A LOW NOISE AMPLIFIER FOR A MULTI-BAND AND MULTI-MODE HANDSET

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ABSTRACT

Using a low noise active balun and a push-pull active matching circuit, a wideband low noise amplifier MMIC is designed and fabricated. For the frequency up to 3 GHz, output VSWR is less than 1.3 and the output power handling capability of 9.4 dB is enhanced compared with conventional active matching circuit.

INTRODUCTION

There are many types of mobile telecommunication system in the world. Even in a country, several mobile services are being operated. In the deployment of these various systems, the demand for a multi-band and/or multi-mode handset is increasing. For the multi-band and multi-mode handset, a wide band low noise amplifier (LNA) is essential. To implement a wideband amplifier, feedback circuit [1] or active matching circuit [2,3] can be used. Active matching circuit is more powerful than feedback circuit to achieve wideband characteristic for an amplifier operating below several GHz. Because of their poor noise characteristic, the active matching topology was adopted only at the output port of a LNA.

Another important property of a LNA is the linearity that can be represented by the third order intercept point (IP3) at the input port. In order to increase the IP3 of a circuit, the output power handling capability that is represented by the one dB compression point (P1dB) should be increased and the number of gain stage of a LNA should be decreased. A push-pull amplifier [4,5] circuit is a kind of active matching circuit and its output power handling capability is higher than that of a simple active matching circuit such as a common drain amplifier.

To implement a push-pull circuit with only N-type MESFETs, a balun circuit which generate a pair of differential signal from a single ended input signal is required. There are many balun circuits proposed. However, the circuits have poor noise characteristic, a low noise balun circuits is necessary to implement a low noise push-pull amplifier. The tapped dual cascode circuit is proposed in this paper for a low noise active balun.

CIRCUIT TOPOLOGY

In general, the bandwidth and the noise figure of a circuit are the properties that should be compromised. However, handsets for multi-band operation use a separate LNA for each band, and each LNA needs not to have wideband low noise characteristics. The purpose of this work is developing a LNA that shows low noise characteristics especially in the band determined by the input matching circuit and shows low output VSWR characteristics in the wide frequency range of up to 3GHz for the convenience of implementing a multi-band and/or multi-mode handset. For this purpose, active matching circuit was used only at the output port for wideband characteristics and the input port which is to be matched with external chip components was left alone without any matching circuit.

The sensitivity of a receiver is mainly determined by the noise figure and the gain of a LNA which is the most front-end part of a receiver. As the gain of the LNA being increased, the sensitivity of the total receiver can be enhanced. However, increased gain leads early saturation for the input power when the output power capability is fixed. In order to increase the output power capability and enhance the linearity, the push-pull circuit that is a kind of active matching was used. To implement a push-pull circuit with only N-type MESFETs, a pair of differential signal that has to be generated from a single ended input signal is required. One of the important characteristics required for the components in a mobile handset is low power consumption. To lower the power consumption of an amplifier, it is necessary to reduce the number of amplifying stages. More detailed analysis showed that two stage amplifier is sufficient in this case, and additional inter-stage amplifying circuits reduce the input IP3. Hence, a low noise balun is necessary to implement a push-pull amplifier that has low noise, low power consumption, and high IP3 characteristics.

There are various ways to implement a balun. For the compactness of a MMIC, passive balun circuits are not considered in this work. Some active balun circuits are depicted in figure 1. A conventional circuit for an active balun[6] is depicted in figure 1-(a). The resistor connected at source terminal degenerates noise characteristics, and the phase difference between each output signals is quite dependent on frequency.

