High-Gain Wideband CMOS Low Noise Amplifier with Two-Stage Cascode and Simplified Chebyshev Filter

Sung-Soo Kim, Young-Sop Lee, and Tae-Yeoul Yun

ABSTRACT—An ultra-wideband low-noise amplifier is proposed with operation up to 8.2 GHz. The amplifier is fabricated with a 0.18-μm CMOS process and adopts a two-stage cascode architecture and a simplified Chebyshev filter for high gain, wide band, input-impedance matching, and low noise. The gain of 19.2 dB and minimum noise figure of 3.3 dB are measured over 3.4 to 8.2 GHz while consuming 17.3 mW of power. The Proposed UWB LNA achieves a measured power-gain bandwidth product of 399.4 GHz.

Keywords—Cascode, Chebyshev, CMOS, LNA, UWB.

I. Introduction

In recent years, numerous methods have been proposed for ultra-wideband (UWB) communication systems of IEEE 802.15.3a. Two of the most promising proposals are multi-band OFDM based on frequency-hopping QPSK OFDM and DS-CDMA PSK. Both methods must operate effectively across the range of 3.1 to 10.6 GHz; however, first generation UWB systems will probably operate below 5 GHz, using the band group 1 from 3.1 to 4.752 GHz due to likely limitations in Si CMOS technology.

Multiple techniques have been adopted to improve the frequency bandwidth of low-noise amplifiers (LNAs), including distributed [1] and resistive-shunt feedback [2] topologies. Additionally, an LNA using a third-order Chebyshev band-pass filter, comprising four capacitors and four inductors, has been shown to effectively optimize the input reflection coefficient [3].

In this letter, we propose a simplified second-order Chebyshev filter which is smaller and less complicated than the third-order Chebyshev filter, yet it is capable of achieving input impedance matching and a low noise figure (NF). To ensure that the LNA has a significant gain across the ultra-wide band, thereby effectively reducing noise from the following mixer, a two-stage cascode structure is adopted. The proposed LNA, designed for multiband OFDM UWB systems, employs a Samsung 0.18 μm CMOS process with an f_t of greater than 40 GHz; thus, it is operable up to 8.2 GHz across band groups 1 to 3 (from 3.1 to 7.92 GHz) and in part of band group 4 (from 7.92 to 9.504 GHz).

II. Design

Cascode topology generally improves the frequency response of the amplifier and reverse isolation. As shown in Fig. 1, a two-stage cascode is employed to simultaneously achieve a high gain and a wide band. The proposed UWB LNA consists of a second-order Chebyshev filter, cascode stages, and inter-stage matching. Additionally, a buffer amplifier is included to ease measurement.

To achieve a low NF over a wide band, the channel noise of MOS and the input matching network must be considered. The channel noise is related with a γ-factor, the process parameter of which depends on the bias condition, that is, the gate-source voltage V_{gs} and transconductance (g_m). Therefore, the noise contributed by M_1 can be minimized by considering its gate width and bias current [4]. Simulation with Agilent's Advanced Design System (ADS) produced an optimized M_1 with a width of 200 μm, a gate bias V_{g1} of 0.6 V, and a drain current of 5.3 mA.

A parallel external capacitor C_{ext} between M_1's gate and

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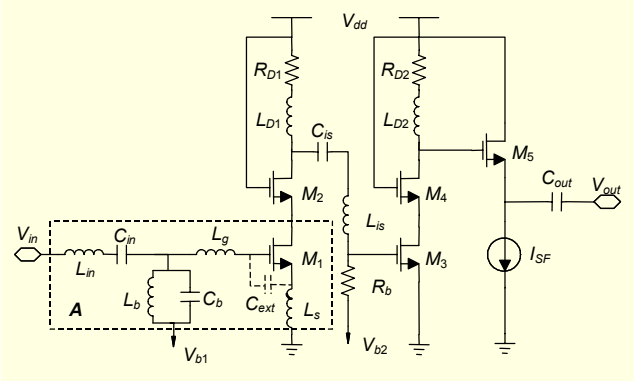

Fig. 1. Schematic of the proposed UWB LNA.

