

# Blocker filtering low-noise amplifier for SAW-less Bluetooth receiver system

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*A 2.4 GHz CMOS blocker filtering low-noise amplifier (BF-LNA) suitable for Bluetooth™ application is presented. The circuit employs a differential amplifier topology with a current mirror active load and a notch filter. Each path amplifies differentially with the common mode input signal, but there is a notch filter rejecting only the wanted signal at one path. By subtracting the two signals from each path, the large interferers are rejected and only the wanted signal is amplified. Therefore, it becomes a narrow-band amplifier with blocker filtering capability, realizing a receiver system without need of the off-chip SAW filter. The BF-LNA is designed using a 0.13- $\mu\text{m}$  CMOS process. The measured performances are a gain of 11.4 dB, and a noise figure of 1.85 dB. Attenuation levels at 400 MHz apart from the target frequency are  $-13$  and  $-29$  dBc at each sideband. The  $P_{1\text{dB,in}}$  and  $IIP_3$  are  $-8.2$  and  $1.46$  dBm, respectively. The proposed BF-LNA can reject large interferers at the front-end of the receiver system with a good noise figure.*

**Keywords:** Blocker filtering, Bluetooth, LNA, SAW-less

Received 14 April 2009; first published online 7 January 2010

## I. INTRODUCTION

In wireless communication, a receiver system processes a weak, desired signal along with large interferers. These interferers can saturate the receiver system, and the weak signal may experience a vanishingly small gain. Moreover, these interferers generate unwanted inter-modulation components in a signal channel because of non-linear characteristic of the circuit. The linearity specification and power capability should be large enough to avoid the distortion. To relax this hard condition, a surface acoustic wave (SAW) filter is commonly used to reject the interferer. However, the SAW filter is off-chip component which cannot be integrated, and the cost of fabrication increases sharply [1, 2]. In these days, receiver systems without the SAW filter are actively researched.

A low-noise amplifier (LNA) amplifies not only the wanted signal but also the interferers because of the large bandwidth. Without the SAW filter, the large interferer amplified by LNA causes critical problems explained above. In a SAW-less receiver system, the LNA should play the role of the SAW filter to avoid these problems, requiring the blocker filtering LNA (BF-LNA) we are proposing. In other words, BF-LNA amplifies the wanted signal while attenuating the undesired large interferers. Figure 1 represents the interferer level at the input of the Bluetooth receivers and after the amplification by the normal LNA and BF-LNA. In case of Bluetooth, if the gain of frequency band under 2 GHz and over 3 GHz is below 0 dB, a mixer with  $P_{1\text{dB,in}}$  of  $-10$  dBm can handle the

signal and interferers and is not saturated. After the mixing stage, a finite impulse response (FIR) filter for the charge sampling mixer can sharply reject blockers [3].

Conventional blocker filtering techniques employ down-conversion mixing to filter the out-of-band interferers at a low frequency, and their structures are relatively complex. Because of the additional mixer operation, they consume large power and occupy large chip size, and the noise is added in the complicated process. Moreover, the effects of various mismatches can cause degradation of the blocker rejection performance [4, 5].

In this letter, a new BF-LNA is presented. The proposed BF-LNA employs a differential amplifier structure with a common mode input, and filters the signal at one path using an on-chip notch filter. The two signals are subtracted by the current mirror active load. Finally, the only wanted signal is amplified, and the unwanted interferers are attenuated. Since the noise as well as signal are filtered out at one path, the noise figure is determined only by the amplification of the amplifying path, maintaining a low noise. To eliminate the SAW filter, the BF-LNA should have power capability large enough to handle the large interferers. It employs a common source amplifier structure with single transistor and draws a large DC current to ensure the output voltage swing. Figure 2 shows the operational principle of the proposed BF-LNA.

