Wideband Balun-LNA Employing g_m-Boosting Feedback Technique and CBLD Circuit for Digital Televisions Tuner Application

Nima Rahimzadeh [1] and Pejman Rezaei [2]

***Abstract*-- A balun Low Noise Amplifier (Balun-LNA) with technique of gm-boosting feedback and a modified current bleeding (CBLD) circuit is proposed for application in the tuner of digital television (DTV) and other wideband radio and microwave receivers. Using the technique of gm-boosting feedback causes input impedance matching to not just depend on the CG transistor, and input impedance matching is satisfied by the transconductance of CG and CS transistors. Therefore, the transconductance of the CG transistor increases to boost the differential voltage gain of Balun-LNA and decrease its NF. Also, a modified current bleeding circuit is used in the CS stage in order to make the CS transistor have higher transconductance and its output current be identical to the output current of the CG stage. To compensate for having identical output currents, symmetrical loads are used in differential output so that they cause the gain and phase balance at the differential output. This Balun-LNA is built on 90-nm CMOS technology and operates in the digital television frequency band of 48 to 864 MHz. This Balun-LNA achieves a maximum differential voltage gain of 24 dB, an input return loss of less than -10 dB, and a minimum NF of 5 dB. This Balun-LNA works at 2.8 v nominal supply voltage and consumes the power of 2.5 mW.**

***Index Terms*-- Balanced output, Balun-LNA, Low power consumption, Noise Cancelling, Symmetrical loads, Digital television tuner.**

I. INTRODUCTION

In recent years, wideband radio and microwave receivers, especially digital television receivers, have been mor popular because wireless communication devices must support several features in one IC [1]–[9]. Nowadays, digital televisions are used for different purposes and in many places. Digital television manufacturers compete to produce digital televisions with better quality in displaying video and pictures on digital television screens and better quality in playing audio through digital television speakers. In order to develop the performance of displaying pictures and videos on screen and audio in the speakers of digital television, the low-noise amplifier must be modified. Reducing noise, increasing voltage gain, improving linearity due to higher linear performance of tuner IC next circuits, improving input impedance matching, and lowering LNA power consumption, which are the most important features of designing a LNA for a tuner of digital televisions, are important challenges of modifying LNA for application tuner of digital televisions.

In digital television, first the electromagnetic waves of digital video broadcasting (DVB) are received with the antenna of digital television, and then they are transformed into electrical signals and are transferred to the tuner of digital television. A tuner is an implement with a metal shield which is located at the beginning of the mainboard of digital televisions and has an IC by the name of tuner IC. The Low Noise Amplifier is the first and most important block of the tuner of digital television that has an important effect on the performance quality of digital television in playing pictures, videos, and audio [10]–[15].

There are several challenges in designing a low-noise amplifier for the tuner IC of digital televisions. The digital television frequency band ranges from 48 to 860 MHz, which is very wide. The tuner IC of digital television should handle the signals with broadband and should have good input impedance matching, sufficient gain, high linearity, and low NF over the desired frequency bandwidth. In order to endure strong analogue and digital interference in the terrestrial environment and avoid multiple distortions by hundreds of broadcast channels in the cable environment, the LNA should have a high third-order input referred intercept point (IIP3) and a high second-order input referred intercept point (IIP2) [16] [20].

For the application of a digital television tuner, a single-ended input LNA is usually preferred [21]. Furthermore, differential LNAs are used to achieve higher SNR because differential signal processing has a high common mode rejection ratio, power supply rejection ratio, and low second order distortion [22]-[23]. For wideband applications like the tuner of digital television, the passive transformer like the Balun circuit is too bulky to be integrated on a chip, and its insertion loss degrades the NF and the sensitivity. Hence, it is desirable to adopt the S-to-D LNA, combining the Balun and LNA functionality (as an active Balun-LNA) into a single integrated circuit for application of a digital television tuner. However, the involved antenna is usually single-ended.

