Reconfigurable Multiband Multimode LNA for LTE/GSM, WiMAX, and IEEE 802.11.a/b/g/n

Anh Tuan Phan, and Ronan Farrell
Institute of Microelectronics and Wireless Systems,
National University of Ireland Maynooth (NUIM)
Kildare, Ireland (aphan@eeng.nuim.ie)

***Abstract*— This paper presents a low power multiband multimode low noise amplifier (LNA) targeting for GSM/LTE, WiMAX and IEEE 802.11 family standards. Wireless bands are reconfigurable by using selection of parallel cascode amplifiers and buffers with switching input inductors. Inductively degenerated cascode amplifiers, sharing the same transconductance for different bands, achieve good input matching and NF. Gain control is designed to provide equal gain for each band and for multimode operation. The maximum power gain is from 13 to 17 dB over different bands with controlled range of over 15dB. The NF is 1.6/2.8/2.7/3.1 dB at 1.9/2.4/3.5/5.2 GHz bands, respectively. The LNA achieves an average IIP3 of -17.5 dBm while consumes from 3 to 5.3mW for different bands. The proposed reconfigurable LNA is designed in 0.18-µm CMOS process from 1.5V supply.**

I. Introduction

The rapid evolution of mobile communication to third generation (3G) worldwide interoperability for microwave access (WiMAX), and emerging fourth-generation 4G like long-term evolution (LTE) [1, 2] has put very demanding challenges on the design of the radio front-end of new devices. Future devices will have to combine multiple standards in a single device so that the mobile terminal will be able to connect to different networks for different applications. Thus, next generation wireless communications will require new designs and innovative solutions to create multi-band multi-mode handset with cost and power effective analog RF front-ends [3]. LNA is the foremost and challenging building block in the RF receiver frontend. As it will provide gain and suppress the noise to improve the system selectivity and sensitivity.

There are two main approaches to design multi-band LNAs. The first approach is to adopt concurrent dual-band LNAs, which has been reported with good performances, but off-chip capacitors and inductors are required [4]. However, multiple bands handling capability is the main drawback for this concept. Besides, there are too many inductors are required, which occupy a large chip size.

The other more common approach is to use a radio which is controllable to receive only one system at a time. Several efforts to design multi-band reconfigurable radio have recently been published. There are two main directions to implement multiband reconfigurable radio. The first is to use a broadband LNA which covers all frequency bands of interest. The broadband design techniques can be *LC* band-pass filtering [5], the resistive/source–follower feedback [6], and the common-gate (CG) topologies [7]. The broadband LNA is often achieved at the cost of performance trade-offs

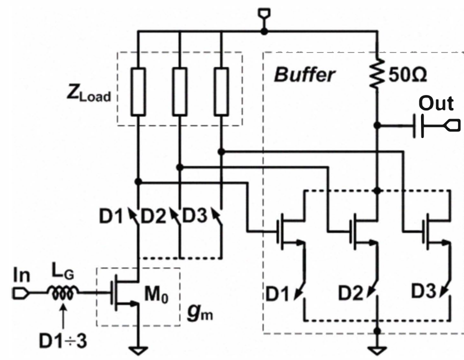

Figure 1. Reconfigurable principle of the LNA

as compared to narrow band LNA. Such as higher power consumption, higher noise figure (NF), and bulky space as complex circuited or number of passive components is added. Moreover, in the jamming environment of densely existing wireless standards, the wideband LNA will require higher linearity as it will provide amplification to both wanted signals and interferences in the pass-band.

The second choice is to adopt tunable narrowband LNAs which can be realized with the tunable multitap inductor [8] or switched inductors [9] or using feedback [10]. The tunable multitap inductor design is challenging and not available in the process design kit (PDK). The switched inductors design is involved with intensive use of switches which may degrade the Q-factor and not optimized for each band. In [10], a reconfigurable narrow band LNA based on voltage feedback CG topology was introduced with poor NF performance and high power consumption.

