IEEE-ICEDSA2012 Proc., 2012, Kuala Lumpur, Malaysia

A Capacitor Cross-Coupled Differential Cascode Low-Noise Amplifier

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***Abstract*— A g_m-boosting technique implemented by capacitor cross-coupling of common-gate devices in a differential cascode low-noise amplifier (LNA) is presented for improving the gain and noise figure (NF) without significant increase in current consumption. The conventional cascode LNA exhibits a relatively low performance at millimeter-wave frequencies due to carrier mobility limitations and device parasitic in the common-gate stage. A cascode LNA is designed in a 180 nm RF CMOS process at center frequency of 40 GHz. It achieves a gain of 8.8 dB and a NF of 4.2 dB while reverse isolation is better than –15 dB. The LNA circuit consumes 6.5 mW from a 1.8 V supply.**

Keywords- low-noise amplifier; millimeter-wave frequencies; g_m-boosting technique; cascode architecture.

I. INTRODUCTION

With the advances in IC fabrication technology, high-frequency devices are available in CMOS for realizing millimeter-wave integrated circuits. In this manner, low power RF circuits are remarkable. The first active stage of an RF receiver is usually a low-noise amplifier (LNA) required to fulfill a low noise characteristic and a high flat gain over the specified band and also good linearity, acceptable stability and then low power consumption. At millimeter-wave frequencies, new circuit techniques are needed to attain these requirements especially in CMOS due to its inherent limitation such as lossy substrate, device parasitic and low carrier mobility [1]. Active feedback [2], positive feedback [1,3], distributed amplification [4] and regular methods like inductive degeneration [5] are good examples in this domain. For enhancing gain and achieving lower noise figure in this paper we have employed a capacitor cross-coupled g_m-boosting scheme. In Section II, the influence of capacitor cross-coupled g_m -boosting technique on circuit performance is discussed, while circuit implementation of the proposed LNA architecture is illustrated in Section III.

II. G_M-BOOSTING TECHNIQUE

G_m-boosting technique is a well-known technique in designing high frequency circuit and systems. Fig. 1(a) shows the principle of this technique where inverting amplification, A, is provided from the source to gate of the transistor. It can be shown that by using this technique the effective trans-

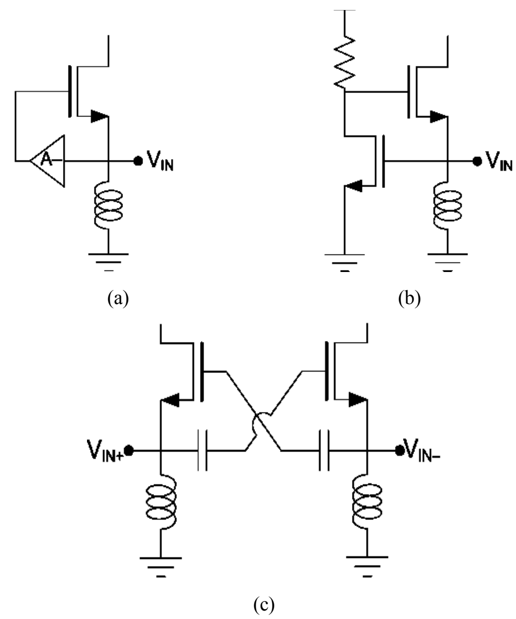

Figure 1. g_m-boosting technique; (a) Principle, (b) Regulated cascode stage and (c) Differential implementation by capacitor cross coupling.

conductance of the transistor will be boosted by a factor of (1+A) [6]. This boosting has many advantages in an amplifier stage in common gate (CG) configuration. For example, in optical pre-amplifiers it helps absorbing more the incoming current from the photo-detector [7, 8]. In the case of the common-gate LNA architectures, ignoring the noise contribution by amplification stage, it causes a reduction of noise factor (F) from approximately [6]

$$F = 1 + \frac{\gamma}{\alpha} \tag{1}$$

to

$$F = 1 + \frac{\gamma}{\alpha(1+A)} \tag{2}$$

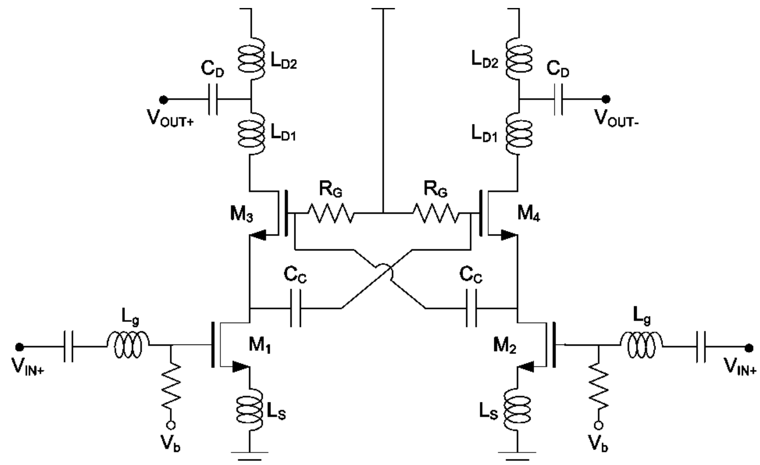

Figure 3. Proposed LNA circuit architecture

where γ is the excess noise factor and α is a bias-dependent parameter.

