A 5.4-mW LNA Using 0.35-μm SiGe BiCMOS Technology for 3.1-10.6-GHz UWB Wireless Receivers

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***Abstract* — A modified low-power and low-noise distributed amplifier for ultra-wideband (UWB) radio systems is first proposed to overcome the bottleneck of conventional DA. The UWB LNA achieves 10-dB gain with 5.4-mW power consumption, and 3-dB roll-off up to 10.6 GHz. The measured noise figures are lower than 5.5 dB from 3.1 to 10.6 GHz with 1.5 V supply. The output P_{1dB} is -5.8 dBm and input IP3 is -4 dBm from 1.5-V supply. The MMIC occupies total chip size of only 0.47 mm^2 including all testing pads.**

***Index Terms* — RFIC, low power, Silicon, SiGe BiCMOS, UWB, LNA.**

I. INTRODUCTION

Ultra-wideband (UWB) communication systems have received significant attention from industry, media and academia recently. UWB system is a new wireless technology capable of transmitting data over a wide spectrum of frequency bands with very low power and high data rates [1]-[3]. Among the possible applications, UWB technology may be used for imaging systems, vehicular and ground penetrating radars, and communications systems. Up to now, two possible approaches have emerged to exploit the allocated spectrum. One is a multiband approach, with fourteen 500-MHz subbands, OFDM modulation, and the other is the impulse radio. Although the UWB standard (IEEE 802.15.3a [2]) has not been completely defined, most of the proposed applications are allowed to transmit in a band between 3.1-10.6 GHz.

In recent years, narrow-band LNA designs have employed inductive source degeneration to achieve good input matching [4]-[7]. This technique also yields nearly optimal noise figure at the resonance frequency of the input network. Some low-noise amplifiers have been demonstrated for wideband applications [8]-[16]. A 30-mW high-gain LNA using LC-ladder matching network was proposed and implemented in 0.18-μm SiGe HBT technology [8]. A 3.4-6.9-GHz LNA with inductive source degeneration consumes 3.5 mW for applications of low-end UWB radio spectrum [9]. A DC-7.8 GHz LNA using 0.25-μm SiGe BiCMOS process was demonstrated for UWB and optical communication [10]. A Chebyshev matching CMOS LNA provides good input return loss with the noise figure from 4 to 9 dB in the desired band [12]. A conventional CMOS distributed amplifier (DA) can cover full-band UWB with low NF, but consumes high dc power [11].

Distributed amplifier (DA) is a well-known wideband amplifier potentially from DC to ultra-high frequency. In design of wideband distributed amplifiers, artificial transmission lines can be realized by multi-order LC ladder network. Distributed amplifier features good gain flatness, return losses, flat group delay and noise figure (NF) over a wide frequency band, making possible its applications for a low-noise millimeter-wave receiver for digital optical communication and other pulse applications. However, for low-power UWB system requirement, the power consumption issue makes the conventional distributed amplifier difficult to be integrated into low-power single radio chip.

In this paper, we proposed a new modified low-power low-noise DA for UWB applications to overcome the bottleneck of conventional DA. Instead of off-chip bias-T and on-chip collector line termination resistor, the bias is through output matching network to achieve low power operation. With the bias network, the supply voltage can operate as low as 1 V even though the active gain cells are cascode configuration. This MMIC fabricated in 0.35-μm SiGe BiCMOS can achieve a good flatness of noise figure and gain frequency responses with only 5.4 mW for possible integrated in single UWB radio chip.

II. MMIC PROCESS

The UWB LNA was implemented using TSMC commercial 0.35-μm 3P3M SiGe BiCMOS technology, which provides three poly layers for the emitters and bases of the SiGe hetero-junction bipolar transistor (HBT) and the gates of the complementary MOS (CMOS) transistors; three metal layers for interconnection. The HBT manufactured in this technology offer maximum oscillation frequency (f_{max}) of 57 GHz. The SiGe BiCMOS process with low-resistivity substrate (~ 10 S/m) provides monolithic inductors with quality factor below 10. A MIM capacitor of 1fF/μm^2 has been developed using oxide inter-metal dielectric. Polysilicon resistors, with several Ω/• and kΩ/•, are provided by choosing the individual dose of ion-implantation separately from the gate electron doping process.

