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A Ka-Band CMOS Low-Noise Amplifier for Ka-Band Communication System

Zhe-Yang Huang

***Abstract* — In this paper a low power and low-noise amplifier (LNA) is designed for Ka-Band communication system. The design consists of an input impedance matching network, two stage cascode amplifiers with inductive load and an output buffer for measurement purpose; it is fabricated in TSMC 0.18um standard RF CMOS process. The measured Ka-Band LNA gives 9.5dB power gain and 1.0GHz 3dB bandwidth (27.7GHz-28.7GHz) while consuming 14.7mW through a 1.8V supply voltage including the buffer. Over the 27.7GHz – 28.7GHz frequency band, a minimum noise figure of 4.7dB and input return loss (S11) lower than -5.8dB have been achieved.**

***Index Terms* — CMOS, Low-Noise Amplifier, LNA, Ka-Band.**

I. INTRODUCTION

In convention, the millimeter wave radio circuits are implemented in Gallium Arsenide (GaAs) or Silicon Germanium (SiGe) technologies; but those technologies are not easy to integrate with baseband circuits and the cost is also high. Due to the CMOS technology is rapidly progressing, CMOS technology is becoming a good choice for millimeter wave components design. This paper is presenting a Ka-Band CMOS low noise amplifier (LNA) for high speed wireless communication applications. 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. 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. This paper is focused on the design and implementation of Ka-Band communication system; and the low–noise amplifier for Ka-Band receiver is implemented in a TSMC 0.18um Standard RF CMOS Process.

II. CIRCUIT IMPLEMENTATION

A. Wideband Amplifier Design

A simple figure of the wideband amplifier which contains input matching network, main amplifier and output buffer; and that is shown as Figure 1. The band frequency of Ka-Band system is defined as 27GHz-40GHz, and this design is target at 28GHz. 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.

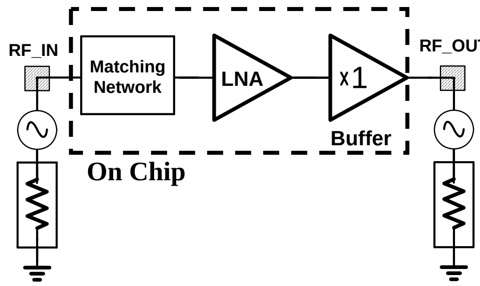

Fig.1 Wideband Amplifier

The proposed Ka-Band low-noise amplifier is shown in figure 2 which consists of the input matching network that is implemented by the source inductive degeneration. Where are C_{dc}, L_g, L_s and C_{gs1}; the main amplifier is containing transistors M_1, M_2, M_3, M_4, inductors L_1, and L_2; the output buffer is the M_5; the C_{dc} are DC blocking capacitors.

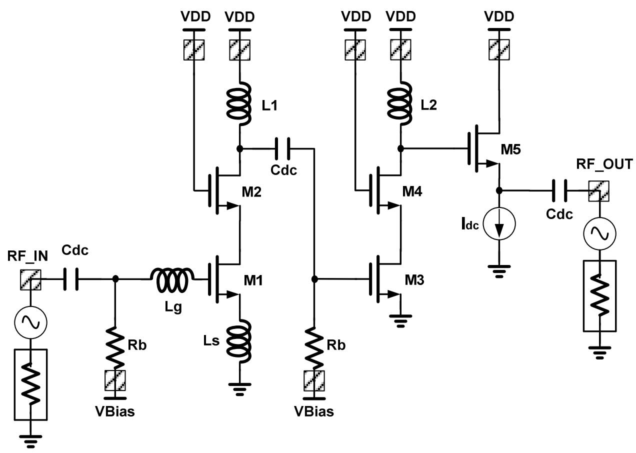

Fig.2 Proposed UWB Low-Noise Amplifier

B. Input Impedance Matching

The input matching network is containing C_{dc}, L_g, L_s and C_{gs1} which is shown in Figure 3; and Z_{in} is the input impedance from the source terminal. R_b is a high impedance which is equal to an open circuit. The modified equivalent circuit with small signal models is shown in the Fig. 4. The equivalent input impedance Z_{in} is expressed in Eq. (1),

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Zhe-Yang Huang, Author is with Industrial Technology Research Institute (ITRI), Hsin-Chu, CO 31040, Taiwan. (phone: 886-3-5914759; fax: 886-3-5820226; e-mail: maverick_huang@itri.org.tw).

where $R_L = \omega_T L_S$. R_L is always design for 50 ohms; L_g and C_{gs1} are designed to cancel each other in image impedance.