Realization of the inverting amplification may be performed by active devices as shown in Fig. 1(b) which resembles regulated cascade (RGC) stage. An implementation of g_m-boosting technique using active stage in a millimeter-wave LNA is reported in [1]. A common realization of differential g_m-boosting technique is shown in Fig. 1 (c) by capacitor cross coupling of two CG amplifiers when input is a differential signal where the value of A would be approximately unity [9]. Aside from gain enhancement, it is shown in [9] that cross coupling causes the noise of cross-coupled transistors to appear in common mode form at the output (drain nodes) thus eliminated when output signal extracted in differential form.

III. Proposed LNA Circuit Topology

Capacitor cross-coupling is usually implemented in LNA and mixers with CG configuration at the input [6-10]. Meanwhile, a cascode stage (Fig. 2(a)) is conventionally preferred for the implementation of the LNA circuits operating at millimeter-wave frequencies because of good stability by elimination of Miller effect and also boosted output resistance which helps the overall gain. However, as shown in Fig. 2(b), in order to compensate for the gain lessening at higher frequencies due to device parasitic, an inductor can be placed at the gate of common-gate stage which acts as a positive feedback [1,3]. Illustrated in Fig. 2(c), another method is to employ g_m-boosting technique. Proper selection of the gain stage will cause not only gain enhancement but also improvement in the noise characteristic.

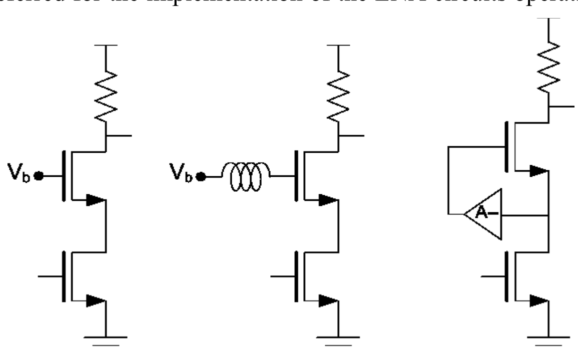

Figure 2. Implementation of a cascode LNA; (a) Principle, (b) Positive feedback technique at the gate of CG stage, (c) g_m-boosting technique applied to CG stage

It should be noted that since the gate of CG transistor is not further ac grounded, the gain and noise improvement in Fig. 2(c) are achieved at the cost of losing the high reverse isolation characteristic of the cascode configuration.

In the case of differential cascode implementation, it is possible to employ capacitor cross coupling at the common-gate stage. Fig. 3 shows the circuit schematic of the proposed LNA. In this circuit, L_g and L_S are used for input matching while L_{D1}, L_{D2} and C_D form a matching network at the output. R_G and C_C perform the action of cross-coupling the M3 and M4. The value of inverting amplification, A, in this circuit is approximately given by capacitive voltage division at the gate of M3 and M4:

$$A \approx \frac{C_C}{C_C + C_{gs}} \tag{3}$$

where setting $C_C >> C_{gs}$ results in $A \approx 1$.

In order to attain the advantages of the cross-coupling, the value of R_G should be sufficiently larger than $(\omega_0 C_C)^{-1}$, where ω_0 is the operating frequency. However, for minimizing the feedback from output to input and diminishing the Miller effect due to gate-drain capacitance, C_{gd}, of M3 and M4, it should be kept sufficiently less than $(\omega_0 C_{gd})^{-1}$:

$$\frac{1}{\omega_0 C_C} << R_G << \frac{1}{\omega_0 C_{gd}} \tag{4}$$

TABLE I. DESIGN PARAMETERS

Parameters	Design Values
L_g	0.13 nH
L_S	0.1 nH
L_{D1}	2.1nH
L_{D2}	1.8nH
C_C	10Pf
R_G	2KΩ
M1, M2	192µm/0.18µm
M3, M4	18.4 µm /0.18 µm

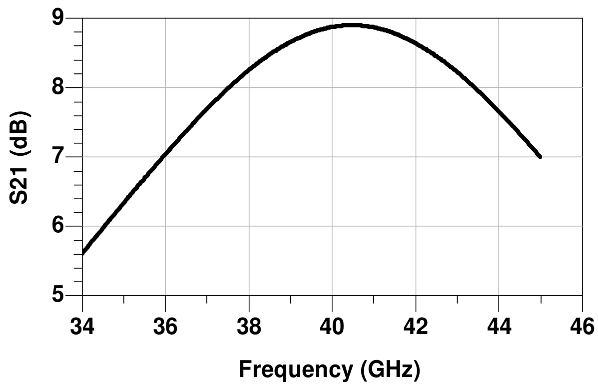

Figure 4. Simulated S21 versus frequency.

