Third order Butterworth bandpass filter using Active inductor

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Abstract—In this paper active inductor circuits are employed to assess their suitability for providing a tuning function in 0.18-μm 1.8-V standard RFCMOS and ED02AH HEMT technology, MMIC circuits. The specifications for a mobile handset bandpass filter operating from a 3V supply rail are used as test vehicles. The design and simulation of the circuits employs a low-cost commercially available low pinch-off RFCMOS and HEMT process. The suitability of active inductors for tuning in such applications considers issues such as frequency tuning range, noise, power consumption and stability.in this paper we compare S21, impedance matching and Gain ripple in filter active RFCMOS technology with HEMT technology in the same state. We used Advanced Design Circuit (ADS) Software for all Design and Simulation.

***Keywords*—Active inductors, MMIC, RFCMOS, HEMT**

I. INTRODUCTION

In a previous paper [1], a number of active inductor circuit topologies were analyzed and compared to assess their suitability for performing a tuning function in MMIC applications. The simulation work was based on a low-cost commercially available low pinch-off voltage GaAs MESFET process [2]. The low pinch-off voltage requirement enabled the circuits to function from a relatively low power supply rail (<3 V). This was believed to be an important consideration in the context of mobile communication handset applic-ations. Issues such as inductance range, inductance bandwidth, series resistance and power consum-ption figured highly in this initial work for the same reasons. The simulation work, whilst employing reasonably accurate models for the active devices in the circuits did not consider the effect which the parasitic components introduced by the layout and passive components would have on the figures of merit mentioned above. The work also did not consider the practicality of using such inductors in a typical application.

In this paper, we describe the problems encountered in the utilization of the active inductors when applied to a filter design. For continuity these two circuit applications employ the RF CMOS and ED02AH technology low pinch-off voltage process.

II. DESIGN FILTER

The circuit topology selected to fulfill the bandpass filter specifications was a third-order Butterworth filter as shown in Figure 1. This circuit and the design procedures have been extensively documented. It was soon determined that the frequency range over which the filter could be tuned solely by altering the inductances was not as large as for the amplifier. In fact the same frequency span could only be achieved by altering the capacitor values as well as the inductances. These results do not take into account interconnect effects and, design considered previously, the passive components were represented as ideal components. The use of more realistic models for the passive elements, especially the inductors, yielded very poor performance due to the losses or poor Q of the components.
Although the need for variable capacitors could be overcome by utilizing active capacitors

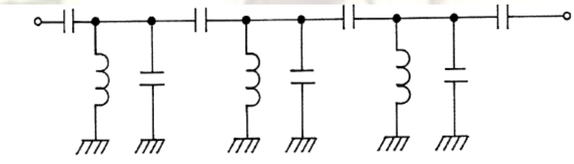

Fig1. Third-order Butterworth filter

This aspect is beyond the scope of this paper. The active filter design will therefore concentrate on the higher of the two frequency bands since this is more relevant to existing and possible future mobile systems.

III. THEORY ACTIVE INDUCTORS

To alleviate the limitations imposed on the chip area and the quality (Q) factors of the spiral inductors, active designs [3]–[15] were proposed to implement the required on-chip inductance.
For RF applications, the regulated cascade topology is commonly used in the design of CMOS active inductors [16].

Fig. 2(a) shows the schematic of the active inductor. As the input voltage applies to the gate terminal of the common-source transistor M1, the transconductance gm1 converts the voltage to a drain current charging the capacitance Cgs2 of transistor M2. The voltage established across Cgs2 is then converted to the input current by the transconductance of M2, emulating the current–voltage characteristics of a shunt inductance. Note that the transistor M3 is used as the gain-boosting stage to enhance the Q factor of the active inductor, while the required bias currents for M1 and M2 are provided by the current mirrors. From the small-signal analysis, the nodal voltages and can be expressed as M4-M7 from the small-signal analysis, the nodal voltages V1 and V2 can be expressed as

$$V_1 = -\frac{g_{m1}}{sC_{gs3}+g_{m3}} V_{in} \quad (1)$$

$$V_2 = \frac{s^2C_{gs3}+sC_{gs2gm3}-gm1gm3}{s^2C_{gs2}C_{gs3}+sC_{gs2gm3}+sC_{gs3gds4}+gm3gds4} Vin \quad (2)$$