## II. BLOCKER FILTERING LOW-NOISE AMPLIFIER

Figure 3 shows schematic of the proposed BF-LNA. It adopts a differential amplifier structure but with a common-mode input. The input signals of each path of the differential

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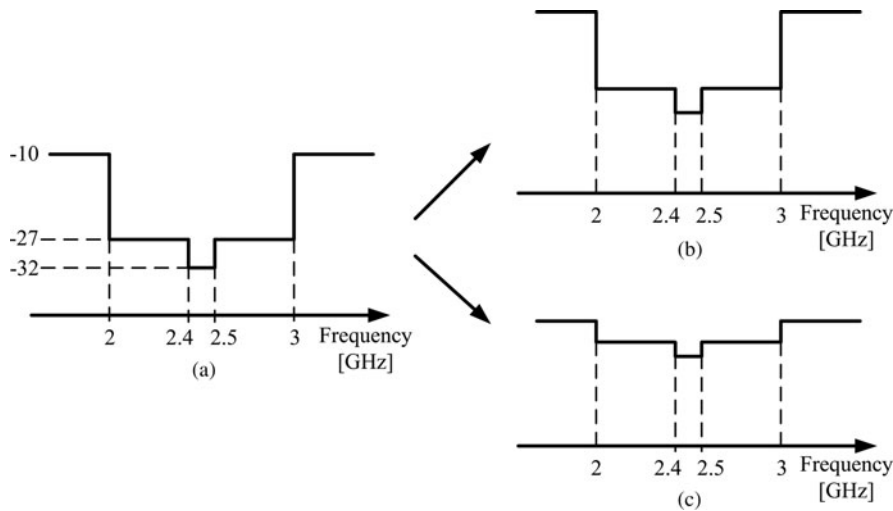


Fig. 1. (a) Interferer information of Bluetooth™ and the amplification by (b) normal LNA and (c) the blocker filtering LNA.

amplifier are amplified and subtracted by the active load. The amplifications through the two paths should be the same to cancel the interferers properly, so the impedance balance of the active load is important. Because of the structure of the active load, the capacitances of the two loads are different. The balancing shunt capacitor  $C_b$  is added at the right-side of the active load, given by

$$C_{ds3} + C_{gs3} + C_{gs4} = C_{ds4} + C_b. \quad (1)$$

The largest interferer level of Bluetooth™ is  $-10$  dBm at 400 MHz apart from the target frequency band [6] and the

$P_{1dB,in}$  of the LNA should be larger than  $-10$  dBm. The amplifier employs a common source amplifier topology to achieve enough voltage headroom and uses large size transistors to draw enough current for the high-power capability. This large DC current leads to a little bit large power consumption, but the proposed BF-LNA does not need any additional block, i.e., down-conversion mixer, and the total current is not large.

A notch filter is placed at the one amplifying path. It is composed of series-connected on-chip inductor and capacitor. The inductor and capacitor are chosen to resonate at the signal frequency and the parasitic capacitance component

