Int. J. Electron. Commun. (AEÜ) 68 (2014) 653–657

Contents lists available at ScienceDirect

International Journal of Electronics and Communications (AEÜ)

journal homepage: www.elsevier.com/locate/aeue

A wideband balun–LNA

Gholamreza Zare Fatin [a,*], Hadi Zare Fatin [b]

[a] Department of Electrical and Computer Engineering, University of Mohaghegh Ardabili, Ardabil 56199-11367, Iran
[b] Department of Computer Engineering, Tarbiat Modares University, Tehran, Iran

ARTICLE INFO

Article history:
Received 12 July 2013
Accepted 2 February 2014

Keywords:
Balun
Imbalance correction
LNA
Wideband

ABSTRACT

In this paper a wideband Low Noise Amplifier (LNA) is introduced which also converts the single-ended input to differential signal at the output. It is based on common-source amplifier with active-feedback to provide input matching. The proposed amplifier has the input matched from 500 MHz to 2.5 GHz. It achieves the maximum voltage gain of 24 dB in this band, while the minimum noise figure (NF) is 2.35 dB. The simulated OIP3 of this amplifier is equal to 21 dBm. The LNA has been designed and simulated in a 0.18 μm CMOS process.

1. Introduction

Wideband LNA can be used in a multi-standard or Software-Defined Receiver (SDR) [1]. Wideband amplifier needs wideband input matching which can be achieved by using common-gate stage. This amplifier has high NF and low gain. Noise cancelation [2] and cross-coupling techniques [3] can be used to improve the NF and gain of the common-gate amplifier; these techniques trade the power consumption and linearity to improve the amplifier noise and gain values. In addition to noise-cancelation, the LNA circuit in [4] converts the single-ended input to differential signal at the output and can also be used as an active balun in the receiver. Common-source (CS) amplifier with resistive [5] or active feedback [6] is another implementation for a wideband amplifier. Wideband LNA with active feedback in [6] has high gain and low NF, but suffers from nonlinearity of the feedback transistor.

The proposed balun + LNA circuit is a CS amplifier with active feedback and differential output, it also cancels the nonlinearity of the feedback transistor and therefore achieves better linearity in compare to the single-ended amplifier [6]. Combining the LNA and balun in a single circuit, alleviates the need for a standalone balun at the input of the receiver. While with a single-ended LNA, there should a balun after to drive the differential mixer [1]. In either case, there is a balun in the receive path. If implemented after LNA, this balun can be realized as an active or passive one. Passive balun usually occupies large area on chip and introduces loss in receive path and increases the NF value at the input of the receiver. Active balun can be used instead which take small area on the chip, but raises the NF and degrades the receiver linearity. Therefore, having the balun and LNA merged into a single circuit, eliminates the drawbacks of using a standalone balun in receive path.

Section 2 of this paper explains the balun–LNA circuit and discusses different specifications of the design. In Section 3 the simulation results are given and finally some conclusions are drawn in Section 4.

2. Balun–LNA

The schematic of the balun–LNA circuit is shown in Fig. 1. As mentioned before, it is a CS amplifier with active feedback. The cascode device M_{cas} improves the reverse isolation of the amplifier. As shown in Fig. 1 the proposed amplifier has differential output. The feedback transistor M2 makes the other side of the differential output. Using feedback transistor to make the differential output also increases the amplifier gain. These advantages are achieved without degrading the other circuit specifications.

2.1. Input matching

Input impedance of the amplifier at low frequencies is equal to,

$$R_{in} = \frac{1 + g_{m2}R_F}{g_{m2}(1 + g_{m1}R_1)} \tag{1}$$

where g_{m1} and g_{m2} represent the transconductances of M1 and M2, respectively. Referring to (1), $g_{m1}R_{CS}$ value is set by NF specification whereas linearity requirement set the R_F value. Therefore, g_{m2} is the

* Corresponding author. Tel.: +98 451 551 2910.
E-mail addresses: zare@uma.ac.ir (G.Z. Fatin), hadi.zarefatin@modares.ac.ir (H.Z. Fatin).