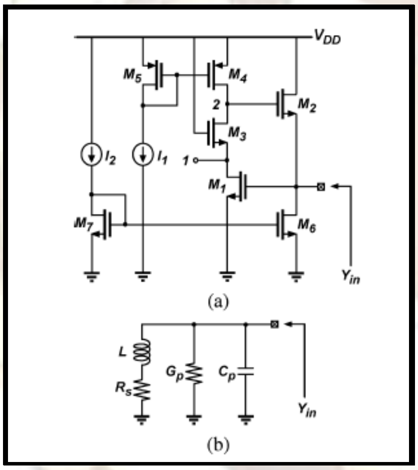

Fig. 2. (a) Schematic and (b) equivalent circuit of the regulated cascode active inductor.

And the input admittance of the active inductor is given by

$$Y_{in} = \frac{1}{Z_{in}} \approx \frac{g_{m1}g_{m2}g_{m3}}{sC_{gs2}\left(g_{m3}+sC_{gs3}\right)} + \frac{g_{m1}g_{m3}}{g_{m3}+sC_{gs3}} + sC_{gs1} \quad (3)$$

Assuming that the operating frequency of the active inductor is much lower than the cutoff frequency of M3, which can be expressed as $W_{T3}=g_{m3}/C_{gs3}$, the input admittance of the active inductor can be approximated by the equivalent circuit, as shown in Fig. 2(b), and the expressions of the L ,R_s ,G_p , and C_p are provided as

$$L \approx C_{gs2} / (g_{m1}g_{m2}) \quad (4)$$

$$R_s = -\omega^2 C_{gs2}C_{gs3} / (g_{m1}g_{m2}g_{m3}) \quad (5)$$

$$G_p = g_{m1} \quad (6)$$

$$C_p \approx C_{gs1} \quad (7)$$

For an active inductor, the value of the inductance L is determined by the small-signal circuit parameters of M1 and M2 , while the Q factor is strongly influenced by the values of G_p and R_s. In the equivalent circuit, G_p represents the shunt conductance, accounting for the loss of the active inductor. On the other hand, Rs is a negative resistance with frequency-dependent characteristics. Based on the simplified circuit model, the resonant frequency of the active inductor is given by

$$f_{RES} = \frac{1}{2\pi\sqrt{LC_P}} = \frac{1}{2\pi}\sqrt{\frac{g_{m1}}{C_{gs1}}}.\sqrt{\frac{g_{m2}}{C_{gs2}}} \approx \frac{1}{2\pi}\sqrt{W_{T1}W_{T2}} \quad (8)$$

Note that $W_{T1}$and W_{T2} are the cutoff frequencies of M1 and M2, respectively, which impose a fundamental limitation on the operating frequencies of the active inductors. Typically, the active inductors are operated at frequencies much lower than the resonant frequency to ensure the desirable circuit characteristics.
mode. As the amplitude of the signal power increases, the excess voltage swing leads to a decrease in the transconductance of the transistors. The inductance L thus deviates from its small-signal value due to the nonlinear characteristics, resulting in undesirable signal distortion. Therefore, the impact of the linearity issues on the circuit performance should be carefully examined when the active inductors are used to replace the spiral inductors in MMIC designs. For a CMOS active inductor using the regulated cascade topology, the deviation in the transconductance due to large-signal operations can be effectively minimized by increasing the overdrive voltage and by reducing the transistor size at the expense of an elevated supply voltage.

IV. DESIGN OF THIRD ORDER BUTTERWORTH BANDPASS FILTER USING RFCMOS

A. DESIGN ACTIVE INDUCTOR RFCMOS

Figure 3 shows schematic active inductor 0.18 μm RFCMOS technology. From (4), the value of L is governed by the transconductances g_{m1} and g_{m2}. Hence, the equivalent inductance can be adjusted by the bias currents I_1 and I_2, resulting in another degree of freedom for the circuit operation. In (3), the value of the inductance L is determined by thetransconductance g_{m1} and g_{m2}, which are considered constant under small-signal approximation. However, it is not very accurate for the active inductors operating in the large-signal. Figure 4 shows Measured equivalent inductance at various bias currents (I1, I2).

