Active Inductor Design for Reconfigurable Bandpass Microstrip Filter Applications

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Abstract ─ Herein, the design of an active inductor and its typical application for a reconfigurable band-pass filter circuit are presented. The Active Inductor design consists of a passive variable phase and amplitude compensating network and a highly linear inverting amplifier in order to form a gyrator-C design. The design allows a wide frequency range for tuning the equivalent inductance and resistance values that enable it to be used as a filter design where the inductor equivalent resistance increases and improves signal rejection for band-pass filter applications. As a typical application, first-order active band-pass filter had been designed and prototyped. The simulation and measurement results of the design are compared with the performance results of counterpart designs in literature. From the experimental results, it can be concluded that the proposed design is a suitable model for design of tunable band pass filter circuits. The design has an operation band of 0.7-2.1GHz with the equivalent inductance value of 2.6nH.

Index Terms ─ Active inductor, band-pass filter, gyrator-C, reconfigurable, UHF Band.

I. INTRODUCTION

A challenge for research is now to design devices that are reconfigurable and adaptive (or tunable) for their characteristics to switch from one standard to another [1-2]. Moreover, whether it is in transmission or receiver mode, the signal filtering is a core function of the processing chain because it realizes the separation of useful signals that one wishes to deal and of out-of-band signals that one wishes to reject. Similarly, the important development of RF equipment imposes new constraints on microwave channels. One of the most critical functions is the re-configurability in the RF filtering. This requires a wide band tuning to meet new specifications, whether technical or financial, and can adapt the model associated with different standards.

Most of traditional architectures of tunable band pass filters use the spiral inductors that include many limitations such as a low Q factor, small and not-tunable inductance, a low self-resonant frequency and a large silicon area [3-4]. Therefore, in order to resolve these crucial problems, realization of Active Inductors (AI) becomes a more promising option having the particular advantage of wide frequency tuning, necessary for multi-standard systems [5-8]. AI shows small silicon area (it only takes about 1% -10% of passive inductor area), a higher inductance value, efficient frequency tuning range, and higher Q factor which make AI a suitable solution for design of tunable filter.

In this work, design of an AI for a typical application of tunable band-pass filter circuit had been studied. Firstly, an AI design which is consist of a passive variable phase, amplitude compensating network and a highly linear inverting amplifier in order to form a gyrator-C design has been studied. The proposed AI design achieves a wide frequency range for tuning the equivalent inductance and resistance values, which make it a suitable solution for being the tuning element in a band pass filter design. In Section IV, a typical application of a first-order active band pass filter circuit has been presented, using the AI model deigned in Section III. The simulated results had been justified with the experimental results. Furthermore, the proposed AI based band-pass filter design had been compared with the counterpart design in literature. From the experimental results, it can be concluded that the proposed design is a suitable model for design of tunable band pass filter circuits.

II. GYRATOR PROPERTIES AND NON-IDEALITIES

The realization of an active inductor relies on the basic gyrator theory [9-13], where two trans-conductors are connected end-to-end and one end of the gyrator is

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bonded to a capacitor as shown in Fig. 1 [14].

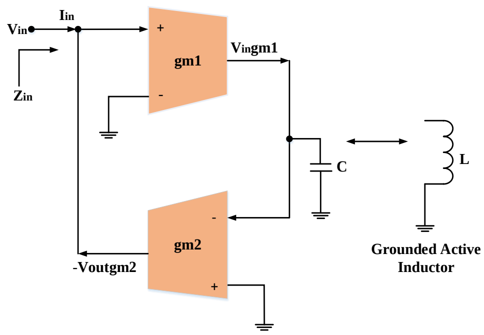


Fig. 1. Basic concept of a gyrator-C.

The expression of its input impedance Z_{in} is expressed as follows:

$$Z_{in} = \frac{V_{in}}{I_{in}} = \frac{j\omega C}{g_{m1} g_{m2}} . \tag{1}$$

Then the equivalent inductance is given by:

$$L = \frac{C}{g_{m1} g_{m2}} . \tag{2}$$

In this case, the realization of an active inductance can be performed by using simple trans-conductance transistors having a similar effect of gyrator. Since these transistors have intrinsic parasitic capacitances, the simulation of the inductance is based on the idea of using these parasites. So, we have no need of external capacity, which is an important technique for minimizing the circuit size.

