A Highly Linear Low-Noise Amplifier Using a Wideband Linearization Technique with Tunable Multiple Gated Transistors

Jaeyoung Lee[1], Jeiyoung Lee[2], Bonkee Kim[3], Bo-Eun Kim[4] and Cam Nguyen[1]

[1]Department of ECE, Texas A&M University, College Station, TX, 77843-3128, USA
[2]Samsung Electronics Co. Ltd., Suwon, Gyeonggi-do, Korea
[3]HiDeep Inc., Seongnam, Gyeonggi-do, Korea
[4]RAONTECH Inc., Seongnam, Gyeonggi-do, Korea

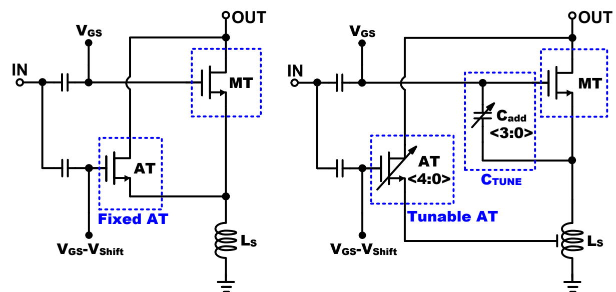
Abstract **— A wideband linearization technique using tunable multiple gated transistors (MGTRs) is proposed. Extra tunable input capacitors and the modified derivative superposition (DS) method are also adopted to increase the amplifier's linearity at RF. A low-noise amplifier (LNA) employing the proposed linearization technique has been developed with 0.18-μm CMOS process for various mobile TV standards in UHF band (470–862 MHz). The LNA achieves 19-dBm IIP_3, 16.5-dB gain, and 1.33-dB NF with 10.8-mW power consumption. Over the desired UHF band, the LNA increases the average IIP_3 obtained with off-state auxiliary transistor by 11.7 dBm.**

Index Terms **— Derivative superposition (DS), low-noise amplifier (LNA), mobile TV, multiple gated transistors (MGTRs), nonlinearity, third-order intercept point (IIP_3).**

I. Introduction

The stringent specifications of various UHF mobile TV standards across 470–862 MHz, e.g. DVB-H, ISDB-T, and T-DMB, require low-noise amplifiers (LNAs) to exhibit high linearity, low noise figure (NF), and wideband input matching simultaneously. LNAs using conventional wideband input matching, such as resistive shunt feedback and common-gate input stage, can provide good input matching. However, they do not satisfy the required stringent low NF (typically under 2 dB) for mobile TV applications. In order to increase the LNA's linearity while maintaining low NF, common-source configuration with multiple gated transistors (MGTRs) was implemented for RF amplifiers [1], [2]. Linearity enhancement techniques using different MGTR configurations were also proposed for LNAs [3], [4], [6], [7]. These reported linearity enhancement techniques, however, are only valid for narrow-band applications. Recently, an LNA that satisfies both high linearity and wide bandwidth has been developed [5] by combining the linearity enhancement techniques in [3] and [4]. This LNA, however, has a high NF of 4.8 dB, which is not suitable for mobile TV applications.

In this paper, we present a new wideband linearization technique using tunable MGTRs and matching capacitors to achieve high linearity and low NF simultaneously. An LNA employing the proposed linearization technique has been developed with low NF, high IIP_3, and wideband matching over the UHF band of 470 to 862 MHz. These results demonstrate that the proposed wideband linearization technique can overcome the narrow-band limitation of the previous linearization techniques using conventional MGTRs.



(a) (b)

Fig. 1. (a) Conventional MGTRs using a fixed AT with DS method, and (b) proposed MGTRs employing tunable ATs and input matching capacitors with modified DS method.