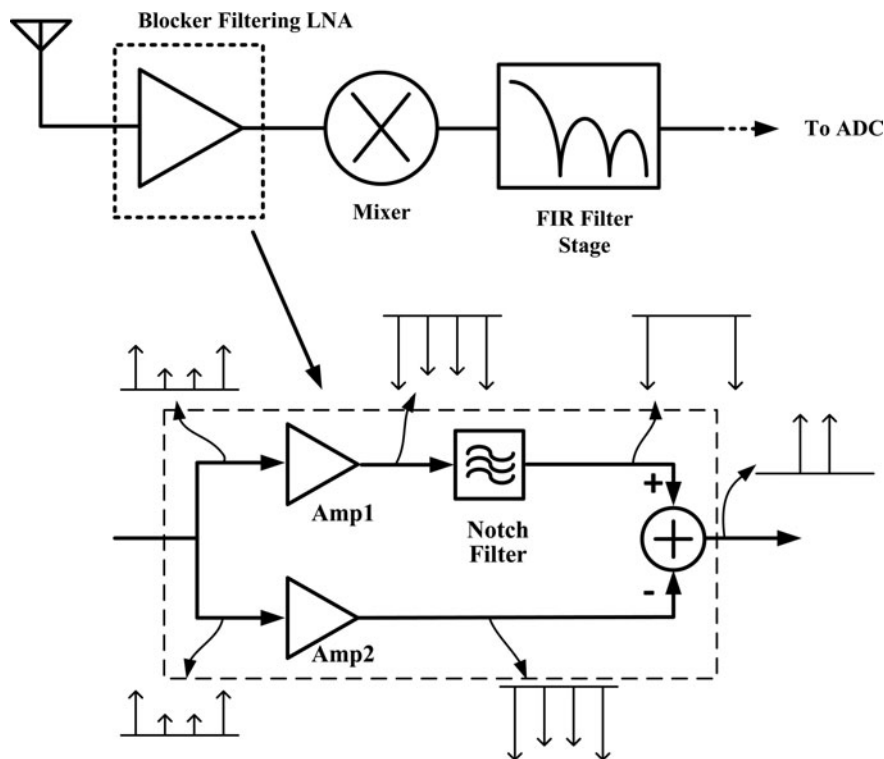


Fig. 2. Principle of the proposed blocker filtering LNA.

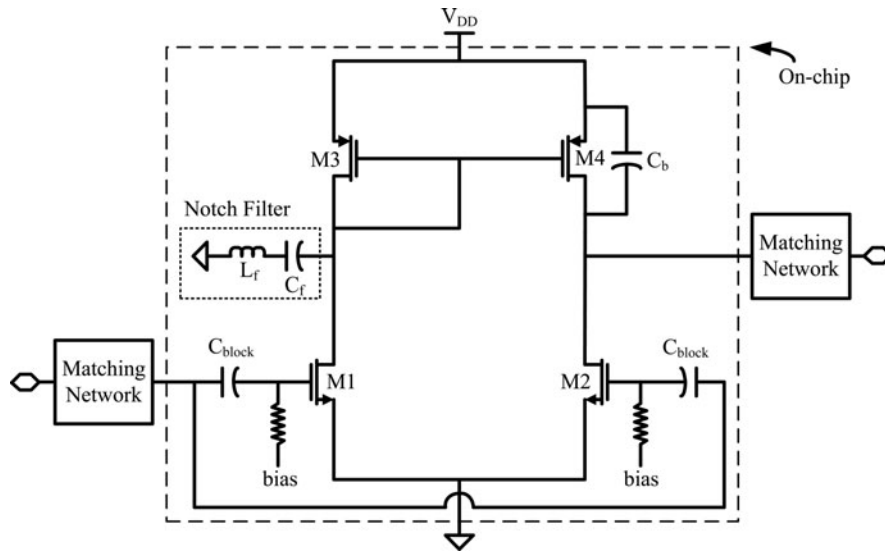


Fig. 3. Schematic of the proposed blocker filtering LNA.

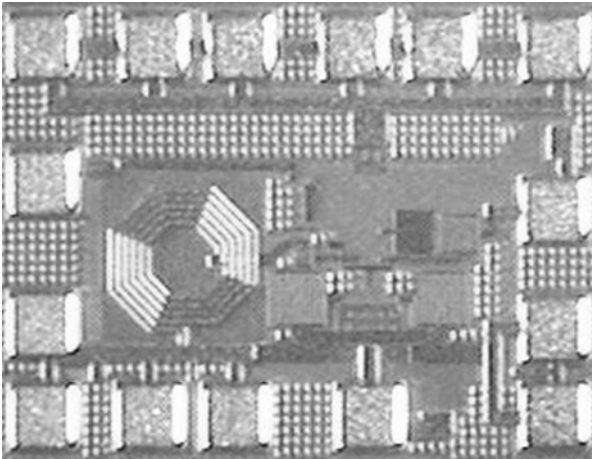


Fig. 4. The fabricated photograph of BF-LNA (chip size :  $790 \mu\text{m} \times 590 \mu\text{m}$ , active area without pads:  $500 \mu\text{m} \times 260 \mu\text{m}$ ).