III. ACTIVE INDICTOR

In Fig. 2 a schematic for an AI design using medium-power bipolar transistors are given. The design consists of a common collector non-inverting and a common emitter inverting trans-conductance amplifiers using BFP450 BJT transistors. In Table 1, a list of the elements used in AI design is presented.

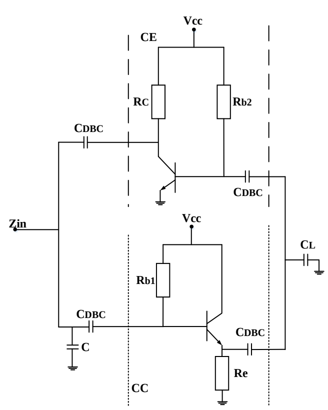


Fig. 2. Simplified schematic of AI design.

Table 1: List of the elements used in AI design

R_{b1}	10 Ω	**C**	4.7pF
R_{b2}	200 Ω	**C_L**	15 pF
R_e	100 Ω	**C_{DCB}**	10pF
R_c	220 Ω	**Substrate**	FR4,1.56mm

The BFP450 [15] is a high linearity wideband NPN bipolar RF transistor. The collector design supports voltages up to V_{CEO}= 4.5 V and currents up to I_C= 170 mA. With its high linearity at currents as low as 50 mA the device supports energy efficient designs. The typical transition frequency is approximately 2.4 GHz, hence the device offers high power gain at frequencies up to 3 GHz in amplifier applications. The simulated input impedance results of the design is given in Fig. 3, where the real values of the input ımpedance has a variation around of 2-3 Ω and the imaginary part has a variation of 2-60 Ω over the frequency band.

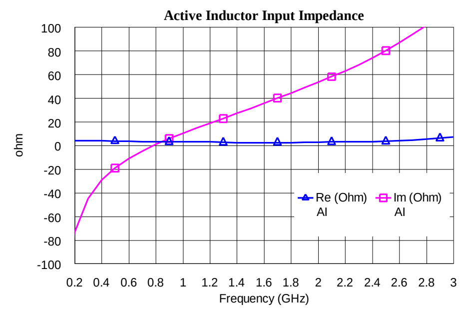
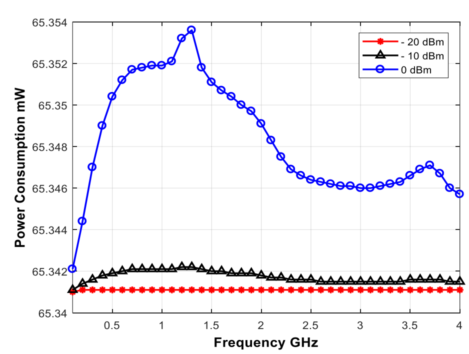
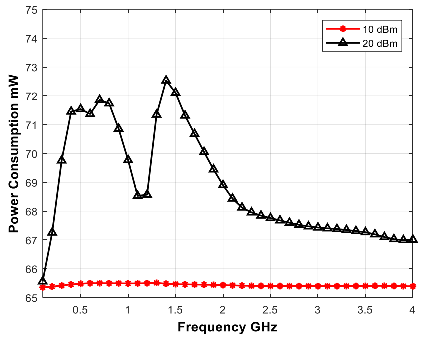


Fig. 3. Simulated input impedance for V_{CC}= 3 V.

In Fig. 4 the simulated results of different input power of -20 dBm to +20 dBm with step width of 10 dBm is applied to the input of the AI design to analyse the power consumption. The design's power consumption is stable within the range of -20dBm to 10dBm which is around 65mW while the design start to consume 10% more power (72mW) with +20dBm input power. Thus, it can be concluded that the transistors used in design enter in saturation state after 10 dBm input power.



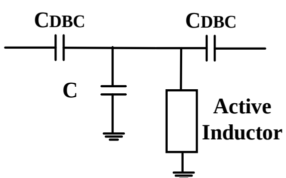
(a)



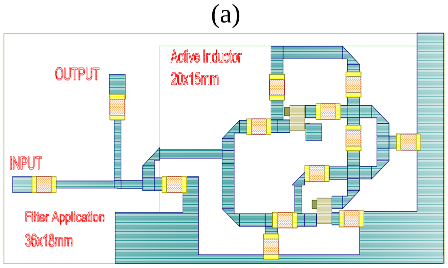
(b)

Fig. 4. Power consumption for input power of: (a) -20dBm, 0dBm and (b) 10dBm, 20dBm for V_{CC}= 3 V.