III. Circuit Design

Low power operation is one of main design goals for UWB systems. Conventional DAs, as shown in Fig. 1, have to be biased through on-chip collector-line termination (R_{c1}) or off-chip bias-T. For on-chip bias, the bias voltage V_{oc} is difficult to achieve low-voltage operation since the voltage headroom in collector-line termination results in higher power consumption. For off-chip bias V_{bT}, the bias-T can provide lower supply voltage than on-chip bias, but it is impossible to be integrated with other front-end circuits into single RF chip.

To overcome this integration difficulty and high power consumption issues, we proposed a new design concept for UWB applications. Figure 2 shows the circuit schematic of the modified distributed type low-noise amplifier. Since the UWB system only need band-pass feature, the lower-band response of conventional distributed amplifier is not needed. This indicates the conventional base and collector resistor (R_b and R_c) need not be 50 ohm to satisfy impedance match at low frequency (e.g. below 3.1 GHz). Instead, the output impedance matching can be achieved by adding C_1 and L_6. For R_c is much larger than 50 •, the low-frequency matching is improved by L_6, while C_1 can improve high-frequency return loss. In Fig. 2, the supply voltage V_c is biased through shunt inductor L_6 of the output matching network instead of collector resistor R_c. The supply current can flow through L_6 to active devices without undesired voltage drop in R_c. The C_{b2} is used to prevent current to ground. The C_{b3}, C_{b4} and R_x serve as bypass network for supply voltage V_C.

The chip photograph is shown in Fig. 3 with chip size of only 0.47 mm^2 including all RF and DC testing pads.

IV. Measurement Results

The UWB LNA was measured using on-wafer probing with GGB ground-signal-ground (GSG) probes. Figure 4 shows the measured power gain and input/output return losses at 1V/5.4mA and 1.5V/9mA conditions. The power gain is 10 dB and 12 dB for consuming 5.4 mA and 9 mA, respectively, with 3-dB roll-off up to 10.6 GHz. The input and output return losses are both better than 7 dB in the entire desired band. The measured noise figures from 1-V and 1.5-V supply are shown in Fig. 5. The flat noise figure is about 4.5 dB from 3 to 8 GHz, and lower than 6.4 and 5.5 dB at 10.6 GHz at 1-V and 1.5-V supply, respectively. The measured P_{out} vs. P_{in} at 10 GHz are shown in Fig. 6, which indicates an input P_{1dB} of -13.6 dBm. The measured third-order inter-modulation distortion (IMD3), as shown in Fig. 7, is -52 dBc at 10 GHz with input power of -30 dBm, which indicates the IIP3 of -4 dBm.

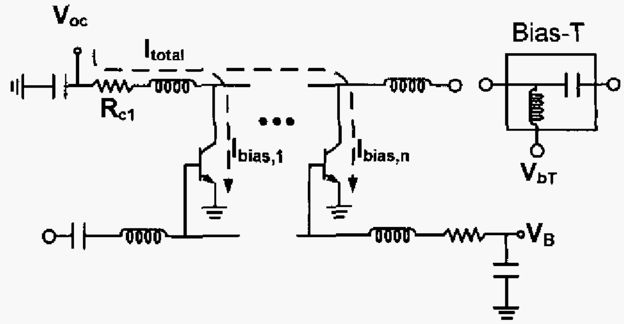

Fig. 1. Conventional distributed amplifier.

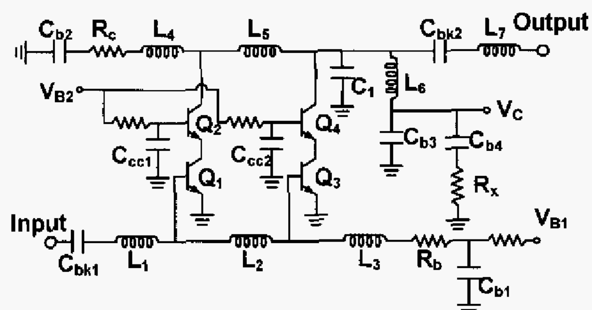

Fig. 2. Modified low-power and low-noise distributed amplifier for UWB LNA applications.

