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A New Low-Voltage Low-Noise High-Gain UWB LNA with Multi-Band Tunable Notch Filter for Interference Rejection

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Abstract*—A new ultra-wideband (UWB) low-noise amplifier (LNA) with multi-band tunable notch filter for interference rejection is presented in this paper. The proposed multi-band tunable notch filter consists of two sections, the first section aims for 2.4-GHz interference rejection, and the second section is designed to block 5.2-GHz interference. Moreover, each notch filter section comprises a high-Q active inductor and varactors for interference rejection and center frequency tuning. Based on the proposed circuit architecture, the UWB LNA has been designed in 0.18-µm RF CMOS process. Simulated results confirm the UWB LNA combining the proposed multi-band tunable notch filter can effectively achieve high gain of 22 dB, low noise figure of 2.7 dB, low LNA supply voltage of 0.7 V, and total dc power consumption including multi-band tunable notch filter of 26.3 mW. In addition, the simulated interference rejections at 0.9 GHz, 1.8 GHz, 2.4 GHz, and 5.2 GHz are 50 dB, 39 dB, 53 dB, and 53 dB. Compared to the previous published 0.18-µm CMOS UWB LNAs with notch filters, the proposed circuit topology in this work exhibits superior performance in terms of gain, noise figure, supply voltage, and interference rejection.

***Index Terms*—interference rejection, low-noise amplifier (LNA), noise figure, notch filter**.

I. INTRODUCTION

Due to requirements of the high-data-rate wireless transmission, the wideband low-noise LNAs with operation frequencies around multi-giga hertz are presented [1]-[7]. In [2], a wideband low-noise amplifier consisting of the common-gate and common-source stages with a parallel-to-series resonant interstage matching circuit is illustrated. Due to the conjugate matching in high band and low band, the wideband 3.1-10.3-GHz LNA is achieved, exhibiting maximum power gain of 12.71 dB, minimum noise figure of 2.5 dB, and power consumption of 13.4 mW. In [3], a 3.1-10.6-GHz 0.18-µm CMOS UWB LNA was presented. By taking advantage of the RC shunt-shunt feedback in conjunction with a parallel RLC load, the wideband S_{11} is achieved. Moreover, simultaneous wideband S_{11}, low and flat noise figure was achieved by controlling the pole frequency and pole *Q*-factor of the LNA's input stage.

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To block interferences for UWB LNAs, notch filters are widely used for unwanted signals rejection [4]-[7]. In [4], a CMOS dual-band UWB LNA with interference rejection was presented. Measurement results exhibit maximum interference rejections in 2.45 GHz and 5.8 GHz are 12.8 dB and 19.6 dB. To adjust the rejection frequency for the interference, a tunable notch filter combining a 3.1-10.6-GHz UWB LNA is reported in [5]. The fabricated 0.18-µm CMOS LNA achieves the maximum power gain of 13.2 dB, the minimum noise figure of 4.5 dB, and an interference rejection of 8.2 dB at 5.2 GHz. In order to exhibit high interference rejection (IR), a third-order notch filter was designed in an ultra-wideband low-noise amplifier [6]. According to the measured results, the IR-LNA delivered a maximum gain of 14.7 dB, a minimum noise figure of 5.3 dB, and an interference-rejection ratio of 35.7 dB at 5.8 GHz. In [7], a low-power 3.2-9.7-GHz LNA with excellent stop-band rejection in 0.18-µm CMOS is presented. High stop-band rejection is realized in a passive band-pass filter with three finite transmission zeros. Moreover, an active notch filter was adopt to the LNA's output port for generating another low-frequency stop-band transmission zero at 2.4 GHz. As a result, the stop-band rejection at 0.9 GHz, 1.8 GHz, and 2.4 GHz are 53.3 dB, 26.4 dB, and 26.5 dB.

