Design Trade Off on Noise Figure and Chip Area in Multi-Stage Low-Noise Amplifier for Ultra-Wideband Wireless Receiver

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***Abstract* - A multi-stage low-noise amplifier (LNA) with LC-tank load to extend the bandwidth is designed for ultra-wideband (UWB) wireless receiver. The design consists of three LC-tank cascode amplifier and one output buffer and is implemented in 0.18um RF CMOS process. The trade off on noise figure and chip area in low-noise amplifier design is discussed. The two LNA (LC and Res) gives 14.5dB gain; 7.2GHz and 7.0GHz 3dB bandwidth (3.1-10.3GHz and 3.1-10.1GHz) while consuming 22.8mW and 23.8mW through a 1.5V supply. Over the 3.1GHz - 10.3GHz and 3.1GHz-10.1GHz frequency band, a minimum noise figure of 2.6dB and 6.3dB and input return loss lower than -8.8dB and -6.8dB have been achieved.**

***Index Term* – RFIC, Ultra-Wideband, UWB, LC-Tank, Multi-Stage, LNA and Low-Noise Amplifier.**

I. INTRODUCTION

Since the approval of the ultra-wideband (UWB) radio technology for low power wireless communication application in February, 2002, [1] UWB systems has become an increasingly popular technology which is capable of transmitting data over a wide spectrum of frequency with very low power and high data rate. The band definition of MB-OFDM is illustrated in Fig.1 which extended from 3168MHz to 10296MHz and the band definition of DS-UWB is from 3100MHz to 4900MHz and 6000MHz to 9700MHz. The bandwidth of MB-OFDM is containing Group-A, Group-C and Group-D. The Group-B is not considered in current UWB system which caused by the U-NII band and WLAN (IEEE 802.11a). The bandwidth of DS-UWB is with Low-Band and High-Band which is in Fig.1.

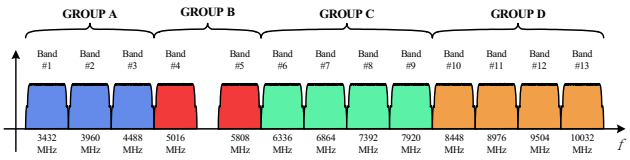


Fig.1 Groups of MB-OFDM

This paper is focused on the design and implementation of ultra-wideband systems which coexists with MB-OFDM and DS-UWB radio systems. The wideband low–noise amplifier for ultra-wideband receiver is implemented in a 0.18um Standard RF CMOS Process.

II. DESIGN OF ULTRA-WIDEBAND LNA

A. Cascode Amplifier with LC-Tank Load

The most popular topology of low-noise amplifier is cascode amplifier with LC tank, as illustrated in Fig. 2(a), which eliminates the Miller effect on input transistor to achieve high-frequency performance. The LC-tank of the load is mostly used in narrow-band systems due to its excellent frequency-selective characteristics that are shown as Figure 2(b). And the voltage gain A_{L1} of this low-noise amplifier is expressed in equation (1), where g_{m1} is the transconductance of the MOSFET, r_{o1}, r_{o2} are the output impedance of the transistors, and inductor L, capacitor C are the load of the LC-tank. But the bandwidth is too narrow for ultra-wideband applications, thus the wideband low-noise amplifier consists of matching network, three stages of amplifiers and an output buffer for measurement consideration which shows in Fig. 3. The power gain is extended in a very wide frequency band which is shown in figure 4.

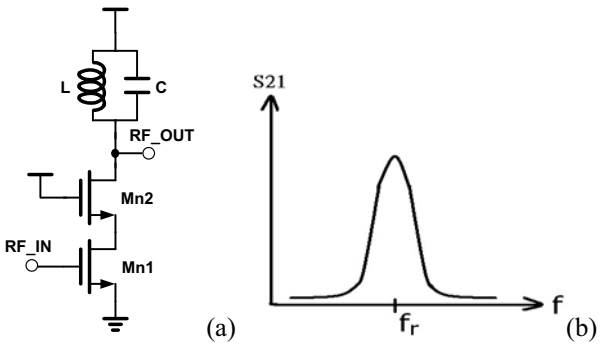


Fig. 2 Cascode LNA with LC-tank (a) and Power Gain (b)

$$A_{L1} \approx -g_{m1} \cdot \frac{s g_{m2} r_{o1} r_{o2} L}{s^2 g_{m2} r_{o1} r_{o2} LC + sL + g_{m2} r_{o1} r_{o2}} \qquad (1)$$