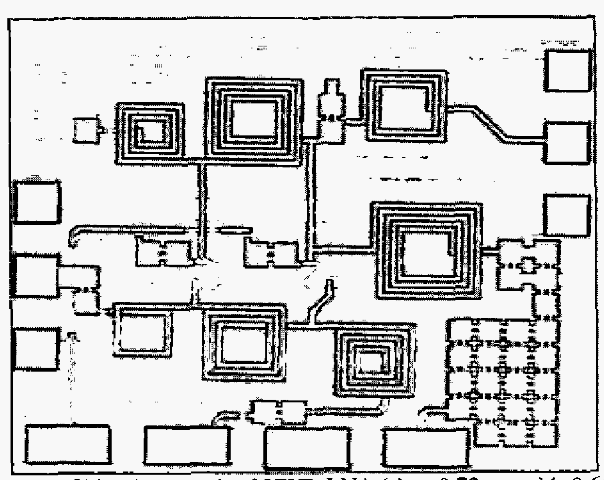

Fig. 3. Chip photograph of UWB LNA (size: 0.72 mm × 0.65 mm).

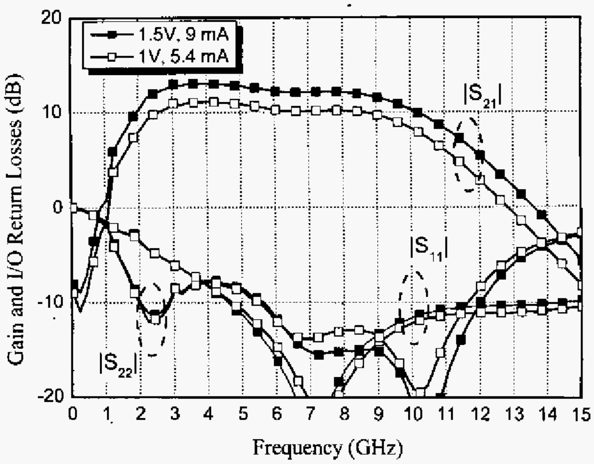

Fig. 4. The measured power gain and input/output return losses at 1V/5.4mA and 1.5V/9mA.

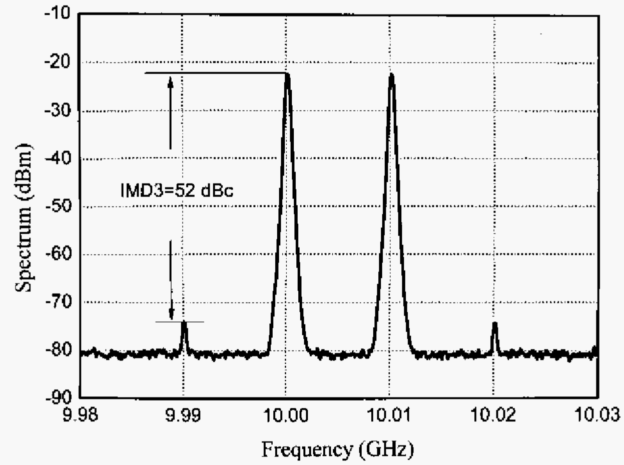

Fig. 7. Measured two-tone test at 10 GHz with input power of -30 dBm.

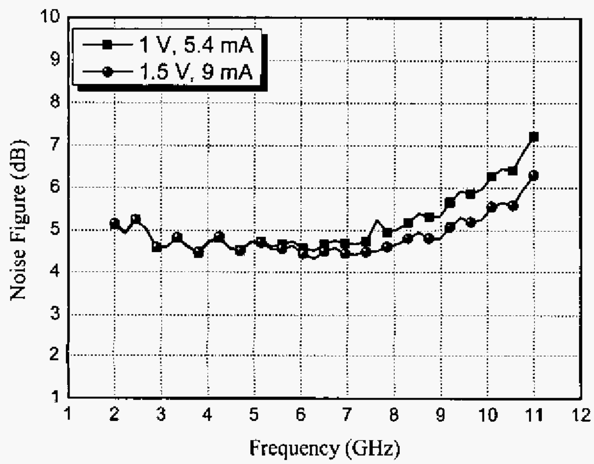

Fig. 5. Measured noise figure for the UWB LNA.