of the interconnect should also be included:

$$Z_f = j\omega L_f + \frac{1}{j\omega C_f} = 0, \quad (2)$$

$$L_f C_f = \frac{1}{(2\pi f)^2}. \quad (3)$$

The impedance at the resonance frequency of notch filter is zero, and the signal is shorted by the notch filter. At the left-hand side of differential amplifier with the filter, interferers are amplified while the wanted frequency band component is shorted. The active load has two roles. First, it is used as a load of the each amplifier. Second, it subtracts the right-side signal, which is amplified normally, from left-hand side signal, which is amplified and notched. The subtracted signal has only the wanted frequency component of the input signal and delivers to output node. The structure of the BF-LNA is very simple and the noise figure is low, determined by the single amplifying channel.

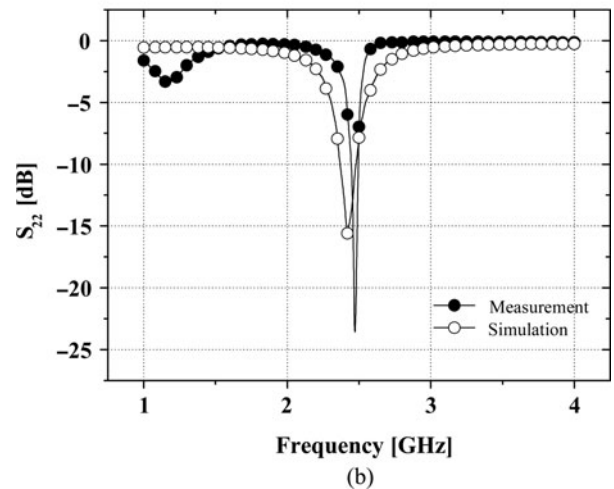
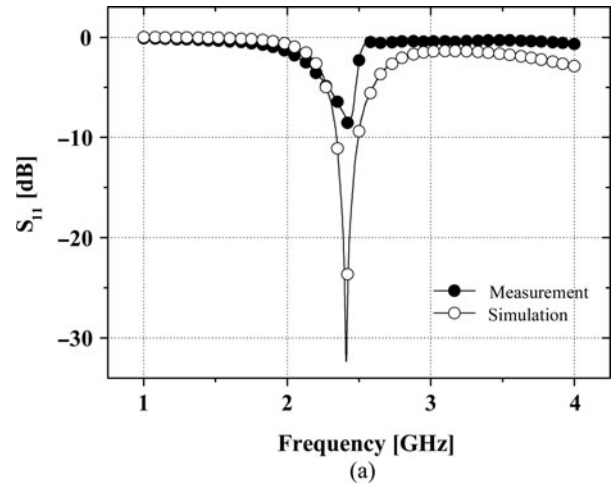


Fig. 5. Simulation and measurement results of (a)  $S_{11}$  and (b)  $S_{22}$ .

### III. MEASUREMENT RESULTS

The BF-LNA is fabricated using a  $0.13\text{-}\mu\text{m}$  CMOS process and the fabricated die photograph is represented in Fig. 4. It occupies an active area of  $500\ \mu\text{m} \times 260\ \mu\text{m}$  without pads. The measurement results of the proposed LNA are plotted in Figs 5 and 6. At  $2.4\ \text{GHz}$ ,  $S_{11}$  and  $S_{22}$  are  $-8.5\ \text{dB}$  and  $-28.7\ \text{dB}$ , respectively. The gain is  $11.4\ \text{dB}$  and the noise figure is  $1.85\ \text{dB}$ . Attenuation performances at  $400\ \text{MHz}$  apart from the signal band are  $-13\ \text{dBc}$  for the left sideband and  $-29\ \text{dBc}$  for the right sideband. This attenuation level means that blockers of maximum  $-10\ \text{dBm}$  under  $2\ \text{GHz}$  and over  $3\ \text{GHz}$  will not be amplified and only be attenuated. The attenuation level increases as further away from signal frequency band. The measured  $P_{1\text{dB},in}$  is  $-8.2\ \text{dBm}$ , which is large enough to handle the signal and interferers of Bluetooth™ standard at the front-end without any filter and  $IIP_3$  is measured to be  $1.46\ \text{dBm}$ . The proposed BF-LNA amplifies only wanted signal and small blockers close to signal, and attenuates the large blockers of out-band, which causes saturation problem. The measurement results of these parameters are shown in Fig. 7. The dissipated power is  $23.85\ \text{mW}$  with DC voltage of  $1.5\ \text{V}$ . This large power dissipation is needed for the enough power