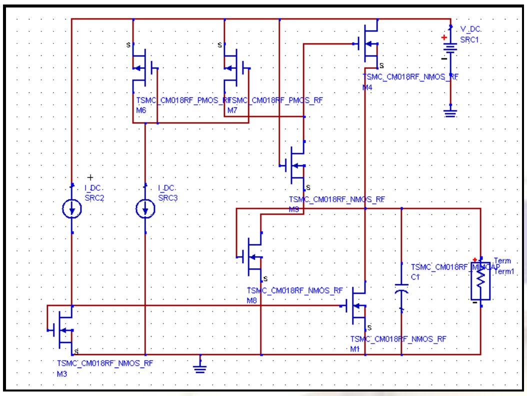

Fig 3. Schematic active inductor

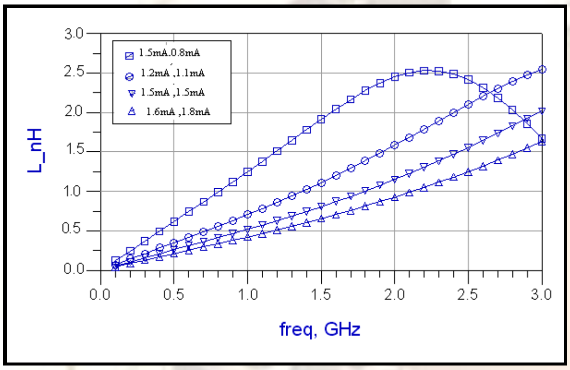

Fig. 4. Measured equivalent inductance at various bias currents (I_1, I_2).

B. DESIGN OF FILTER WITH COMPONENT ELEMENT

We first design Filter with RFCMOS component element. Figure 5 shows Schematic Design of component element. Fig 6 And 7 Shows the Result of Filter with Component Element in 2GHz center frequency.

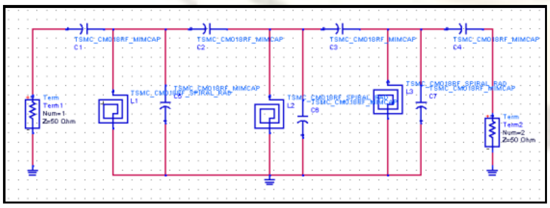

Fig 5. Schematic Design of component element

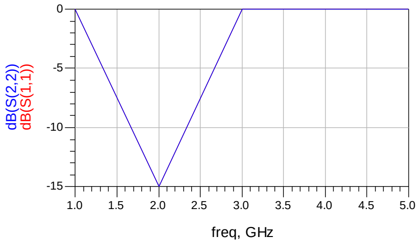

Fig 6. Impedance Matching Butterworth Filter with Component Element

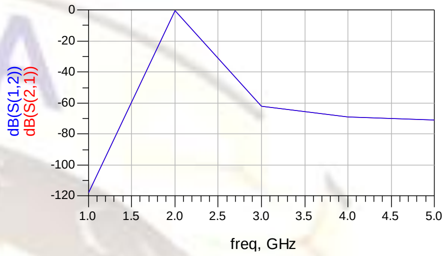

Fig 7. dB (S21) and dB(S12) Butterworth Filter With Component Element

C. DESIGN OF FILTER WITH ACTIVE INDUCTOR

In this step we use active inductor instead of component inductor. Fig 9 to 11 shows the Result of Third order Butterworth Filter with Active inductor in 2GHz center frequency.