II. LNA Design with Proposed Tunable MGTRs

Fig. 1(a) shows a conventional MGTR configuration with a derivative superposition (DS) method [3]. Note that the sources of the main transistor (MT) and fixed auxiliary transistor (AT) are tied together and connected to a single source degeneration inductor L_S. A CMOS LNA based on Fig. 1(a) achieved a high IIP_3 by minimizing the drain load impedance and the source degeneration inductance [2]. Nevertheless, minimizing the source inductance value leads to design difficulty in achieving good input matching and low NF simultaneously. Therefore, a modified DS method was proposed using two source degeneration inductors, and it provides simultaneous noise and power match [3]. However, both these linearization techniques are effective only for narrow-band applications due to the fixed AT

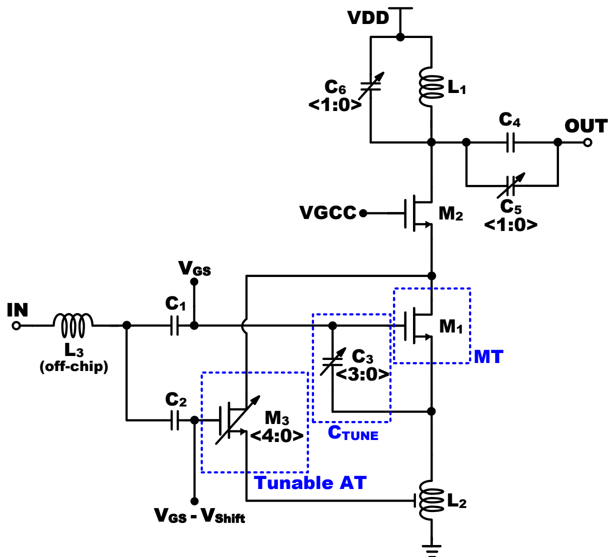


Fig. 2. Schematic of the proposed UHF LNA employing tunable MGTRs and matching capacitor banks. Bias circuits are not shown.

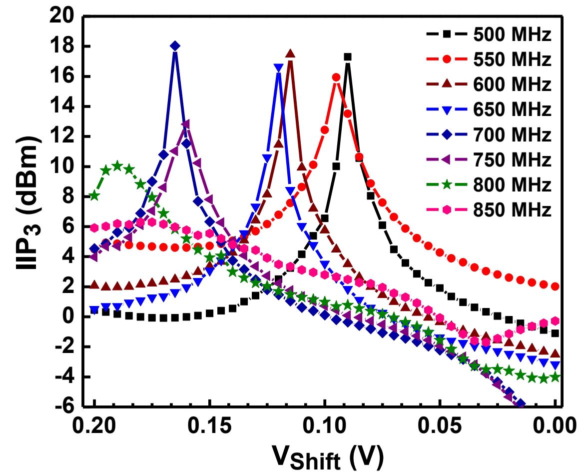


Fig. 3. Simulated IIP_3 at different frequencies as a function of the offset voltage, V_{Shift}.

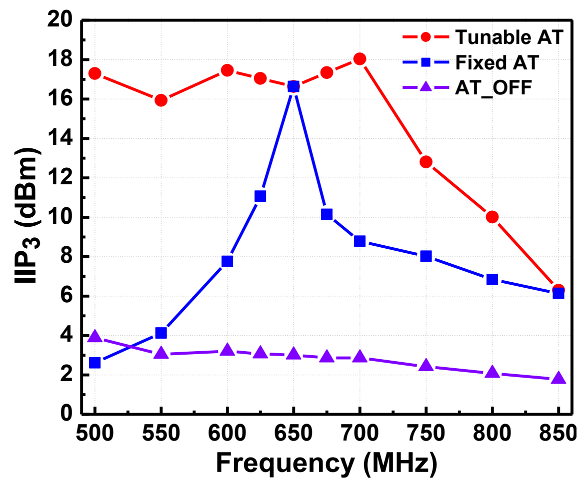


Fig. 4. Simulated IIP_3 comparison with AT off, conventional fixed AT, and proposed tunable AT.

size leading to a limited transconductance (g_m) over wide frequency range.

