

A COMPACT WIDEBAND MATCHING 0.18- μ M CMOS UWB LOW-NOISE AMPLIFIER USING ACTIVE FEEDBACK TECHNIQUE

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Abstract—This work presents an ultra-wideband (UWB) low noise amplifier (LNA) with active shunt-feedback technique for wideband and flat gain by using standard 0.18 μ m CMOS processes. Different from past resistive shunt-feedback technique, the capacitor supersedes by a transistor in active shunt-feedback technique. The active shunt-feedback provides input matching generating a 50 Ω real part with proper design and achieves flat gain from 2.5 GHz to 12 GHz. The UWB LNA achieved 11.4 ± 0.2 dB gains, 4.5 \sim 5.2 dB noise figure (NF), 13.5 mW power consumption at frequency 3.1 GHz to 10.6 GHz, -15 dBm of 1-dB compression point (P_{1dB}), and -3 dBm of input third intercept point (IIP3) at 6 GHz. The chip size including pads is only 0.6×0.5 mm².

1. INTRODUCTION

Recently, ultra-wideband (UWB) emerges as a communication technology to get high data-rate (> 100 Mb/s) transmission and transmit information using very low power, short impulses thinly spreading over a wide bandwidth. By the regulations from the Federal Communications Commission (FCC), the frequency of the

UWB devices for communication applications is from 3.1 GHz to 10.6 GHz with 7.5 GHz bandwidth [1]. For UWB applications, the low noise amplifier (LNA) in the RF receiver front-end needs to provide decent and flat gain over a wide bandwidth. The impedance of UWB LNA matching network should be close to 50Ω across a very wide band. Generally, in order to extend the bandwidth and to achieve high gain, the UWB LNA matching networks require several orders of matching and amplifier stages to increase bandwidth, which inevitably increase the chip area, power consumption, uneven gain, and cost increasing. However, low cost, small size, and high performance UWB LNAs are required for the orthogonal frequency-division multiplexing (OFDM). For wideband input matching, common gate (CG) LNAs [2] and resistive shunt-feedback technique [3] are published. The common gate amplifiers have a good wideband input matching but suffer from poor gain performance. A resistive shunt-feedback technique proved good input matching and tends to have flat gain for wideband LNA application by reducing the quality factor (Q) of input matching network [3]. The UWB LNA using resistive shunt-feedback technique can achieve wideband input matching and flat gains, but suffer from poor noise figure (NF) [3]. In order to reduce the chip size, an active feedback technique is published in [4]. The active feedback technique provides wideband input matching without using passive inductor to reduce the chip size.

In this study, an UWB LNA using feedback amplifier with wideband, flat gain and small size is proposed. The feedback capacitor supersedes by a transistor in this active shunt-feedback technique. The active shunt-feedback technique for wideband matching not only tends to flat gains but also increases the isolation from input to output. The feedback resistance ($R_{feedback}$) is determined by feedback amplifier to get a 50Ω matching and decrease the noise figure (NF) by using few numbers of matching devices. The proposed UWB LNA is suitable for both the UWB pulse-radio and OFDM system applications.

2. CIRCUIT DESIGN

The UWB LNA combines a cascode amplifier (M_1 and M_2) with a feedback amplifier (M_3) for wideband and flat gain response, as shown in Fig. 1(a). The center-tapped inductor (L_1 and L_2), modeled by Taiwan Semiconductor Manufacturing Company (TSMC), is a three-port inductor. C_1 is a bypass capacitor and M_2 behaves as common-gate (CG) circuit. The feedback transistor M_3 is beneficial to improve the isolation from point 1 to point 2.

The cascode amplifier and common-drain feedback amplifier [5]