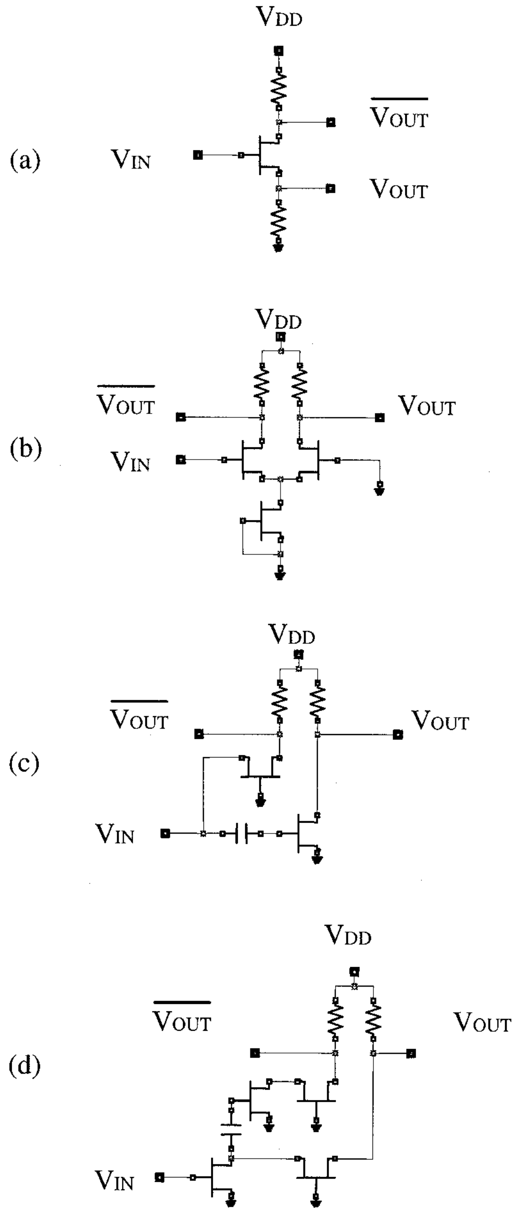

Figure 1 : Active Balun Circuits

A differential amplifier depicted in figure 1-(b) also can be used for an active balun. The source terminal of the MESFET that has the gate grounded degenerates noise characteristics in same manner as the circuit of figure 1-(a). Another balun circuit that can be used for an active balun is CS-CG (common source and common gate) pair as depicted in figure 1-(c)[7]. Output signals of the circuit are quite out of phase. However, because of low input impedance, CS-CG pair has low gain and high noise figure compared to CS only. The balun circuit used in this work is depicted in figure 1-(d). The circuit uses cascode structure and idea of CS-CG pair mentioned above. Output signals of the circuit are quite out of phase like CS-CG pair. In addition, it has high gain and low noise figure like CS only.

The first cascode receives an input signal of a LNA with its CS MESFET, and its output is tapped and connected to the CG MESFET of the first cascode and CS MESFET of the second cascode, simultaneously. Because the impedance of the tapped point is determined by the transconductance of the CG MESFET of the first cascode and is very low values compared to the input impedance of CS MESFET of the second cascode connected together, the noise and the gain characteristics of the first cascode are not affected by connection of the second cascode. Since the gate-source voltage of the CG MESFET of the first cascode and that of CS MESFET of the second cascode is reciprocal, output current and output voltage of two cascode circuits are reciprocal.

Figure 2 shows the circuit diagram of the LNA that is comprised of the push-pull output stage and low noise active balun proposed in this work. The gate bias voltage for all CS MESFETs in the circuit is supplied by bias circuit that can compensate the parameter variation of MESFETs and temperature variation. To reduce the chip size no inductor is used except the inductor (L1) that is connected at source terminal of the first CS MESFET. The inductor (L1) is used to enhance the input VSWR when the input port is matched externally to the optimum impedance for low noise characteristic.

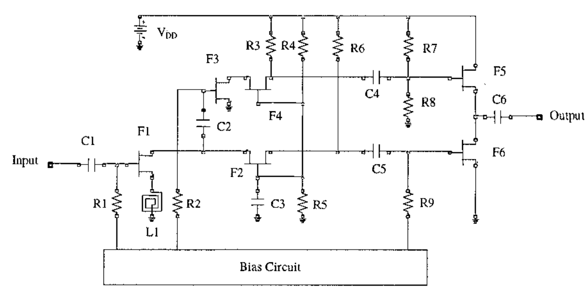

Figure 2 : Schematic diagram of the LNA

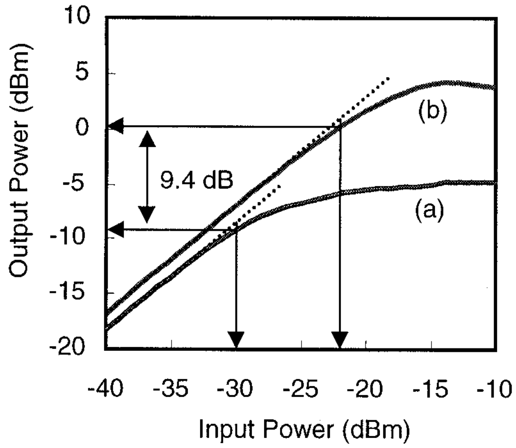

Figure 3 : Power Transfer Characteristics at 880 MHz (a: conventional active matched LNA, b: push-pull LNA)

Figure 3 shows power transfer characteristics of the push-pull LNA and the conventional active matched LNA at 880 MHz. The push-pull active matching circuit proposed in this paper enhance the output power capability of 9.4 dB compared to that of simple active matching circuit.