To overcome the narrow-band linearity enhancement characteristics of conventional MGTRs, we propose tunable MGTRs based on the modified DS method using a three-port source degeneration inductor as shown in Fig. 1(b). The tunable MGTRs are composed of a MT and five-bit switching ATs with four-bit switching capacitors to achieve wideband input matching and linearity enhancement simultaneously. This MGTR structure has been employed into the cascode LNA to achieve low NF as shown in Fig. 2. The width of the MT is 300 μm and the tunable ATs have 160/80/40/20/10-μm weighted widths with a 0.18-μm channel length. Therefore, the tunable ATs provide variable transconductance over wide frequency range and compensate the low g_m outside the linearity enhancement range of conventional MGTRs using a fixed AT.

Moreover, the added input matching tunable capacitors (C_3) between the gate and source of the MT can relax the second-order distortion contributions to the third-order inter-modulation distortion (IMD_3) as well as reduce the induced-gate noise contribution to the overall NF of the LNA [6]. Also, two-bit switching capacitors, C_5 and C_6, are used at the LNA output and the load, respectively. The input matching inductor (L_3) is the only off-chip component, while the load inductor (L_1) and the three-port source degeneration inductor (L2) are integrated on chip. Full EM simulations were carried out thoroughly to customize the size and inductance value of L_1 and L_2. The proposed LNA can be fully controlled by combining the digital words of the tunable ATs, input/output switching capacitors, and current mirror bias circuits. Therefore, the LNA provides good flexibility to obtain low NF and high linearity over wide bandwidth at the same time.

As shown in Fig. 3, the proposed LNA using tunable ATs can achieve several IIP_3 peaks at various frequencies by varying the offset voltage (V_{Shift}) with a fixed gate-to-source voltage (V_{GS}) of the MT. On the other hand, the LNAs using a conventional fixed AT in [2]-[4] have only one IIP_3 peak at a single desired frequency with a particular V_{Shift}. Consequently, by controlling the size of ATs and varying its bias voltage (V_{GS}–V_{Shift}), the proposed LNA can achieve high linearity over the desired UHF band.

Fig. 4 shows the significant linearity increase of the proposed LNA over the UHF band of interest by comparing the simulated IIP_3 results for the off-state AT, conventional fixed AT, and proposed tunable ATs. As seen in Fig. 4, the LNA with the off-state AT achieves an average IIP_3 of 3 dBm. With the conventional fixed AT, the LNA exhibits only a single IIP_3 peak of 16.5 dBm at 650 MHz, and IIP_3 higher than 10 dBm over only 60-MHz bandwidth (620–680 MHz). The 0.63-V V_{GS} for MT and the 0.12-V V_{Shift} were used for this simulation. By varying V_{Shift} and control words of tunable ATs and input/output switching capacitors, the proposed LNA with tunable ATs can achieve IIP_3 higher than 10 dBm up to 800 MHz covering entire lower frequencies, which is typically the most important frequency range (470–800 MHz) in many mobile TV standards.

Fig. 5 shows the simulated gain, NF, and matching of the proposed LNA with four significant control words showing around 16-dB power gain, 1-dB NF, and S_{11} and S_{22} of -10 dB while maintaining the high linearity performance obtained above.