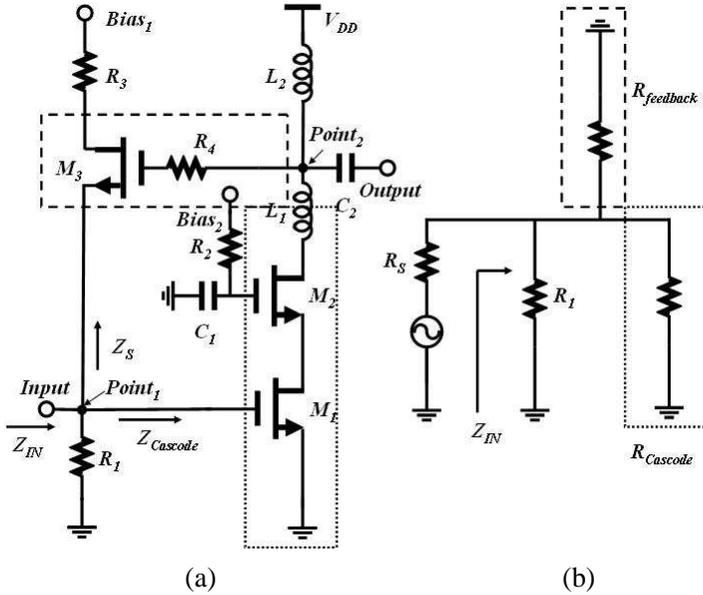


Figure 1. (a) The schematic diagram of proposed LNA for UWB system application, and (b) equivalent circuit for the proposed UWB LNA input network including the feedback network.

form a negative feedback network to increase stability of the circuit. The resistance $R_{feedback}$ represents the Miller equivalent theory input resistance of feedback network. Equivalent circuit of the proposed UWB LNA input network with feedback network is shown in Fig. 1(b) [6].

The input impedance of the proposed UWB LNA is

$$Z_{in} = R_1 // R_{feedback} // Z_{cascode} \tag{1}$$

where $R_{feedback}$ represents impedance of the feedback network and $Z_{cascode}$ is the impedance referring to cascode amplifier. The input impedance of proposed UWB LNA Z_{in} is dominated by low impedance of the feedback network ($R_{feedback}$) [3].

On the proposed UWB LNA input network, the small-signal equivalent circuit with feedback network is shown as Fig. 2 [3]. The $R_{feedback}$ is determined by g_{m3} and size of the transistor M_3 . By selecting optimum value of g_{m3} , input matching network impedance of 50Ω is achieved and complexity of the input matching network is reduced.

The input matching bandwidth is affected by the quality factor of the input matching network. For wideband matching, matching

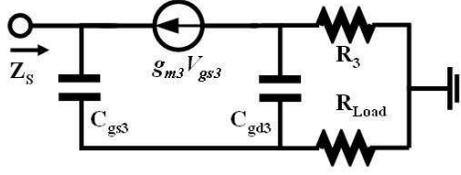


Figure 2. Small-signal equivalent circuit for the proposed UWB LNA input network including the feedback network.

network must have a low quality factor to enhance the bandwidth. The input network Q factor of the resistive shunt-feedback LNA can be expressed as [6].

$$Q \approx \frac{1}{\left[R_S + \left(\frac{1 - A_v}{R_{feedback}} \right) \right] \cdot \omega_0 \cdot C_{gs1}} \propto \frac{R_{feedback}}{1 - A_v} \quad (2)$$

where $R_{feedback}$ is feedback resistance and A_v is open-loop gain. According to Eq. (2), low $R_{feedback}$ and high A_v can reduce the input network Q factor to increase bandwidth. Through appropriate selecting size and bias of the transistor M_3 , the proposed UWB LNA has a wideband input matching. The output matching of the proposed UWB LNA uses a center-tapped inductor for second-order matching design. By using the additional resistance, the active feedback network reduces Q factor of the output matching network for bandwidth extension. For shunt-feedback LNA, the noise figure (NF) can be calculated as [7].

$$NF \approx 1 + \frac{\gamma_{gm}}{R_S g_m} + \frac{1}{R_S R_L g_m^2} + \frac{4R_S}{R_{feedback}} \left(\frac{-1}{1 + \frac{R_{feedback} + R_S}{(1 + g_m R_S) R_L}} \right)^2 \quad (3)$$

where γ_{gm} are noise excess parameters of M_1 [8], R_L is the impedance of load network, and $R_{feedback}$ is the resistance of the feedback network. According to Eq. (3), high $R_{feedback}$ yields a low noise figure; however, high $R_{feedback}$ reduces bandwidth, and therefore there exists a trade-off between noise figure and bandwidth. By selecting a proper value of g_{m3} and R_2 , the proposed LNA can achieve wideband matching, applicable NF and flat gain.

3. EXPERIMENTAL RESULTS

The proposed UWB LNA is fabricated by employing Taiwan Semiconductor Manufacturing Company (TSMC) 0.18 μm 1P6M RF CMOS process. The die microphotograph is shown in Fig. 3 and the chip size is $0.6 \times 0.5 \text{ mm}^2$ including the pads.