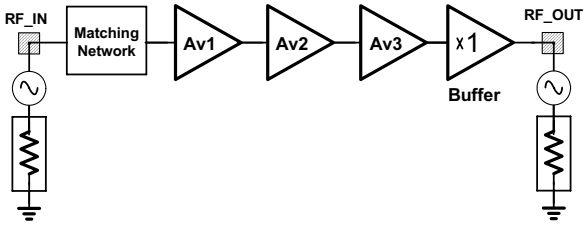


Fig. 3 Wideband LNA Design

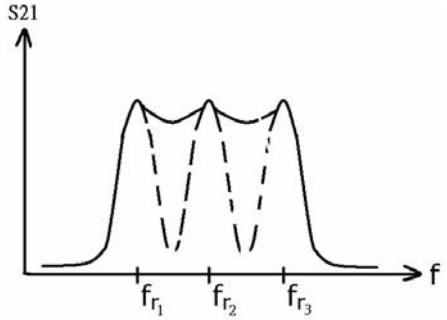
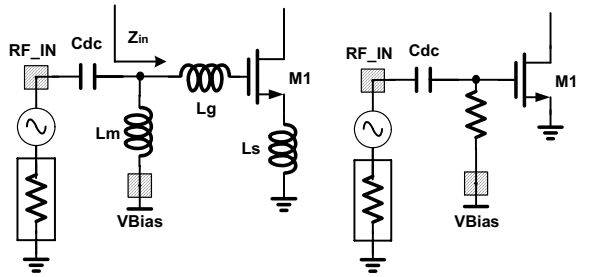


Fig. 4 Frequency Response of Wideband LNA

B. Wideband Input Impedance Matching

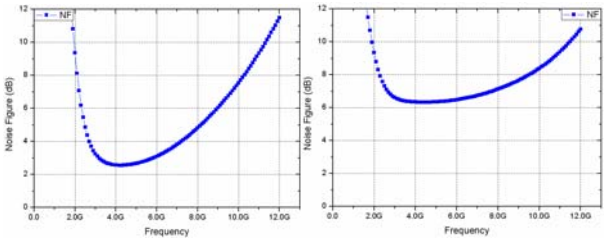
Wideband input impedance matching is a critical design challenge in ultra-wideband system. Some excellent wideband input impedance matching solutions are proposed in [3]. The wideband input impedance matching network including the conventional source-degeneration input matching and an inductor shunted in input RF path which is shown in Fig. 5(a); both of the circuits contribute one resonated frequency fr_1 and fr_2 to extend the bandwidth of the input matching. Equation (2) is the total equivalent input impedance Z_{in}, where L_g, L_s, L_m are gate inductor, source inductor and matching inductor, C_{gs1} is the parasitic capacitor in MOS transistor and ω_T is the unity gain frequency of the transistor. The other wideband input impedance matching is shown in Fig. 5(b) a shunted resistor in RF signal path; the three inductors are saved compared to the Butterworth filter input matching network. The noise figure of Butterworth filter input matching network and the shunted resistor are in Fig. 6(a) and Fig. 6(b); the noise figure of shunted resistor is higher than Butterworth filter type. Therefore, there are trade offs on noise figure and chip area. It depends on the demand of circuit design.



(a) (b)

Fig. 5 Input Impedance Matching Network (a) Butterworth Filter (b) Shunted Resistor

$$Z_{in} = \frac{s^2 L_m L_g C_{gs1} + s\omega_T L_m L_s C_{gs1} + L_m}{s^2 L_g C_{gs1} + s(\omega_T L_s C_{gs1} + L_m C_{gs1}) + 1} \qquad (2)$$



(a) (b)

Fig. 6 Noise Figure (a) Butterworth Filter (b) Shunted Resistor

C. Wideband Amplifier Design

Wide bandwidth amplifier is shown in Fig. 7 which consists of three stages of cascoded amplifier with LC-tank load. The power gain of the amplifiers which compensated into a wide bandwidth that shows in Fig. 4.

