A WIDE DYNAMIC RANGE SWITCHED-LNA IN SIGE BICMOS

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Abstract — **A wide dynamic range, high current efficient switched-LNA has been developed by using SiGe BiCMOS technology. The low loss RF MOSFET reduced silicon substrate effect at high frequency is used as a bypass switch of LNA. The 800-900 MHz LNA is demonstrated in this work. In high gain / low distortion mode for transmitting and receiving simultaneously, the amplifier achieves 15.3 dB gain, 1.4 dB noise figure and +1.6 dBm IIP3 with 5.9 mA DC current. In high gain / low current mode for receiving only, 13.3 dB gain, 1.6 dB noise figure and –0.6 dBm IIP3 are achieved with 3.0 mA. In low gain mode, 1.5 dB insertion loss and +16.1 dBm IIP3 with < 10 uA are realized by the bypass switch. The switched-LNA is housed in a very small and low cost SON12 plastic package with a Down-Mixer.**

I. INTRODUCTION

LNAs with wide dynamic range are indispensable to CDMA systems for high capacity and high communication quality. At low input signal levels, very low noise figure and high gain is required. On the other hand, at high input signal levels, a very high 3rd-order intercept point (IP3) is required to guarantee linearity and low gain amplifiers are easy to realize high IP3. In these CDMA systems, it is often advantageous to be able to switch out amplification. Several types of switched-LNA ICs were reported to have good RF performance by using Si bipolar or GaAs FET technologies [1]-[3]. But much current was required in [1] and a high cost GaAs IC was used in [2] and [3], so a higher current efficient and lower cost IC is necessary.

Furthermore, in transmitting and receiving simultaneously, cross-modulation is one of the problems in CDMA systems [4]. It occurs when the TX power leakage gets cross-modulated on a single-tone jammer in the LNA 3rd-order non-linearity. So a higher IP3 are required than in receiving only, and the dissipation current has to be increased. In these systems, it is advantageous to be able to switch out dissipation current for current efficiency.

The purpose of this work is to develop a wide dynamic range and high current efficient switched-LNA with 3 different modes by using the high performance SiGe BiCMOS process for CDMA systems.

II. DESIGN OF THE IC

The switched-LNA has 3 modes, that is, high gain / low distortion mode (mode-1) for low input signal levels and transmitting and receiving simultaneously, high gain / low current mode (mode-2) for low input signal levels and receiving only and low gain mode (mode-3) for high input signal levels. In order to attain the objectives, the following techniques have been introduced into the design of the switched-LNA;

(1) Low loss RF switch using a triple-well MOSFET for low gain mode.
(2) 3 mode switched-LNA circuit with optimal combination of SiGe HBTs, RF MOSFETs and MIM capacitors.
(3) Very small and low cost SON12 plastic package.

To realize ~ 0 mA DC current of the switched LNA in mode-3, we use a MOSFET bypass switch. Usually MOSFET switches are of large gate width to reduce on-resistance, which is related to insertion loss. But in the case of microwave frequency, if the gate width becomes too large, an insertion loss of switch increases because signal leakage from channel to substrate increases.

To reduce this leakage, we use MOSFET with a triple-well structure. A schematic cross-section view of the RF MOSFET switch is shown in fig. 1. For more isolation, DC source voltage is supplied to n-well, and 0 voltage is supplied to p-well. Besides 10 kOhm resistors are inserted between gate and Von/Voff node, between the p-well and DC ground and between the n-well and Vcc node. Because not only DC grounds but also DC sources are AC ground, and the gate, p-well and n-well have to be isolated from the AC ground to prevent signal leakage.

Furthermore, the RF MOSFET switch improves the noise figure of the LNA in mode-1 and mode-2. Usually the bypass switch causes noise figure to be high because signal leaks from drain to substrate when the switch is ‘off’. But the RF MOSFET switch has strong isolation between drain and substrate and the signal leakage is reduced.

