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The Design of SiGe HBT LNA for IMT-2000 Mobile Application

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Abstract

This paper describes a SiGe HBT low noise amplifier (LNA) design for IMT-2000 mobile applications. This LNA is optimized for linearity in consideration of the out-of-band-termination capacitance. This LNA yields a noise figure of 1.2 dB, 16 dB gain, an input return loss of 11 dB, and an output return loss of 14.3 dB over the desired frequency range (2.11-2.17 GHz). When the RF input power is −23 dBm, the input third order intercept point (IIP3) of 8.415 dBm and the output third order intercept point (OIP3) of 24.415 dBm are achieved.

Key words : SiGe HBT, low noise amplifier, out-of-band-termination technique.

Ⅰ. Introduction

The world is currently preparing for the advent of IMT-2000 service to enable the efficient use of radio frequency spectrum for emerging applications. The IMT-2000 frequency band is 1.92∼1.98 GHz for uplink and 2.11∼2.17 GHz for down link. Using the IMT-2000 service, everyone can communicate everywhere on the earth, over both voice service and also multimedia service. With increasing data demands, RF linearity is rapidly becoming an important design issue. Because LNA is the first stage in the receive path, its noise figure directly adds to that of the system and hence LNA noise figure and gain are important design considerations[1]. In addition, power consumption is also a key constraint for handset applications given that battery power is limited. Therefore, IMT-2000 LNAs should be designed to trade-off bias current, noise figure, gain, and return loss, such that an optimum implementation is realized. The LNA requirements for IMT-2000 mobile applications are summarized in Table 1.

The concept behind the SiGe HBT is to use "bandgap engineering" in the silicon material system by introducing a small amount of germanium (Ge) into the silicon bipolar junction transistor (Si BJT) and to selectively tailor the properties of the transistor. SiGe HBTs have excellent characteristics of higher operation frequency: low noise figure, high gain and high linearity at low current consumption compared to Si BJTs[2]. Given its high performance and low-cost, SiGe HBTs are emerging as replacements for expensive P-HEMT, GaAs MESFETs, and GaAs HBTs.

Ⅱ. SiGe HBT Model Verification

Table 1. LNA requirement for IMT-2000 mobile application.

Parameter	Required Specification
Frequency (GHz)	2.14
Band Width (MHz)	60
Gain (dB)	≥ 15
Gain Flatness (dB)	± 0.5
Noise Figure (dB)	< 1.5
Current Consumption (IC, mA)	< 10
IIP3 (dBm)	≥7
Stability	Unconditionally stable
Input Return Loss (dB)	> 10
Output Return Loss (dB)	> 14

Calibrated Gummel-Poon SPICE model parameters for the SiGe HBT (Infineon Technologies) were used in the Agilent Technologies' Advanced Design System (ADS). The Gummel-Poon SPICE model parameters and measured S-parameter data were provided by vendor. A comparison of measured and simulated small-signal S-parameters are shown in Figures 1 (a)∼(d). The bias point is 2 V, 8 mA, which is the operating point in this amplifier design. Simulations were performed over the frequency range from 50 MHz to 6 GHz. The solid line and the square in Figure 1 indicate simulated data and measurement data, respectively. Figure 2 shows the measured and simulated noise figure. Taken together, Figures 1 and 2 indicate that the SiGe HBT model gives a reasonable reproduction of the measured S-parameter data over the frequency range of interest, and is sufficiently accurate for practical LNA design.