In this work, a multi-band tunable notch filter is proposed in this work. This notch filter consists of high-*Q* active inductors and varactors. According to the simulation results, the proposed UWB LNA utilizing the proposed notch filter achieves the impressed interference rejections at 0.9 GHz, 1.8 GHz, 2.4 GHz, and 5.2 GHz.

II. PROPOSED UWB LNA WITH MULTI-BAND TUNABLE NOTCH FILTER

Fig. 1 illustrates the circuit schematic of the proposed 3.1-10.6-GHz UWB LNA. To exhibit low-voltage and high gain, three common-source stages are cascaded, leading to a 0.7-V supply voltage and 22-dB power gain. Moreover, the common-source topology serves as the first stage for achieving a low noise figure of 2.7 dB. In order to block the interference signals, a high-rejection multi-band tunable notch filter is proposed to integrate with the UWB LNA, as shown in Fig. 1. The notch filter is deposited between the LNA's second and third stages for lowering the noise figure. Fig. 2 depicts the proposed high-rejection multi-band tunable notch filter. It consists of two sections, the first section is designed for 2.4-GHz interference rejection, and the second section is targeted for 5.2-GHz interference blocking. Moreover, each notch filter section comprises a high-*Q* active inductor and varactors for interference rejection and center frequency tuning.

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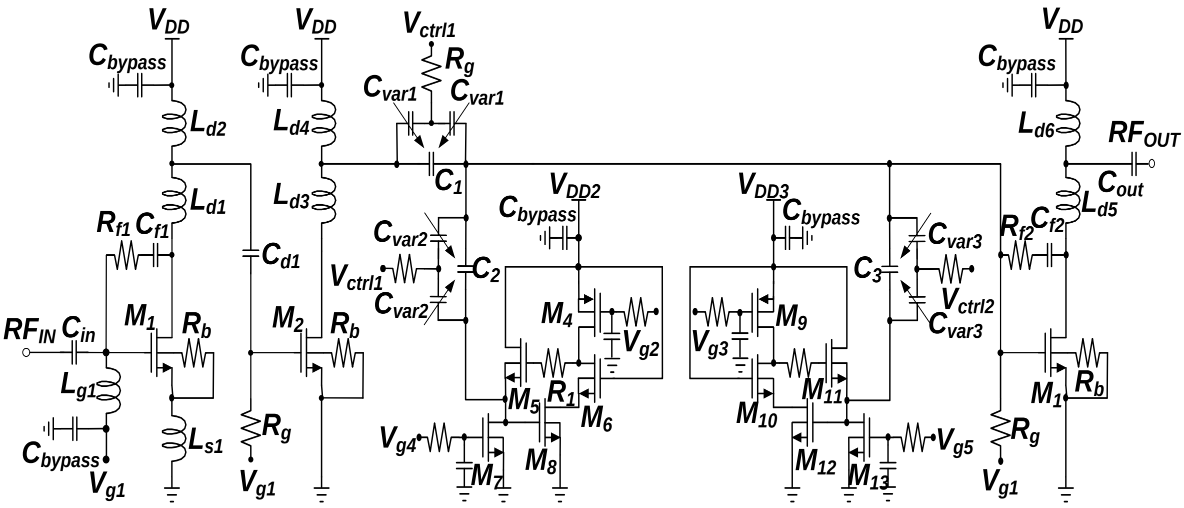

Fig. 1. Schematic of the UWB LNA with the proposed multi-band tunable notch filter.