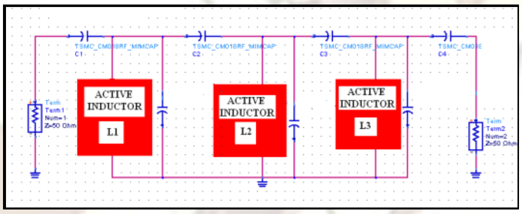

Fig 8. Schematic of Third order Butterworth Filter active inductor

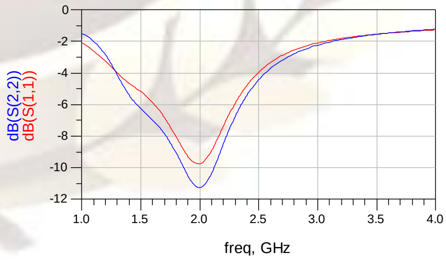

Fig 9. Impedance matching of Third order Butterworth Filter active inductor

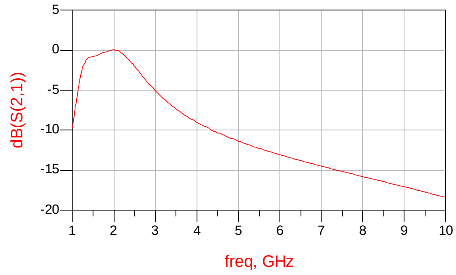

Fig 10. dB (S21) of Third order Butterworth Filter active inductor

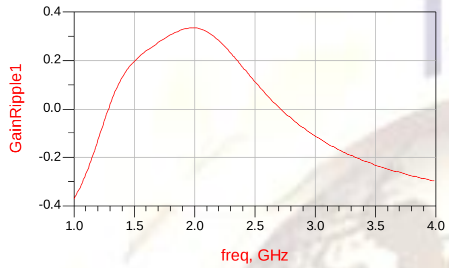

Fig 11.Ripple of Third order Butterworth Filter active inductor

V. DESIGN OF THIRD ORDER BUTTERWORTH BANDPASS FILTER USING HEMT

A. DESIGN ACTIVE INDUCTOR HEMT

Figure 12 shows schematic active inductor ED02AH, HEMT technology and Figure 13 shows measured equivalent inductance at various bias currents (I1, I2).

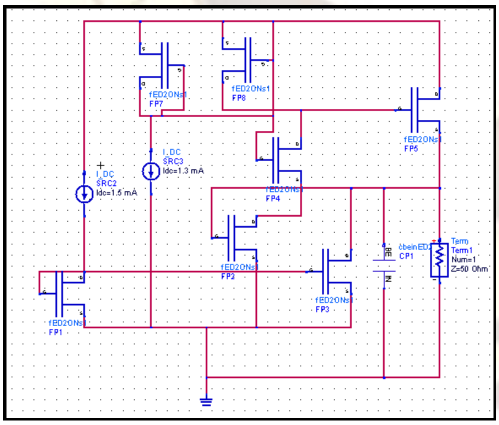

Fig 12. Schematic active inductor for this work

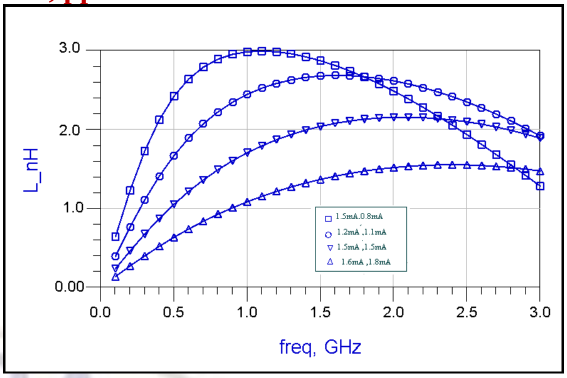

Fig. 13. Measured equivalent inductance at various bias currents (I_1, I_2).

B. . DESIGN OF FILTER WITH COMPONENT ELEMENT

We first design Filter with HEMT component element. Figure 14 shows Schematic Design of component element. Fig 15 And 16 Shows the Result of Filter with Component Element in 2GHz center frequency.

