters are noted in Table 2.

The simulated result using Agilent's Advanced Design System (ADS 2009) of an active resonator circuit shows that it resonates at 5.5 GHz and has a negative resistance around 5.5 GHz.

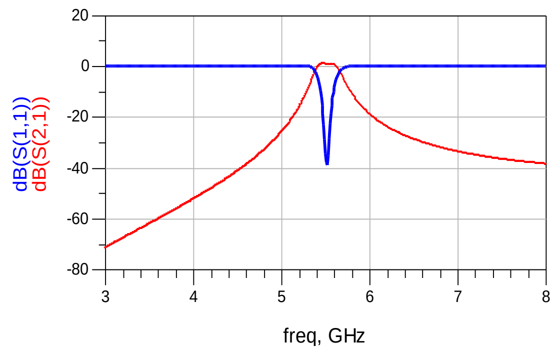

Fig. 4. S parameter of the active BPF

A stability problem might be critical for the existence of a feedback circuitry. If the circuit is not absolutely stable over the entire frequency range, oscillation would cause a problem.

The oscillation may cause gain degradation, increasing noise, and so on. In order to keep the circuit absolutely stable, we observed the stability factor (K factor). We can say a circuit is stable, in general, if K the factor is larger than unity. We added a series resistor at the drain feedback circuit in order to enhance the stability, as well as the flatness at the passband. The circuit would be unstable if the negative resistance of the HEMT exceeds the inductor loss. As the drain resistance Rd, which reduces them negative resistance, goes to a higher value, the stability factor becomes more than unity, 15Ohm of Rd for a stable operation and low insertion loss. In this case, the noise figure was also considered, and it was durable for usage also shows the simulated frequency response with almost zero insertion loss at the center frequency of 5.5 GHz. Its 3-dB bandwidth is approximately 150 MHz. Figure 5 shows the simulated noise figure active BPF. The simulation noise figure is approximately 1.7 dB at the center frequency and Q=32.

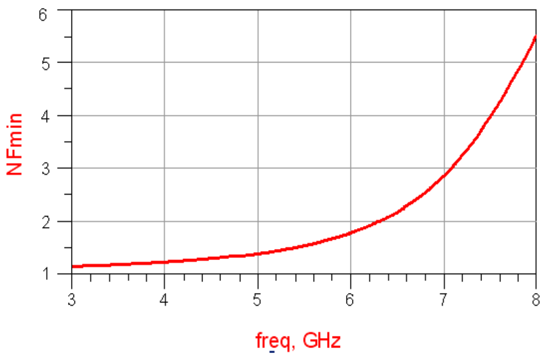

Fig. 5. Noise figure of the active

5 Conclusion

We have presented a low-noise active BPF using a new type of active capacitor. The active capacitor could be made of high electron-mobility transistor (HEMT), and its equivalent circuit was derived. From theoretical Analysis, we have found that the active capacitor provides a negative resistance to compensate for the loss introduced by inductor when used as a resonator. At the same time, it was also shown that low-noise performance could be obtained by adopting this topology and the theoretical analyses were discussed.

In detail Compared with conventional design methods of the active filters, the proposed scheme is better in several areas such as less complexity, reliability of a narrow bandwidth, and better noise performance. We have verified the low-noise property of the proposed filter by analyzing and measuring it.

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