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

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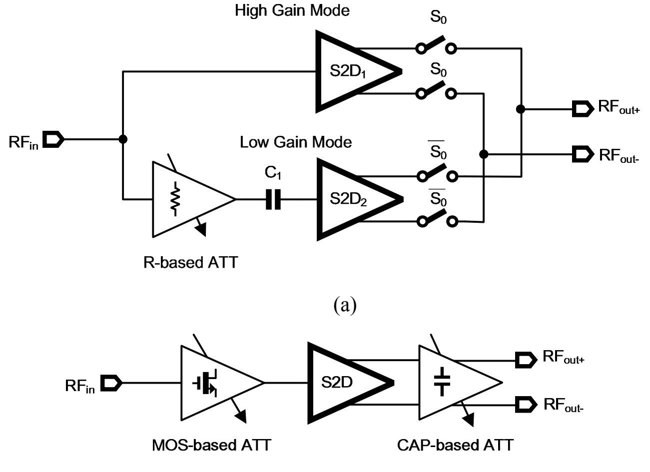
***Abstract*—Presented is a novel active-balun low noise amplifier (LNA) with forestage-poststage gain controls for VHF/UHF mobile-TV tuners. It consists of two passive attenuators inter-operating with an active core to optimize the RF performances under different reception scenarios. The forestage is 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 dynamicity 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.**



(a)

(b)

Fig. 1 Active-balun LNA with gain control: (a) [3] and (b) proposed.

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 $S2D_2$. 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 re-configurability. Since there exists dc current passing through the MOS-based ATT, the grounding of the bias circuit (M_x and I_{bx}) 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 ($1/g_m=R_S$).

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,

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

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,

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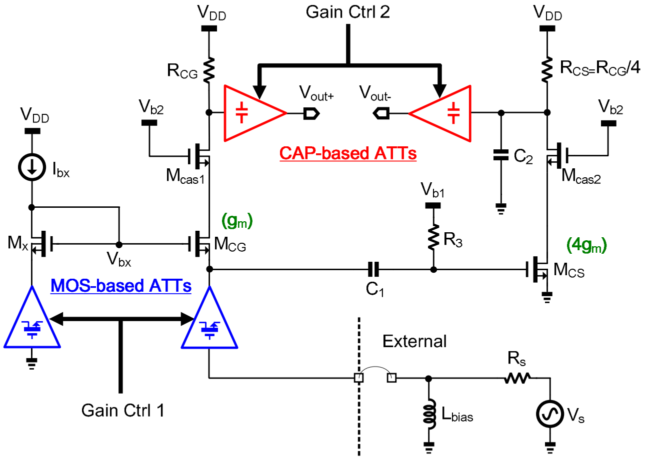


Fig. 2 Proposed active-balun LNA with forestage-poststage gain controls.

$$C_2 = 3\, C_{equ}\,. \tag{2}$$

III. MOS-BASED AND CAP-BASED ATTS

The schematic and equivalent circuits of the MOS-based ATT at different attenuation levels are shown in Fig. 3. For an R-based ATT, the switches for gain control must be large enough to minimize the gain inaccuracy due to their finite ON resistance. Differently, for the proposed MOS-based ATT, transistors are biased in triode region to behave as both resistors and switches. Since the input terminal is dc-grounded, the overdrive voltage of all switches is maximized as V_{GS} - V_T = V_{DD} - V_T. A high overdrive is critical to enhance linearity and bandwidth as the device size can be minimized for a given resistance value.

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_{IN} is sized at 30 Ω and all switches are sized in relationship with that value of R_{IN} (Fig. 3 upper left). At maximum gain, the equivalent resistance of the triode-biased transistor R_{ON} is sized as ~5 Ω, resulting in R'_{IN} = ~35 Ω. This value minimizes the NF penalty and attenuation (1.4 dB) due to R_{ON}, while maintaining an acceptable S_{11} <-10 dB for R_S = 50 Ω. At other attenuation levels, according to the gain setting of Table I, R'_{IN} is maintained at 50 Ω, guaranteeing a superior S_{11} for 8-, 14- and 20-dB attenuation.

TABLE. I GAIN CONTROL OF THE MOS-BASED ATT.