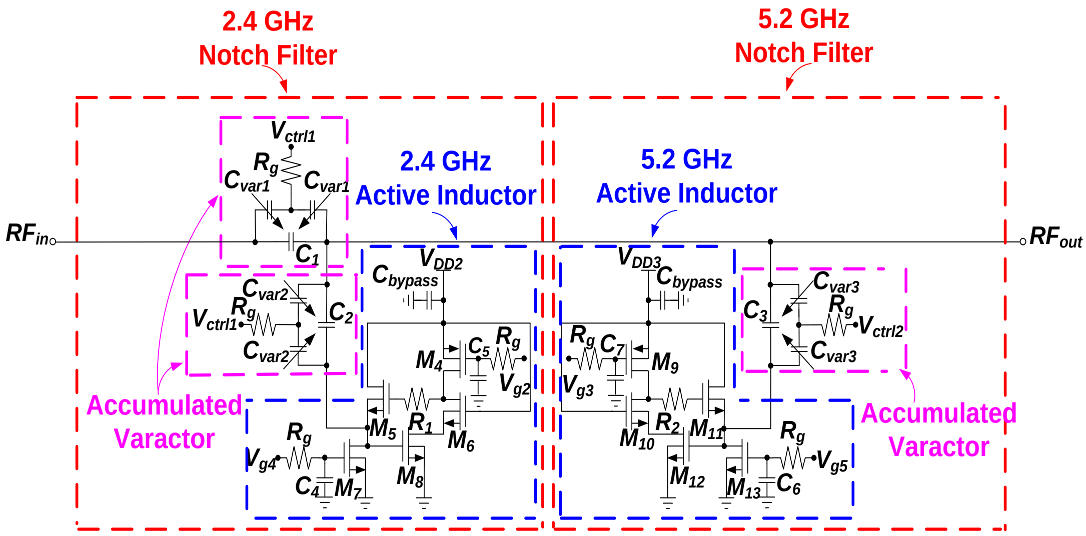

Fig. 2. Schematic of the proposed multi-band tunable notch filter.

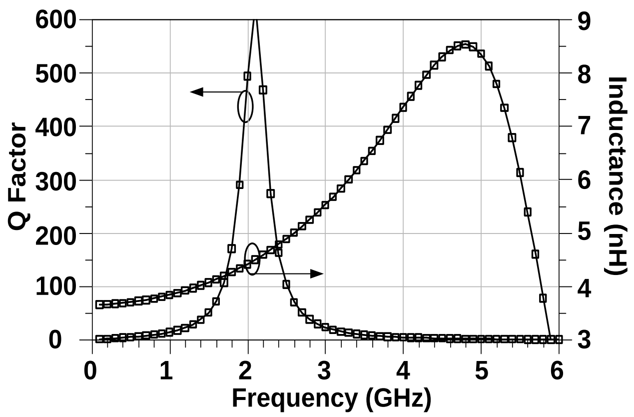

Fig. 3. Simulated Q factor and inductance of the 2.4-GHz active inductor.

Fig. 3 shows the simulated Q factor and inductance of the 2.4-GHz active inductor. From Fig. 3, it is observed that the Q factor and inductance at 2.4 GHz are 180 and 4.6 nH, respectively. Moreover, the simulated Q factor and inductance of the 5.2-GHz active inductor are illustrated in Fig. 4. It is indicated that the Q factor and inductance at 5.2 GHz great than 600 and 3.4 nH, respectively. Therefore, using active inductors indeed achieve extremely high Q factors at 2.4 and 5.2 GHz. Based on the proposed circuit topology, the simulated transmission coefficient (S_{21}) of the multi-band tunable notch filter is shown in Fig. 5. It is observed that the transmission coefficient (S_{21}) exhibits high rejections of -43.2 dB at 2.4 GHz and -64.8 dB at 5.2 GHz.

