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Design and Realization of Broadband Active Inductor Based Band Pass Filter

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Abstract — With the latest developments in the wireless communication systems, the alternative design methodologies are required for the broadband design of microwave components. In this paper, a compact broad band pass filter (BPF) design is introduced through the microwave design technique based on the active inductor (AIN) with the numerical computation and experimental measurement studies. The proposed AIN based BPF has operating frequency band extending from 0.8 GHz to 2.7 GHz in compact size with high selectivity in comparison to conventional LC based BPF. The experimental measurement results agree well with the numerical computation results. The proposed AIN based BPF design has technical capability to be conveniently tuned to operate at different frequency bands.

Key words — UHF Band, Bandpass filter, Gyrator-C, Active inductor, Microwave and electronic.

I. Introduction

The design of broadband microwave devices is one of the challenging problems in microwave engineering field. The signal filtering is at most importance in signal processing chain due to the need of separating the intended signals to be transmitted through the microwave device while filtering out the unintended signals to be rejected. One of the most critical requirement in high speed communication systems is that the filter design has to have a broadband operation frequency which also requires a high performance RF filtering.

One of the frequently addressed method in high performance filtering systems is the usage of tunable filters. Most of tunable band-pass filter designs usually use spiral inductors with the performance limitations including low Q factor, low inductance value without tuning capability, small self-resonance frequency and high silicon surface area [1]–[3]. One of the efficient solutions for the mentioned challenges is the realization of the active inductor (AIN), which has become a promising solution with the advantages to be listed as wide range of operation frequency and tuning capabilities for multi-standard systems [4]–[6]. AIN has a relatively small silicon surface area (approximately around 1%−10% of conventional inductors), adjustable inductance with high Q factor, which result AIN to be a suitable solution for the design of electronically tunable filters. However, the tunable inductor design usually suffers from low bandwidth and requires additional components to be included in the basic circuit topology to improve the RF performance.

In this paper, a broad band pass filter (BPF) design based on electronically tunable AIN is investigated with numerical computation and experimental measurement studies. In Section II, the implementation of gyrator-C design using microwave transistor (BFP720) is explained where the proper AIN implementation exhibiting a wide frequency range is utilized for the design of AIN based broad BPFs. In Section III, the fabricated prototype of AIN based BPF is presented with numerical computation and experimental measurement results along with the performance comparison to the

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conventional LC BPF model. In Section IV, the concluding remarks are conducted.

II. Active Inductor Design

AIN can be simply designed by placing two end-to-end connected transconductance amplifiers and one capacitor shown in Fig.1(a) [7]–[10], which is also known as gyrator-C design. The inductance of gyrator-C AIN is proportional to the load capacitance C and inversely proportional to the product of trans-conductance parameters of the gyrator design as $L_{\rm act} = C/g_{\rm m1}g_{\rm m2}$ for ideal transconductance amplifier operation. By using equations (1)–(3), it is possible to analytically calculate the scattering parameters of the AIN design. As it can be observed from (1) and (2), the scattering parameters of the design are reciprocal.

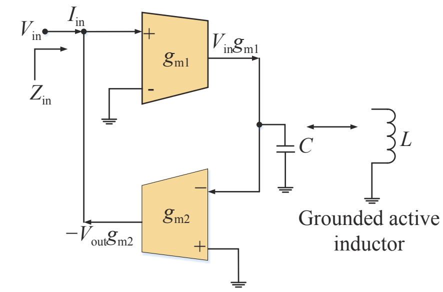
$$S_{22} = S_{11} = \frac{\dfrac{(j\omega C_{\rm DBC}Z_{\rm o}+1)Z_{\rm eq}}{j\omega C_{\rm DBC}(Z_{\rm o}+Z_{\rm eq})+1} + \dfrac{1}{j\omega C_{\rm DBC}} - Z_{\rm o}}{\dfrac{(j\omega C_{\rm DBC}Z_{\rm o}+1)Z_{\rm eq}}{j\omega C_{\rm DBC}(Z_{\rm o}+Z_{\rm eq})+1} + \dfrac{1}{j\omega C_{\rm DBC}} + Z_{\rm o}} \tag{1}$$