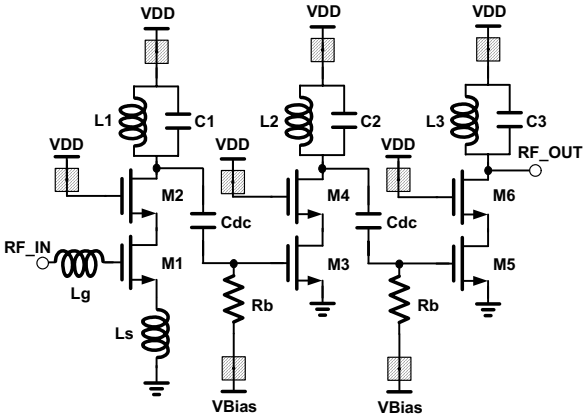


Fig. 7 Wide Bandwidth Amplifier

The proposed low-noise amplifier with Butterworth filter input matching network is shown in Fig.8 which consists of wideband input impedance matching networks, three stages cascode amplifier with LC-tank load and an output buffer. The constituent of wideband matching networks are inductors L_m, L_g and L_s and transistor M_1. First stage cascoded amplifier are transistors M_1 and M_2 with LC-tank load consists of inductors L_1, C_1, and the second stage cascoded amplifier are transistors M_3 and M_4 with LC-tank load consists of inductor L_2 and C_2. Third stage cascaded amplifier is transistors M_5 and M_6 with LC-tank load consists of inductor L_3 and C_3. A common-drain amplifier is a good choice of wideband output impedance matching for measurement purpose. In similar way, the other proposed low-noise amplifier with shunted resistor in RF path is shown in Fig.9, it's almost the same with Fig.8, but the input network is quite different; the input matching network only containing R_m.