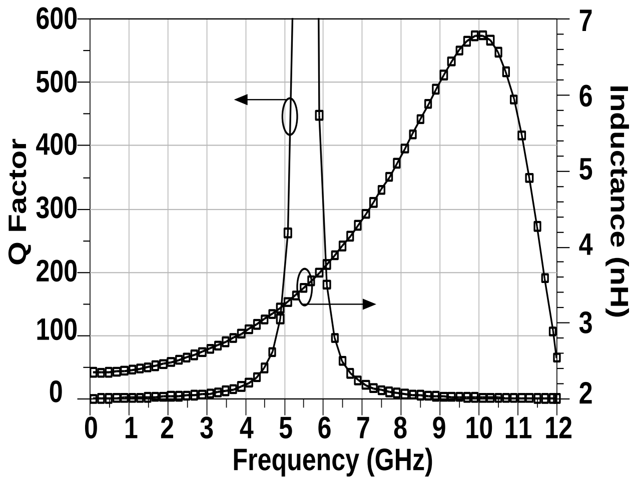

Fig. 4. Simulated Q factor and inductance of the 5.2-GHz active inductor.

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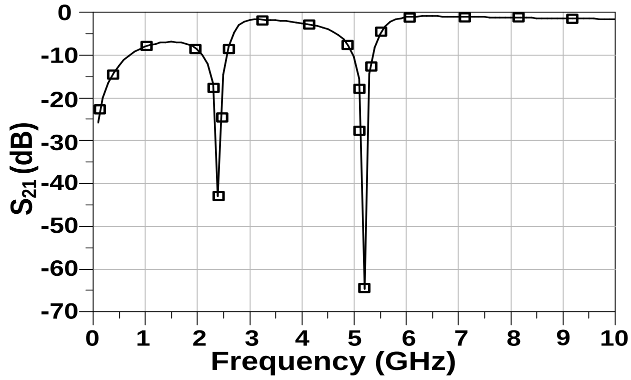

Fig. 5. Simulated transmission coefficient (S_{21}) of the proposed multi-band tunable notch filter.

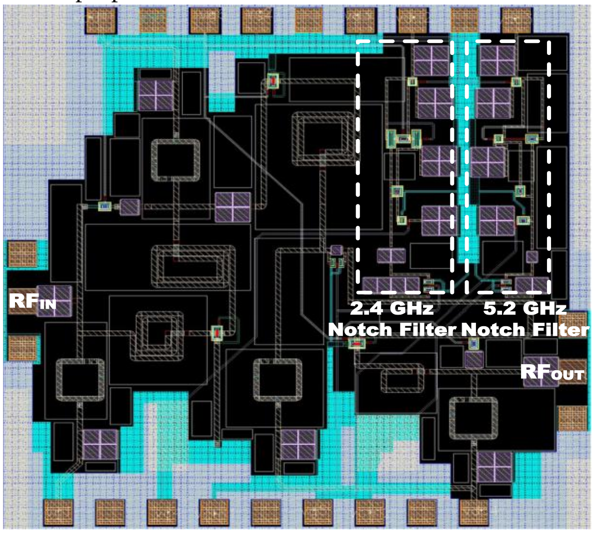

Fig. 6. Chip layout of the UWB LNA with the proposed multi-band tunable notch filter (the overall chip size is 1.13 × 1.125 mm^2).

III. SIMULATION RESULTS

The proposed low-voltage low-noise high-gain UWB LNA with multi-band tunable notch filter has been designed in 0.18-μm RF CMOS process. Fig. 6 shows the chip layout of the proposed UWB LNA. The chip size is 1.13 x 1.125 mm^2 including the testing pads. The supply voltage of this UWB LNA is 0.7 V. The total dc power consumption of the proposed UWB LNA including the multi-band tunable notch filter is 26.3 mW. The simulation is performed by using circuit simulator Agilent's Advanced Design System (ADS) software. In addition, the inductors, capacitors, and interconnections are considered by adopting full-wave electronic-magnetic (EM) simulation tools, Sonnet and HFSS.