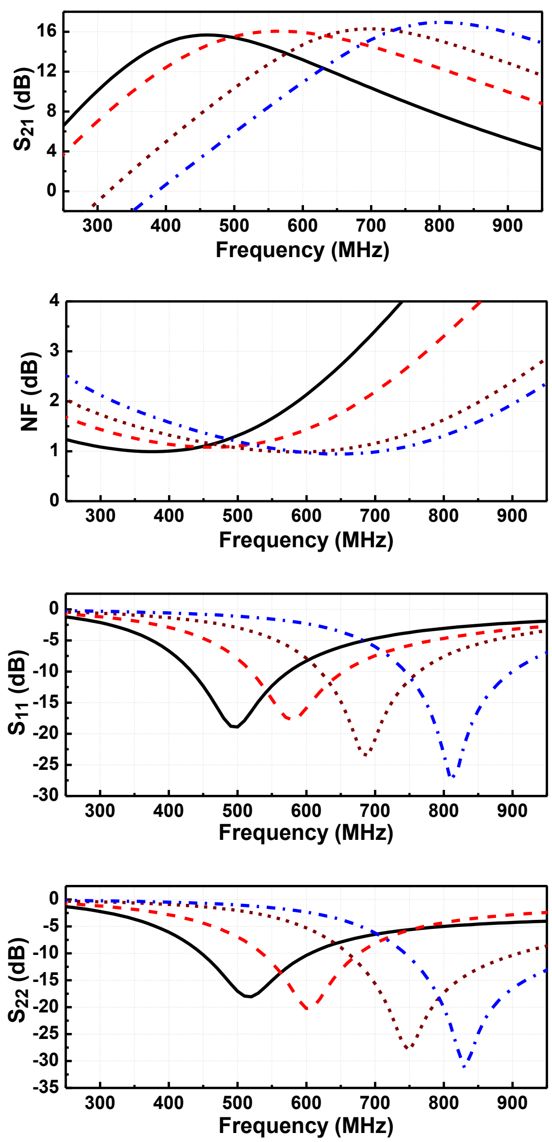


Fig. 5. Simulated S_{21}, NF, S_{11}, and S_{22} covering the desired UHF band with four representative control words.

III. Fabrication and Measurement Results

Fig. 6 shows the die photograph and layout of the fabricated UHF LNA in a 0.18-μm CMOS process. The LNA occupies an area of 0.43 mm^2, and consumes 10.8 mW from a 1.8-V supply voltage. The LNA was mounted on a PCB board using a 24-pin QFN package, and measured to achieve low NF as well as high linearity with good gain and input matching performances by adjusting the digital control words for every 10 MHz.

The LNA obtained the maximum power gain of 16.5 dB at 700 MHz and the best NF of 1.33 dB at 610 MHz as shown in Fig. 7. The average power gain and NF were

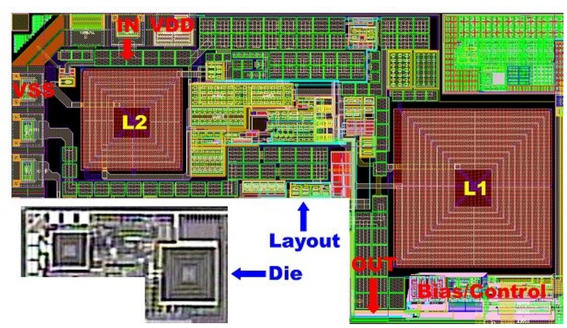


Fig. 6. Die photograph and layout of the developed LNA.

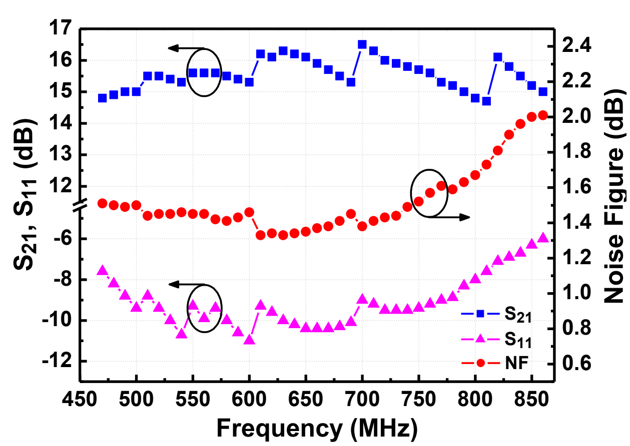


Fig. 7. Measured S_{21}, S_{11}, and NF.

