A Ku-band CMOS Low-Noise Amplifier

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Abstract—A Ku-band monolithic low-noise amplifier is presented in this paper. This LNA fabricated in commercial 0.18- μm CMOS technology is a two-stage common-source design instead of cascode configuration for lower noise performance. This CMOS LNA demonstrates a gain of better than 10 dB and a NF of better than 3.2 dB from 14 to 15 GHz. The measured output $P_{1\text{dB}}$ is about 5.2 dBm and input IP3 is 1.6 dBm. The chip size including all testing pads is $0.88 \times 0.77 \text{ mm}^2$.

Index Terms—Ku band, CMOS, RFIC, microwave, low-noise amplifiers.

I. INTRODUCTION

Low-noise amplifiers (LNAs) are very important components of the RF front-end for transceiver application. As the wireless communication become more popular, operating frequency is moving toward higher frequency range for high data rate communication system. Most of the previously reported MMIC LNAs operated above 10 GHz such as Ku-band (12-18 GHz) are implemented by using GaAs MESFET (or HEMT) process due to the high-gain, low-noise characteristics and low substrate loss [1]-[4]. However the high cost problem of the GaAs process is an important issue. Owing to the improvement of the CMOS technology in recent years, CMOS technology is another choice for the RF circuits above 10 GHz. Recently, a 24-GHz and a 13-GHz CMOS LNAs were reported [5], [6]. For Ku-band applications, a 12-GHz silicon bipolar receiver was demonstrated for digital satellite applications [14].

A Ku-band LNA using standard commercial 0.18- μm CMOS technology is demonstrated in this paper. This CMOS LNA demonstrates a measured gain of better than 10 dB and 3.2-dB NF at 14 GHz. Table I summarizes the previously reported CMOS LNAs operated above 7 GHz. Our chip demonstrates good NF and reasonable small-signal gain at Ku band.

II. MMIC PROCESS

This Ku-band LNA is implemented by commercial standard 0.18- μm MS/RF CMOS technology which provides one poly layer for the gate of the MOS and six metal layers

for inter-connection [9], [10]. The substrate conductivity is approximately 10 S/m. With optimized CMOS technology and deep n-well, this technology provides f_T and f_{MAX} of better than 60 GHz and 55 GHz, respectively. High-Q inductors can be formed using the top AlCu metallization layer of 2- μm thickness without additional masks. A MIM capacitor of $1 \text{ fF}/\mu\text{m}^2$ has been developed using oxide inter-metal dielectric.

III. CIRCUIT DESIGN

The typical CMOS LNA topology is cascode with the source inductance degeneration with the shortcoming of the relative high supply voltage. Since the drain of the common-source stage is terminated with the source of the common-gate device, the gain of the common-source stage is not high enough and the total noise performance will be degraded by the noise of the common-gate stage.

To achieve low supply voltage and avoid noise performance degradation, a common-source topology is adopted as in Fig. 1. The input matching condition and noise performance of an inductive degeneration topology with ideal inductors was fully analyzed in [13], and the parasitic resistance was also considered. The input impedance is

$$Z_{in} = s(L_g + L_s) + \frac{1}{sC_{gs}} + R_g + R_{Lg1} + R_{Ls1} + \frac{g_{m1}}{C_{gs1}} L_{s1} \quad (1)$$

where C_{gs} is the gate-source capacitance and g_{m1} is the transconductance of transistor M1. R_g is the effective gate resistance. R_{Lg1} and R_{Ls1} are the parasitic resistance of the inductors L_{g1} and L_{s1} . The matching condition occurs when

$$\omega^2 C_{gs} (L_g + L_s) \approx 1 \quad (2)$$

$$R_s = R_g + R_{Lg1} + R_{Ls1} + \frac{g_{m1}}{C_{gs}} L_s \quad (3)$$

A two-stage topology is used to simultaneously optimize the gain and noise performances as in Fig. 1. The first stage is designed for noise performance and the second stage is designed for power gain. The transistor size of the first stage is $160\mu\text{m}/0.18\mu\text{m}$, and the second stage is the same.

Fig. 1. Schematic of the Ku-band CMOS LNA.