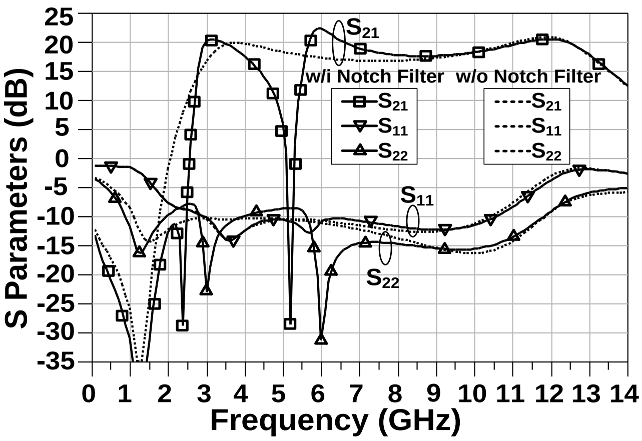

Fig. 7. Simulated S parameters of the proposed UWB LNA.

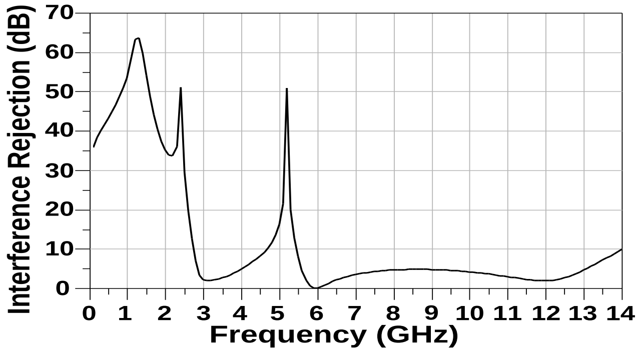

Fig. 8. Simulated interference rejection of the proposed UWB LNA.

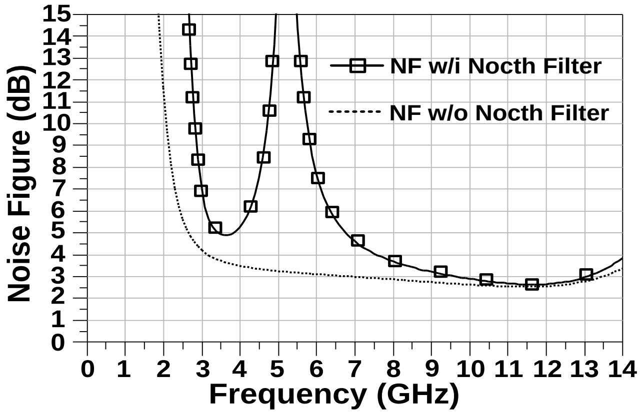

Fig. 9. Simulated noise figure of the proposed UWB LNA.

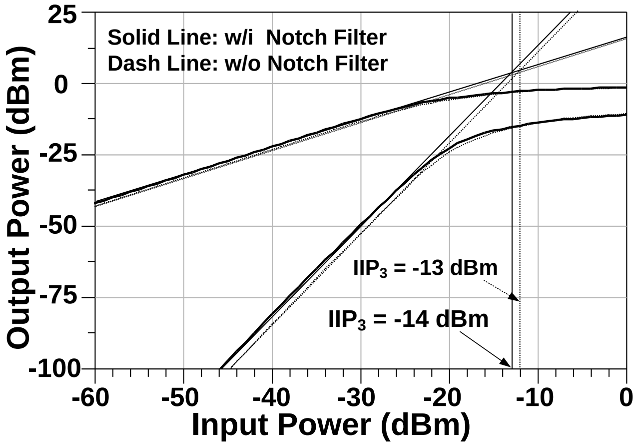

Fig. 10. Simulated input-referred third-order intercept point (IIP_3) of the proposed UWB LNA.

