An Active-Balun LNA with Forestage-Poststage Gain Controls for VHF/UHF Mobile-TV Tuners

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Abstract—Presented is a novel active-balun low noise amplifier (LNA) with forestage-poststage gain controls for VHF/UHF mobile-TV tuners. It consists of two passive attenuators inter-operating with an active core to optimize the RF performances under different reception scenarios. The forestage is a MOS-based attenuator configured in a way that, at all attenuation levels, a broadband input impedance match can be obtained. The interstage is a single-to-differential amplifier exploiting a common-source-common-gate structure for noise cancellation. The poststage is a capacitor (CAP)-based attenuator, which adjusts the linearity of the output signal before driving the mixer. With this forestage-poststage gain controls the system noise figure and linearity can be easily traded at different gain levels. Optimized in a 0.18-µm CMOS process the LNA attains 0.85-dBm IIP3 at a maximum voltage gain of 26 dB, a 37-dB gain range with a 6-dB step size, and an average noise figure of 2.9 dB. The power consumption is 10.8 mW at 1.8 V.

I. INTRODUCTION

Recent works on wideband low-noise amplifiers (LNAs) [1] based on an active-balun structure have shown reliable RF performances such as moderate noise figure (NF), high linearity and broadband input impedance match. This structure has great potential in minimizing the required external components of multi-band mobile-TV tuners, i.e., an active-balun LNA requires just one radio frequency (RF) input pin and eliminates the need of external balun for each band, which is necessary in the current design [2].

For TV applications, an active-balun LNA has to feature a wide gain-control range. From the example reported in [3], as shown in Fig. 1(a), two single-to-differential (S2D) amplifiers are entailed to provide high- and low-gain modes with a resistor (R)-based attenuator (ATT). The ATT is an R-2R ladder to guarantee an input impedance match, at the expense of needing a capacitor $C_1$ to isolate the ATT with the S2D. This $C_1$ consumes a significant amount of chip area [3].

In this paper, a novel active-balun LNA [Fig.1(b)] with forestage and poststage gain controls is described. Just one S2D amplifier is required, while $C_1$ is eliminated. The LNA supports both VHF-III (170 to 240 MHz) and UHF (470 to 860 MHz) bands while offering low NF and $S_{11} < -10$ dB at all gain levels. Forestage and poststage gain controls flexibly befit reception at different signal-to-interferer levels.

II. ACTIVE-BALUN LNA WITH FORESTAGE-POSTSTAGE GAIN CONTROLS

The proposed active-balun LNA with forestage-poststage gain controls is depicted in Fig. 2. A MOS-based ATT is placed at the input node of the common-gate amplifier ($M_{CG}$) for coarse-gain control. This node is externally dc-grounded by $L_{bias}$ to provide a wideband input impedance match. An external $L_{bias}$ can have a high quality factor and allows reconfigurability. Since there exists dc current passing through the MOS-based ATT, the grounding of the bias circuit ($M_x$ and $I_{bias}$) is operated with the same MOS-based ATT to reduce the dc-operating point variation of the CG branch. The current mirror ratio is 1:1. Basically, the transconductance ($g_m$) of $M_{CG}$ is sized to match the source impedance ($1/g_m = R_q$).

For the CS branch, the components are sized related with the CG branch to cancel the thermal noise of $M_{CG}$ [1]. The cascode devices $M_{cas1}$ and $M_{cas2}$ are to improve the reverse isolation. The differential outputs are interfaced with two identical capacitor (CAP)-based ATTs to offer extra coarse-gain controllability. The gain controls are all digitally executed in both forestage and poststage ATTs, providing different combinations of gain (so as to trade the NF and IIP3).

$R_{CS}$ has a lower resistance value than $R_{CG}$. A capacitor $C_2$ is added to minimize the mismatch of the differential output bandwidth (BW) as given by,

$$ R_{CG} (C_{equ}) = R_{CS} (C_{equ} + C_2), \quad (1) $$

where $C_{equ}$ is the equivalent input capacitance of the CAP-based attenuator. With $4R_{CS} = R_{CG}$, the size of $C_2$ is obtained as given by,
With the help of the CG-CS noise-canceling technique, the NF of the LNA is still limited by the MOS-based ATT. To ensure an acceptable $S_{11}$, $R_{\text{IN}}$ is sized at 30 $\Omega$ and all switches are sized in relationship with that value of $R_{\text{IN}}$ (Fig. 3 upper left). At maximum gain, the equivalent resistance of the triode-biased transistor $R_{\text{ON}}$ is sized as $-5$ $\Omega$, resulting in $R'_{\text{IN}} = -35$ $\Omega$. This value minimizes the NF penalty and attenuation (1.4 dB) due to $R_{\text{ON}}$, while maintaining an acceptable $S_{11} < -10$ dB for $R_S = 50$ $\Omega$. At other attenuation levels, according to the gain setting of Table I, $R'_{\text{IN}}$ is maintained at 50 $\Omega$, guaranteeing a superior $S_{11}$ for 8-, 14- and 20-dB attenuation.

