

Active Inductor Based Differential Low Noise Amplifier for Ultra Wide Band Receiver

M. Chandra Praveen, V. Vaithianathan, J. Raja, and R. Srinivasan

Abstract—In this paper, an Active Inductor (AI) based three stage Low Noise Amplifier (LNA) for Ultra Wide Band (UWB) receiver is proposed. A fully differential topology has been adopted for both LNA and AI in order to improve the circuit robustness against unwanted common mode signals. T-coil peaking is used to enhance the bandwidth of LNA over the entire UWB frequency range. AI has been used because of its low area, tunable inductance and high quality factor. The proposed LNA is designed using 90nm CMOS technology. The figure of merits of the LNA with passive inductor and with Active Inductor are analyzed and compared. This LNA achieves power gain (S_{21}) greater than 13dB throughout the UWB spectrum providing a 3-dB bandwidth of 2 - 11 GHz. The input matching (S_{11}) and output matching (S_{22}) are kept well below -20 dB and -8dB respectively, while the reverse isolation (S_{12}) is less than -53 dB. The noise figure of this LNA reaches 8dB due to increased number of stages and addition of Active Inductor.

Index Terms—DS-CDMA, MB-OFDM, T-coil peaking, power gain, noise figure, input matching.

I. INTRODUCTION

As the consumer demand for higher capacity, faster service, and more secure wireless connections increases, new enhanced technologies have to find their place in the overcrowded and scarce radio frequency (RF) spectrum. Also present wireless technologies such as WLAN and WPAN find it difficult to provide high bandwidth required for wireless home video data links. Ultra Wide Band technology provides high data rates across multiple devices within the network. UWB transceivers can legally operate in the range from 3.1GHz to 10.6 GHz with a limited transmit power spectral density of -41.3 dBm. The UWB systems find applications in the areas of target recognition, high data rate wireless monitors, health monitoring and Personal Area Networks.

In Direct Sequence UWB the entire spectrum is divided

into two bands as shown Fig. 1. The lower band falls in the range of 3.1 GHz to 4.85GHz while the upper band is allocated 6.2GHz to 9.7GHz [1]. The entire spectrum is divided into 5 groups (14 bands) where the operation within the first group is mandatory in case of Multi Band Orthogonal Frequency Division Multiplexing (MB-OFDM) as illustrated in Fig. 2. MB-OFDM, each band should have bandwidth greater than 500MHz [2].

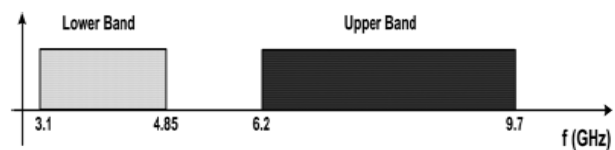


Fig. 1. DS UWB

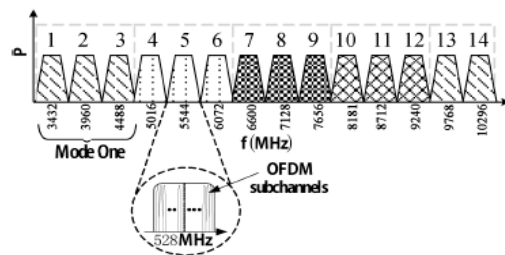


Fig. 2. MB-OFDM UWB

The received UWB signal exhibits very low Power-Spectral Density (PSD) at the receiver antenna. The main goal of the Low Noise Amplifier is to amplify the weak signal received from the antenna and minimize the additional self generated noise simultaneously [3]. Traditional LNA designs depend mainly on the on-chip (passive) inductors to achieve optimized figure of merits such as Power Gain, Input & Output Matching, and Noise Figure etc. This in turn leads to large silicon area as the inductance of passive inductor directly depends on the number of turns used.

Inductors synthesized using active devices are known as Active Inductors. It offers a number of unique advantages over passive inductors including less chip area requirement, large and tunable inductances with large inductance tuning ranges, large and tunable quality factors, high self-resonant frequencies, and full compatibility with digital oriented CMOS technologies. Several Active Inductors have been discussed for achieving high quality factor, high inductance and reduced noise figure in [4].