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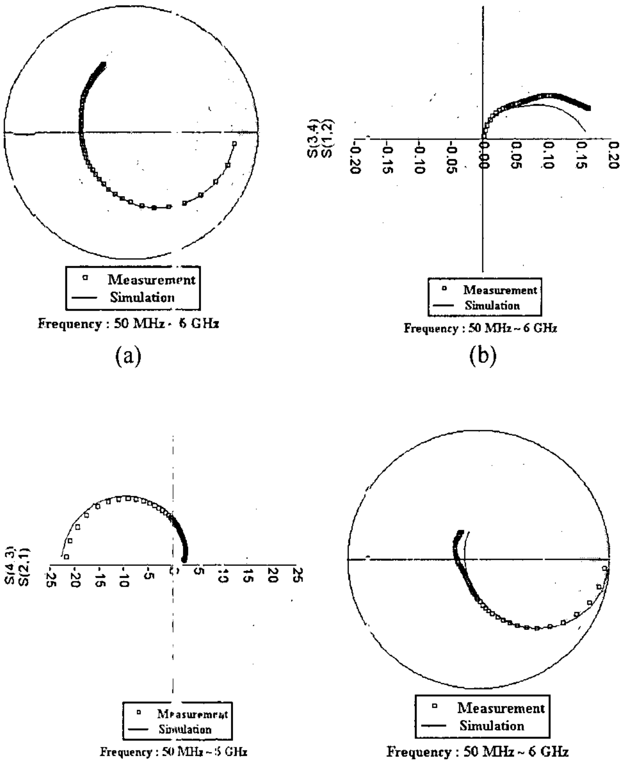


(a) (b) (c) (d)

Fig. 1. (a) Measured and simulated S_{11}.
(b) Measured and simulated S_{12}.
(c) Measured and simulated S_{21}.
(d) Measured and simulated S_{12}.

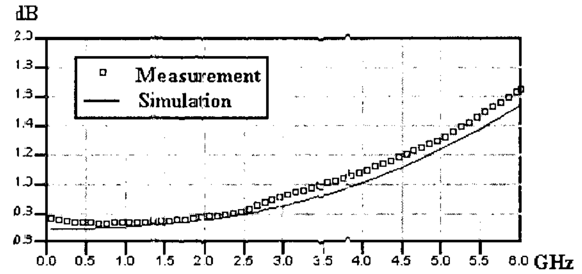


Fig. 2. Comparison of the noise figure.

Ⅲ. LNA Design

The SiGe HBT LNA was designed with a single stage. The bias point was fixed at 2.0 V and 8 mA, in consideration of collector-emitter breakdown voltage, power consumption, gain, and noise figure. Figure 3 shows the schematic of the LNA. The resistor was added in the bias network to prevent low frequency oscillation, and the emitter degeneration technique was used for stability[1],[3]. However, inductive degeneration does not seriously impact noise figure performance in this technology[4]. Additional series inductance for emitter degeneration technique was realized by microstripline.

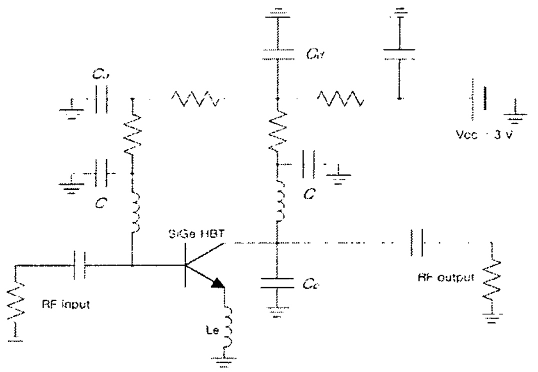


Fig. 3. Schematic of designed LNA.

An input-matching network that terminates the transistor with a conjugate of the optimum reflection coefficient was used to achieve the best noise match. In general, the input return loss was sacrificed for the noise match. Conjugate matching is used in the output-matching network to maximize the gain out of the circuit[3]. A simulated small-signal gain of 15 dB, a gain flatness of ± 0.3 dB, an input return loss of 13 dB, an output return loss of 18 dB, and a noise figure of 0.8 dB for the desired frequency bandwidth were achieved. This LNA generated 1 dB compression input power ($P_{1dB,in}$) of −9 dBm and 1 dB compression output power ($P_{1dB,out}$) of 5 dBm.