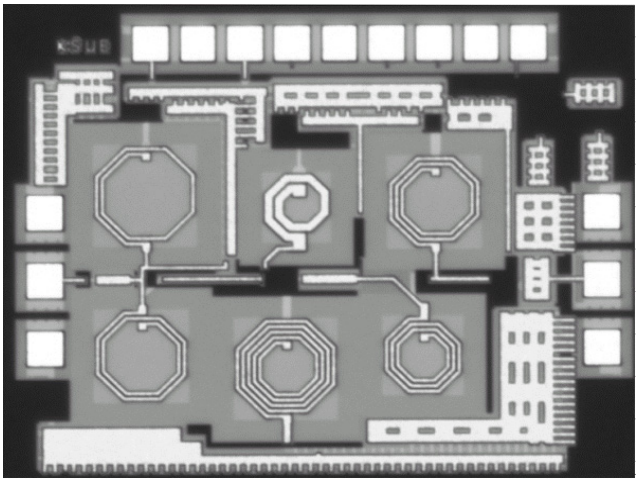

Fig. 2. Photograph of the UWB LNA (1 mm ×1 mm).

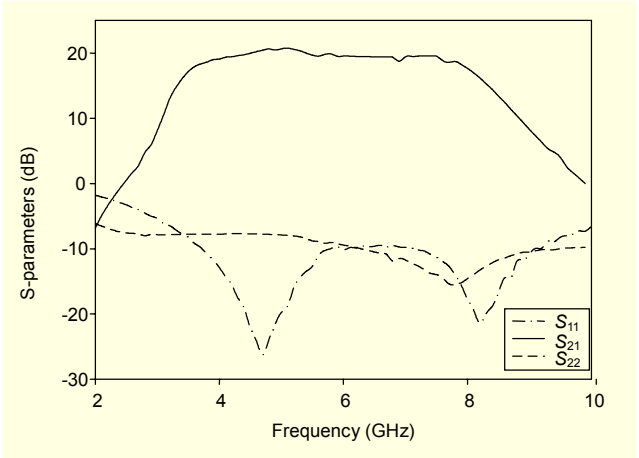

Fig. 3. Measured S-parameters.

source has been widely used for narrowband LNA applications. Such a capacitor was adopted in [3], where input network *A*, shown in Fig. 1, comprised the third-order Chebyshev filter with four large inductors. In the proposed LNA, C_{ext} is removed to obtain wider-band noise matching. In addition, to reduce the order of the filter, a series-resonant section with L_{in} and C_{in} is removed, while the capacitor C_{in} is still employed to achieve only DC blocking. Thus, the second-order Chebyshev filter, which produces a low noise over 3 to 8 GHz, has a construction similar to that of input network *A*, but without the dotted components. All filter elements are optimized to simultaneously achieve a small input reflection coefficient and a low NF over the band, which results in $C_{in} \approx 1.17$ pF, $L_b \approx 2.3$ nH, $C_b \approx 0.103$ pF, $L_g \approx 1.5$ nH, and $L_s \approx 0.53$ nH. The cascode MOS M_2 is not chosen for its contribution to noise reduction, but as a trade-off between the gain and frequency response, which is finally optimized to a width of 80 μm. Although the first stage is designed to produce a low noise, the second stage elicits a great increase in gain. Optimization yields an M_3 of 160 μm, an M_4 (= M_2) of 80 μm, and a V_{g2} of 0.6 V for a drain current of 4.0 mA.

Three techniques are adopted to achieve a flat gain vs. frequency response. First, each stage is designed to have a high gain at a higher or lower band. Second, a small resistance of R_{D1} decreases the quality-factor of parallel-resonance at a lower band between the load inductor L_{D1} and capacitance seen by this inductor, which makes the gain smaller but flatter. At a higher band, R_{D2}, L_{D2} and capacitance seen by this inductor perform similarly; L_{D1} and L_{D2} are chosen to be approximately 1.9 and 4.6 nH, respectively. Third, an inter-stage network composed of capacitor C_{is} and inductor L_{is} serially resonates at a middle band. Together, these three techniques balance the gain versus the frequency response at each band to finally obtain a flat gain.