Most of the recent works done on the LNA have focused on achieving optimal trade off between the LNA parameters through different topologies. The distributed amplifier topology provides moderate flat gain with large power consumption [5]. The Common Gate amplifier topology achieves wideband input matching and better input-output

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isolation [6]. But it exhibits high noise figure and low power gain. Inductive source degenerated LNA provides wider bandwidth, high power gain and better noise figure with large power consumption [7]. The resistive shunt feedback amplifier provides a low power gain and high noise figure [8]. The resistive shunt feedback amplifier faces a tough task for providing high gain and low noise figure simultaneously while satisfying impedance matching. The differential LNA is preferred over other topologies as gain is independent of common node impedances to ground. Common mode and substrate noise effects are reduced in case of differential topology. Also the use of mixers and image rejection schemes require to be fed from a differential source.

This paper proposes a three stage differential LNA with T-coil peaking technique to enhance the bandwidth. Section II discusses the operation of the proposed LNA with its equivalent circuit. In Section III, operation of the Differential Active Inductor proposed in [9] which is employed in our design is discussed. One of the passive inductor (L16) in the proposed LNA is replaced by the Differential Active Inductor. The simulation results of the proposed LNA employing passive inductor and Active Inductor are compared and discussed in Section IV.

II. LOW NOISE AMPLIFIER

A. Proposed Low Noise Amplifier

The proposed UWB LNA consists of three stages with T-coil peaking for bandwidth enhancement. A fully differential topology has been adopted because of its noise reduction properties and its ability to achieve a wide dynamic range at the cost of increase in power consumption with respect to a single-ended implementation. The first differential common gate stage (M1 & M2) provides a wideband input impedance matching with low gain.

It is possible to obtain high gain and large bandwidth by using two differential common source stages (M3, & M4, M5 & M6). The combination of shunt and double series peaking is called T-Coil Peaking [7]. The mutually coupled inductors (L11 and L21) form a letter T and it gains the name T-coil Peaking. It has highest Bandwidth Enhancement Ratio of about 2.72 when compared with other bandwidth extension techniques [3]. We have employed asymmetrical T-coil Peaking (L11≠L21) in three stages to attain 3-dB bandwidth over the entire UWB range. Transistors M7, M8, M9 and M10 have been utilized for biasing purpose. The simplified schematic of the proposed UWB LNA is shown in Fig. 3

B. Analysis and Design

The dimensions of the input transistors are chosen in such a way that they provide an input matching of 50Ω. The equation for the input impedance is obtained from the small signal equivalent circuit given by (1)

$$Z_{in} \approx \left(\left(\frac{1}{sC_{gs1}} \parallel \left(\frac{1}{g_{m1}} + \frac{1}{r_{ds1}} \right) \right) + (sL_1 + R_1) \right) + \left(\frac{1}{sC_{gs2}} \parallel \left(\frac{1}{g_{m2}} + \frac{1}{r_{ds2}} \right) \right) + (sL_2 + R_2) \quad (1)$$

where

- L1: Effective inductance of the T-coil L11 and L21,
- L2: Effective inductance of the T-coil L12 and L22
- L3: Effective inductance of the T-coil L13 and L23
- L4: Effective inductance of the T-coil L14 and L24
- L5: Effective inductance of the T-coil L15 and L25
- L6: Effective inductance of the T-coil L16 and L26

The transconductance and the gate-to source capacitance of transistor M1 are represented by gm1 and Cgs1 respectively.

The T-coil network used in the output stage performs the wideband output matching. This network is chosen in such a way to provide 50Ω impedance matching.