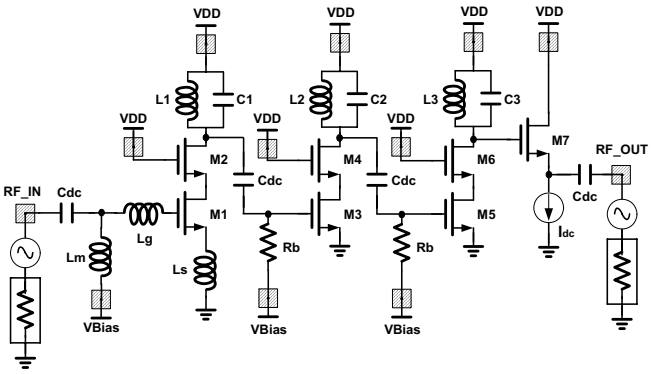


Fig.8 Proposed UWB LNA with Butterworth Input Matching Network

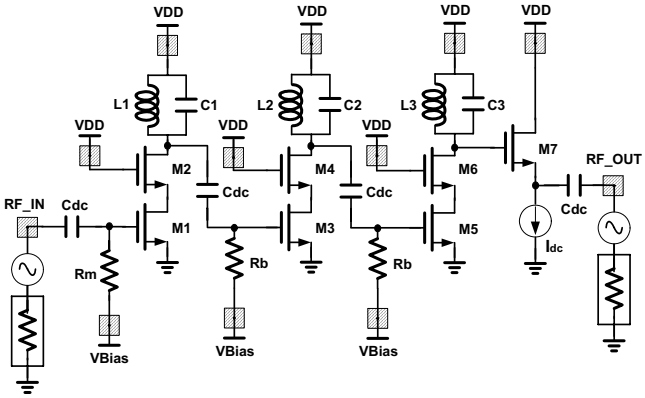


Fig.9 Proposed UWB LNA with Shunted Resistor Input Matching Network

III. SIMULATION RESULTS

The simulation results of the proposed UWB LNA using Agilent ADS 2006A simulator are given in Figure 10 to Figure 13. The characteristic of Butterworth filter input matching network LNA are shown below. In Figure 10 that can be seen the input return loss (S11) are lower than -8.8dB between 3.1GHz to 10.3GHz. In Figure 11, that can be seen that the output return loss (S22) are lower than -9.5dB between 3.1GHz to 10.3GHz, respectively. The power gain whose peak value is 14.5dB at 9.5GHz and which is shown in Figure 12. In Fig. 13, it can be seen that the noise figure is below 8.0dB between 3.1GHz to 10.3GHz and the minimum noise figure are 2.6dB at 4.2GHz through 1.5V supply voltage. The input-referred 1dB compression point (IP1dB) is -28dBm at 7.0GHz. Third-Order Input Intercept Point (IIP3) at 6336MHz and 6346MHz is -15dBm. The power consumption is 22.8mW through 1.5V supply voltage which neglects the power of output buffer. The characteristic of shunted resistor input matching network LNA are shown below. In Figure 10 that can be seen the input return loss (S11) are lower than -6.8dB between 3.1GHz to 10.1GHz. In Figure 11, that can be seen that the output return loss (S22) are lower than -9.5dB between 3.1GHz to 10.1GHz, respectively. The power gain whose peak value is 14.5dB at 3.5GHz and which is shown in Figure 12. In Fig. 13, it can be seen that the noise figure is below 8.5dB between 3.1GHz to 10.1GHz and the minimum noise figure are 6.3dB at 4.0GHz through 1.5V supply voltage. The input-referred 1dB compression point (IP1dB) is -27dBm at 7.0GHz. Third-Order Input Intercept Point (IIP3) at 6336MHz and 6346MHz is -15dBm. The power consumption is 23.8mW through 1.5V supply voltage which neglects the power of output buffer.

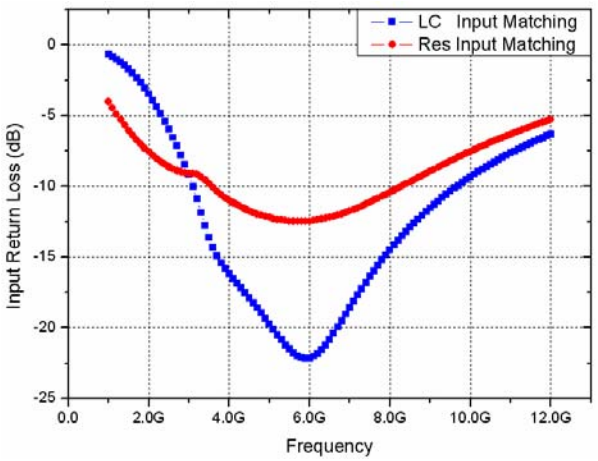


Fig. 10 Input Return Loss (S11)

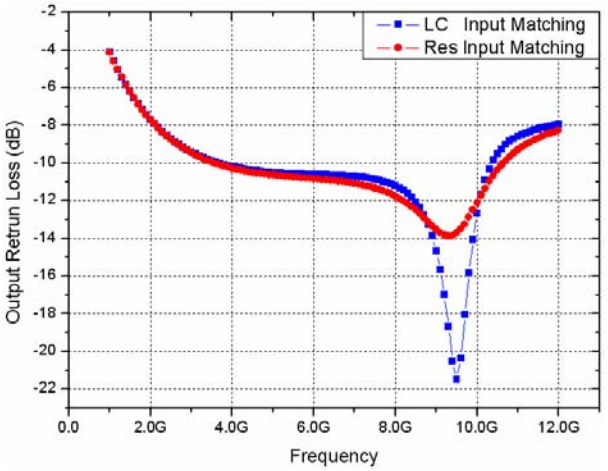


Fig. 11 Output Return Loss (S22)

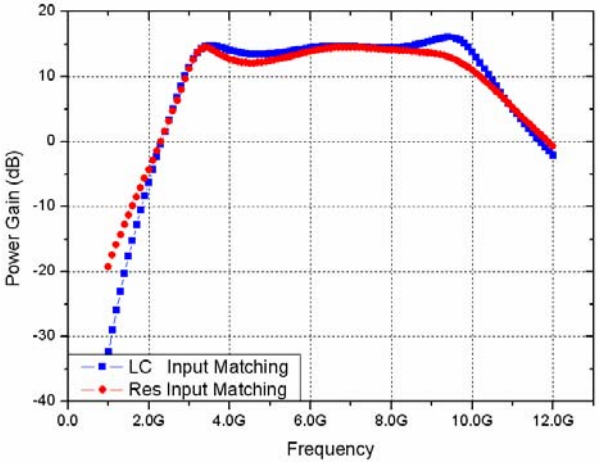


Fig. 12 Power Gain (S21)