$$S_{12} = S_{21} = \frac{1+S_{11}}{\dfrac{(j\omega C_{\rm DBC}Z_{\rm o}+1)}{-\omega^2 C_{\rm DBC}^2 Z_{\rm o}Z_{\rm eq}} + \dfrac{1}{j\omega C_{\rm DBC}Z_{\rm o}} + \dfrac{(j\omega C_{\rm DBC}Z_{\rm o}+1)}{j\omega C_{\rm DBC}Z_{\rm o}}} \tag{2}$$

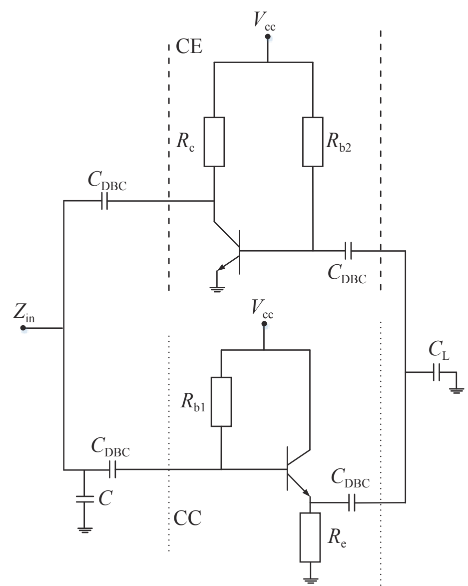
where $Z_{\rm o}$ is the reference termination impedance and

$$Z_{\rm eq} = \frac{j\omega L_{\rm act}}{1-\omega^2 L_{\rm act}C} \tag{3}$$

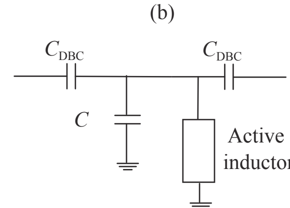
One of the techniques for the miniaturization of circuit size of AIN is the usage of transistors in the circuit design. Since the transistors have parasitic junction capacitances which are also used in the numerical modelling of AIN, there is no need for an additional capacitor to be included in the circuit topology with the result of small microwave circuit surface area. In Fig.1(b) the simplified schematic of the AIN design is illustrated where the non-inverting amplifier has a common collector configuration, and inverting transconductance amplifier is in the form of common emitter configuration. Resistances $R_{\rm b1}$, $R_{\rm e}$, $R_{\rm b2}$, and $R_{\rm c}$ are the bias elements with relatively high values. The AIN circuit layout is shown in Fig.1(c). The optimal values of the network elements are obtained by numerical means of circuit optimization. CDCB is the DC block capacitance, and $C_{\rm L}$ is the load of the gyrator design. The values of circuit components in Fig.1(b) are given in Table 1 using BFP720 microwave transistors for Gyrator-C designs. The mentioned values are obtained via trial



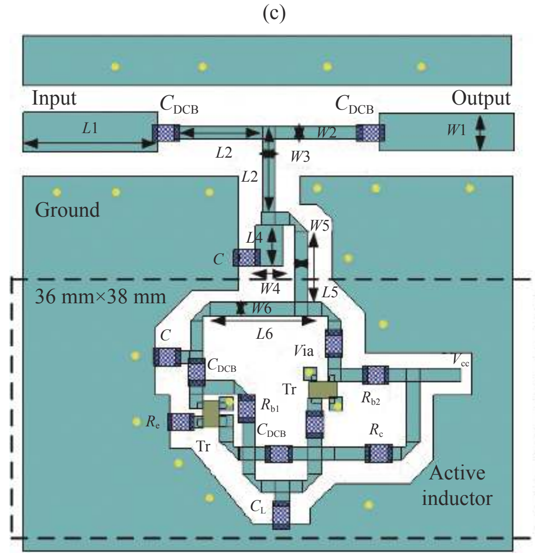
(a)



(b)



(c)



(d)

Fig. 1. Block scheme of (a) Traditional gyrator-based AIN [11], (b) Electrical scheme [4], (c) Schematic, and (d) Layout, of proposed AIN based BFP.

and error method alongside of local optimization technique in CAD environment to obtain optimal response characteristic for the proposed band-pass filter design.