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The digital television tuner IC must process the electrical signals with a wideband input frequency range of 48 to 864 MHz. Also, digital television tuner ICs and other radio and microwave receivers have several blocks like low noise amplifiers, mixers, oscillators, and other circuits that all of them have very linear and low power consumption performance characteristics. For this reason, the tuner IC of digital televisions needs a wideband low noise amplifier which has good input impedance matching, high differential voltage gain, low noise factor, and high linear and low power consumption performance characteristics in the desired frequency bandwidth [24].

Usually, all of these characteristics do not happen in one low-noise amplifier. But like many other low-noise amplifiers, this proposed Balun-LNA has an acceptable tradeoff between different characteristics like voltage gain, NF and power consumption. In this paper we propose a balun low-noise amplifier for high third order input intercept point and high second order input intercept point, high differential voltage gain, low noise factor, and low power consumption, which is one of the most important characteristics in low-noise amplifiers in wideband receivers, especially for tuners of digital television and for other wideband wireless radio and microwave receivers too.

II. The Topology and Properties of Typical Balun-LNAs

Single-ended input low noise amplifiers are typically addressed, as are single-ended output low noise amplifiers [25-27]. However, because differential signal processing has high common mode signal reflection and low second order distortion, inductorless differential low noise amplifiers have higher SNR [28-33]. For wideband applications like the tuner of digital television, integrating the passive transformer onto a chip is difficult. Accordingly, the single-input to single-output low noise amplifiers is used so that this technique integrates the Balun and low noise amplifier into one chip.

In recent years of study, several active Balun-LNAs with the performance of low noise, high differential voltage gain, and high linearity have been introduced. The technique of noise cancellation is one of the most satisfactory ways of designing a Balun-LNA with low noise and high gain that has been discussed. Fig. 1. (a) Shows the most basic Balun-LNA. In this circuit, CS and CG transistors are used in two different stages so that the source of the CG transistor is connected to the gate of the CG transistor and the input voltage.

In this figure, the CG transistor satisfies input impedance matching and the CS transistor cancels noise and distortion generated by the CG transistor because they appear in the form of common mode signals at differential outputs and are cancelled by the process of differential signals at the output of the LNA [34]. But this basic Balun-LNA can't afford high voltage gain and low power consumption with a low noise factor. Decreasing NF of CG-CS Balun-LNA requires that noise of the CS transistor decreases, because NF in this CG-CS Balun-LNA is approximately limited by the CS transistor. With increasing size and the transconductance of the CS transistor, the noise of it reaches a limited amount.

Fig. 1. (b) shows this designed structure. In Fig. 1. (b), the transconductance (gm) of the CS transistor is increased N times compared to the CG transistor, and the load resistor of the CS transistor is divided N times compared to the load resistor of CG [35]. In this circuit, since the transconductance of the CS transistor is increased N times, the current of the CS stage is increased N times too. In order to have identical current at the differential outputs of the CS and CG stages, the output resistor of the CS stage is divided N times. It causes the nonsymmetrical output load at the differential output. This condition leads to imbalance and mismatch in gain and phase of differential output, which increases second-order distortion and third-order distortion and makes the noise cancellation less perfect.