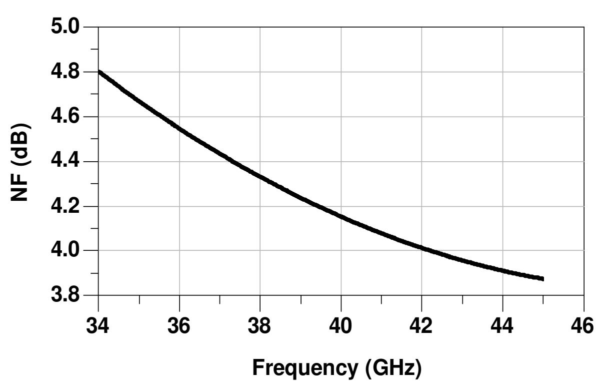

Figure 5. Simulated NF of the LNA

IV. RESULTS AND DISSCUTION

The proposed LNA circuit is designed and simulated in a 0.18 µm RF CMOS process. It consumes nearly 6.5 mW from a 1.8 V supply. All transistor sizes and inductor values are chosen so that to achieve a high gain and minimum possible NF. The circuit parameters are given in Table I.

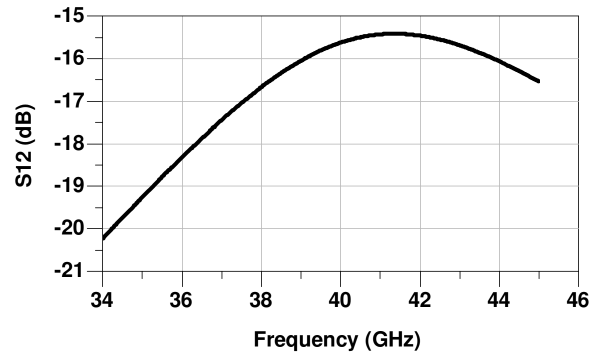

Figure 6. Reverse isolation of the LNA

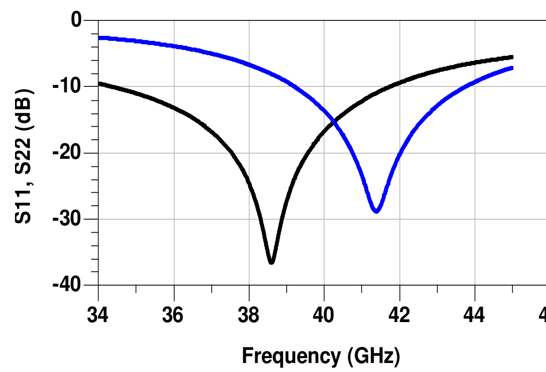

Figure 7. Simulated S11 and S22.

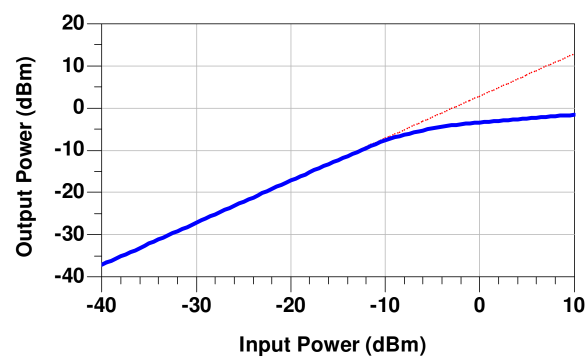

Figure 8. Extrapolated 1-dB compression point.

The simulated S21 of the LNA is depicted in Fig. 4 while the NF is plotted in Fig.5. The gain and NF at the center frequency are 8.87 dB and 4.15 dB, respectively. The reverse isolation, presented by S12, is drawn in Fig. 6 which has the value of –15.6 dB at center frequency. This value for S12 is achieved using R_G=2 KΩ. S11 and S22 have the value of, –16.7 dB and –12.8 dB, respectively, as given in Fig.7. The extrapolated input 1 dB compression point, shown in Fig. 8, is about –8.5 dB.

Table II summarizes the performance of the proposed LNA along with the results obtained from the circuit when cross coupling capacitors are removed and the gates of CG transistors are directly connected to the supply ($R_G \cong 0$). As it is obvious, by cross coupling the CG transistors, gain and NF have been improved extensively while the reverse isolation has been ruined. Removing cross-coupled capacitors has also a negative impact on matching characteristic at both the input and output. It should be noted that by choosing a smaller value for R_G in Fig. 3, S12 can be further decreased at the expense of gain reduction and increasing the NF

TABLE II. SUMMARIZED CIRCUIT CHARACTERISTICS

Specifications	**unit**	**Proposed LNA**	
		without CCC	***with CCC***
Frequency	GHz	40	
Supply Voltage	V	1.8	
$\|S_{21}\|$	dB	1.82	8.87
$\|S_{11}\|$	dB	–4.1	–16.7
$\|S_{22}\|$	dB	–2.9	–12.8
$\|S_{12}\|$	dB	–32.2	–15.6
NF	dB	7.58	4.15
P-1dB	dBm	–1.5	–8.5
Power consumption	mW	6.5	

V. CONCLUSION

A capacitor cross-coupling technique for improving the gain and NF of differential cascode LNAs is described. The proposed technique makes cascode architecture more attractive for implementing LNAs operating at millimeter wave frequencies.

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