Table 1. Circuit component values of AIN design

R_{b1} (Ω)	50	C (pF)	2.7
R_{b2} (Ω)	220	C_L (pF)	10
R_e (Ω)	10	C_{DCB} (pF)	1
R_c (Ω)	220	Substrate (mm)	FR4 1.56
$L1$ (mm)	5	$W1$ (mm)	3
$L2$ (mm)	6.2	$W2$ (mm)	0.9
$L3$ (mm)	5.5	$W3$ (mm)	0.9
$L4$ (mm)	3	$W4$ (mm)	2
$L5$ (mm)	5.2	$W5$ (mm)	1
$L6$ (mm)	6.3	$W6$ (mm)	1

In Fig.2, the numerically computed input impedance, Z_{in} results of the AIN design are shown, where the circuit parameter values vary between 0 and 2 Ω for the real part of Z_{in} and between −200 and 150 Ω for the imaginary of Z_{in} over the whole frequency band ranging from 0.8 and 2.7 GHz. Furthermore, in order to analyse the power consumption performance of AIN design, numerically computed results of total DC power consumption (TPC) for different input power levels (−20 dBm, 0 dBm, 20 dBm) are as almost equal to 76.1 mW under DC biasing voltage of 3 V.

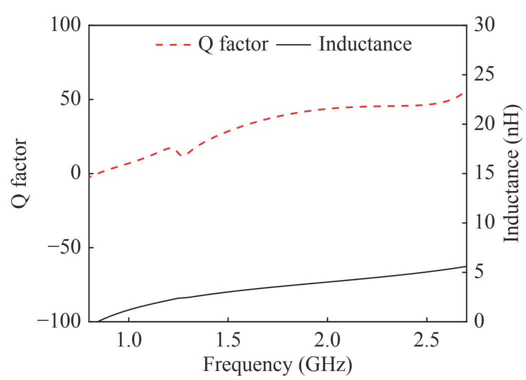


Fig. 2. Simulated AIN input impedance.

III. AIN Based Broad BPF Realizations

In this section, AIN based broad BPF has been fabricated on FR4 substrate with the thickness of 1.56 mm as shown in Fig.3(a). Anritsu 37397d Vector Network Analyser has been used to obtain the experimental results of prototyped AIN based broad BPF. The experimental results are shown in Fig.3(b) along with the numerical computation results. The numerically computed and experimentally measured results agree well with slight differences. The proposed BPF design has broad band operation characteristics ranging from 0.8 GHz to 2.7 GHz with 2 dB insertion loss. In addition, a conventionally designed LC element based broad BPF with ideal element values is also designed to point out the validity of the current AIN based broad BPF design. The LC element design variables are determined via, AWR filter toolbox and an optimization pro-