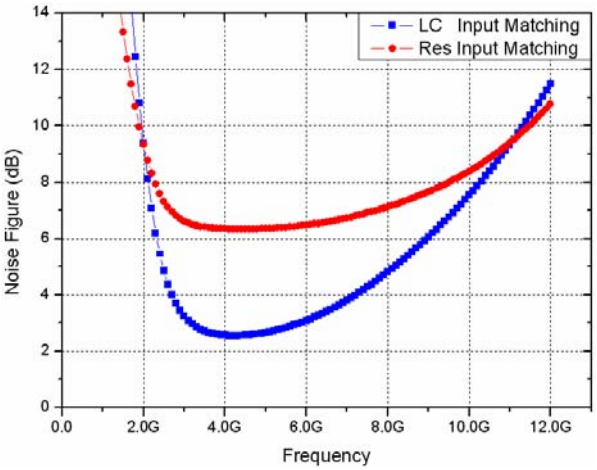


Fig. 13 Noise Figure

Table.1 Performance Conclusions

Input Matching	LC I/M	Res I/M
S11 (dB)	< -8.8	< -6.8
S22 (dB)	< -9.5	< -9.5
S21 (dB)	11.2 ~ 14.5	11.0 ~ 14.5
S21 Max. (dB)	14.5	14.5
Working Bandwidth (GHz)	3.1 ~ 10.3	3.1 ~ 10.1
3dB Bandwidth (GHz)	3.0 ~ 10.3	2.9 ~ 10.1
NF (dB)	2.6 ~ 8.0	6.3 ~ 8.5
NFmin (dB)	2.6	6.3
IP1dB (dBm)	-28	-27
IIP3 (dBm) [10MHz]	-15	-15
Power Consumption (mW)	22.8	23.8

IV. CONCLUSIONS

A CMOS UWB LNA is designed with multi-stage amplifiers for ultra-wideband system which the bandwidth extended from 3.1GHz to 10.3GHz (LC) and 3.1GHz to 10.1GHz (Res). The simulation results show that the proposed LNA gives 14.5dB power gain for 3.1-10.3GHz (LC) and 3.1-10.1GHz (Res), 7.3GHz 3dB bandwidth 3.0 – 10.3GHz (LC) and 2.9-10.1GHz (Res) while consuming 22.8mW (LC) and 23.8mW (Res) through 1.5V power supply.

ACKNOWLEDGMENT

The authors would like to thank the chip implementation center (CIC) for technical support.

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Table.2 Comparison of the Proposed UWB LNA with Other Reported Wideband LNA

Paper	Circuit Topology	Technology	S11(dB)	S22(dB)	S21(dB)	BW(GHz)	Gmax(dB)	NF(dB)	NFmin(dB)	Pdiss(mW)
[4]	resistive feedback	0.18um CMOS	< -9	< -10	6.8-9.8	2.0-4.6	9.8	2.3-5.2	2.3	12.6
[5]	3-stages comm.-source	0.18um CMOS	<-12.2	< -10.1	13.5-15.8	3.0-6.0	15.76	4.7-6.7	4.7	59.4
[6]	3-stages shunt-peaked	0.18um CMOS	< -7	< -12	6.7-9.7	1.2-11.9	9.7	4.5-5.1	4.5	20.0
[7]	2-stages comm.-source	0.18um CMOS	< -8.7	< -9.2	9.0-12.0	3.0-11.0	12.0	4.2-7.6	4.2	7.3
Butterworth	3-stages LC-tank	0.18um CMOS	< -8.8	< -9.5	11.2-14.5	3.0-10.3	14.5	2.6-8.0	2.6	22.8
Resistor	3-stages LC-tank	0.18um CMOS	< -6.8	< -9.5	11.0-14.5	2.9-10.1	14.5	6.3-8.5	6.3	23.8