$$Z_{out} \approx s(L_5 + L_6) + R_5 + R_6 \quad (2)$$

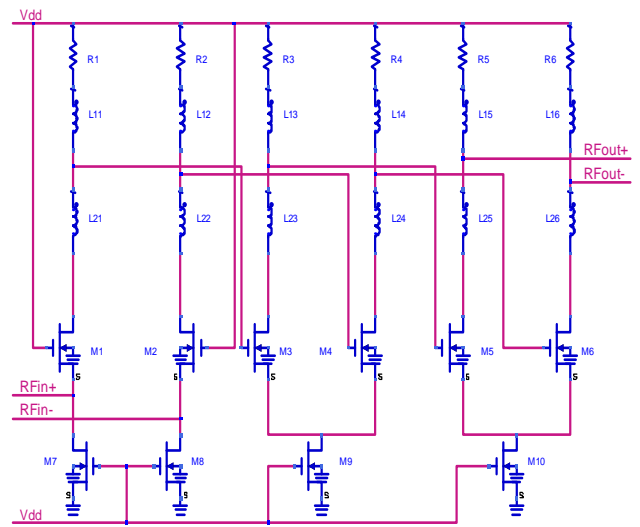


Fig. 3. Proposed LNA

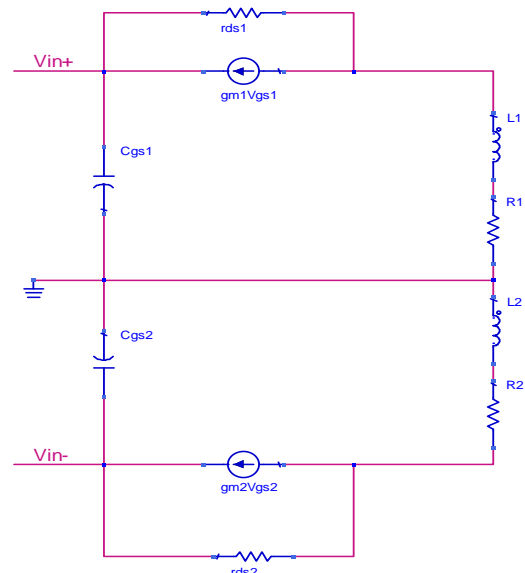


Fig. 4. Equivalent circuit of CG stage.

The gain of this LNA is given by (3)

$$A_{vd} \approx g_{m1} g_{m2} g_{m3} Z_1 Z_2 Z_3 \quad (3)$$

where

$$Z_1 \approx r_{ds1} + r_{ds2} + sL_1 + sL_2 + R_1 + R_2 \quad (4)$$

$$Z_2 \approx [r_{ds3} \parallel (sL_3 + R_3)] + [r_{ds4} \parallel (sL_4 + R_4)] \quad (5)$$

$$Z_3 \approx [r_{ds5} + (sL_5 + R_5)] + [r_{ds6} + (sL_6 + R_6)] \quad (6)$$

Here g'_{m1} , g'_{m2} and g'_{m3} are the effective transconductances of the first, second and third stages respectively. The passive inductor L16 is replaced by the following active inductor and the simulation results have been analyzed.

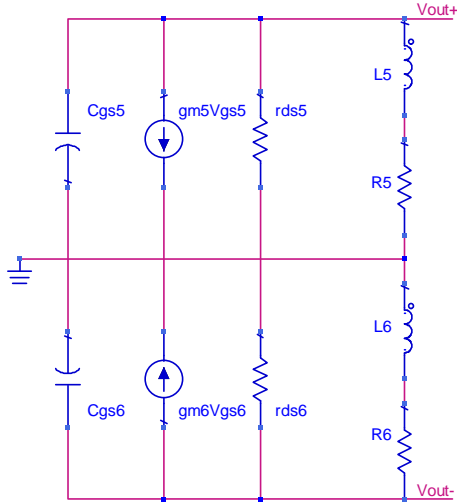


Fig. 5. Equivalent circuit of CS stage

III. ACTIVE INDUCTORS

The Differential Active Inductor shown in Fig. 6 has been used to replace the passive inductor (L16) in the proposed LNA [9]. Simple gyrator can be visualized as a differential circuit as it requires input signals of opposite sign as shown. M2a and M2b act as the core circuit whereas a pair of stabilizers (M3a and M3b) and negative impedance cross coupled MOSFET pair (M1a and M1b) has been utilized in order to remove the instability problem.

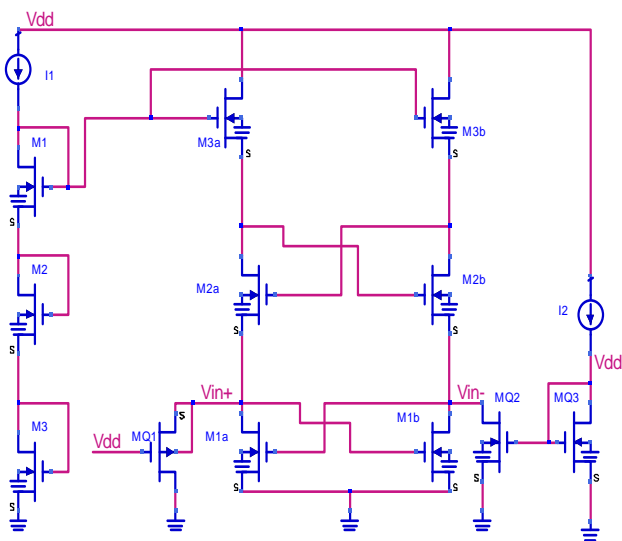


Fig. 6. DAI with current controlled Q and inductance [9]