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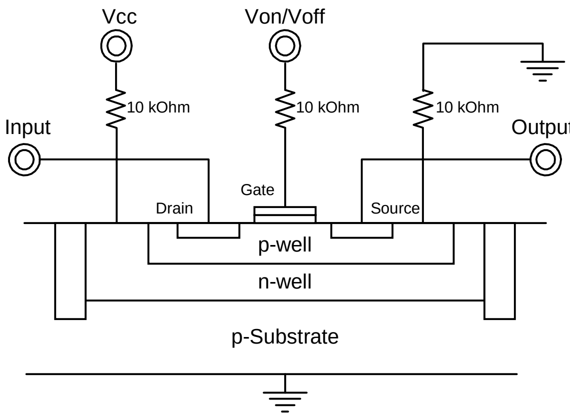


Fig. 1. Schematic cross-section view of the RF MOSFET switch.

The circuit schematic is shown in fig. 2. The amplifier is a cascode connection. The bias circuit linked with the DC controller controls the current of the amplifier. The feedback resistor and the DC block capacitor are used for a negative feedback circuit improving the stability of the amplifier. The LNA Emitter is an independent pin because an off-chip inductor is connected between the pin and the ground. The inductor enables Γopt to be near 50 Ohm.

The bypass switch consists of the RF MOSFET switch shown in fig. 1. The gate voltage is controlled by the DC control. The DC block capacitor is also used for a bypass circuit.

The amplifier and the bypass switch are controlled by the control voltage Vctl-1 and Vctl-2. The combination between control voltage and mode is shown in TABLE I. In mode-1 and mode-2, the amplifier is ‘on’ and the bypass switch is ‘off’. The current in mode-2 is reduced because the requirement of IP3 is lower than in mode-1, and the switched LNA can provide high current efficiency in a stand-by situation. In mode-3, the amplifier is ‘off’ and the bypass switch is ‘on’. In this mode, Vcc node which has very large capacitance doesn’t have to be set to 0 V. So switching time is very fast.

In mode-3, the drain and source voltages of the bypass switch are set to 0 V and the on-resistance of the RF MOSFET switch becomes low. On the other hand, in mode-1 and mode-2, the drain and source voltages are set to ~ 0.7 V and the RF MOSFET switch is able to have strong off-isolation between drain and source because the depletion layer between the drain/source and p-well widens and parasitic capacitance becomes small.

Furthermore, the MIM capacitor is used as the DC block capacitor in fig. 2. It has not only a small Rs but also a small Cp to substrate and enables the switched LNA to have a low insertion loss in mode-3.

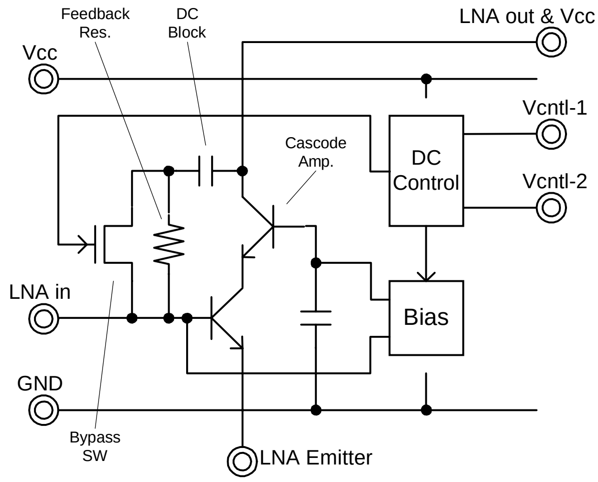


Fig. 2. Circuit schematic of the switched-LNA.

TABLE I
The combination between control voltage and mode

	Vctl1	Vctl2
mode-1	H	H
mode-2	L	H
mode-3	don't care	L

The chip was fabricated using the high RF performance 0.25um SiGe BiCMOS technology of Matsushita Electronics Corporation. It’s a process employing Ft_{max} ~ 50 GHz SiGe HBTs, triple-well MOSFETs and 700 pF/mm^2 MIM capacitors. The microphotograph of switched-LNA is shown in fig. 3. The chip including LNA and Down-Mixer is 0.94 x 1.8 mm^2.