The inter-stage is complex conjugate matched achieved by the inter-stage inductor L_{d1} and the drain inductor L_{d2} . The inductance of L_{d1} and L_{d2} is 150 and 167 pH, respectively. The bias current of the input stage is fed through the bypass network, consists of C_{p1} , C_{p2} and R_x . The C_{p1} is design for in-band bypass and C_{p2} for low-frequency band bypass. The R_x is placed to depress the low-frequency gain and prevent resonance of bypass capacitor and effective inductance of the bias line (bonding wire or dc probe). The output impedance matching network is shunt-inductor L_{d3} . Since the operation frequency is Ku band, the parasitic capacitance of I/O pads must also be considered. The RF pads are implemented by top metal with bottom ground-shielding metal. The complete schematic of the Ku-band LNA is in Fig. 1. All inductors are realized as planar inductors. For the drain bias networks, resistor and capacitor networks are designed for providing the RF short circuit and low frequency stability concern.

The circuit simulation was performed in the software, Agilent ADS (Advanced Design System) [11]. The models of the resistors and MIM capacitors are provided by the foundry, and the S-parameters of the inductors were simulated by the full-wave EM simulator, Sonnet [12]. Fig. 2 presents the chip photo of the Ku-band CMOS LNA, and the chip size is $0.88 \times 0.77 \text{ mm}^2$.

IV. MEASUREMENT RESULTS

The LNA is measured via on-wafer probing. The measured NF and small-signal gain are shown in Fig. 3. The NF is better than 3.2 dB from 14 to 16 GHz while the small-signal gain is higher than 10 dB between 12.5 GHz and 15 GHz. The best measured NF and gain are 3.1 dB at 15 GHz and 11 dB at 13.5 GHz, respectively. The measured input and output return losses are shown in Fig. 4. The input return loss is better than 10 dB from 13.5 GHz to 18 GHz, and the output return loss is better than 10 dB from 11 GHz to 18 GHz. The power performance of this amplifier is also measured at 14 GHz, and the measured results are shown in Fig. 5. The output and input P_{1dB} is about 5.2 dBm and -5

dBm, respectively. The measured input IP3 is 1.6 dBm, as shown in Fig. 6. The dc consumption is 1.3 V/11 mA for each stage.

V. CONCLUSION

A CMOS LNA for Ku-band applications has been designed, fabricated and measured. This CMOS LNA demonstrates a gain of better than 10 dB and a NF of better than 3.2 dB from 14 to 15 GHz. The measured output P_{1dB} is about 5.2 dBm and input IP3 is 1.6 dBm. The chip size including all testing pads is $0.88 \times 0.77 \text{ mm}^2$.

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Fig. 2. Chip photo of the Ku-band CMOS LNA, and the chip size is 0.88 x 0.77 mm².

Fig. 3. Measured NF and small-signal gain of the Ku-band CMOS LNA.

Fig. 4. Measured input and output return losses of the Ku-band CMOS LNA.

Fig. 5. Measured output power versus input power of the LNA at 14 GHz.

Fig. 6. Measured IP3.

TABLE I. THE PREVIOUSLY REPORTED CMOS LNAs OPERATED ABOVE 7 GHz.

References	Process	Architecture	Frequency (GHz)	Gain (dB)	NF (dB)	P _{1dB} (dBm)	DC Consumption	Chip Size (mm ²)
K. W. Yu <i>et al.</i> , [5]	0.18- μ m CMOS	CS 3 stages	23.5	12.86	5.6	–	1.8 V/30 mA	1.05 x 0.7
J. Gil <i>et al.</i> , [6]	0.18- μ m CMOS	Cascode 1 stage	13	4.9	4.67	IIP3: 8.5	1.8 V/5.4 mA	0.31 x 0.33
R. Fujimoto <i>et al.</i> , [7]	0.25- μ m CMOS	Cascode 1 stage	7	6.2	3.3	1.6	2 V/6.9 mA	0.86 x 0.61
T. T. K. Tsang <i>et al.</i> , [8]*	0.18- μ m CMOS	Folded cascode 1 stage	8	13.5	3.2	-13.2	1 V/22.4 mA	–
T. T. K. Tsang <i>et al.</i> , [8]*	0.18- μ m CMOS	Folded cascode 1 stage	9	12.2	3.7	-8.7	1 V/19.8 mA	1 x 0.9
This Work	0.18- μ m CMOS	CS 2 stages	14	10.71	3.16	5.16	1.3 V/22 mA	0.88 x 0.77

*: variable gain amplifier, gain control range > 10 dB