Additional bypassing capacitors C_d in Figure 3 were added to improve the IP3 characteristics[5]~[8]. The effect of C_d on LNA performance is shown in Figure 4 (without C_d) and Figure 5 (with C_d), which give OIP3 and IIP3 as a linearity figure-of-merit. The cross symbol and the square in Figures 4 and 5 indicate IIP3 and OIP3, respectively. Two-tone intermodulation distortion simulations with a 1 MHz tone spacing at 2.14 GHz were performed using harmonic balance simulation. When the input power is −23 dBm, an OIP3 of 17.6 dBm, and IIP3 of 2.5 dBm resulted, as shown in Figure 4. Figure 5 shows an OIP3 of 23.8 dBm, and an IIP3 of 8.7 dBm, respectively. An IP3 improvement of 6 dB was achieved by adding the additional capacitors (C_d). Therefore, the present out-of-band-termination

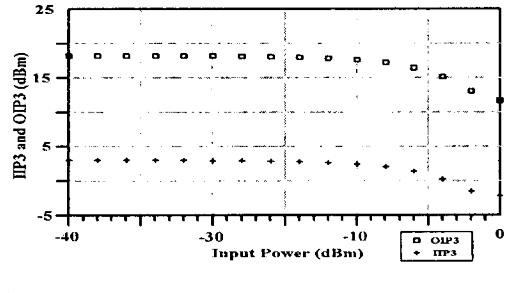


Fig. 4. Simulation results of IP3 without C_d

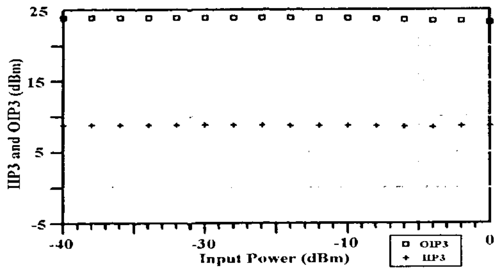


Fig. 5. Simulation results of IP3 with C_d.

technique can be applied to improve LNA linearity without significant gain reduction or additional current consumption.

Ⅳ. Implementation and Measurement

The designed LNA was fabricated and mounted on a teflon substrate (ε_r = 2.52, conductor thickness = 0.018 mm, substrate height = 0.54 mm), using a packaged SiGe HBT (Infineon Technologies) and chip type passive components. The supply voltage was 3 V, collector emitter voltage (Vce) was 2 V, and collector emitter current (Ice) was 8 mA. The small signal characteristics of the fabricated LNA was measured by network analyzer (HP 8753). Figure 6 shows the measured S-parameters. The gain of the SiGe LNA was 16 dB, the passband ripple was ± 0.3 dB, the input return loss was 11 dB, and the output return loss was 14.3 dB as shown in Figure 6. The implemented LNA has less than 1.2 dB noise figure in the desired frequency range (2.11~2.17 GHz), as shown in Figure 7. Figure 8 shows $P_{1dB,out}$ of 5.2 dBm, and $P_{1dB,in}$ of −10 dBm.

Figure 9 and 10 show the measured data for the effect of C_d and C_p on Δ IM3 (the difference in amplitude between one of the two equal amplitude test tones present at the amplifier output, and the level of the highest third order distortion product). The frequencies of the RF input two tones are 2.1395 GHz (f_1) and 2.1405 GHz (f_2), and the spacing is 1 MHz. The linearity is improved by not only C_d but also C_p as shown in Figure 9 and 10. C_p is more effective to perform the out-of-band-termination in this SiGe HBT LNA design. Figure 11 and 12 show the second order IMD product ($f_2 - f_1$ = 1 MHz and $f_1 + f_2$ = 4.28 GHz, respectively) variation by using small shunt capacitors in the output matching path (C_p). The out of band (i.e. $f_2 - f_1$ = 1 MHz, $f_1 + f_2$ = 4.28 GHz) is suppressed in proportion to C_p. However, large C_p affects adversely high frequency operation and output matching. Therefore, C_p should be determined to trade-off operation frequency, output matching network, linearity, and so on.