The chip was on wafer to measure with pitch 100 μm ground-signal-ground (GSG) RF probes and the results of the S -parameters is shown in Fig. 4.

It can be clearly seen that input impedance is very close to 50Ω in the frequency range of 2 to 20 GHz and return loss is all less than -10 dB . The gain of the proposed UWB LNA (S_{21}) is $11.4 \pm 0.2 \text{ dB}$ and all greater than 10 dB at frequency 3.1 ~ 10.6 GHz. The output matching of the proposed UWB LNA is also close to 50Ω and S_{22} is all below -10 dB . The frequency band of the gain is above 10 dB with the 3-dB bandwidth spanning from 2.5 to 12 GHz.

The measured results of noise figure (NF) is shown in Fig. 5. The proposed UWB LNA achieved 4.5 ~ 5.2 dB at frequency 3 GHz to 10 GHz.

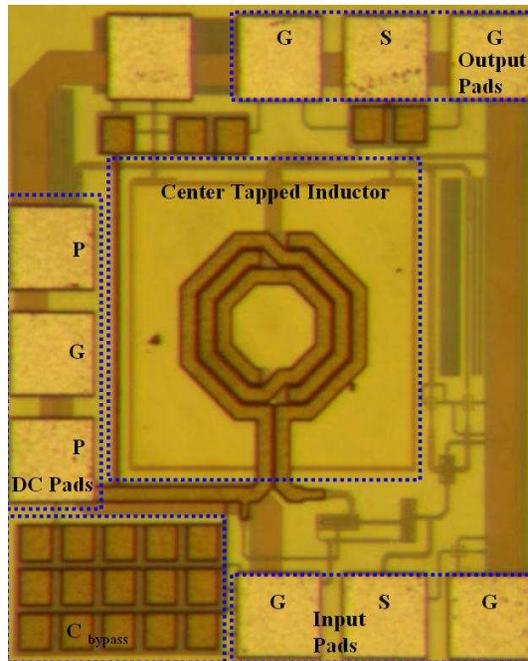


Figure 3. The die microphotograph of the proposed UWB LNA and the chip size is 0.3 mm^2 including the pads.

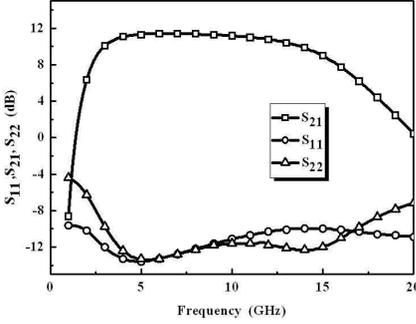


Figure 4. The measurement S -parameter results of proposed UWB LNA. The S_{11} , S_{22} are all less than -10 dB, and S_{21} is all greater than 10 dB.

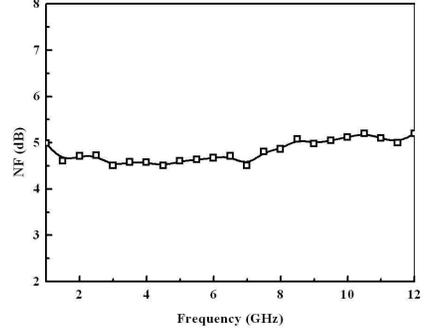


Figure 5. The measured results of noise figure of the proposed UWB LNA and NF is $4.5 \sim 5.2$ dB at frequency 3 GHz to 10 GHz.

The linearity performance of the proposed UWB LNA with input power -30 dBm to -10 dBm is shown in Fig. 6. As been seen, the linearity performance 1-dB compression point ($P_{1\text{dB}}$) of the proposed UWB LNA is -15 dBm.

While two tones at 5.995 GHz and 6.005 GHz with equal input power -30 dBm the third-order intermodulation distortion (IMD3) can be calculated with fundamental output power (P_{fun}) and three-order output power ($P_{3\text{-oder}}$). The input third intercept point (IIP3) of the proposed UWB LNA with two tones can be written as:

$$\text{IIP3} = \frac{\text{IMD3}}{2} + P_{in} \quad (4)$$

According to Eq. (4), the IIP3 calculated with measurement of fundamental output power (P_{fun}) and three-order output power ($P_{3\text{-oder}}$) is -3 dBm. As shown Fig. 7 the measured output power P_{fun} and IMD3 (P_{IMD3}) characterize as linear functions of the input power per tone are plotted and an IIP3 of -3 dBm was achieved.