1434-8411/$ – see front matter © 2014 Elsevier GmbH. All rights reserved.
http://dx.doi.org/10.1016/j.aeue.2014.02.001

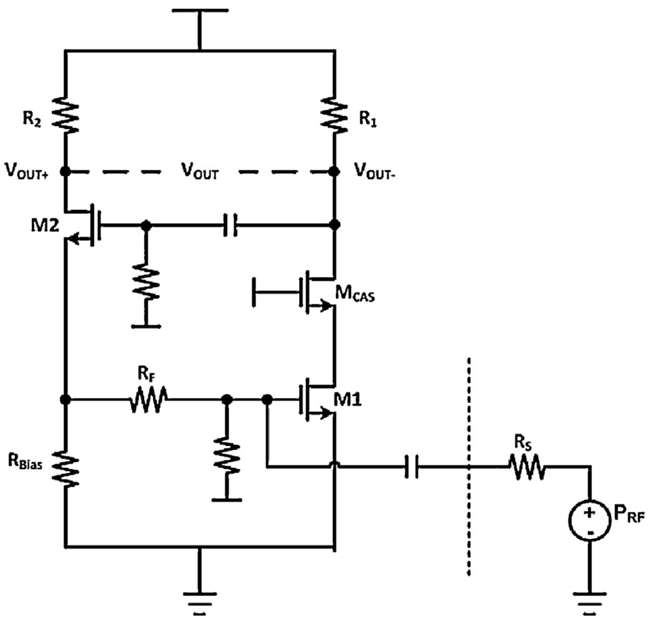

Fig. 1. The circuit schematic of the balun–LNA circuit.

only variable which can be used to set the required input impedance value to match the source. This value of g_{m2} is determined by,

$$g_{m2} = \frac{1}{R_s(g_{m1}R_1 + 1) - R_F} \tag{2}$$

According to (2), the R_F value should be smaller than $R_s(1+g_{m1}R_{CS})$, otherwise g_{m2} value will be negative which is not possible to be realized by the proposed circuit in Fig. 1.

2.2. Gain and NF

In the proposed amplifier, voltage gain is given by,

$$A_V = g_{m1}R_{1+}\frac{g_{m1}g_{m2}}{1+g_{m2}(R_F||R_{Bias})}R_1R_2 + \frac{1+g_{m2}r_{o2}}{1+(r_{o2}/R_2)+((1+g_{m2}R_{Bias}R_F)/(g_{m2}R_{Bios}R_2))} \tag{3}$$

where r_{o2} is the output resistance of M2 and the third term accounts for the contribution of M2 in common-gate mode. If we neglect the third term in voltage gain equation, it would be like 1.5 dB reduction in gain value which is negligible. Then voltage equation can be rewritten as,

$$A_V \cong g_{m1}R_1\left(1+\frac{g_{m2}R_2}{1+g_{m2}(R_F||R_{Bias})}\right) \tag{4}$$

If gain of the single-ended amplifier in [6] be represented by A_{VS}, then gain of the amplifier in Fig. 1 can be written as,

$$A_V \cong A_{VS}\left(1+\frac{g_{m2}R_2}{1+g_{m2}(R_F||R_{Bias})}\right) \tag{5}$$

This equation (5) indicates that gain of the amplifier in Fig. 1 is $\left(1+((g_{m2}R_2)/(1+g_{m2}(R_F||R_{Bias})))\right)$ times larger than gain of the single-ended amplifier.

