CMOS Low-Noise Amplifier for 6-11GHz MB-OFDM UWB Wireless Radio System

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***Abstract* - This paper presents a low-power low-noise amplifier (LNA) with switching bands for MB-OFDM Group-C and Group-D ultra-wideband wireless radio system. The LNA is designed and implemented in TSMC 0.18um RF CMOS process. Simulation results show that power gain of 12.4dB, input and output matching lower then -8.5dB and -14.5dB, and a minimum NF of 4.0dB can be achieved, while the power consumption is 11.2 mW through 1.8V power supply.**

I. INTRODUCTION

The Ultra Wide-Band (UWB) is a new technology for wireless personal area networks (WPAN) which contains many advantages of high data transmission rate, low cost, and low power consumption that is better than narrowband wireless system. In February, 2002, UWB system is approved by the Federal Communications Commission (FCC) [1]. Although the UWB standard (IEEE 802.15.3a) has not been defined which there are two specifications, DS-UWB and MB-OFDM, and this paper mainly design for MB-OFDM UWB system in the band of 6.0GHz-11GHz for future applications. The band definition of MB-OFDM is illustrated in Fig.1 which extended from 3168MHz to 10296MHz, and the bandwidth of MB-OFDM is containing Group-A, Group-C and Group-D.; and the proposed LNA is design for 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).

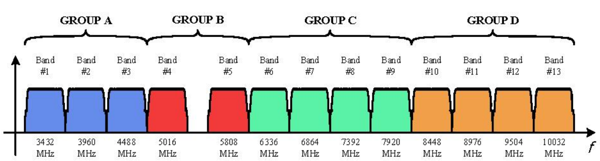

Fig.1 Band Definition of MB-OFDM

In RF wireless receiver, LNA is one of the most critical building blocks caused by the noise figure is dominated in 1st stage of the receiver that is illustrated in Fig. 2. For LNA design, there are many trade-off between different specifications. For example, the power gain affects noise figure, the die area affect cost, and the power consumption affects the battery life.

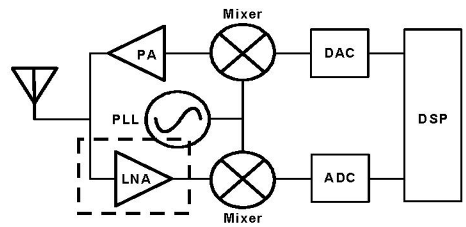

Fig.2 UWB Transceiver Architecture of MB-OFDM

II. DESIGN OF ULTRA-WIDEBAND LNA

A. *Wideband Amplifier Design*

A sketch of the wideband amplifier which contains input matching network, main amplifier and output buffer and that is shown as Figure 3. The specification of ultra-wideband system is defined as 3.1GHz-10.6GHz, therefore a very wide bandwidth input matching network is necessary in the UWB LNA. In this wideband amplifier, the main amplifier is including the low-noise amplifier and switching capacitors, and the switching capacitors are design for switching groups for MB-OFDM UWB wireless radio system. For measurement consideration, the output impedance is always designed for 50 ohms in the output buffer. The design considerations of low-noise amplifier are mainly in input return loss, power gain, and noise figure (NF), linearity (P1dB, IIP3) and power consumption, but there are some trade-off between these important characteristics.

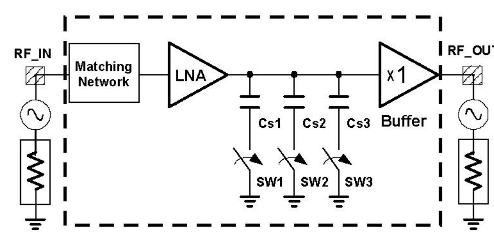

Fig.3 Wideband Amplifier

B. *Proposed Low-Noise Amplifier*

In the Figure 4, the proposed low-noise amplifier comprises the input matching network which is implemented by the

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Chebyshev Filter [3] where are L_1, C_1, L_2, C_2, L_g, L_s and C_{gs1}; the main amplifier is containing M_1, M_2, L_{L1}, C_{s1}, C_{s2}, C_{s3}, SW_1, SW_2 and SW_3; the output buffer is the M_3; and L_{sp} is the series peaking inductor, the C_{dc1}, C_{dc2} are DC blocking capacitors. The voltage gain of cascade amplifier is A_V which is described in (1), where g_{m1} is the transconductance of M_1, L_{L1} is the loading of the cascode amplifier C_{caps} is the total capacitor which including the switching capacitor and parasitic capacitors.