By adopting a bank of cascode amplifiers which share the same transconductance stage and reuse of inductors, the LNA with band tuning capability can be optimized to operate in a single band at a time with low NF and high gain while maintains low cost and low power consumption.

In this paper, we propose a multiband multimode LNA reconfigurable for GSM/LTE, WiMAX, and IEEE 802.11 standards. The proposed LNA is designed in 0.18-μm CMOS process with the targets of low power consumption, and low cost

II. Band Selection Principle

A. Proposed approach

Topology selection is the first step to consider when designing a high performance multi-band LNA. Based on literature study, the LNA using inductively degenerated common-source (CS) stage is the most preferable as it can

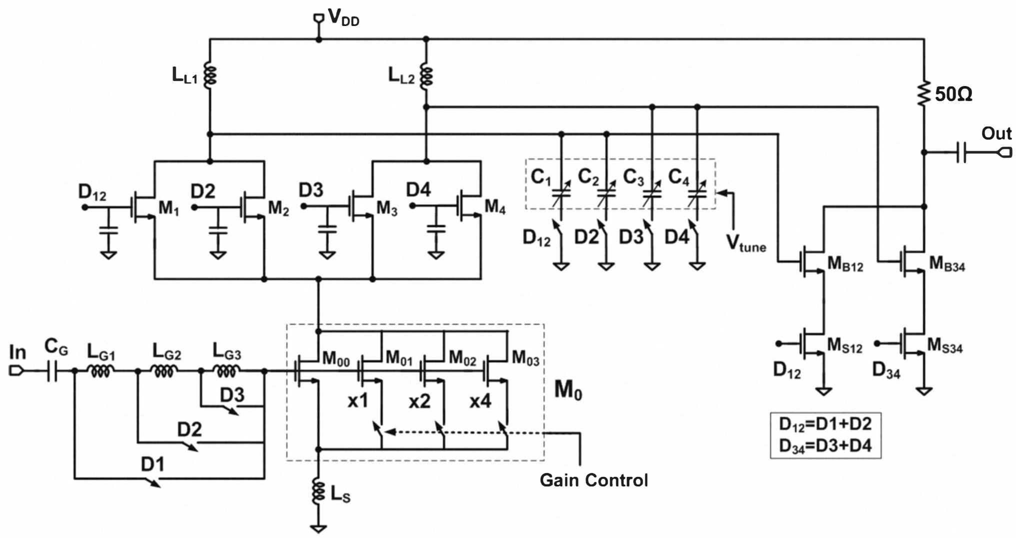

Figure 2. Schematic of the proposed multiband multistandard LNA

provide good input matching with lowest NF given power constraint.

The principle of reconfigurable LNA is shown in Fig .1. By observing that, a cascode amplifier is basically consisted of a g_m transconductance stage (CS device), a switch (CG device), and output load, one may put the bank of cascode together and selecting the needed one solely or jointly by switching CG devices. The advantage of the approach is that the performance of each frequency can be optimized independently. The same principle is applied for the output buffer, which leads to the adoption of unity gain buffer with 50Ω load, shown in Fig. 1. The load will be shared, while the different branches will be selected independently by turning ON/OFF the current source.

III. Reconfigurable LNA Design

A. *Proposed multiband LNA*

Fig. 2 presents the detail circuitry of the proposed reconfigurable LNA for multiband multimode wireless standards. The standard targets are LTE/GSM at 1.9GHz band, WLAN/Bluetooth or 802.11.b/g/n standards at 2.4GHz band, WiMAX at 3.5GHz, and 802.11.a/n WLAN at 5.2GHz band. As explained in the above section, a bank of cascode amplifiers is combined in a configurable way. In addition, the cascode amplifier can provide high gain, good isolation, good NF and input matching by using inductive degeneration matching. However, to reduce the chip size, the number of inductors will be minimized by reuse. Two bands with close resonant frequency will share the same load and buffer.