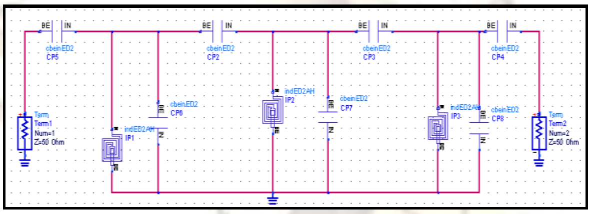

Fig 14. Schematic Design of component element

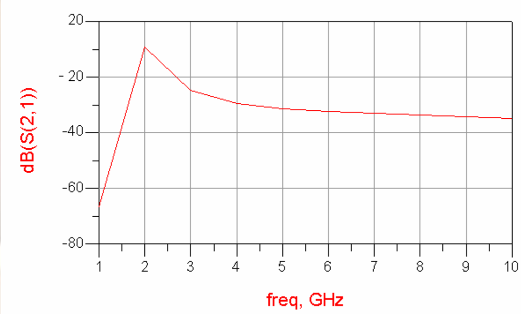

Fig 15. dB(S21) and dB(S12) Butterworth Filter With Component Element

Fig 16. Impedance Matching Butterworth Filter with Component Element

C. DESIGN OF FILTER WITH ACTIVE INDUCTOR

In this step we use active inductor instead of component inductor. Fig 18 to 20 shows the Result of Third order Butterworth Filter with Active inductor in 2GHz center frequency.

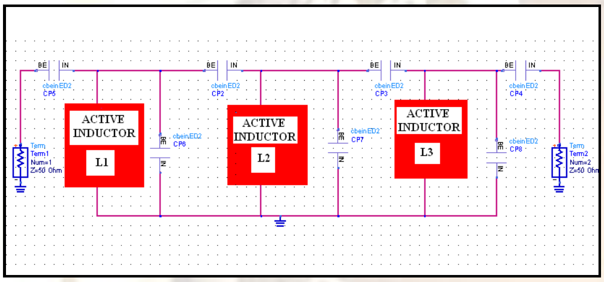

Fig 17. Schematic of Third order Butterworth Filter active inductor

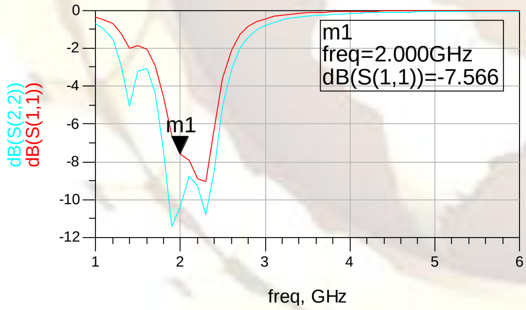

Fig 18. Impedance matching of Third order Butterworth Filter active inductor

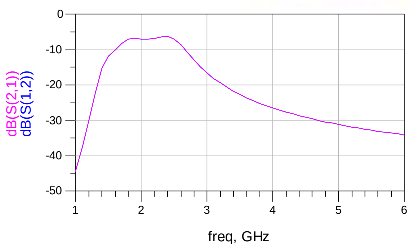

Fig 19. dB(S21) of Third order Butterworth Filter active inductor

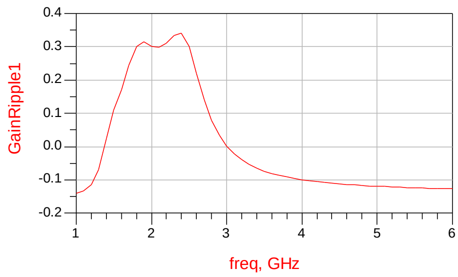

Fig 20.Ripple of Third order Butterworth Filter active inductor

TABLE I
COMPARE FILTER ACTIVE RFCMOS AND HEMT TECHNOLOGY

	RFCMOS	HEMT
frequency	2 GHz	2 GHz
S21	0.3dB	-7dB
S11	-9.1dB	-7.566dB
S22	-11.2dB	-11.2dB
Gain Ripple	0.32	0.3

VI. CONCLUSIONS

In this work we present Design with two technology RFCMOS and HEMT .achieved result, for Impedance matching and (S21) the result RFCMOS technology better of HEMT but result Ripple is inverse.

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