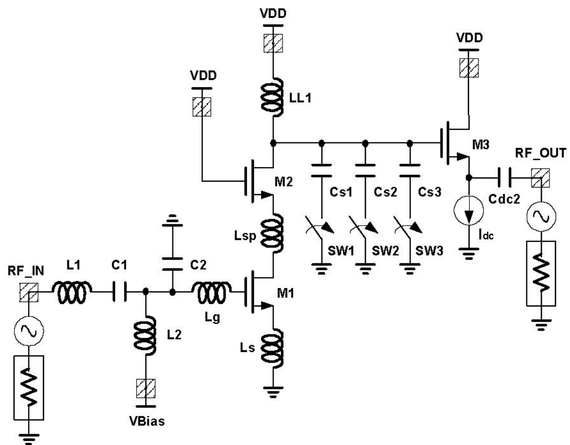

Fig.4 Proposed Low-Noise Amplifier

$$A_V = \frac{-s\, g_{m1} L_{L1}}{1 + g_{m1} L_S + s(L_{LL1} C_{caps} + g_{m1} L_S L_{L1} C_{caps})} \quad (1)$$

C. Wideband Input Matching Network

The wideband input matching network are containing L_1, C_1, L_2, C_2, L_g, L_s and C_{gs1} which is shown in Figure 5; and Z_{in} is input impedance from the source terminal. The modified equivalent circuit with small signal models is shown in the Fig. 6. The equivalent input impedance Z_{ins} is expressed in Eq. (2), where $R_L = \omega_T L_S$. R_L is always design for 50 ohms; Lg and Cgs1 are design to cancel each other in image impedance.

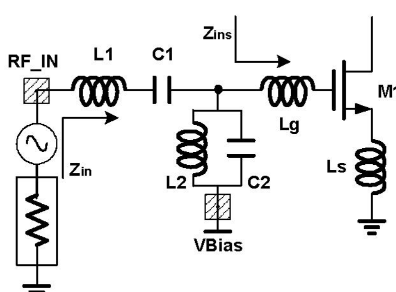

Fig.5 Input Matching Network

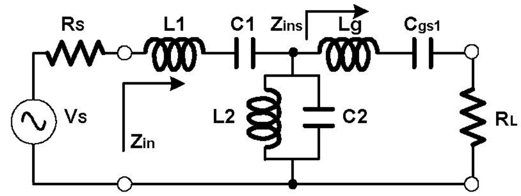

Fig.6 Input Matching Network in Small Signal Models

And Z_{in} is expressed in equation (3), B(s) is the equivalent impedance of L_1, L_2, C_1 and C_2; Z_{in} is an impedance of a 6[th] order band-pass filter which is too complicated to express in the equation; and the equation (3) is the basic form.

$$Z_{ins} = sL_g + \frac{1}{sC_{gs1}} + \frac{g_{m1}}{C_{gs1}} L_S \approx sL_g + \frac{1}{sC_{gs1}} + \omega_T L_S \quad (2)$$

$$Z_{in} = (sL_1 + \frac{1}{sC_1}) \,||\, (sL_2 \,||\, \frac{1}{sC_2}) \,||\, (sL_g + \frac{1}{sC_{gs1}} + \omega_T L_S)$$

$$= B(s) \,||\, (sL_g + \frac{1}{sC_{gs1}} + \omega_T L_S) \quad (3)$$

D. Series Peaking

When designing a wideband amplifier, the most critical problem is the bandwidth limited by large capacitance which affects the high frequency response. Thus, the high frequency response is difficult to reach higher frequency. Therefore, series peaking is a good solution to solve the important problem that is adding inductance L_{sp} along the RF path. Figure 7 illustrates the frequency response with series peaking inductor, the inductor raise the high frequency response. In the other way, series peaking is also could be viewed in time constant issue. And the time constant without series peaking is shown in (4); adding the inductor L_{sp}, and the new time constant is derived as (5). The C_{eq} is modified as a new capacitor, and the capacitance is also smaller; for this reason, the time constant is becoming reduced.