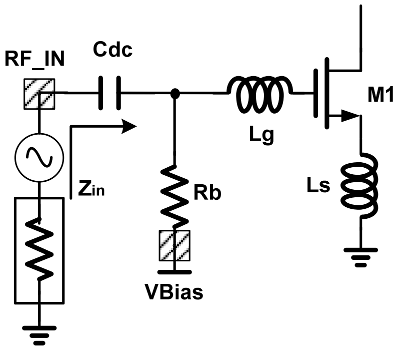

Fig.5 Input Matching Networks

Fig.3 Input Matching Network in Small Signal Models

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

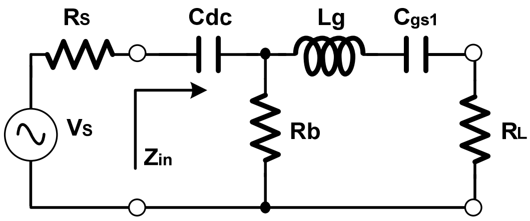

Fig.4 Input Matching Networks in Small Signal Model

C. Gain Stage

The conventional amplifier with LC-tank resonated load is shown in figure 5; and the LC-tank of the load is mostly used in narrow-band systems due to its excellent frequency-selective characteristics. The conventional narrow band low-noise amplifier using LC-tank resonated loading is very often used which caused by the highly frequency-selective in resonated center frequency. The proposed inductive resonated Ka-Band amplifier is also highly frequency-selective in frequency spectrum; different operation frequency could only modify the inductance of L_1 and L_2, there is not necessary to modify any other devices when all sizes are carefully optimized.

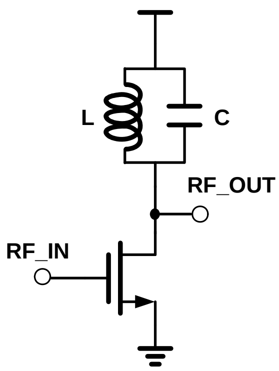

Fig.5 Common-Source Amplifier with LC-Tank Resonated Loading

Due to the weak amplification of the 0.18um NMOS transistor at Ka-Band, thus two stages of amplifiers are designed at 28GHz to contribute higher power gain. The resonated center frequency of the 1st stage cascode amplifier is design at 28GHz. And the 2nd stage cascode amplifier is also design at 28GHz. Therefore, two stages of inductive resonated amplifiers could achieve higher power gain and wider bandwidth.

III. EXPERIMENT RESULTS

The chip photo of the proposed Ka-Band LNA is presented in Fig. 6. The die area including the pads and by-pass capacitors is 0.84mm X 0.72mm. The on-wafer measurements using Ground-Signal-Ground (GSG) probes and DC probes have been considered during the testing phase. The measurement results of the proposed Ka-Band LNA using Agilent 5230A Network Analyzer and are given in Figure 7 to Figure 10. In Figure 7 that can be seen the input return loss (S11) are lower than -5.8dB between 27.7GHz to 28.7GHz. In Figure 8, that can be seen that the output return loss (S22) are lower than -4.5dB between 27.7GHz to 28.7GHz, respectively. The power gain whose peak value is 9.5dB at 28.3GHz and which is shown in Figure 9. In Fig. 10, it can be seen that the noise figure is below 5.4dB between 27.7GHz to 28.7GHz and the minimum noise figure are 4.7dB at 27.7GHz through 1.8V supply voltage. The power consumption is 14.7mW through 1.8V supply voltage which contains the power of output buffer. Table 1 is the performance at 1.8V supply voltage.