	G_0	G_1	G_2	m_{HG}	m_{LG}
-1.4dB	OFF	OFF	OFF	ON	OFF
-8dB	ON	OFF	OFF	OFF	ON
-14dB	OFF	ON	OFF	OFF	ON
-20dB	OFF	OFF	ON	OFF	ON

Figure 4 shows the CAP-based ATT. For a better linearity, transmission gates are employed for all switches since the dc levels of V_{out+} and V_{out-} are almost midway the V_{DD}. Attenuation is realized by controlling the voltage V_{C0}, 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_{equ} 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-μm CMOS

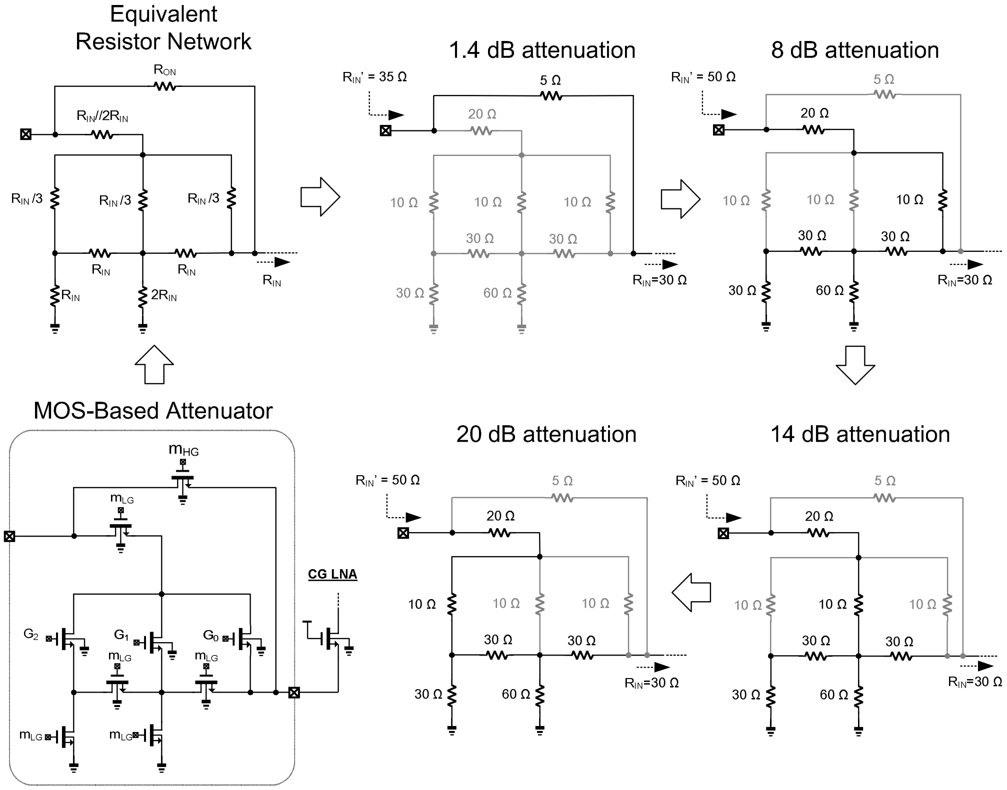


Fig. 3 MOS-based ATT and its equivalent circuits at different attenuation levels.

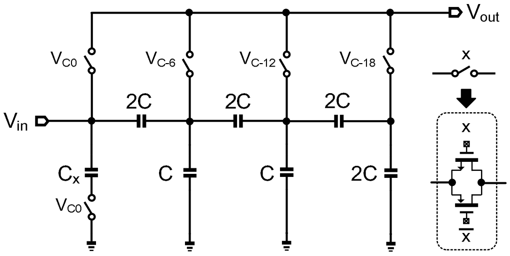


Fig. 4 CAP-based ATT.

TABLE. II GAIN CONTROL OF THE CAP-BASED ATT.

	V_{C0}	$V_{C\text{-}6}$	$V_{C\text{-}12}$	$V_{C\text{-}18}$	C_{equ} With C=125fF
0dB	ON	OFF	OFF	OFF	C_x+125fF
-6dB	OFF	ON	OFF	OFF	125fF
-12dB	OFF	OFF	ON	OFF	125fF
-18dB	OFF	OFF	OFF	ON	125fF