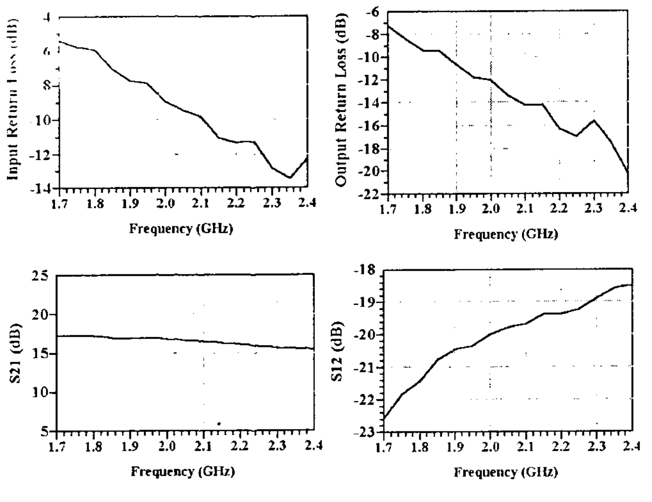


Fig. 6. Measured S parameter.

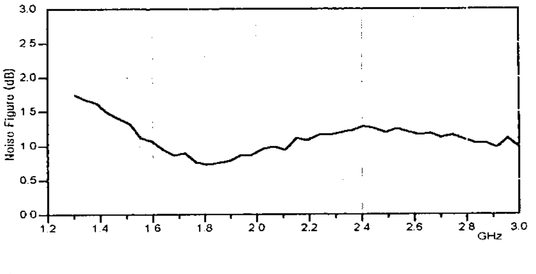


Fig. 7. Noise figure measurement.

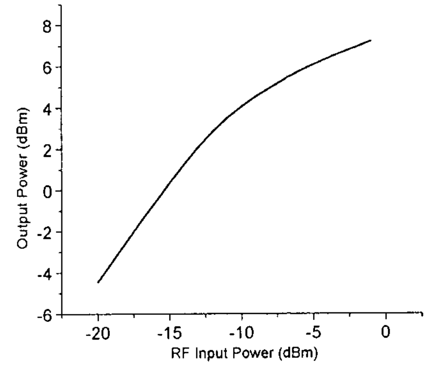


Fig. 8. Output power characteristics measurement.

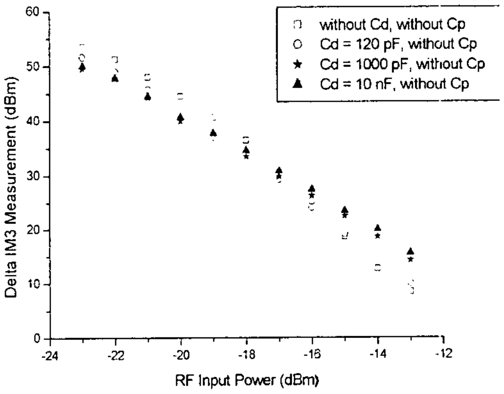


Fig. 9. The effect of C_d on Δ IM3.

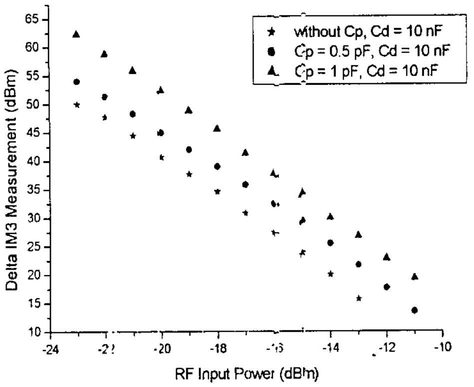


Fig. 10. The effect of C_p on Δ IM3.

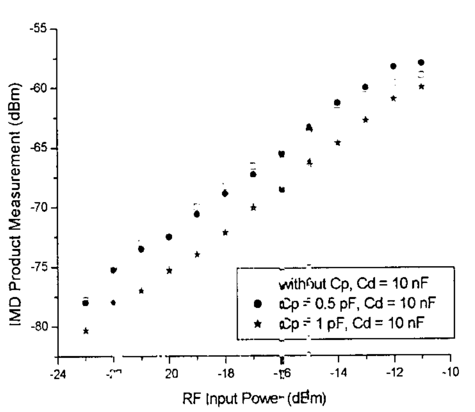


Fig. 11. The effect of C_p on $f_2 - f_1$ IMD product.