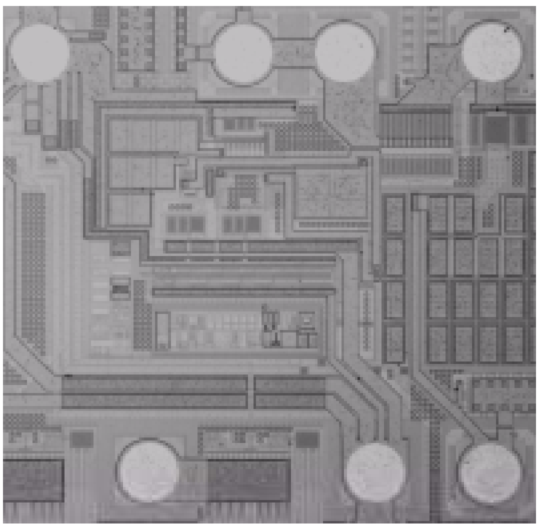


Fig. 3. Microphotograph of the switched-LNA.

The chip was housed in a low cost SON12 plastic package as shown in fig. 4. The package size is 2.5 x 3.0 mm^2. It is very small for the chip size. As a result, bonding wires are so short that the RF characteristic of the ICs is excellent. Furthermore a 0.4 mm pin pitch enables the package to have 12 pins.

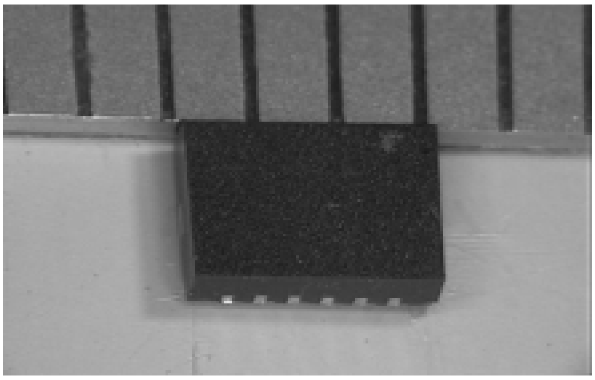


Fig. 4. External view of the SON12 plastic package. (package size : 2.5mm x 3.0mm)

III. PERFORMANCE

The switched-LNA IC can be used in various applications requiring a wide dynamic range. As a design example, the performance in the 800-900 MHz band with a power supply of 2.8 V is demonstrated.

The off-chip matching circuit schematic is shown in fig. 5. Only 2 chip inductors, 2 chip capacitors and some bypass capacitors are needed. A strip line inductor (about 1 nH) is connected with LNA Emitter to match the input for optimum noise performance in the band.

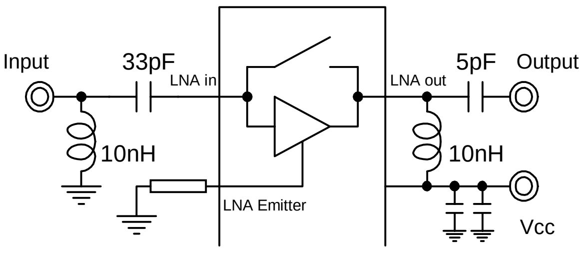
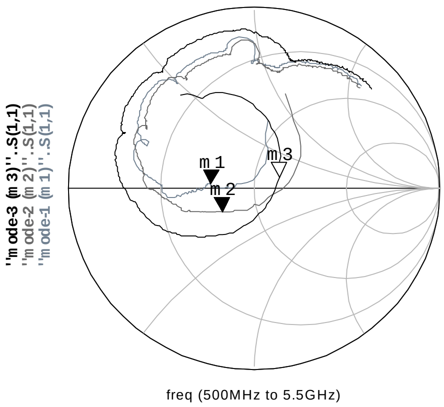
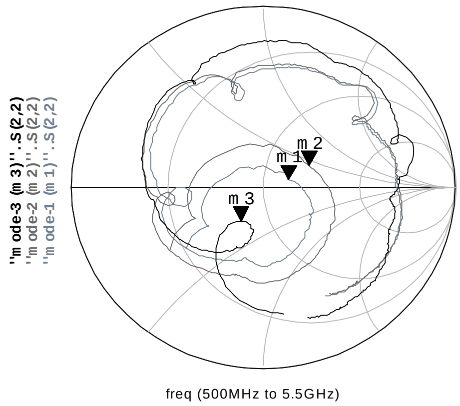


Fig. 5. Matching circuit schematic at 800-900 MHz.

Fig. 6 (a) shows the input S-parameter and (b) shows the output S-parameter. Both input and output of each mode have to be matched for suitable VSWR. To optimize capacitance of the on-chip DC block capacitor, the switched-LNA is satisfied |S11|, |S22| < -10 dB, which is equivalent to VSWR < 2, in all modes.