The Q factor is affected by inductance tuning due to non-linear nature of active inductor. So a pair of current sinks (MQ) is introduced to eliminate this effect. In order to control the current flow, one branch of the differential circuit is used

as a current mirror. This leads to low current dissipation because of current reuse technique. This active inductor proposed in [9] is designed to produce inductance in the range of 1.5nH-3nH throughout the desired UWB range.



Fig. 7. Inductance vs frequency



Fig. 8. Noise figure vs frequency

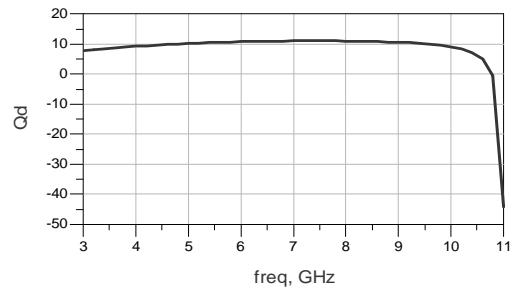


Fig. 9. Quality factor vs frequency

The Inductance and Quality Factor has been calculated using the formula given in [9]

$$Z_d = Z_{11} - Z_{12} - Z_{21} + Z_{22} \quad (6)$$

$$L_d = \frac{\text{imag}(Z_d)}{\omega} \quad (7)$$

$$Q_d = \frac{\text{imag}(Z_d)}{\text{real}(Z_d)} \quad (8)$$

The above designed Active Inductor has been used instead of passive inductor L16 in the proposed LNA and the simulation results have been analyzed in the following section.

IV. SIMULATION RESULTS

The proposed LNA is simulated using 90 nm CMOS technology. The LNA is designed with and without Active Inductor and the simulation results are presented in Fig. 10 through Fig. 14.

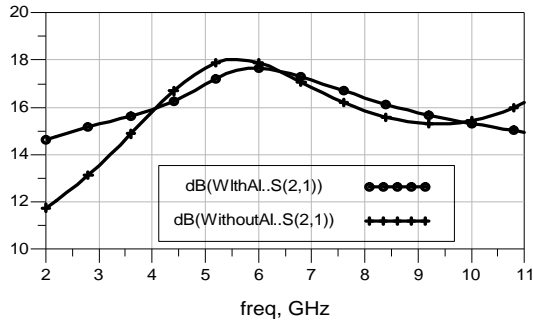


Fig. 10. Power gain (S_{21})

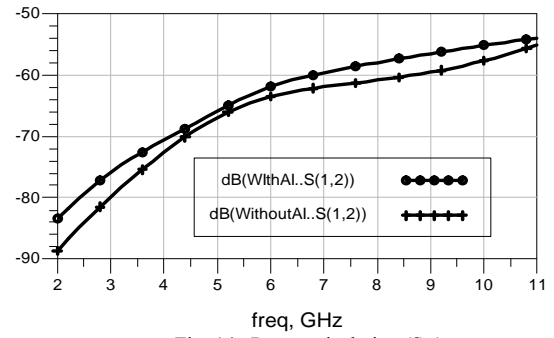


Fig. 14. Reverse isolation (S_{12})

From the Fig. 10, maximum gain of 17.5 dB is achieved at 5.5 GHz while gain more than 13 dB is maintained from 3.1 GHz to 10.6 GHz in both the design. The noise figure (NF) for LNA without active inductor falls in the range 6.8-8.7dB due to increased stages. Due to addition of active inductor which induces some self generated noise, the noise figure reaches 7.9-8.4dB. This is illustrated in Fig. 11.