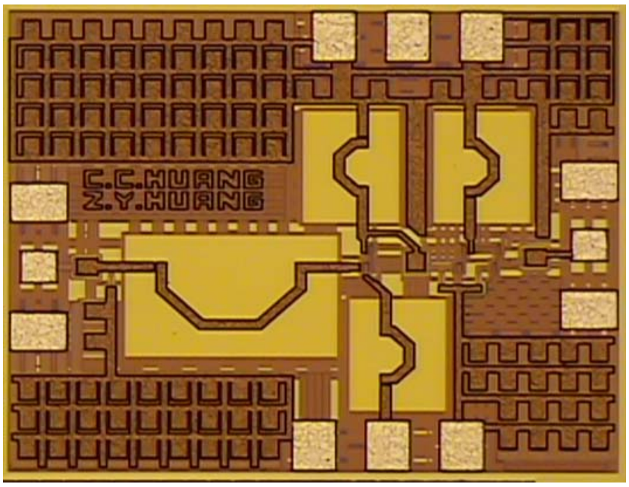

Figure6 Micro-Photography of Chip

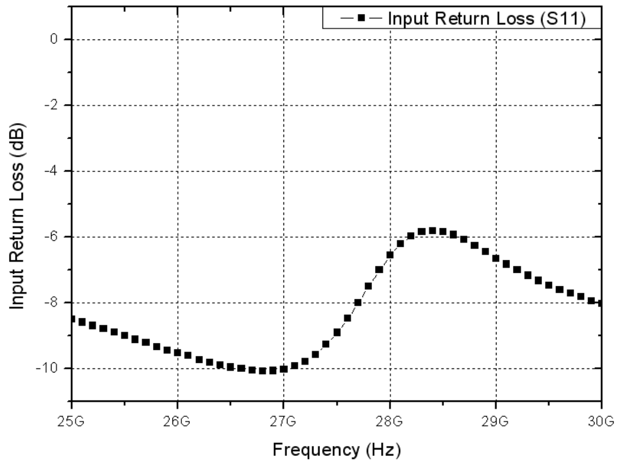

Figure7 Input Return Loss (S11)

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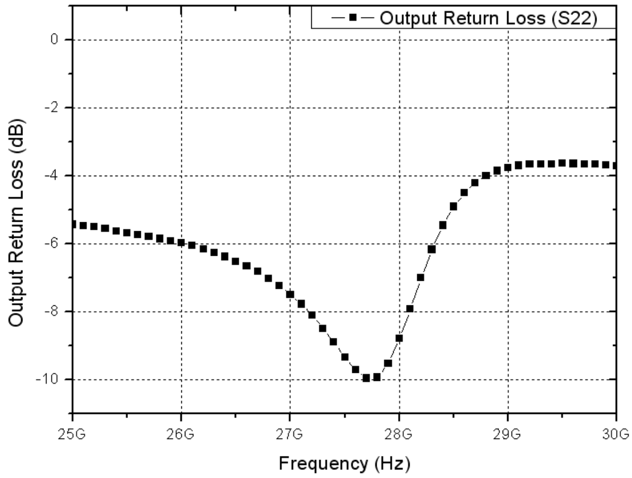

Figure8 Output Return Loss (S22)

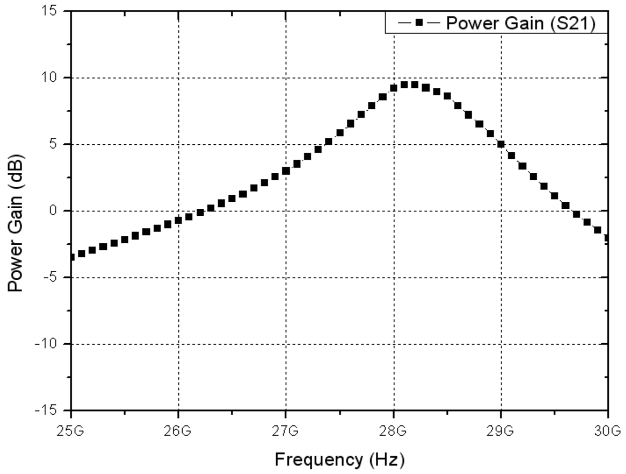

Figure9 Power Gain (S21)