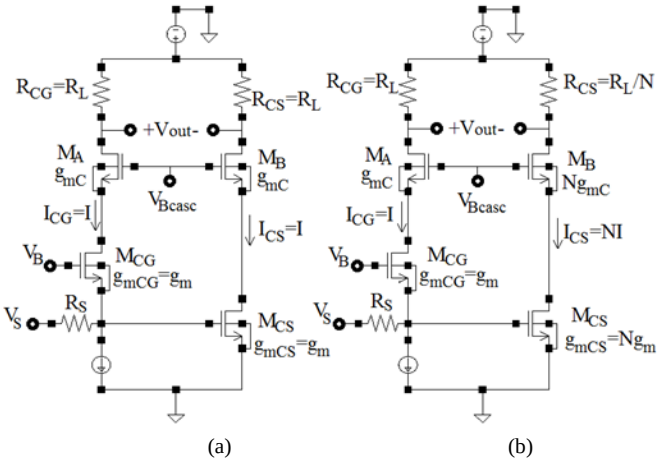

Fig. 1 CG-CS Balun LNAs: (a) conventional topology with gmCS=gmCG, RCS=RCG and ICS=ICS (b) practical topology with gmCS=NgmCG, RCS=RCG/N and ICS=NICG.

Thus, the designed circuit does not have an acceptable noise and linear coefficient, which is one of the most important features of low-noise amplifiers in digital television tuners. For this reason, we must solve this essential problem.

Another CGCS-based Balun-LNA that has been presented uses feedback between the CS and CG stages to increase CG transconductance while lowering power consumption [36]. The gain of the CS transistor is reused for this feedback to increase the transconductance of the CG transistor. A Balun-LNA is used with balanced loads in another paper [37]. A modified current bleeding is used in this structure to allow the Balun-LNA to use symmetrical currents at differential output. The performance of this structure is as follows: by increasing the transconductance of the CS transistor N times, the current of the CS transistor increases N times, and N-1 times of this current is consumed in the transistor of the current bleeding circuit, while the current of the CS stage at differential output remains constant.

As a result, this structure of Balun-LNA can have differential output with symmetrical loads and with any gain and phase unbalancing. In another LNA, feedback is used to reduce power consumption, so that in this structure, the local feedback increases the transconductance of the CG transistor [38]. In this Balun-LNA, a current bleeding circuit is also used for boosting the transconductance of the CS transistor and improving the voltage gain and reducing power consumption. A Balun low noise amplifier which has three invertors at its output is presented in another structure [39].

In this structure, because the differential output is determined by the second and third stages, it can't reach an acceptable output balance. In one paper, an attempt to solve this problem has led to the use of a BLIXER circuit with balanced differential signals at the IF stage, but this low-noise amplifier can't have symmetrical loads without the mixer stage [40].
In other LNAs, a modified current bleeding circuit is introduced that includes pMOS transistors instead of nMOS transistors [41]. A method of cancelling second order distortion using the theory of feedback is presented in other work [42]. In this structure, which is based on CGCS Balun-LNA, feedback from common mode output to single-ended input removes the second order distortion and reduces the noise.

Other CGCS Balun-LNAs use diode-connected loads to reduce noise and improve the linearity of CG and CS transistors [43]. The output signal is applied to the diode-connected load of the CS stage using this technique. Because the voltage gain of this Balun-LNA is determined by the transconductance of symmetrical nMOS transistors, the noise factor and power gain are insensitive to PVT variations. Another inductorless Balun-LNA structure is presented in which the CGCS Balun-LNA uses a nMOS-pMOS configuration to double transconductance and voltage gain and a capacity coupled in loads of CG and CS stages to eliminate the tradeoff between voltage gain and voltage headroom [44]. Other low-noise amplifiers have been designed using various techniques, but these structures still have high power consumption and low voltage gain [45-49]. In this paper, we propose a Balun-LNA that uses feedback to boost the transconductance of the CG transistor and a modified current bleeding circuit to boost the transconductance of the CS transistor as well, without changing the current of the CS stage at the differential output. The rest of this paper is organized as follows: At first, the schematic design, differential voltage gain, input impedance matching, and noise factor of this proposed Balun-LNA are introduced and analyzed in section III. In section IV, the results of the simulation are presented. Finally, in section V, the conclusion of this designed Balun-LNA is provided.