The whole LNA will be configured using selection signals D1÷4 for four bands at 5.2G/3.5G/2.4G/1.9G, respectively. The selection signal can be used solely as D1÷4 or jointly as D_{12}=D1+D2 and D_{34} =D3+D4. These signals will control the selection of input inductor ($L_{G1\text{-}3}$) for matching, CG transistors $M_{1\text{-}4}$, output capacitors $C_{1\text{-}4}$, and buffer current source $M_{S12\text{-}34}$ for band selection. For fine tuning at each standard band, the output varactors $C_{1\text{-}4}$ are inserted with V_{tune} between the load and buffer. Those varactors also help create different resonant frequencies for different bands by combining with two load inductors L_{L1} and L_{L2}. When one band operates, only one CG device is ON and one output capacitor is selected. However, at 3.5GHz band, both M1/M2 and C_1/C_2, are activated. Thus, D_{12} is applied at the gate of M1 and at C_1.

Along with band selection, there is a gain control signal. It will control the needed amount of current, thus the gain, by selecting various combination of M_0 or the size of transconductance stage transistor.

1) *Input matching*

The inductive degenerative matching for better noise and input matching is used with L_S (0.8nH) as in single wireless standard design. To simplify the reconfigurable LNA, common transconductance stage, M_0, is used for different bands. Input inductor L_G is inserted to obtain good matching. However, at different frequencies, the value of L_G should be different. In principle, there will be four different inductors according to four different ranges of wireless standards at 1.9G, 2.4G, 3.5G, and 5.2GHz, respectively. However, at 5.2GHz, it is inherently matched with small input inductor, which can be replaced by bonding wire. Therefore, the three remaining bands can be matched by three input inductors.

To configure the input inductance to select proper value, switches D1, D2 and D3 are used along with L_{G1}, L_{G2}, and L_{G3}. 5.2GHz band is matched when D1 is ON. When D2 is ON, 3.5GHz band is matched with input inductor L_{G1} of 2.5nH. When D3 is ON, it means D1 and D2 are OFF. Thus, the 2.4GHz band is matched with input inductance value of L_{G2} +L_{G3} (6nH). The lowest band at 1.9GHz is matched when all the switches are OFF. Thus, the input inductor value is the sum of L_{G1} +L_{G2} +L_{G3} (11nH). Alternatively, multi-tap inductor can be adopted to save the size which is effectively as small as one inductor.

The switches are designed with minimum channel length available in the technology for high frequency operation.

The channel widths are large enough to provide a small ON-resistance for low power loss and low thermal noise while the required operation frequency is ensured.

2) Load and buffer

The inductive load is adopted in this work, thus allowing more headroom for the cascode amplifier to improve linearity. Generally, different load inductors are needed for different frequency bands corresponding to each standard. In order to save the chip size, however, the band of 3.5GHz and 5.2GHz can share the same load, L_{L1}. For 1.9G and 2.4GHz bands, the loads also have close inductor values. Thus, L_{L2} is also can be shared for these two wireless bands by optimizing the design with proper choices of CG devices $M_{1\text{-}4}$ and different output capacitances $C_{1\text{-}4}$. Fig. 2 shows only two reuse load inductors in this design, L_{L1} and L_{L2}, with the values of 4nH and 8nH, respectively. The size of CG devices $M_{1\text{-}4}$, and buffer devices $M_{B12\text{-}B34}$, are properly selected and optimized independently to resonate with the load inductors at different resonant frequencies residing in each band.

Output matching is realized by adopting 50Ω load in the unity gain common-source buffer at the output. To improve the isolation among different bands, the buffer is split into two branches, which will be powered ON corresponding to selected bands. The current source devices, M_{S12} and M_{S34}, will be controlled with the band selection signal D_{12} for band 1 at 5.2GHz and band 2 at 3.5GHz, and D_{34} for band 3 at 2.4GHz and band 4 at 1.9GHz, respectively. Therefore, only one buffer branch is ON at a time, which will allow the signal of only one selected band to go through to the output. The buffer dissipates 2.7mA of DC current.