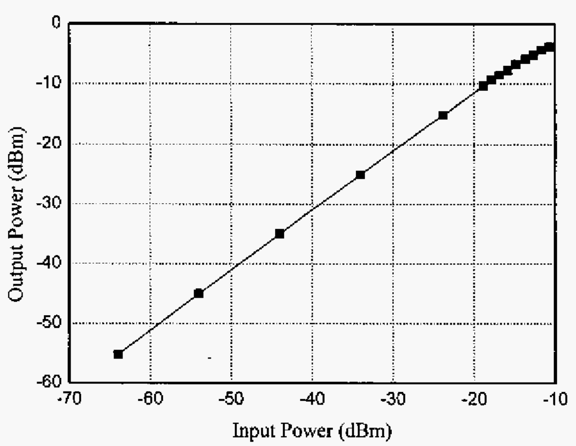

Fig. 6. Measured P_{out} vs. P_{in} at 10 GHz.

V. Conclusion

A low-power and low-noise amplifier for 3.1-10.6-GHz ultra-wideband radio systems is first proposed in this paper. The broadband amplifier is based on distributed amplifier with on-chip low supply voltage operation to achieve low-power performance. The MMIC achieves 10-dB gain with 5.4-mW power consumption, and a 3-dB roll-off up to 10.6 GHz. The I/O return losses are better than 7 dB. The measured noise figures are less than 5.5 dB from 3.1 to 10.6 GHz with 1.5 V supply. The output P_{1dB} is -5.8 dBm and input IP3 is -4 dBm from 1.5-V supply. The chip size is only 0.47 mm^2 including all testing pads. Table I summaries the recently reported LNAs for UWB applications. This MMIC is indeed the first 3.1-10.6-GHz UWB LNA with a good flatness of noise figure and gain frequency responses, miniature die size and lowest power consumption.

Acknowledgement

This work is supported in part by the MediaTek Fellowship and National Science Council of Taiwan, R.O.C. (NSC 93-2219-E-002-016, NSC 93-2219-E-002-024, NSC 93-2213-E-002-033, and NSC 93-2752-E-002-002-PAE). The chip is fabricated by Taiwan Semiconductor Manufacturing Company (TSMC) through Chip Implementation Center (CIC) of Taiwan, R.O.C.

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Table I
RECENTLY REPORTED PERFORMANCES OF UWB LOW NOISE AMPLIFIERS.

Process	Freq. (GHz)	Gain (dB)	NF (dB)	I/O RL (dB)	Chip Size (mm^2)	Total P_{dd} (mW)	Topology	Ref.
0.18μm SiGe HBT	3 ~ 10	21	< 4.2	< -9	1.8	30*	LC-ladder match	ISSCC04 [8]
0.25μm SiGe HBT	3.4 ~ 6.9	10	< 5	< -6	1.39	3.5	Narrow-band L degeneration	MWCL04 [9]
0.25μm SiGe BiCMOS	DC ~ 7.8	10.6	< 4.4	< -7.8	0.45	6.5	Input active match	IMS04 [10]
0.18μm CMOS	0.5 ~ 14	10.6	< 5.4	< -11	1.6	54+	Conventional DA	VLSI03 [11]
0.18μm CMOS	2.3 ~ 9.2	9.3	< 9.5	< -10	1.1	9*	Band-pass Chebychev match	ISSCC04 [12]
0.35μm SiGe BiCMOS	3.1 ~ 10.6	10	< 6.4	< -7	0.47	5.4	Modified low-power DA	This Work

+: Bias by off-chip Bias-T. *: excluding power consumption of output stage for output matching.