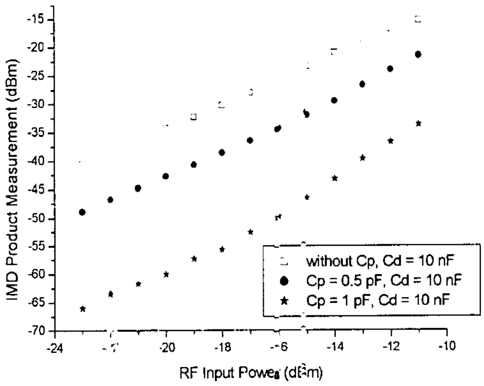
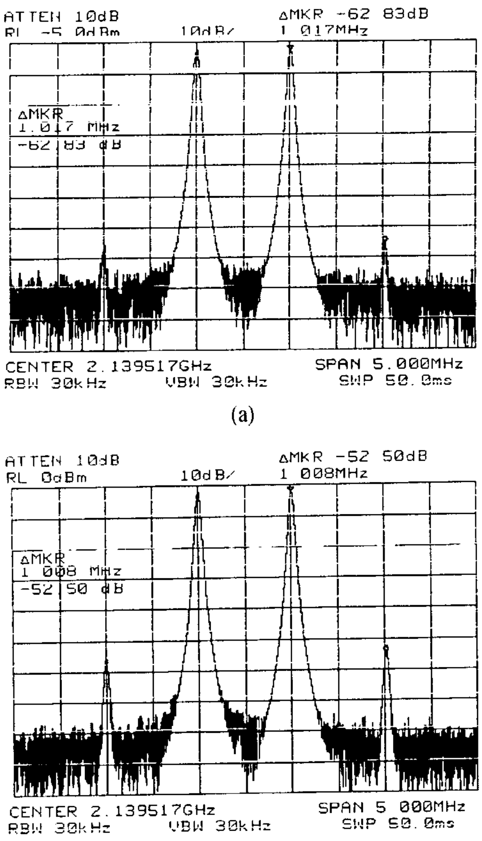


Fig. 12. The effect of C_p on $f_1 - f_2$ IMD product.

Figures 13 (a)-(b) present the Δ IM_3 of the LNA when the input power was: −23 dBm, −20 dBm, respectively. When the two tone RF input power was −23 dBm, ΔIM_3 was 62.83 dBc, IIP3 was 8.415 dBm, and OIP3 was 24.415 dBm. The tone spacing was 1 MHz.

V. Results



(a)

(b)

Fig. 13. (a) Δ IM_3 of 62.83 dBc at P_{in} of −23 dBm.
(b) Δ IM_3 of 52.5 dBc at P_{in} of −20 dBm.

A SiGe HBT LNA for IMT-2000 mobile applications was designed using the microwave simulation tool of ADS 1.3. The LNA was implemented on a teflon substrate using a packaged SiGe HBT and chip type passive components. The out-of-band-termination technique was used to improve linearity without significant gain reduction or additional current consumption. This SiGe LNA resulted in an input return loss of 11 dB, an output return loss of 14.3 dB, a noise figure of 1.2 dB, and 16 dB gain over the desired frequency range. The supply voltage was 3 V and the current consumption was 8 mA. The LNA generated $P_{1dB,out}$ of 5.2 dBm and $P_{1dB,in}$ of −10 dBm. When the RF two tone input power was −23 dBm, a ΔIM_3 of 62.83 dBc, an IIP3 of 8.415 dBm and an OIP3 of 24.415 dBm were achieved for a tone spacing of 1 MHz at 2.14 GHz.

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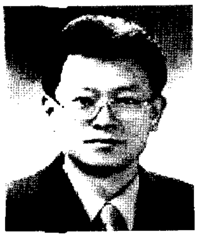

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