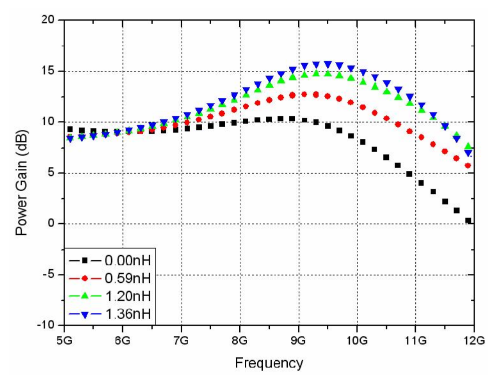

Fig.7 Inductance of Series Peaking

$$\tau_1 = RC = r_{eq} \cdot C_{gs2} \quad (4)$$

where $C_{eq} = (C_{gs2} \parallel C_{caps})$,

$$r_{eq} = [1 + (g_{m2} + g_{mb2})r_{o2}]r_{o1} + r_{o2}$$

$$\tau_2 = RC = r_{eq} \cdot C_{eq} \quad (5)$$

where $C_{eq} = \dfrac{1 - \omega^2 L_{sp} C_{caps}}{C_{caps}}$,

$$r_{eq} = [1 + (g_{m2} + g_{mb2})r_{o2}]r_{o1} + r_{o2}$$

III. Simulation Results

The simulation results of the proposed UWB LNA using Agilent ADS 2005A simulator are given in Figure 8 to Figure 12. In Figure 8 that can be seen the input return loss (S11) are lower than -12.7dB/-9.5dB/-11.3dB/-8.5dB (Band #6, 7/ #8, 9/ #10, 11/ #12, 13) between 6.0GHz to 10.6GHz. In Figure 9 that can be seen that the output return loss (S22) are lower than -14.5dB/-14.8dB/-15.8dB/-15.6dB (Band #6, 7/ #8, 9/ #10, 11/ #12, 13) between 6.GHz to 10.6GHz, respectively. The power gain whose peak value are 8.3dB, 10.8dB, 12.4dB and 11.7dB at 6.5GHz, 7.5GHz, 8.9GHz and 9.7GHz which covers the Group-C and Group-D of the MB-OFDM, and that is shown in Figure 10. In Fig. 11, it can be seen that the noise figure is below 4.9dB, 4.3dB, 4.1dB and 4.5dB between 6.0GHz to 10.6GHz and the minimum noise figure are 4.8dB, 4.1dB, 4.0dB and 4.0dB at 6.6GHz, 7.5GHz, 8.8GHz and 9.5GHz (Band #6, 7/ #8, 9/ #10, 11/ #12, 13) through 1.8V supply voltage. In Fig. 12, the input-referred 1dB compression point (IP1dB) is -15dBm, -17dBm, -18dBm and -17dBm at 6.5GHz, 7.5GHz, 9.0GHz and 10.0GHz (Band #6, 7/ #8, 9/ #10, 11/ #12, 13). Third-Order Input Intercept Point (IIP3) [528MHz] at 6336MHz and 6864MHz is -4dBm (Band #6, 7);[10MHz] at 6864MHz and 6874MHz is -3dBm (Band #6, 7); Third-Order Input Intercept Point [528MHz] at 6864MHz and 7392MHz is -2dBm (Band #8, 9);[10MHz] at 7392MHz and 7402MHz is -1dBm (Band #8, 9); Third-Order Input Intercept Point [528MHz] at 8448MHz and 8976MHz is +1dBm (Band #10, 11);[10MHz] at 8448MHz and 8458MHz is +1dBm (Band #10, 11); Third-Order Input Intercept Point [528MHz] at 6336MHz and 6864MHz is +1dBm (Band #12, 13);[10MHz] at 6336MHz and 6346MHz is +1dBm (Band #12, 13); The power consumption is 11.2mW through 1.8V supply voltage which neglects the power of output buffer. And the layout is illustrated in Figure 16.

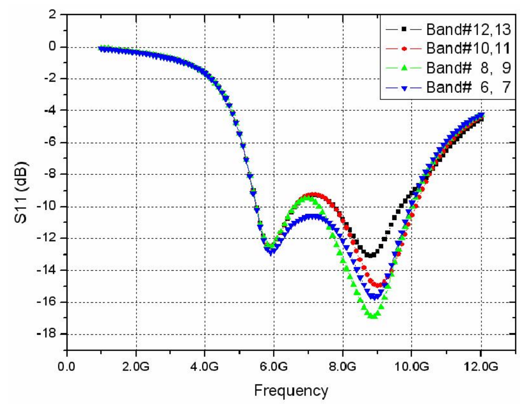

Fig.8 Input Return Loss (S11)

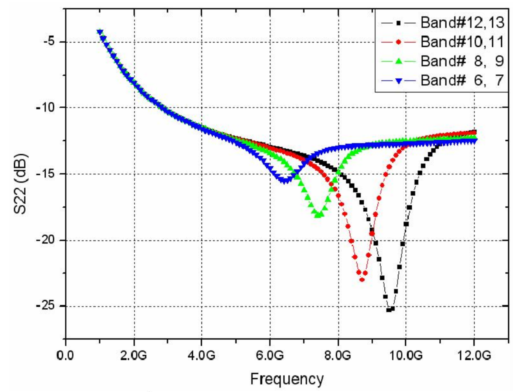

Fig.9 Output Return Loss (S22)