III. Results

A microphotograph of the fabricated UWB LNA is shown in Fig. 2. The total chip size, including pads, is 1 mm × 1 mm.

Figure 3 shows the measured *S*-parameter results. As the figure shows, S_{21} has a gain of 19.2 ± 1.2 dB and a 3 dB bandwidth operable from 3.4 to 8.2 GHz. To our knowledge, the measured power-gain bandwidth product of 399.4 GHz achieved by our proposed UWB LNA is the best to date. The 3 dB frequency range of S_{21} performs adequately across band groups 1 to 3 and a portion of band group 4, as is necessary for UWB systems. However, the measured values of S_{11} and S_{21} shift from 3.1 to 3.4 GHz because a sensitive capacitance of C_b in the parallel resonant-section is changed by an unexpected parasitic capacitance on a long connection-line. The cascode topology yields an excellent reverse isolation of less than –30 dB across all bands. A group delay of 175 ± 75 ps was measured.

Figure 4 shows simulated and measured NF results. The minimum measured NF of 3.3 dB occurred at 5 GHz, and the maximum noise figure was less than 6.3 dB across all bands. The

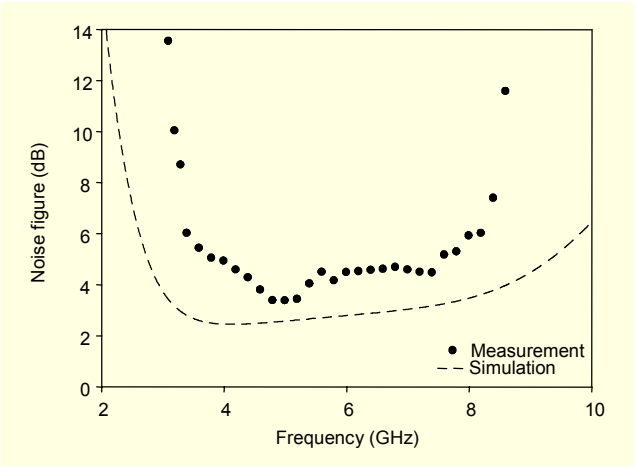

Fig. 4. Simulated and measured noise figures.

Table 1. Performance summary and comparison to other wideband 0.18-μm CMOS LNAs.

Ref.	Power-gain × BW (GHz)	BW (GHz)	S_{21} (dB)	NF (dB)	IIP_3 (dBm)	Power (mW)
[1]	126.4	3 - 7	15	1.9	-	21
[2]	75.9	3.1 - 4.8	16.5	3.95 - 4.3	-	-
[3]	77.8	2.4 - 9.5	10.4	4.2 - 8	–8.8	9
[5]	357.6	2.8 - 7.2	19.1	3.8	–2.2	32
This work	399.4	3.4 - 8.2	19.2	3.3 - 6.3	–14.7	17.3

two-tone test executed a frequency sweep from 3.1 and 8.2 GHz. The measured input-referred third-order intermodulation distortion (IIP_3) and the input-referred 1 dB compression-point (P_{1dB}) resulted in –14.7 and –23.3 dBm, respectively, during the worst-case operation at 8.2 GHz. The proposed LNA consumed 17.3 mW with 1.8 V and 9.4 mA with bias circuits.

Table 1 summarizes the measurement results and compares them to those of previous works [1]-[3], [5]. The proposed CMOS amplifier was found to give outstanding performance in terms of gain, NF, and power-gain bandwidth product.

IV. Conclusion

A UWB LNA has been proposed. Simulation and measurement demonstrate that the proposed LNA yields a high gain and a low noise figure over a wide bandwidth. The LNA using a 0.18-μm CMOS process consists of two stages of cascode for high gain over wideband and an input matching network with a modified second-order Chebyshev filter. Three techniques were employed to improve the flatness of the gain. According to our measured results, the proposed LNA has the largest power-gain bandwidth product to date and satisfies UWB system requirements; therefore, it should be very useful for UWB and other wideband applications.

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