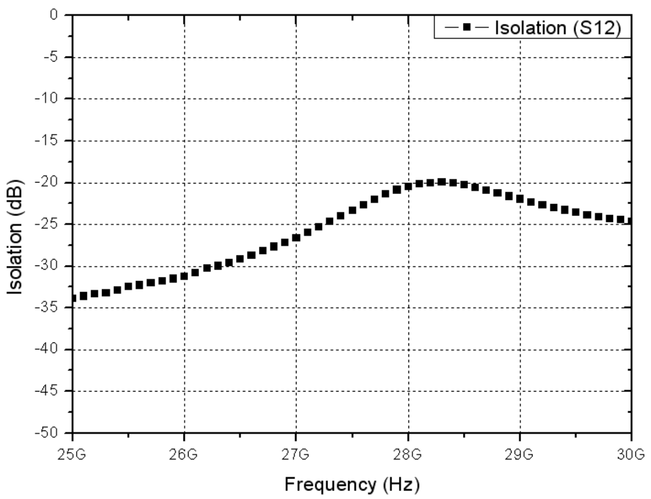

Figure10 Isolation (S12)

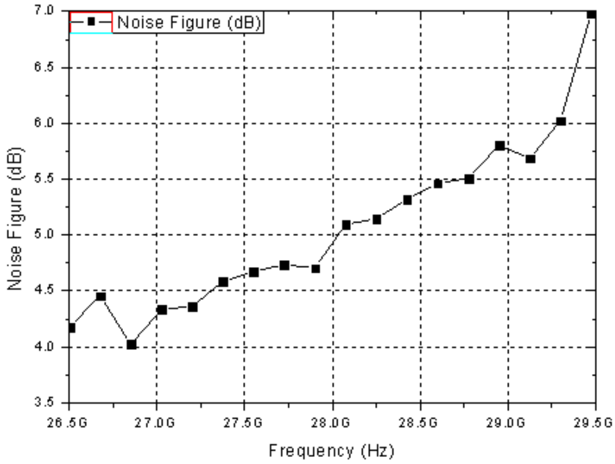

Figure11 Noise Figure (NF)

IV. CONCLUSIONS

A CMOS low-noise amplifier is design for Ka-Band communication system applications. The experimental results show that the proposed Ka-Band LNA gives 9.5dB maximum power gain between 27.7GHz to 28.7GHz while consuming 14.7mW though 1.8V power supply including output buffer. The circuit is implemented with TSMC 0.18um standard RF CMOS process.

Table.1 Performance Conclusions

Technology	CMOS 180nm
Supply Voltage	1.8 V
S11 (dB)	< -5.8
S22 (dB)	< -4.5
S12 (dB)	< -20.0
S21 (dB)	7.3 – 9.5
S21 Max. (dB)	9.5
3dB Frequency (GHz)	27.7 – 28.7
Bandwidth (GHz)	1
NF (dB)	4.7 – 5.4
Power Consumption (mW)	14.74
Die Area (mm^2)	0.60

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Table.2 Performance Comparisons

Paper	Technology	S11(dB)	S22(dB)	S21(dB)	BW(GHz)	S21max(dB)	NF(dB)	NFmin(dB)	Pdiss(mW)
[2]	AlGaN/GaN	N/A	N/A	18	28	18	4.0	4.0	2000+
[3]	90nm CMOS	< -8	< -12	16-19	31-34	19	3	3	10.0+
[4]	180nm CMOS	<-10	<-10	4-7.3	35-37	7.3	6.5-9.0	6.5	28.9+
[5]	180nm CMOS	<-13.3	< -13.4	7-10.2	31-33	10.2	4.6*	4.6*	26.9+
This work	180nm CMOS	< -5.8	< -4.5	7.3-9.5	27.7-28.7	9.5	4.7-5.4	7.7	14.7+

*: simulation results +: including buffer

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