From the Fig. 12, this circuit claims input matching (S_{11}) of less than -24 dB over the entire bandwidth for both the designs. The output matching (S_{22}) is less than -12 dB at the lower band and reaches 20dB at 5GHz, but it declines to -6dB for upper band in the design of LNA without active inductor as depicted in Fig. 13. But output matching falls well below -8dB throughout the band in design with active inductor

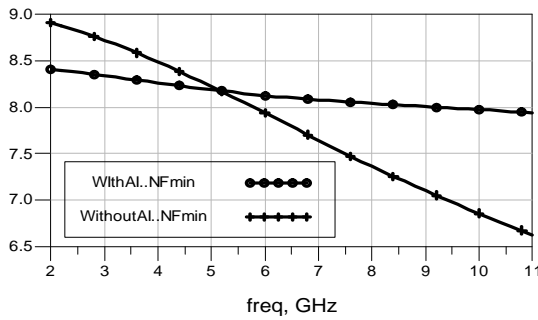


Fig. 11. Noise figure (NF)

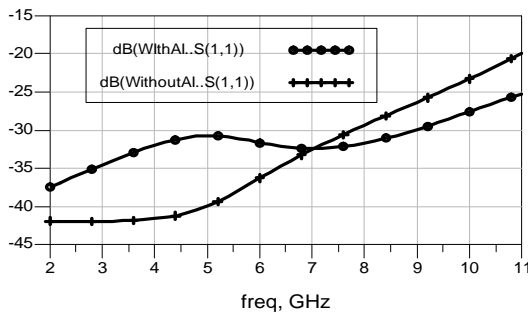


Fig. 12. Input matching (S_{11})

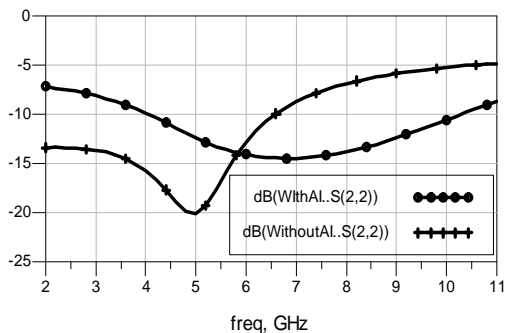


Fig. 13. Output matching (S_{22})

TABLE I: SIMULATION RESULTS SUMMARY AND PERFORMANCE ANALYSIS

Parameter	[10]	[11]	[12]	[13]	*This Work (WO AI)	**This Work (WAI)
Technology (nm)	90	90	90	90	90	90
3-dB BW (GHz)	2-11	14.5	0.5-8.2	4-8	3.5-11	2-11
Gain S_{21} (dB)	12	10	12.5	12.2	18	17.6
NF (dB)	5.5-8	5.8-6	1.9-2.6	2-2.4	6.8-8.7	7.9-8.4
Input Matching S_{11} dB	< -10	< -10	-13	< -5	< -24	< -25
Reverse Gain S_{12} (dB)	-	-	-	-	< -57	< -53
Output Matching S_{22} (dB)	< -10	-	< -10	< -10	< -6	< -8
Power (mW)	17	30	42	9.2	12.84	15.74

* WOAI-Without Active Inductor, ** WAI-With Active Inductor

The reverse gain (S_{12}) is maintained well below -53dB for both the designs throughout the UWB frequency range as shown in Fig. 14. The proposed LNA consumes 12.84 mW due to increased number of stages while operating at 1V power supply. As active inductor is an active element, it increases the power consumption of LNA to 15.74 mW upon its replacement with passive inductor L16.

The Table I summarize the results achieved by the proposed LNA (with and without Active Inductor). From the Table I, we can claim that our proposed LNA performs better as compared to other LNAs at the cost of increase in power consumption.

V. CONCLUSION

A three stage differential LNA is designed using 90nm CMOS technology and simulated. A power gain of more than 13dB is achieved throughout the UWB spectrum. The input matching (S_{11}) and output matching (S_{22}) are kept well below -24 dB and -8 dB respectively while the reverse isolation (S_{12}) is less than -53 dB. A single passive inductor is replaced by active inductor and the results are compared. Increased number of stages and addition of active inductors lead to noise figure of about 8dB. The power consumption of this LNA is quite high due to increased number of stages while operating at 1V power supply. Thus the proposed LNA

claims a high gain with good input and output matching providing a bandwidth of 2 – 11 GHz.

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