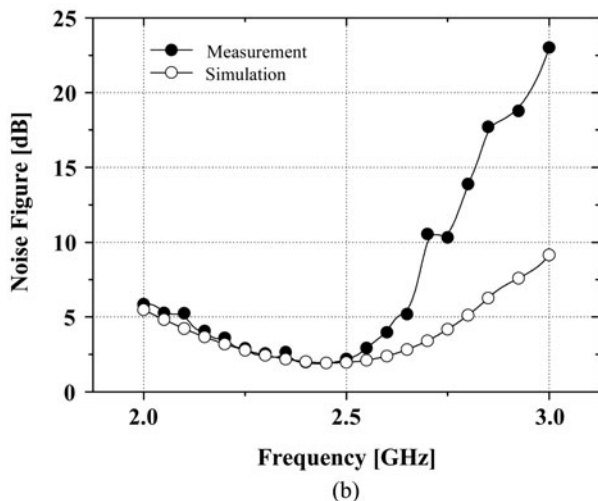
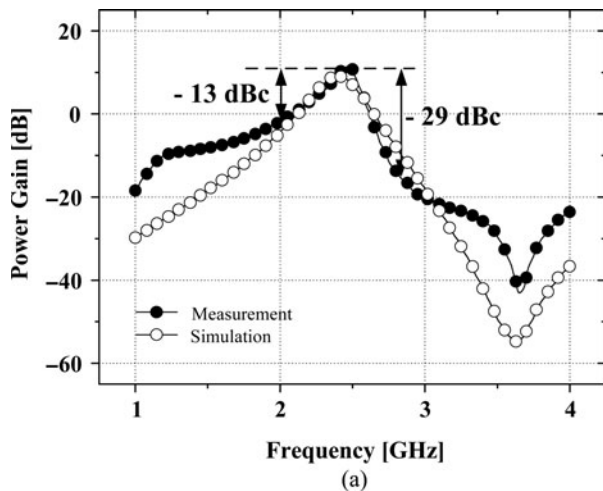


Fig. 6. Simulation and measurement results of (a) power gain and (b) noise figure.

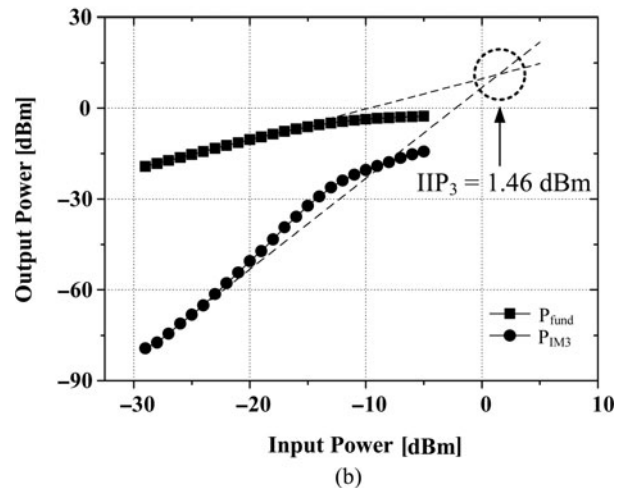
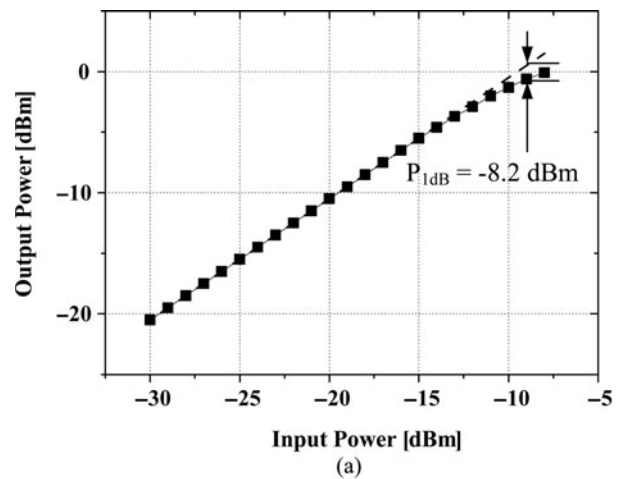