3) Gain control

To operate in multimode, the LNA is designed with variable gain function, which controls the level of signals at the output not to saturate the succeeding stages. It is also necessary to optimize the power consumption by reducing it when high gain is not required. Fig. 2 shows the transconductance stage consisting of four parallel transistors, $M_{01\div4}$, with size ratio of 1:1:2:4. The total size of M_0 can be controlled by switches which connecting the source node to ground. At high gain mode, all of the switches are ON to increase the overall size of M_0, thus the transconductance. As a result, the gain is enhanced with the increase in current dissipation, and vice versus. Low gain mode is performed with only M_{00}, which is always ON. The combination of transistors will provide various levels of gain in the designed LNA.

IV. Simulation Results and Discussion

The proposed LNA is simulated and designed in 0.18-µm CMOS process using 1.5V supply.

Simulation of the power gain (S21) over different wireless standards in shown in Fig. 3. The four different operation bands are 1.9/2.4/3.5/5.2GHz corresponding to the radio standards of LTE/GSM/WiMAX/802.11.family, respectively. Most the bands achieve a S21 larger than 15dB except for WiMAX band, which is high enough for the receiver front-end requirement.

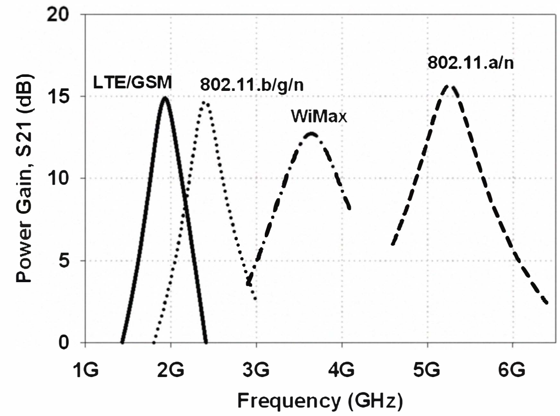

Figure 3. Simulated S21 for different standards in typical condition.

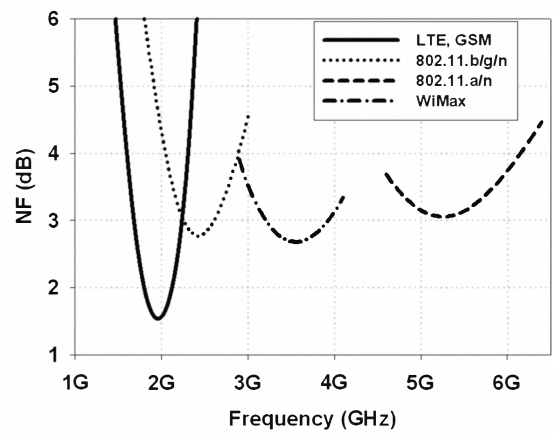

Figure 4. Simulated NF for different standards in high gain mode.

Fig .4 presents the NF of different bands. As the operation frequency increases, the NF also features the increasing trend. It varies from 1.6dB at 1.9GHz band to around 3.1dB at 5.2GHz band. The NF values are better than previously reported designs of LNA for multi-standard radios.

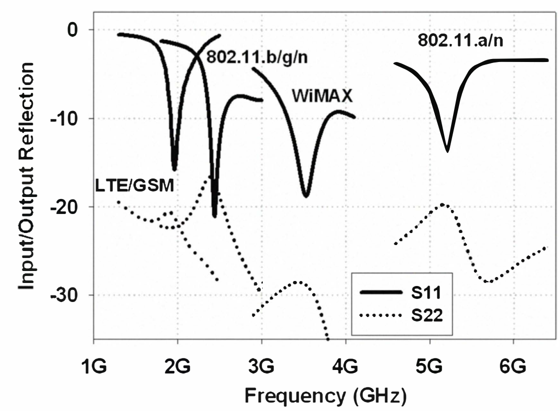

Figure 5. Simulated S11 and S22 for different standards.