As can be seen, the proposed UWB LNA operated at frequency 3.1 to 10.6 GHz exhibits 11.4 ± 0.2 dB gain (S_{21}), input return loss (S_{11}) less than -10 dB, output return loss (S_{22}) below -10 dB, 13.5 mW power consumption from 1.8 voltage supply, and measured noise figure (NF) $4.5 \sim 5.2$ dB.

While the $\text{IIP3} < 0$ dBm, the figure of merit (FOM) is used to evaluate overall performance of LNA and is defined as follows:

$$\text{FoM} = \frac{G_{\text{max}} \cdot \text{BW}_{-3\text{dB}}}{(F - 1)P_{dc} \cdot |\text{IIP3}| \cdot \text{size}} \quad (5)$$

where the G_{max} is the maximum gain (S_{21} , dB), BW_{-3dB} is the 3-dB bandwidth (GHz), P_{dc} is the dc power consumption (mW), IIP3 is the input third intercept point, F is the minimum noise factor ($F = 10^{NF/10}$), and size is the chip area (mm^2) By using active shunt-

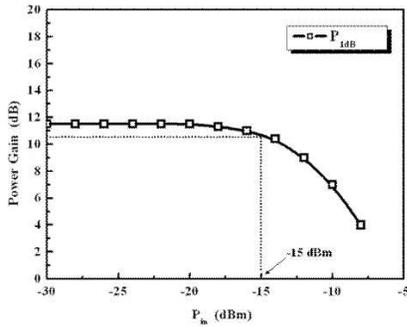


Figure 6. The measurement P_{1dB} of the proposed UWB LNA with input power -30 dBm to 0 dB is -15 dBm at 6 GHz.

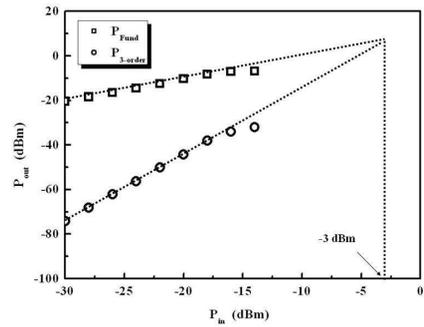


Figure 7. The measurement IIP3 results of the proposed UWB LNA with input power from -30 dBm to -10 dBm at 6 GHz.

Table 1. The performance of the proposed UWB LNA accompanied by the other previously published work.

	[6]	[9]	[10]	[11]	This work
Tech.	0.18	0.18	0.18	0.18	0.18
BW_{-3dB} (GHz)	3 ~ 8	3.1 ~ 10.6	2.2 ~ 11	3.1 ~ 10.6	2.5 ~ 12
G_{max} (dB)	15.2	16	14.1	13.2	11.6
NF_{min} (dB)	3.1	3.1	3.4	3.3	4.5
P_{dc} (mW)	3.8	11.9	30.0	9.3	13.5
IIP3 (dBm)	-7	-7	-3	-3.3	-3
Size (mm^2)	0.97	1.2	1.26	0.91	0.30
FoM	20.6	8.4	2.7	10.6	15.1

feedback amplifier technique, the proposed UWB LNA has smaller size (0.3 mm^2) and FOM (15.1) is superior to previously reported results using standard $0.18\text{ }\mu\text{m}$ process as shown in Table 1.

4. CONCLUSION

An ultra-wideband (UWB) low noise amplifier (LNA) with active shunt-feedback technique for wideband and flat gain by using standard $0.18\text{ }\mu\text{m}$ CMOS processes has been proposed. By employing active shunt-feedback technique, the UWB LNA achieves wideband input matching characteristic. Thus, input matching network could use few devices numbers to reduce the chip size. The active shunt-feedback technique extends the bandwidth and gain flatness of the LNA by utilizing the feedback amplifier complements the gain at wideband frequency. The fabricated UWB LNA exhibits gain over 10 dB from 2 to 11 GHz, noise figure (NF) $4.5 \sim 5.2\text{ dB}$, the linearity performance $P_{1\text{dB}} - 15\text{ dBm}$, $\text{IIP3} - 3\text{ dBm}$, and the power consumption is 13.5 mW at 1.8 V supply voltage. Hence, the proposed LNA is suitable for the full $3.1 \sim 10.6\text{ GHz}$ UWB frequency band applications.

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