Fig. 7. Measurement results of (a)  $P_{1\text{dB}}$  and (b)  $IIP_3$ .

Table 1. Performance of the fabricated chip.

Parameter	Value
Technology	$0.13\text{-}\mu\text{m}$ CMOS process
Active area (without pads)	$500\ \mu\text{m} \times 260\ \mu\text{m}$
Frequency	$2.4\ \text{GHz}$
3-dB bandwidth	$180\ \text{MHz}$
Gain	$11.4\ \text{dB}$
Noise figure	$1.85\ \text{dB}$
Attenuation (at $-400\ \text{MHz}$ apart)	$-13\ \text{dBc}$
Attenuation (at $400\ \text{MHz}$ apart)	$-29\ \text{dBc}$
$P_{1\text{dB}}$	$-8.2\ \text{dBm}$
$IIP_3$	$1.46\ \text{dBm}$
DC current	$15.9\ \text{mA}$

handling capability but is not bad compared to the other filtering LNA. The performance of the circuit is summarized in Table 1.

### IV. CONCLUSIONS

In conclusion, the BF-LNA for a SAW-less receiver system is presented. By employing the differential amplifier structure, a

notch filter and current mirror active load, the proposed BF-LNA amplifies the wanted signal while attenuates the unwanted large interferers. It employs common source amplifier structure and draws a large DC current to ensure the output voltage swing required for a large power handling capability. Even though it uses an on-chip inductor, the proposed BF-LNA can remove the SAW filter and reduce total size. The circuit structure is very simple but provides a good blocker filtering with a low-noise figure. The measured performances are good enough to be used in Bluetooth receiver system. The circuit is fabricated in 0.13- $\mu\text{m}$  CMOS process, and it consumes 23.85 mW with 1.5 V supply voltage. The proposed BF-LNA exhibits a gain of 11.4 dB and a noise figure of 1.85 dB at 2.4 GHz. The attenuation levels of each sideband are  $-13$  dBc and  $-29$  dBc, respectively. The  $P_{1dB,in}$  is  $-8.2$  dBm and  $IIP_3$  is 1.46 dBm.

## ACKNOWLEDGEMENTS

This work was supported by the Center for Advanced Transceiver Systems, which was sponsored by the next-generation new technology development programs of the Ministry of Knowledge and Economy (MKE), and supported by the WCU (World Class University) program through the Korea Science and Engineering Foundation funded by the Ministry of Education, Science and Technology (Project No. R31-2008-000-10100-0), and also supported by the ETRI SoC Industry Promotion Center, Human Resource Development Project for IT SoC Architect.

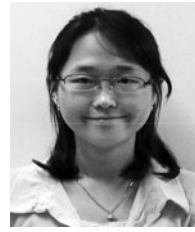
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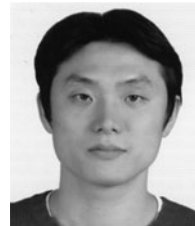
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