**Table I. Gain Control of the MOS-Based ATT.**

<table>
<thead>
<tr>
<th>$C_0$</th>
<th>$G_1$</th>
<th>$G_2$</th>
<th>$m_{\text{eq}}$</th>
<th>$m_G$</th>
</tr>
</thead>
<tbody>
<tr>
<td>+1 dB</td>
<td>OFF</td>
<td>OFF</td>
<td>OFF</td>
<td>ON</td>
</tr>
<tr>
<td>-4 dB</td>
<td>ON</td>
<td>ON</td>
<td>OFF</td>
<td>OFF</td>
</tr>
<tr>
<td>-14 dB</td>
<td>OFF</td>
<td>OFF</td>
<td>OFF</td>
<td>ON</td>
</tr>
<tr>
<td>-20 dB</td>
<td>OFF</td>
<td>OFF</td>
<td>OFF</td>
<td>ON</td>
</tr>
</tbody>
</table>

Figure 4 shows the CAP-based ATT. For a better linearity, transmission gates are employed for all switches since the dc levels of $V_{\text{out}+}$ and $V_{\text{out}-}$ are almost midway the $V_{\text{DD}}$. Attenuation is realized by controlling the voltage $V_{C_0}$, $V_{C_6}$, $V_{C_{12}}$ and $V_{C_{18}}$. When one of the transmission gates is switched ON, as shown in Table II, the equivalent capacitance $C_{\text{eq}}$ is identical, but with different levels of attenuation. At a 0-dB attenuator level, a small capacitor $C_X$ is added to maintain the output BW relatively constant.

IV. Simulation Results

The active-balun LNA is optimized in a 0.18-$\mu$m CMOS
process at 1.8 V. The simulated $S_{11}$ at different gain steps are plotted in Fig. 5. $S_{11} < -10$ dB is achieved from 150 MHz to more than 1 GHz. The voltage gain and NF for VHF III and UHF bands as functions of the gain control steps are shown in Fig. 6(a)-(b) to 7(a)-(b), respectively. The small gain step error is acceptable for this coarse-gain adjustment. The simulated NF ranges from 2.9 to 3.4 dB from 170 to 860 MHz. The increment of NF at high frequency is due to gain drops. The maximum $S_{21}$ versus frequency is 26 dB and the gain step is close to 6 dB as shown in Fig. 8. In both reception bands, two-tone tests at maximum gain give an IIP3 of >0.85 dBm.

With different combinations of MOS-based and CAP-based attenuation levels, the same gain levels give different linearity and NF performances as shown in Fig. 9(a) and (b) for VHF III and UHF bands, respectively. For instance, when the MOS-based ATT is activated while CAP-based ATT is fixed, the linearity improves significantly with the attenuation levels, at the expense of the NF. Gain control by the CAP-based ATT, on the other hand, gives smaller NF penalty, but the linearity is limited by the MOS-based ATT and the S2D amplifier. This flexibility facilitates the reception of the desired signals with respect to the strength of its interferers.

**Table II** Gain Control of the CAP-Based ATT.

<table>
<thead>
<tr>
<th>$V_{C0}$</th>
<th>$V_{C6}$</th>
<th>$V_{C12}$</th>
<th>$V_{C18}$</th>
<th>$C_{C}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>ON</td>
<td>OFF</td>
<td>OFF</td>
<td>OFF</td>
<td>123$\Omega$</td>
</tr>
<tr>
<td>-6$\Omega$</td>
<td>OFF</td>
<td>ON</td>
<td>OFF</td>
<td>123$\Omega$</td>
</tr>
<tr>
<td>-12$\Omega$</td>
<td>OFF</td>
<td>OFF</td>
<td>ON</td>
<td>123$\Omega$</td>
</tr>
<tr>
<td>-18$\Omega$</td>
<td>OFF</td>
<td>OFF</td>
<td>OFF</td>
<td>123$\Omega$</td>
</tr>
</tbody>
</table>

*Fig. 4* CAP-based ATT.

*Fig. 5* Simulated $S_{11}$ versus frequency in VHF III and UHF bands.

*Fig. 6* Voltage gain versus gain steps (a) VHF-III and (b) UHF bands.

*Fig. 7* NF versus frequency: (a) VHF-III and (b) UHF bands.

*Fig. 8* Noise figure versus frequency: (a) VHF-III and (b) UHF bands.
Fig. 8 Simulated S21 at different gain steps.

Fig. 9 NF and IIP3 at all gain steps: (a) VHF-III and (b) UHF bands.

V. CONCLUSIONS AND COMPARISONS

This paper describes a novel active-balun LNA with forestage-poststage gain controls. Forestage MOS-based ATT and poststage CAP-based ATT inter-operated with an active core provide a wide gain range and a flexible tradeoff between NF and linearity. Simulation results show that within the VHF-III and UHF bands, the LNA achieves sufficient input impedance match (S11<-10dB) against 37-dB gain control range, 2.9-dB average NF and >0.85-dBm IIP3 at a maximum voltage gain of 26 dB. The power consumption is 10.8 mW at 1.8 V. As compared in Table III, this work achieves competitive RF performances respect with the prior arts [3]-[5].

VI. ACKNOWLEDGMENT

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REFERENCES