III. The Structure of Proposed Balun-LNA

The structure of the proposed Balun-LNA will be introduced in this section, as will how this designed Balun-LNA can have symmetrical loads by using gm boosting feedback and a modified current bleeding circuit to achieve high voltage gain, low power consumption, and appropriate NF.

a. The schematic of new Balun-LNA

The schematic of designed and proposed Balun-LNA is showed in Fig. 2. As it was mentioned in the previous section, in order to boost the differential voltage gain of Balun-LNA and reduce its NF, the transconductance (gm) of CG and CS transistors must increase. In conventional Balun-LNA, if the transconductance of the CS transistor increases N times, the current consumption of the CS transistor increases N times too, and therefore the current of the CS stage at the differential output increases N times too. Therefore, the load resistor of the CS stage output at the differential output must decrease N times. As a result, it generates the gain and phase misbalancing at the differential output. Thus, by employing a method, we should keep constant the amount of current and output load of the CS stage at the differential output. For this purpose, we use a modified current bleeding circuit in this paper. In this circuit of modified current bleeding, we use a transistor by the name of M_{BLD} and a resistor by the name of R_{BLD}.

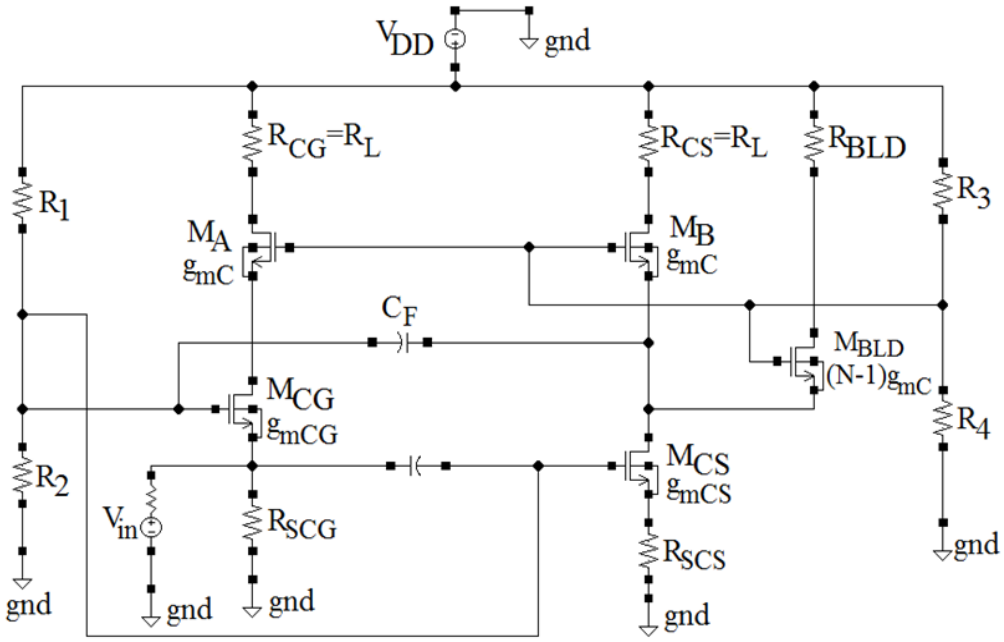

Fig. 2. Schematic of the proposed Balun-LNA.

We consider the transconductance of the M_{BLD} transistor to be (N-1) times the transconductance of the cascade transistors of M_A and M_B. In addition, we consider the resistive load of R_{BLD} to be $R_{L1}/(N-1)$. we multiply N times the transconductance of the CS transistor and therefore we multiply N times its current, the current amount of (N-1)I goes through the M_{BLD} transistor and the current of I goes through the cascade transistor of M_B. As a result, the current and resistive load of the CS stage at the differential output remain constant and equal to the current and resistive load of the CG stage at the differential output. On the other hand, in the conventional Balun-LNA circuit, because input impedance matching is just determined by the CG transistor, the transconductance of the CG transistor and the output current of the CG stage remain fixed.