In Fig. 5 (a) the schematic of a first-order band pass filter with AI is given where with this concept it is possible to achieve high Q value in designs. Moreover since usage of a spiral inductor requires larger space in substrate, has narrow band, impedance and interference usage of active inductor which provides higher band and higher Q factor value is much efficient than the traditionally spiral inductors. Also in Fig. 5 (b), the schematic layout of the AI filter is given.



(a)



(b)

Fig. 5. AI based filters: (a) schematic and (b) layout.

IV. A TYPICAL APPLICATION: ACTIVE BAND-PASS FILTER

Herein, the measurement results of the fabricated first-order active Band-Pass filter design given in Fig. 6 are studied. The filter design has been fabricated on a FR4 substrate using standard SMD passive components and two BFP450 transistors. The measured S_{11} & S_{21} parameters of the prototyped filter have been obtained using an Anritsu 37397d vector network analyzer and had been presented in Fig. 7 alongside of the simulated results.

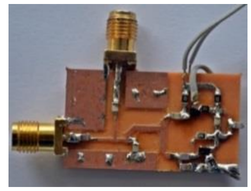


Fig. 6. Fabricated AI-based band-pass filter.

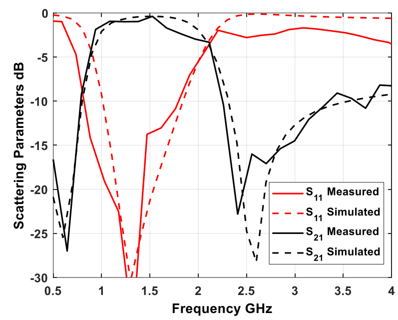
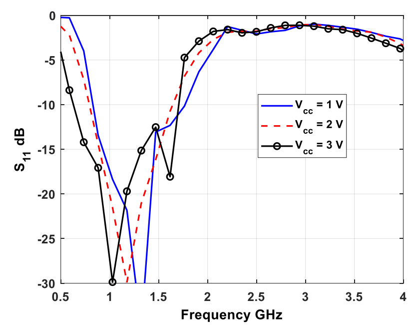
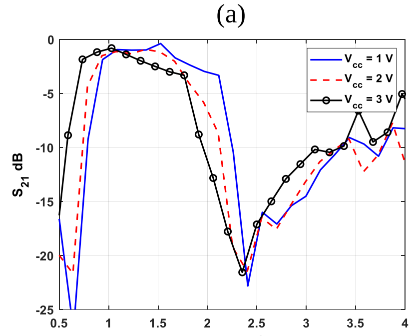


Fig 7. Simulated and measured scattering parameters for V_{CC}= 1V.

As it can be observed from Fig 8, by changing the DC bias voltage value of AI from 1-3 V it is possible to shift the frequency of the band pass filter by 300MHz. Furthermore, in Table 2 a compression of the proposed AI based filter with counterpart design has been presented.



(a)



(b)

Fig. 8. Measured: (a) return loss and (b) insertion loss, with respect to the variation of voltage.

Table 2: Comparison of the proposed filter design with counterpart models in literature

Model	Type	Order	f_c or Tunining Range GHz	Bandwidth GHz	Voltage Range
Here	SiGe	1	1.165-1.435	~1	1 to 3
[5]	SiGe	1	0.6	0.3	---
[14]	0.35um CMOS	4	0.52-0.72	0.25	2.7
[16]	0.45um CMOS	2	2.56	0.03	+/-1
[17]	0.35um CMOS	2	0.980-1.09	---	2.7

V. CONCLUSION

As it can be seen from the measurement results, a suitable model for design of a tunable AI had been achieved. The design has an operation band of 0.7-2.1GHz with the equivalent inductance value of 2.6nH. Also, for a typical application example for the designed AI, it implementation for a first order band-pass active filter is studied. The measured scattering parameter performance of the tunable band pass filter make it a suitable candidate for use in practical system applications.

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