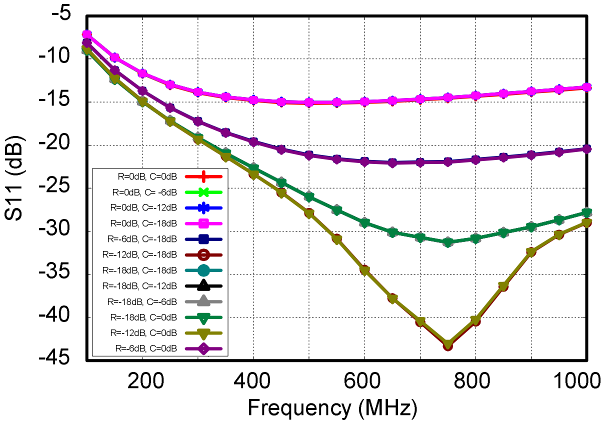
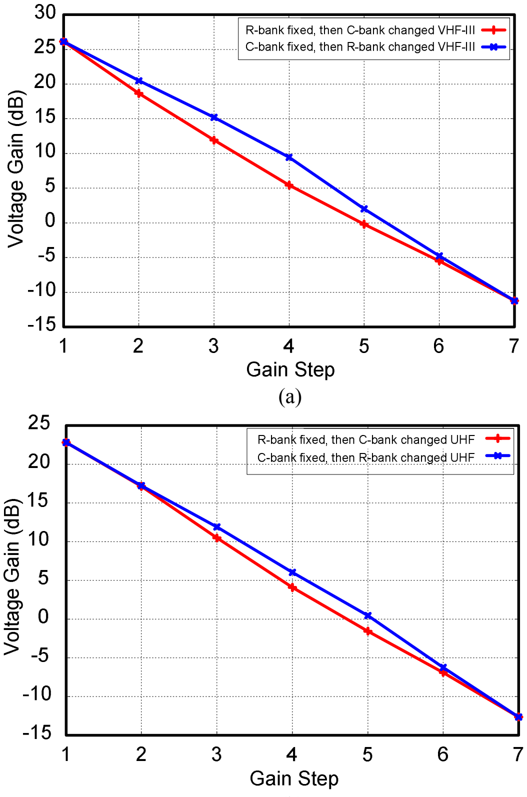


Fig. 5 Simulated S_{11} versus frequency in VHF III and UHF bands.

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.

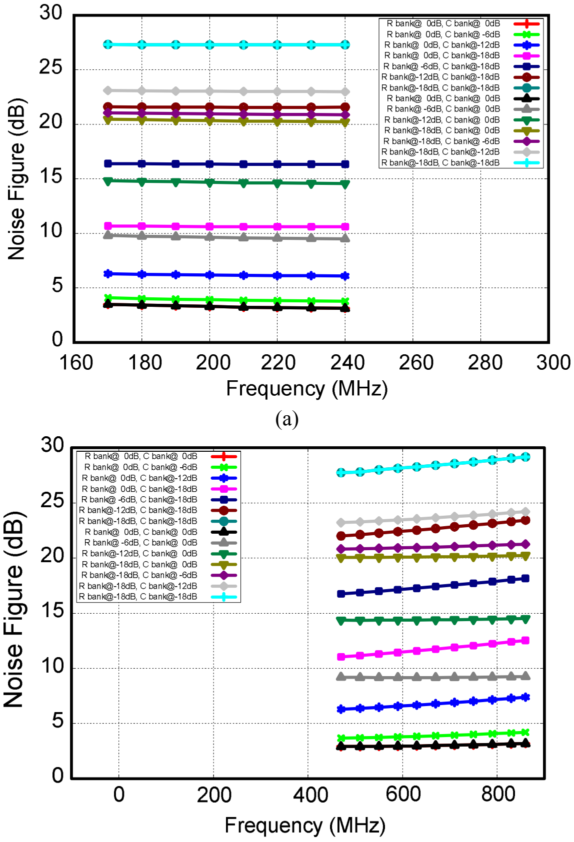
With different combinations of MOS-based and CAP-based attenuation levels, the same gain levels give different linearity and NF performances as shown in Fig. 9(a) and (b) for VHF III and UHF bands, respectively. For instance, when the MOS-based ATT is activated while CAP-based ATT is fixed, the linearity 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.



(a)

(b)

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



(a)