We use a local feedback technique in this proposed structure to increase the transconductance of the CG transistor and thus the current of the CG stage's output. This feedback multiplies the transconductance of the CG transistor by the transconductance of the CG transistor, increasing the amount of transconductance of the CG stage and the load current of the CG stage.

Also, as it will be shown by this feedback, the input impedance matching of the designed Balun-LNA does not just depend on the transconductance of the CG transistor, and the input impedance matching is determined by the transconductance of the CS transistor too. Therefore, we can change the transconductance of the CG transistor. Thus, by employing the technique of g_m boosting feedback and a modified current bleeding circuit, this proposed Balun-LNA achieves symmetrical resistive loads and current at the differential output.

b. Voltage Gain

The voltage gain from V_{in} to the output of the CS transistor stage (inverting output) is obtained as:

$$\frac{V_{out+}}{V_{in}} = g_{mCG}(1 + g_{mCS}R_{CS})R_{CG} \quad (1)$$

Also, the voltage gain of the proposed Balun-LNA from V_{in} to the output of the CG transistor (noninverting output) is obtained as this equation. :

$$\frac{V_{out-}}{V_{in}} = -g_{mCS}R_{CS} \quad (2)$$

As a result, the proposed Balun-LNA's differential voltage gain is calculated as:

$$A_V = g_{mCG}(1 + g_{mCS}R_{CS})R_{CG} + g_{mCS}R_{CS} \quad (3)$$

Which g_{mCG} is the transconductance of the CG transistor, R_{CG} is the load resistor of the CG transistor, gmCS is the transconductance of the CS transistor, and R_{CS} is the load resistor of the CS transistor. According to equation (3), it can be seen that the differential voltage gain of the designed Balun-LNA has a direct relationship with the transconductance of CG and CS transistors and resistive loads of R_{CS} and R_{CG}. The differential voltage gain of the designed Balun-LNA increases if the transconductance of CG and CS transistors and load resistors of R_{CS} and R_{CG} are boosted.

c. Input Impedance Matching

Input impedance matching of the proposed Balun-LNA is obtained by the following equation:

$$R_S = \frac{1}{g_{mCG}(1+g_{mCS}R_{CS})} \quad (4)$$

As it can be seen in the equation of (4), by applying feedback, the transconductance of the CS transistor is multiplied by the transconductance of the CG transistor by a coefficient of $(1+g_{mCS}\ R_{CS})$. Thus, the input impedance matching of this proposed Balun-LNA is not just determined by the transconductance of the CG transistor, and the transconductance of the CS transistor is another parameter in determining the input impedance matching. As a result, the transconductance of the CS transistor determines the impedance matching of this proposed Balun-LNA, and the amount of the transconductance of the CG transistor can be changed to boost the differential voltage gain, reduce the noise factor, and improve the power consumption of the proposed Balun-LNA.

d. Noise Analysis

In this proposed Balun-LNA, all noise sources are uncorrelated to each other. The generated noise of cascode transistors is negligible because most of their noise is rotated in their loops and doesn't appear at the output. By using the noise factor equation, because the generated noise by R_{BLD} is small enough to be negligible, it can be excluded from the noise factor [37], [28], [43]. Thus, almost the noise factor of Balun-LNA is limited by CS and CBLD transistors and resistive loads, and can be expressed as:

$$NF \cong 1 + \frac{\gamma}{g_{mCG}R_S} + \frac{\gamma g_{mC}}{g_{mCG}}\left(\frac{1}{1 + g_{mC}\left(\frac{r_o}{N}\|Z_{INBLD}\right)}\right)^2 + \frac{(R_{CG}+R_{CS})(1+g_{mCG}(1+g_{mCS}R_{CS})R_S)^2}{R_S A_V^2} \quad (5)$$

Which in this equation, Z_{INBLD} is equal to:

$$Z_{INBLD} \cong \frac{R_{BLD}+r_{oBLD}}{1+g_{mBLD}r_{oBLD}} = \frac{1}{g_{mCG}-1}\frac{R_L}{1+g_{mC}} \quad (6)$$

R_S is the resistive of input source which has been aligned to 50Ω.