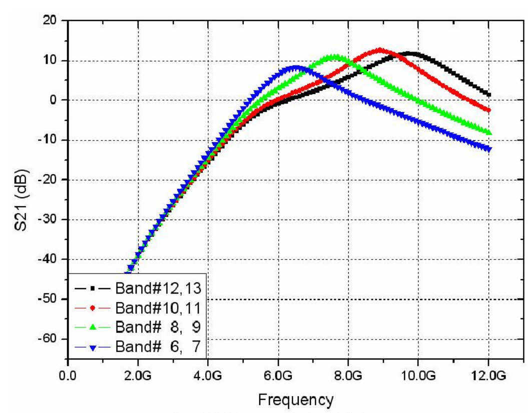

Fig.10 Power Gain (S21)

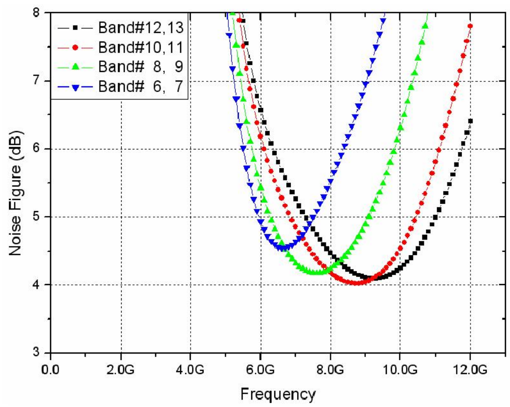

Fig.11 Noise Figure

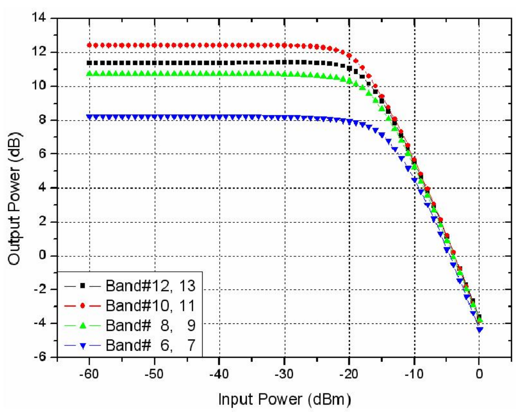

Fig.12 Input-Referred 1dB Compression Point (P1dB)

IV. Conclusions

A CMOS low-noise amplifier is design for MB-OFDM Ultra-Wideband wireless radio system which using the switching capacitor technique to implement the multi-group applications. The simulation results show that the proposed UWB LNA gives 8.3dB/10.8dB/12.4dB/11.7dB (Band #6, 7/ #8, 9/ #10, 11/ #12, 13) maximum power gain between 3.1GHz to 10.3GHz while consuming 11.2mW though 1.8V power supply.

Band	# 6, 7	# 8, 9	#10, 11	#12, 13
S11 (dB)	< -12.7	< -9.5	< -11.3	< -8.5
S22 (dB)	< -14.5	< -14.8	< -15.8	< -15.6
S21 (dB)	5.9 - 8.3	8.7 - 10.8	9.5 - 12.4	8.7 - 11.7
S21 Max. (dB)	8.3	10.8	12.4	11.7
Working Bandwidth (GHz)	6.0 - 7.2	7.0 - 8.2	8.1 - 9.3	8.7 - 10.6
NF (dB)	4.8 - 4.9	4.1 - 4.3	4.0 - 4.1	4.0 - 4.5
IP1dB (dBm)	-15	-17	-18	-17
IIP3 (dBm) [10MHz]	-3	-1	+1	+1
IIP3(dBm) [528MHz]	-4	-2	+1	+1
Power Consumption (mW)	11.2	11.2	11.2	11.2

Table.1 Performance Conclusions

Acknowledgment

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Paper	Circuit Topology	Technology	S11(dB)	S22(dB)	S21(dB)	BW(GHz)	Gmax(dB)	NF(dB)	NFmin(dB)	Pdiss(mW)
[4]	3-stages comm.-source	0.18um CMOS	<-12.2	< -10.1	13.5-15.8	3.0-6.0	15.7	4.7-6.7	4.7	59.4
[5]	2-stage shunt-peaked	0.18um CMOS	< -9.5	< -8.1	15.3-18.0	3.1-5.0	18.03	2.7-3.1	2.7	25.9
[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
This Work	Switching Capacitors	0.18um CMOS	< -8.5	< -14.5	5.9-12.4	6.0-10.6	12.4	4.0-4.9	4.0	11.2

Table.2 Performance Comparisons