One of the challenges in designing reconfigurable radios is to ensure the matching condition when tuning from one standard to the others. Simulated S-parameters of input/output refection ratios for different standards are shown in Fig. 5. The S11 is below -14dB while S22 is below -16dB with wideband characteristic in all bands. Good S11 matching ensures a better NF performance and power delivery to the output. Simulated S22 results show the wideband characteristics as we adopt 50Ω matching at the output buffer stage.

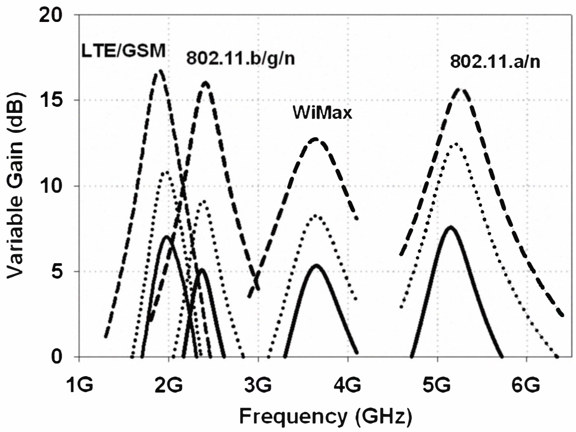

Figure 6. Simulated variable gain over different bands

The gain control function is included in this design to support the multimode operation for different standards. Fig. 6 shows different gain levels from low to maximum gain mode in each band. When changing the gain, the amount of current consumption also changes proportionally.

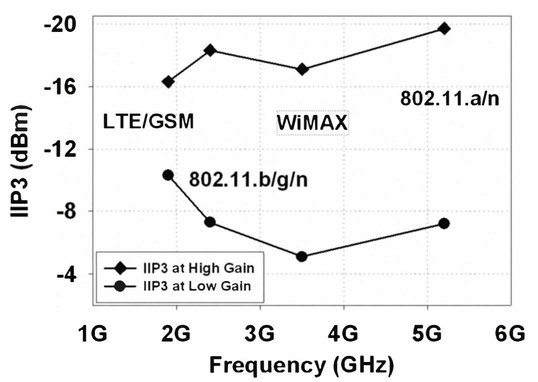

Figure 7. Simulated IIP3 at different bands in low and high gain mode.

The linearity performances are reported in Fig. 7 with the simulated results of IIP3 in low and high gain modes. The two-tone test is applied with 1MHz spacing for each band. At 1.9/2.4/3.5/5.2GHz, the IIP3 results in high gain mode are -16.2/-18.3/-17.1/-19.6dBm, respectively. The LNA consumes 3/3.4/3.4/5.3mW at 1.9/2.4/3.5/5.2GHz bands, respectively, from 1.5 V supply in high gain mode. Table I compares the LNA performance with previously reported works. It is superior in terms of power consumption while maintains good performance over multiple bands.

TABLE I: PERFORMANCE COMPARISON

	Freq. (GHz)	Power (mW)	S21 (dB)	S11 (dB)	NF (dB)	IIP3	Tech. μm	Topology
This work	1.9-5.2	3-5.3	13-17	-14	1.5-3.1	-17.5	0.18	Cascode bank selection
[4]	2.4/5.2	10	14/15.5	-15	2.3/4.5	0/5.6	0.35	Concurrent Dual-band
[6]	DC-6.5	9.7	16.5	-10	> 2.7	-2	90n	Res.SF.Feedback
[8]	2.4-5.4	4.6	22-24	-12	2.2-3.1	-21	0.13	Multitap Ind.
[9]	0.9÷5.2	7.5	13-16	-12	2.3-2.9	-14	0.18	Switched Ind.
[11]	5.2	10	11	<-10	2.17	0.3	0.18	CS. Single band

V. CONCLUSION

A reconfigurable multi-standard LNA working from 1.9 to 5.2GHz was designed in 0.18-μm CMOS process. The channel tuning is based on the cascode bank selection and switching input matching inductors. Inductors and the buffer are shared to reduce the chip size, thus the cost. The proposed LNA is capable of working in various next generation wireless standards like LTE/GSM, WiMAX, and IEEE 802.11 family. Its performance is comparable to the single band radio with modest power consumption. The design is suitable for the single chip next generation radio solution with low cost and low power consumption.