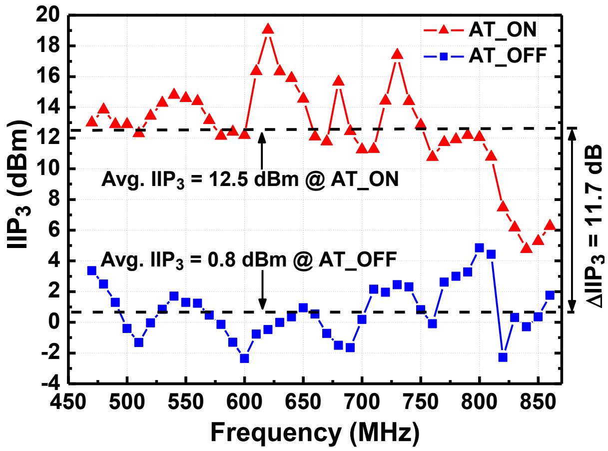


Fig. 8. Measured IIP_3 with on- and off-state ATs.

TABLE I
PERFORMANCE COMPARISON OF HIGHLY LINEAR LNAS EMPLOYING MGTR LINEARIZATION TECHNIQUES

Ref.	Freq. (GHz)	Gain (dB)	NF (dB)	IIP_3 (dBm)	Power (mW)	FOM	CMOS Tech.
[2]	0.9	10	2.85	15.6	21.1	19	0.35-μm
[3]	0.9	15.5	1.65	22	24.2	503	0.25-μm
[4]	0.9	11	2.95	21	22.5	92[3)]	0.35-μm
[5]	2.3–6.0	12.7	4.8	10.6[1)] 21.5[2)]	8.3	156.9	0.13-μm
	2.3–5.3	12.4	4.9	12.0[1)] 15.6[2)]	8.3	36.4	0.13-μm
[6]	0.9	14.9	1.8	9.4	5.55	94	0.18-μm
[7]	0.9	15	1.76	12.45	6.75	164.8	0.18-μm
This Work	**0.47–0.862**	**16.5**	**1.33**	**12.5[1)] 19.0[2)]**	**10.8**	**728.3**	**0.18-μm**

[1)] Average IIP_3 and [2)] peak IIP_3.
[3)] Results are from the original chip measurement results, not from the estimated de-embedding results.

measured as 15.5 dB and 1.67 dB, respectively, and the input return loss was higher than 6 dB across the desired UHF band of 470–862 MHz. The measured results include the effect of the ESD pads and bonding wires.

Fig. 8 shows the measured wideband IIP_3 performance at every 10-MHz frequency step over 470–862 MHz band using a 4-MHz two-tone space. The LNA obtained the best IIP_3 of 19 dBm at 620 MHz and an average IIP_3 of 12.5 dBm with on-state tunable ATs. With off-state ATs, an average IIP_3 of only 0.8 dBm was achieved. The developed LNA increases the average IIP_3 obtained with off-state ATs by 11.7 dBm over the desired UHF band.

Table I compares the performance of the LNAs employing the MGTR linearization techniques. The proposed LNA exhibits the lowest NF and the highest average IIP_3 over the desired band. Moreover, it achieves the highest figure-of-merit (FOM) defined as [3]

$$FOM = \frac{OIP_3(mW)}{(F-1)\times P_{dc}(mW)}$$

where F is the noise factor, $OIP_3 = PowerGain \times IIP_3$, and P_{dc} is the dc power consumption.

VI. CONCLUSION

A wideband linearization technique using tunable MGTRs was proposed to overcome the narrow-band limitation of the previous linearization techniques using conventional MGTRs. A highly linear wideband LNA employing tunable MGTRs has been developed, and it increases the average IIP_3 obtained with off-state ATs by 11.7 dBm over 470–862 MHz with excellent gain and low NF. The LNA verifies the superior performance of the proposed linearization technique which can be an effective solution to develop wideband low-noise high-linearity circuits.

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