Knowing the amplifier gain, its noise value can be obtained. Noise factor (F) of the amplifier is equal to,

$$F = F_{R_s} + F_{M1} + F_{M2} + F_{R_F} + F_{R_1} + F_{R_2} + F_{R_{Bias}} \tag{6}$$

Assuming that frequency of operation of circuit is low for the selected process, noise of the cascode device (M_{cas}) has been neglected. Substituting the noise factor of circuit elements into (6), then amplifier noise factor can be written as (7). After simplifying and assuming matched condition, using g_{m2} value for complete matching at the input then noise factor of the amplifier will be like (8).

$$\begin{aligned} F = {} & 1+\frac{\gamma_1 R_s}{g_{m1}}\left(\frac{1}{R_s}+\frac{g_{m2}}{1+g_{m2}R_F}\right)^2+\gamma_2 g_{m2}R_s\times\left(\frac{1}{1+g_{m2}R_F}\right)^2 \\ & +R_F R_s\times\left(\frac{g_{m2}}{1+g_{m2}R_F}\right)^2+\frac{R_s}{g_{m1}^2R_1}\left(\frac{1}{R_s}+\frac{g_{m2}}{1+g_{m2}R_F}\right)^2 \\ & +\frac{4}{g_{m2}^2R_2R_S}+\frac{R_s}{R_{Bias}}\times\frac{1}{(1+g_{m2}R_F)^2} \end{aligned} \tag{7}$$

$$\begin{aligned} F = {} & 1+\frac{\gamma_1}{R_s g_{m1}}\times\left[\frac{(2+g_{m1}R_1)}{(1+g_{m1}R_1)}\right]^2+\frac{\gamma_2}{1+g_{m1}R_1} \\ & \times\left(1-\frac{R_F}{R_S(1+g_{m1}R_1)}\right)+\frac{R_F}{R_s}\times\frac{1}{(1+g_{m1}R_1)^2} \\ & +\frac{1}{R_s g_{m1}^2R_1(1+g_{m2}R_2)}\left[\frac{2+g_{m1}R_1}{1+g_{m1}R_1}\right]^2+\frac{4}{g_{m2}^2R_2R_s} \\ & +\frac{R_s}{R_{Bias}}\times\left(1-\frac{R_F}{R_s(1+g_{m1}R_1)}\right)^2 \end{aligned} \tag{8}$$

According to (7) and (8), the noise of M1 and M2 will be reduced with larger R_F values. In addition, a larger R_F value improves the linearity [6] and therefore is desirable. The transistor M1 contributes the most to amplifier noise; according to (8) its contribution can be diminished by larger values for g_{m1}, although, larger g_{m1} values will increase the power consumption of the amplifier.

Reducing the noise of M1 with larger values for R_F is not possible, indefinitely, because according to (8) the larger R_F values will increase the noise of R_F itself as well and therefore will compensate the improvement obtained in noise factor from M1.

2.3. Amplifier distortion

The distortion of the single-ended amplifier has been explained in [6,7]. The nonlinearity of the feedback transistor M2 is the dominant factor in amplifier distortion. This is due to large voltage swing at the amplifier output that is applied to gate of the feedback transistor. The R_F is added to circuit to improve the linearity of the feedback transistor. The IIP3 of the single-ended amplifier has been derived in above mentioned references and the positive effect of R_F on amplifier linearity has been shown.

In the proposed amplifier with differential output, assuming that total distortion of the feedback transistor M2 can be modeled by a current source between drain and source then it can be shown that distortion of M2 can be canceled at the differential output [4]. The distortion of M2 is a major contributor to amplifier nonlinearity; therefore by canceling its nonlinearity at the output, OIP3 can be improved considerably.

It can be shown that the desired value of R_2 to have the optimum distortion cancelation is,

$$R_2 = R_s g_{m1} R_1 \tag{9}$$

2.4. Gain and phase imbalance

There is gain and phase imbalance between outputs of the differential amplifier. This is due to difference between paths of input signal to each individual output and so they are not completely matched differential signals.

In order to remove these imbalances in gain and phase, although the gain imbalance is quite negligible, a capacitor is inserted