ACKNOWLEDGMENT

The authors would like to thank Centre for Telecommunication Value-Chain Research (03/CE3/I405) supported by Science Foundation Ireland under the National Development Plan.

REFERENCES

[1] "Evolved universal terrestrial radio access (UTRA) and universal terrestrial radio access network (UTRAN) radio interface protocol aspects," 3GPP TR25.813, Nov. 2005.

[2] F. Agnelli, G. Albasini, I. Bietti, A. Gnudi, A. Lacaita, D. Manstretta, R. Rovatti, E. Sacchi, P. Savazzi, F. Svelto, E. Temporiti, S. Vitali, and R. Castello, "Wireless multi-standard terminals: system analysis and design of a reconfigurable RF front-end", *IEEE Circuits and Systems Magazine*, vol. 6, no. 1, 1st quarter 2006, pp. 38-59.

[3] R. Bagheri, A. Mirzaei, M.E. Heidari, S. Chehrazi, L. Minjae, M. Mikhemar, W.K. Tang, and A. A. Abidi, "Software-defined radio receiver: dream to reality", *IEEE Circuits and Systems Magazine*, vol. 44, no. 8, pp. 111-118, Aug. 2006.

[4] Hossein Hashemi and Ali Hajimiri, "Concurrent Multiband Low-Noise Amplifiers-Theory, Design, and Applications," *IEEE Trans. Microwave Theory Tech.*, vol. 50, no.1, pp288-301, Jan 2002.

[5] A. Ismail and A. A. Abidi, "A 3–10-GHz low-noise amplifier with wideband *LC*-ladder matching network," *IEEE J. Solid-State Circuits*, vol. 39, no. 12, pp. 2269–2277, Dec. 2004.

[6] J. Borremans, P. Wambacq, C. Soens, Y. Rolain, and M. Kuijk, "Low-Area Active-Feedback Low-Noise Amplifier Design in Scaled Digital CMOS," *IEEE J. Solid-State Circuits*, vol. 43, no. 11, pp. 2422–2433, Nov. 2008.

[7] S. Chehrazi, A. Mirzaei, R. Bagheri, and A. A. Abidi, "A 6.5 GHz wideband CMOS low noise amplifier for multi-band use," in *Proc. IEEE Custom Integr. Circuits Conf.*, Sep. 2005, pp. 801–804.

[8] C.-T. Fu, C.-L. Ko, C.-N. Kuo, amd Y.-Z. Juang, "A 2.4–5.4-GHz Wide Tuning-Range CMOS Reconfigurable Low-Noise Amplifier," *IEEE Trans. Microwave Theory Tech.*, vol. 56, no. 12, part I, pp.2754-2763, Dec. 2008.

[9] V.K. Dao, Q.D. Bui, and C.S. Park, "A Multi-band 900MHz/1.8GHz/5.2GHz LNA for Reconfigurable Radio", IEEE RFIC Symposium, 2007.

[10] J. Park, S.-N. Kim, J.-H. Seok, Y.-S. Roh, C. Yoo, K. Lim, and J. Kim;, "A direct-conversion CMOS RF receiver reconfigurable from 2GHz to 6GHz," in *IEEE Symp. VLSI Circuits*, June 2008, pp. 38–39.

[11] H. W. Chiu, S. S. Lu, and Y. S. Lin, "A 2.17-dB NF 5-GHz-band monolithic CMOS LNA with 10-mW DC power consumption," *IEEE Trans.Microw. Theory Tech.*, vol. 53, no. 3, pp. 813–824, Mar. 2005.