RESULTS

The fabricated LNA MMIC using an ion implanted 0.5 ㎛ GaAs MESFET process is shown in figure 4. The chip size is 1.4 mm × 0.6 mm. For the supply voltage of 3 V, the current of the LNA is 8.8 mA. Simulated and measured VSWR for the output port and gain characteristics for several bands with artificial external input matching circuit are depicted in Fig. 5. Frequency bands to demonstrate the possibility of multi-band operation are selected for the hand-held phone, PCS handset, and WLL terminal. Gains for those bands are above 14 dB and VSWRs are bellow 1.25. Figure 6 shows the simulated noise characteristics. The noise figures are increasing as frequency is increased. Noise figure of the LNA for WLL application is 1.7 dB. Results for each band is summarized in table 1.

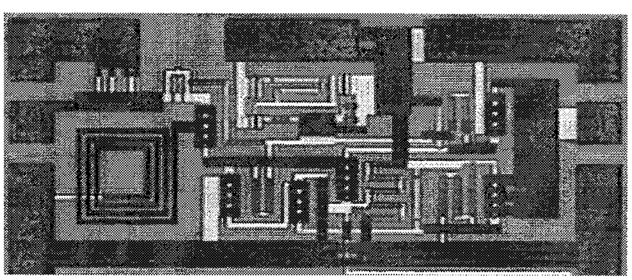

Figure 4 : Photograph of fabricated LNA

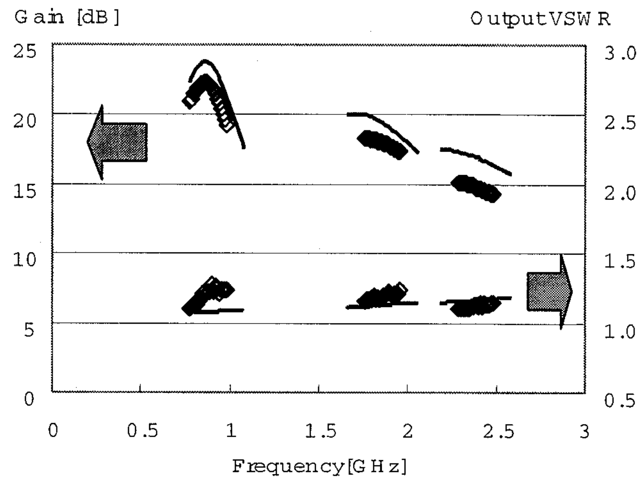

Figure 5 : Output VSWR and gain for several bands estimated with on-wafer results and artificial input matching circuits. (——— : simulated , ◊ : measured)

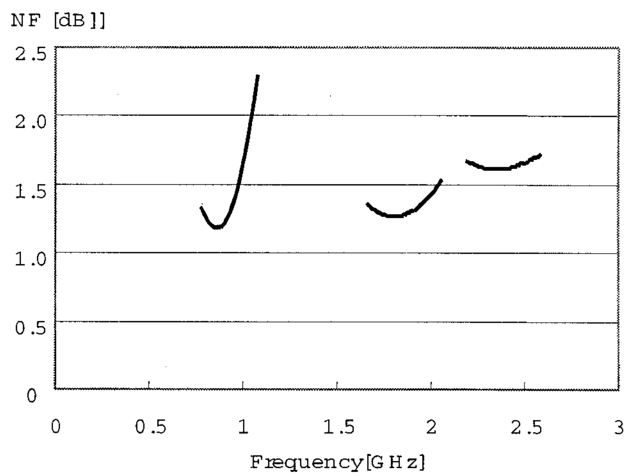

Figure 6 : Simulated Noise figure for several bands with artificial input matching circuits.

Table 1. Summary of the LNA

Item	Unit	Band-1	Band-2	Band.-3
Voltage	V	3		
Current	mA	8.8		
Frequency	MHz	869 ~ 894	1,840 ~ 1,870	2,470 ~ 2,500
Gain	dB	22	17	14
NF	dB	1.3	1.4	1.7
VSWR	-	1.3 : 1	1.3 : 1	1.2 : 1
P1dB,out	dBm	0	-2	-3
IP3,in	dBm	-11	-8	-7

CONCLUSION

A LNA MMIC for multi-band and/or multi-mode handset was developed using 0.5 ㎛ GaAs MESFET technology. In order to increase the output power capability and enhance the linearity, the push-pull circuit that is a kind of active matching was used. To implement a push-pull circuit without degrading noise characteristics, the low noise balun circuit was proposed and adopted. The power gain and the VSWR of the LNA MMIC show above 14 dB and bellow 1.25 respectively for the frequency of up to 3 GHz. The characteristics of the LNA MMIC is sufficient to be used for multi-band and/or multi-mode handset

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