Fig. 7 shows the simulated S parameters of the proposed UWB LNA. From this figure, it is indicated that the maximum gain of S_{21} is 22 dB. Moreover, the input/output reflection coefficients (S_{11} and S_{22}) are below -10 dB for 3.1-10.6-GHz UWB bandwidth, performing the well matched input/output circuits. Fig. 8 shows the simulated interference rejection of the proposed UWB LNA. From this figure, it is observed that the interference rejections are 50 dB at 0.9 GHz, 39 dB at 1.8 GHz, 53 dB at 2.4 GHz, and 53 dB at 5.2 GHz. Fig. 9 shows the simulated noise figure of the proposed 3.1-10.6-GHz UWB LNA. It is indicated that the minimum noise figure is 2.7 dB at 10.6 GHz. To consider the linearity of the UWB LNA, the simulated input-referred third-order intercept point (IIP_3) of the proposed UWB LNA is shown in Fig. 10. The two-tone test is carried out at 8 GHz, and the frequency spacing is 1 MHz. It is indicated that the IIP_3 for the proposed UWB LNA is -14 dBm. Fig. 11 describes the simulated S parameters of the proposed UWB

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LNA with varactor tuning. From Fig. 11, it is exhibited that the S_{21}<-15 dB for interference rejections can have frequency tolerance around 2.4 and 5.2 GHz.

Process	3-dB BW (GHz)	Max Gain (dB)	Min. NF (dB)	Supply Voltage (V)	DC Power (mW)	Interference Rejection (dB)	Ref.
0.18-μm CMOS	10.5 (0.5–11)	10.2	3.9	n.a.	14.4	w/o	[1] MWCL'10
0.18-μm CMOS	7.5 (3.1–10.6)	12.7	2.5	0.7 @ 1st stage 1.5 @ 2nd stage	13.4	w/o	[2] TMTT'11
0.18-μm CMOS	7.5 (3.1–10.6)	13.33	2.68	1.8	11.8	w/o	[3] RWS'12
0.18-μm CMOS	9.4 (2.9–12.3)	20.3	4.0	1.8	24*	12.8dB @ 2.45 GHz 19.6 dB @ 5.8GHz	[4] EL'07
0.18-μm CMOS	7.5 (3.1–10.6)	13.2	4.5	1.8	23*	8.2 dB @ 5.2 GHz	[5] MWCL'10
0.18-μm CMOS	8.3 (1.2–9.5)	14.7	5.3	1.8	16*	35.7dB @ 5.8 GHz	[6] TCAS-II'11
0.18-μm CMOS	6.5 (3.2–9.7)	10.8	4.8	1.2	4.68 (LNA only)	53.3 dB @ 0.9 GHz 26.4 dB @ 1.8 GHz 26.5 dB @ 2.4 GHz	[7] RWS'12
0.18-μm CMOS	**7.5 (3.1–10.6)**	**22**	**2.7**	**0.7**	**26.3***	**50 dB @ 0.9 GHz 39 dB @ 1.8 GHz 53 dB @ 2.4 GHz 53 dB @ 5.2 GHz**	**This work**

Table I summarizes the performance of this work and compared with the recently published 0.18-μm CMOS UWB LNAs. It is indicated that the proposed UWB LNA with multi-band tunable notch filter can achieve a high gain of 22 dB, a minimum noise figure of 2.7 dB, a low supply of 0.7 V, high interference rejections of 50 dB at 0.9 GHz, 39 dB at 1.8 GHz, 53 dB at 2.4 GHz, and 53 dB at 5.2 GHz.

IV. CONCLUSION

A 3.1-10.6-GHz UWB LNA with multi-band tunable notch filter for interference rejection is proposed. Based on the presented circuit topology, the UWB LNA can deliver high gain of 22 dB, low noise figure of 2.7 dB, low LNA supply voltage of 0.7 V, and total dc power consumption including multi-band tunable notch filter is 26.3 mW. Moreover, the simulated interference rejection at 0.9 GHz, 1.8 GHz, 2.4 GHz, and 5.2 GHz are 50 dB, 39 dB, 53 dB, and 53 dB. Compared to the previous published LNA with notch filter, the proposed circuit topology in this work exhibits superior performance in terms of gain, noise figure, supply voltage, and interference rejection.

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