As can be seen in equation (5), by boosting the transconductance of CG and CS transistors, the NF of this proposed Balun-LNA reduces, besides the boosting of differential voltage gain.

IV. Simulation Results

In 90-nm CMOS technology, the proposed Balun-LNA is designed and simulated. Resistors R1 and R2 are biased by the CG and CS transistors, while R3 and R4 are biased by the cascode transistors MA and MB, as well as the modified current

bleeding transistor MBLD. The output load resistors $R_{CS} = R_{CG}$ are designed to be equal to 3 kΩ. In this designed balun-LNA, the amount of N = 5 is considered. Furthermore, the output load resistor of the MBLD is equal to RBLD = RL/(N-1) = 750. The current of output loads is equal to I = 0.9 mA. The transconductance of CS and CG transistors is equal to 12 mS. This proposed Balun-LNA works in the operating frequency band of digital television, namely 48 to 864 MHz. Also, the proposed Balun-LNA works at a supply voltage of 2.8 v, which is the supply voltage of most digital television tuners. The power consumption of this proposed Balun-LNA is equal to 2.5 mW, which is very low compared to other LNAs. One of the most important achievements in this Balun-LNA is its low power consumption, which makes it suitable for tuners of digital televisions and other wideband radio and microwave receivers.

In Fig. 3, the curve of the noise factor (NF) of this proposed Balun-LNA is displayed. As it can be seen in this figure, the amount of NF in the whole operating frequency band of the proposed Balun-LNA, which is the operating frequency band of the tuner of digital televisions, is about 5 dB. The minimum amount of obtained NF is equal to 5 dB and is at a frequency of 400 MHz.

In Fig. 4, the curve of input return loss (S_{11}) of the proposed Balun-LNA can be seen. As it can be seen in Fig. 4., the proposed Balun-LNA has an input return loss of much less than -10 dB in the whole frequency band, which is suitable for tuners of digital televisions and other wideband applications.

In Fig. 5., the differential voltage gain of the designed Balun-LNA for application of the tuner of digital television is displayed. As it can be seen in Fig. 5., the differential voltage gain of the proposed Balun-LNA is changed between 23.8 and 24 dB, in a frequency range of 48 to 864 MHz. The maximum obtained voltage gain is until the frequency of 400 MHz, which is equal to 24 dB.

The table I shows the performance summary and comparison between the designed and proposed Balun-LNA with several other Balun-LNAs. As it can be seen in the table I, this designed Balun-LNA has higher differential voltage gain compared to previous structures and has an input return loss of less than -10 dB, which are essential parameters of a low-noise amplifier for wideband applications, especially for the tuners of digital television. Furthermore, the proposed Balun-LNA has a power consumption of 2.5 mW, which is significantly lower than that of many previous works. Having low power consumption is the most important advantage of this designed Balun-LNA. Reducing power consumption is one of the important characteristics, so that should be considered as a major characteristic in the design of the low noise amplifier in the tuner IC of digital television. The noise factor of this designed and proposed Balun-LNA is a little higher than other structures, but it is suitable for the application of tuners of digital television. Also, the proposed Balun-LNA has the performance of both balun and symmetrical loads at the output. The presence of symmetrical loads causes the gain and phase balance at the differential output, which is necessary for the tuner of digital televisions and other wideband applications.

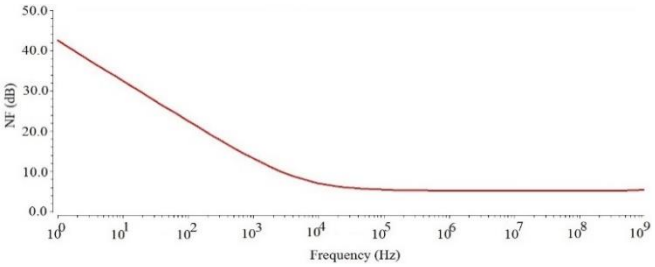

Fig. 3. NF of the proposed Balun-LNA.