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

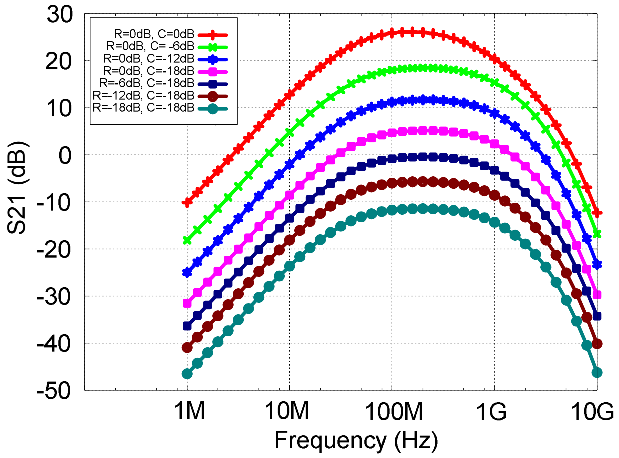
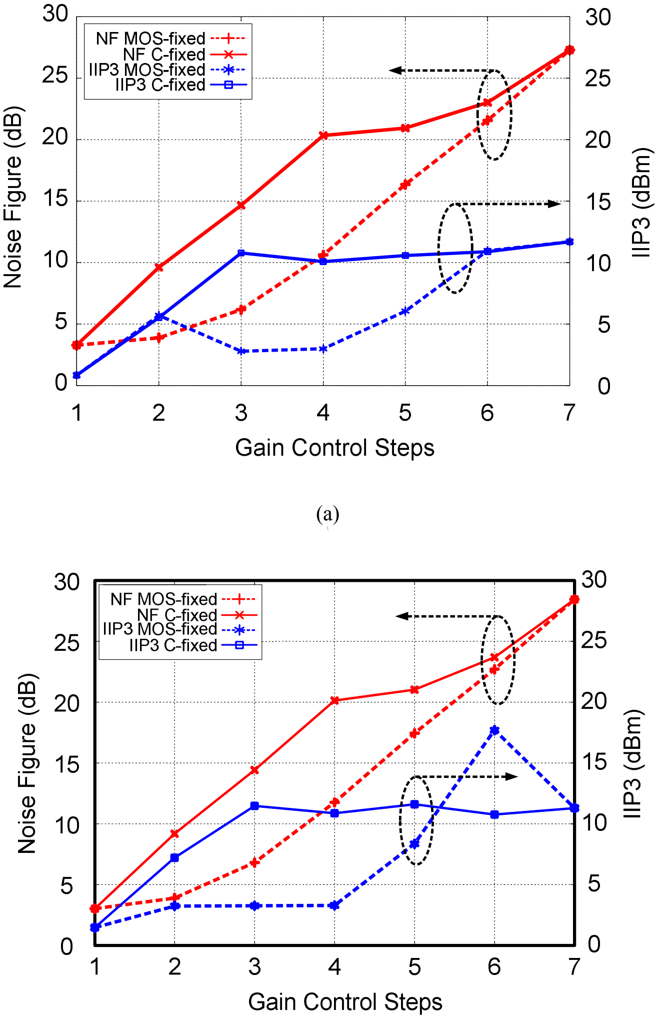


Fig. 8 Simulated S21 at different gain steps.



(a)

(b)

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

TABLE III SUMMARY AND PERFORMANCE COMPARISON.

	[3]	[4]	[5]	This work
Technology	0.18μm CMOS	0.18μm CMOS	0.18μm CMOS	0.18μm CMOS
Supply(V)	1.8	1.8	1.8	1.8
BW(MHz)	50-860	470-860	470-860	170-860
S11(dB)	<-10	<-10	<-11	<-10
Gain(dB)	15	25	16	26
NF(dB)	4.2	4.5	4.3	2.9
IIP3(dBm)	2.6	-4	-1.5	0.85
Power(mW)	10	16	22	10.8
Area(mm^2)	1.117	0.143	0.072	N/A

[3], [4], [5] are experimental results

V. CONCLUSIONS AND COMPARSIONS

This paper describes a novel active-balun LNA with fore-stage-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 sufficed input impedance match (S_{11}<-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

[1] S. C. Blaakmeer, E. A. M Klumperink, D. M. W. Leenaerts, and B. Nauta, “Wideband Balun-LNA with Simultaneous Output Balancing, Noise-Canceling and Distortion-Canceling” *IEEE J. Solid-State Circuits*, vol. 43, pp. 1341-1350, Jun. 2008.

[2] I. Vassilios, K. Vavelidis and N. Haralabidis, *et al*., “A 65nm CMOS Multistandard, Multiband TV Tuner for Mobile and Multi-Media Applications,” *IEEE J. Solid-State Circuits*, vol. 43, pp. 1522-1533, Jul., 2008.

[3] Kefeng Han, Liang Zou, Youchun Liao., *et al*, “A Wideband CMOS Variable Gain Low Noise Amplifier Based on Single-to-Differnetial Stage for TV tuner Apllications,” *IEEE Asian Solid-State Circuits Conf.*, pp. 457-460, Nov. 2008.

[4] Tae Wook Kim., *et al*, “A 13-dB IIP3 Improved Low-Power CMOS RF Programmable Gain Amplifier Using Differential Circuit Transconductance Linearization for Various Terrestrial Mobile D-TV Applications,” *IEEE J. Solid-State Circuits,* Vol.41, No.4, Apr. 2006.

[5] Jianhong Xiao., *et al*, “A High Dynamic Range CMOS Variable Gain Amplifier for Mobile DTV Tuner,” *IEEE J. Solid-State Circuits,* Vol.42, No. 2, Feb. 2007.