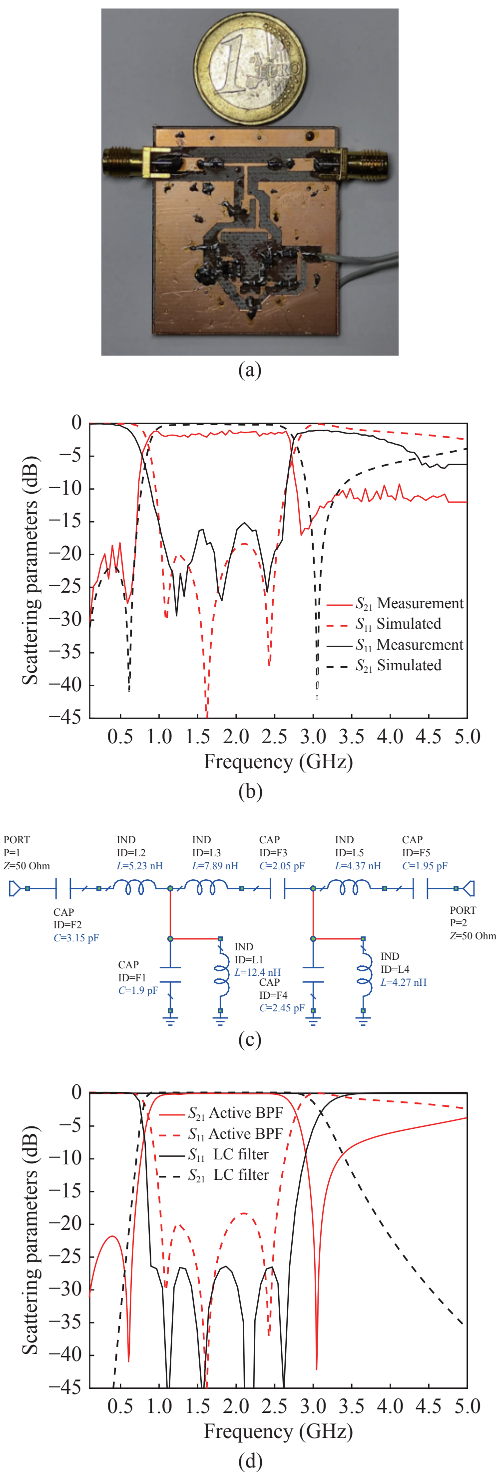


Fig. 3. (a) Fabricated view of AIN-based broad BPF; (b) Simulated and measured S_{11} and S_{21} parameters for V_{cc}= 3 V; (c) Circuit schematic of a traditional LC broad BPF filter; (d) Simulated results of ideal element LC and proposed AIN based BPF.

cess to achieve the optimal design characteristic using the ideal elements. The circuit schematic of the conventional LC broad BPF with microstrip lines and lumped element SMD components is presented in Fig.3(c) along with S parameter results of conventional LC BPF and AIN based BPF models in Fig.3(d). As deduced from Fig.3(d), the proposed AIN based BPF has narrower operation performance than the conventional LC circuit with ideal components based BPF design with higher out-of-band band rejection ratio in the higher frequency end of pass band, which results AIN based BPF to be more selective. Furthermore, for the better performance evaluation of proposed AIN based filter design, the experimental results are compared with the counterpart BPF designs in the literature as illustrated in Table 2 [4], [10]–[16].

Table 2. RF performance comparison table

Ref.	Stage	f_0(GHz)	3 dB BW(MHz)	Insertion loss (dB)	Die size
This work	1	0.8–2.7	1900	2	36×38 mm^2
[4]	1	0.5–1.3	300	0	–
[10]	2	0.4–1.1	–	–	200×140 µm^2
[12]	2	2.51	36	–	16.8×24.6 µm^2
[13]	2	0.98–1.1	130	–	0.62 mm^2
[11]	2	4.9–5.0	30	–	–
[14]	3	1.8–2.5	700	0.8	130×40 µm^2
[15]	2	1.7–2.2	500	1.6	–
[16]	3	2.19–2.55	360	2.8	–

IV. Conclusions

In this paper, a broadband AIN based BPF design is implemented for the operation between 0.8 and 2.7 GHz with 2 dB insertion loss in compact size. The experimentally measured and numerically computed results of RF performance parameters agree well with satisfactory values. Furthermore, the performance comparison of the proposed AIN based filter with alternative BPF designs in the literature shows that the proposed broad BPF is an efficient design solution to be used in applications requiring broad operation frequencies in communication systems with component value tuneability feature.

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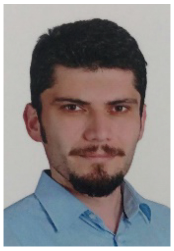

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