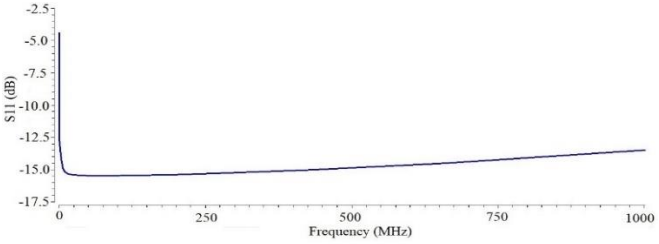

Fig. 4. S11 of proposed Balun-LNA.

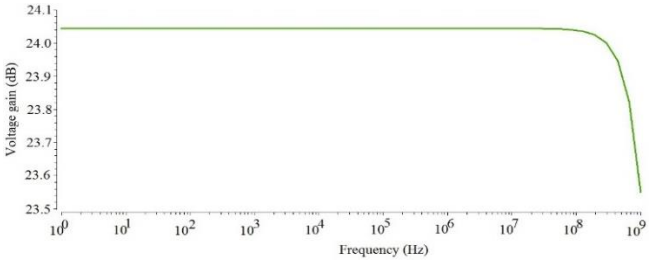

Fig. 5. Voltage gain of proposed Balun-LNA.

V. Conclusion

In 90-nm CMOS technology, a balun low noise amplifier employing gm-boosting feedback technique and current bleeding circuit for application of digital television tuner was designed and proposed. In this Balun-LNA, a circuit of modified current bleeding was used to boost the transconductance of the CS transistor. Also, a technique of g_m-boosting feedback was used for boosting the transconductance of the CG transistor. The proposed Balun-LNA works in the frequency band of digital television, namely 48 to 864 MHz, and achieves a maximum differential voltage gain of 24 dB at the frequency of 400 MHz. Also, input return loss of much less than-10 dB and a minimum NF of 5 dB are achieved in this proposed Balun-LNA. This proposed Balun-LNA has a balun function and symmetrical loads at the differential output. Using the symmetrical loads causes the gain and phase balance at the differential output to be symmetrical. This designed and presented Balun-LNA has achieved a power consumption of 2.5 mW, which is very low and suitable for tuners of digital television.

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TABLE I

Comparison of proposed Balun-LNA and previous works.

Ref.	CMOS Process	Frequency range (GHz)	S11 (dB)	Voltage gain (dB)	NF (dB)	Symmetric load	Power consumption (mW)	Supply voltage (v)
[1]	180 nm	0.05-0.86	<-8.5	17-18	2.5-3	YES	30	1.2
[2]	130 nm	0.2-3.8	<-10	16-19	2.8-3.4	YES	5.7	1
[4]	28 nm	1-6.2	<-10	48.2	3.4-4.2	YES	22.2	1.8
[11]	130 nm	0.01-1	<-10	14.5	2.5	NO	3.6	1.2
[24]	40 nm	1-11	<-10	14-17	3.5-5.5	YES	9	1.2
[30]	28 nm	0.02-2	<-10	18.5	2.5-3.5	NO	4.1	1
[37]	65 nm	0.05-1	<-10	24-30	2.2-3.3	YES	19.8	2.2
[38]	65 nm	0.05-1.3	<-10	24-27.5	2.3-3	YES	5.7	1
[43]	130 nm	0.1-1	<-10	14	2.4	YES	2.7	1.2
[44]	180 nm	0.13-0.93	<-10	16.6-19.6	3.6-5	YES	3	1.8
This work	90 nm	0.04-0.864	<-10	24	5	YES	2.5	2.8

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