(a) S11



(b) S22

Fig. 6. S-parameter of the switched-LNA including the 800-900 MHz matching (Makers indicate 850 MHz points).

Fig. 7, 8 and 9 show measured data for the switched-LNA housed in the SON12 plastic package. Fig. 7 demonstrates the gain and insertion loss from 800 to 900 MHz of three modes. The gain variation over frequency is under 1 dB. Fig. 8 demonstrates the noise figure. In each mode, a low noise figure is achieved with the same matching circuits as shown in fig. 5. A minimum noise figure of 1.4dB is achieved in mode-1 at 850MHz. Fig. 9 demonstrates the input IP3 (IIP3). An IIP3 of -0.6 dBm is achieved in mode-2 at 850MHz. The IIP3 increases to +1.6 dBm in mode-1 and +16.1 dBm in mode-3. The IIP3 variation over frequency is under 1 dB.

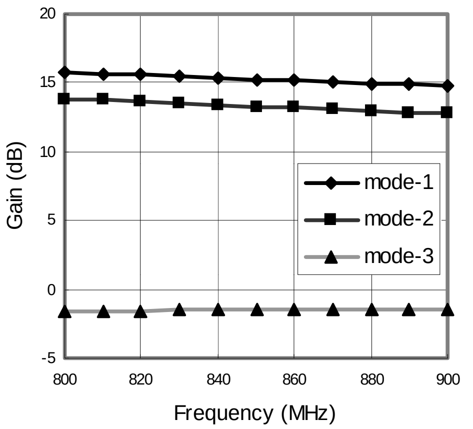


Fig. 7. Gain versus frequency for the switched-LNA.

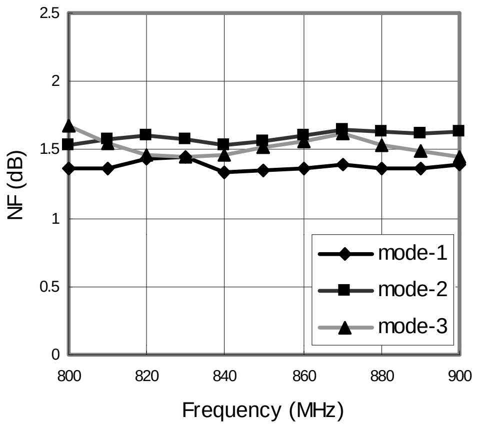


Fig. 8. Noise figure versus frequency for the switched-LNA.

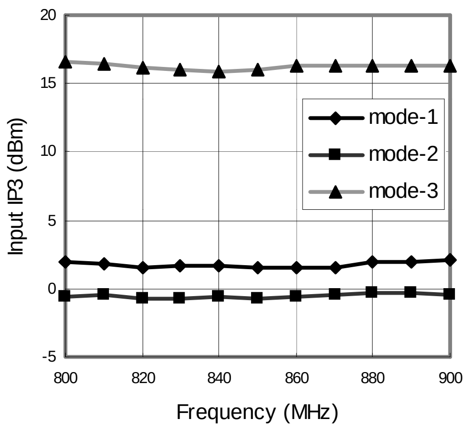


Fig. 9. IIP3 versus frequency for the switched-LNA.

The switched-LNA measuring main performance parameters for 3 modes is summarized in TABLE II. The frequency is 850 MHz.

TABLE II
Mesured performance for 3 modes

	mode-1	mode-2	mode-3
Gain	15.3 dB	13.3 dB	-1.5 dB
NF	1.4 dB	1.6 dB	1.5 dB
IIP3	+1.6 dBm	-0.6 dBm	+16.1 dBm
Current	5.9 mA	3.0 mA	< 10 uA

IV. CONCLUSION

The design of our wide dynamic range, high current efficient switched-LNA has been described. The LNA can be switched 3 modes taking cross-modulation into account. An 800-900MHz switched-LNA has been demonstrated, and a minimum noise figure of 1.4dB with 15.3 dB gain and a maximum IIP3 of +16.1dBm with 1.5 dB insertion loss were achieved. The switched-LNA is designed using SiGe BiCMOS technology and housed in the very small, low cost SON12 plastic package with a Down-Mixer. It is suitable for CDMA handsets where a very wide dynamic range is required.

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