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A 2~8 GHz UWB Low Noise Amplifier using 0.15 µm GaAs pHEMT Technology for Multiband Wireless Application

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ABSTRACT

This paper proposes 2GHz ~ 8GHz UWB LNA with totem pole technique for low noise figure. The LNA was designed using 0.15 µm GaAs pHMET process. The designed LNA was simulated in ADS tool. The LNA exhibits a S(2,1) of 33.4~29.7 dB, minimum noise figure is 1.383~1.391 dB, reverse isolation was better than 40 dB in entire band. The LNA draws 32 mA. Resistive feedback technique was used for wideband matching and low noise figure.

General Terms

RFIC,

Keywords

LNA, Noise Figure, Flat gain, UWB, CMOS, GaAs, pHEMT, resistive feedback.

1. INTRODUCTION

Modern day consumer electronics and communication applications require high data rate multi gigahertz bandwidth for numerous wireless protocols [1]. As a result the research and development was currently being focused towards UWB spectrum to exploit the advantages it offers. The UWB technology provides application in imaging systems, sensor network, Bluetooth, Wi-Fi, Wimax and so on [2]. Such applications need a Low Noise Amplifier with relatively high gain and low noise figure in the 3.1GHz~10.6GHz frequency range [3]. For an UWB transreceiver, LNA is the most critical block which determines the overall performance of the system [4].The recent studies shows that, now it was possible to fabricate LNA on a single chip [5].Recent studies also show compact and integrated LNA for UWB applications [6] [7] Fig 1 showed basic block diagram of Super-heterodyne receiver with LNA as current area of interest.

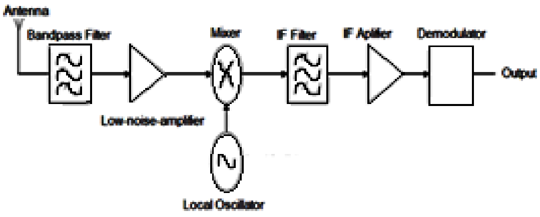


Fig 1: Block Diagram of Super-heterodyne receiver

1.1 Overview of UWB

In 2002 the Federal Communications Commission (FCC) approved the ultra-wideband unlicensed spectrum usages of 1.99-10.6 GHz, 3.1-10.6 GHz and 22-29 GHz for commercial applications [8]. The definition of UWB according to the FCC is either a fractional bandwidth greater than 0.2 or a bandwidth greater than 500 MHz. The fractional bandwidth was calculated as $2(f_H - f_L)/(f_H + f_L)$ [9].UWB systems were capable of transmitting over a large frequency bands and could do so with a very low power and high data rates. Other advantages are coexistence with other radio services, resistance to jamming and multipath fading, excellent signal penetration properties and simple transceiver architecture.

1.2 Overview of UWB LNA topology

Lot of work has been done by researchers in proposing circuit topologies for development of broad-band amplifiers [10] [11]. The distributed architecture is well known for its capability of providing very wide bandwidth. For distributed amplifiers there exists substantial consumption of power, with medium gain, and significant chip area [12]. Shunt resistive feedback is a technique that can provide good impedance matching, better gain flatness. This technique is insufficient to provide flat gain, minimum noise figure and broad bandwidth only on basis of feedback [13] [14]. The common-gate amplifier topology suffers from poor power gain and noise figure [15]. Recent study also shows implementation of LNA by different amplifier topology such as cascade, inductive-series Peaking Technique [16], CG current reuse with noise cancelling, Fully differential CG, current reuse and cascade and so on [15] [16] [17].

The practical challenge in designing UWB LNA is performance trade–offs. To achieve optimal practical solution, fewest trade-offs should be considered for lesser complexity as parameters are inter-releated [18]. Design of LNA requires different design metrics to be considered simultaneously like good transistor selection, suitable DC biasing network, high gain, low noise figure, low power consumption, dynamic range, good input-output matching circuits, high linearity and good stability. This paper proposed the wideband LNA with a analyses on the key performance factors required for UWB

LNA design, such as noise performance, and linearity over a wide bandwidth. LNA consists of two stages, first is acting as a pull down amplifier as its drain is pull down using an LC cascade circuit which helps improving noise figure as well as broadband matching, we can called it as totem pole technique.

The second stage is a power stage to improve broadband gain along with power.

2. DESIGN ANALYSIS OF PROPOSED LNA

Since LNA design is inherently critical, let us understand its design process step by step.

2.1 Q-point determination of Enhancement -mode pHEMT transistor

The FET cure tracer template is chosen to determine Q-point. Fig 2 shows different I-V curves with respect to $V_{GS.}$

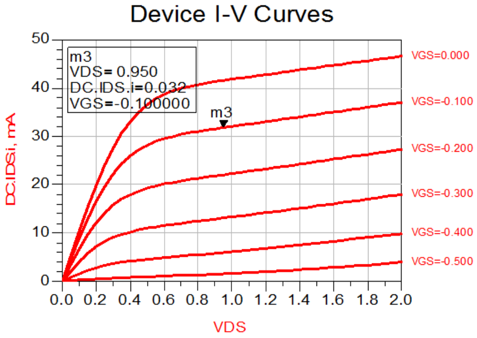


Fig 2: I-V curves for transistor

The targeted comparative current was choose in range of 30-40mA. The device is biased to get current as low as possible in range of 30-40mA along with good Gain and NF. The Q value is chosen considering all the parameters like gain, current etc.

The Q-point is chosen so that the minimum noise figure is obtained through the entire band. The Q-point is shown in Fig 2 with I_{DS} = 32 mA indicated by marker m3.

2.2 Stability

When LNA is operated in its UWB spectrum, the amplifier may become unstable and turns into oscillator at any frequency. Thus oscillation should be avoided else it may result in the failure of the design.

The conditional stability means that it can only keep stable in a certain range of passive source and load impedances; it is potentially unstable and the unconditional stability ensures the network to be stable for all passive sources and load impedances.

LNA will be unconditionally stable if the following necessary and sufficient conditions are met:

$$K = (1-|S11|^2 - |S22|^2 + |\Delta|^2) / 2\,|S12S21| > 1 \qquad (1)$$

$$|\Delta| = |S11S22 - S12S21| < 1 \qquad (2)$$

A new technique is proposed to determine unconditional stability. If μ>1, the LNA is unconditional stability, and the larger value of μ, the greater stability of the LNA [19].

$$\mu = (1-|S11|) / (|S22 - \Delta S11^{*}| + |S12S11|) > 1 \qquad (3)$$

Fig 3 transistor is unconditionally stable in entire bandwidth as K > 1.

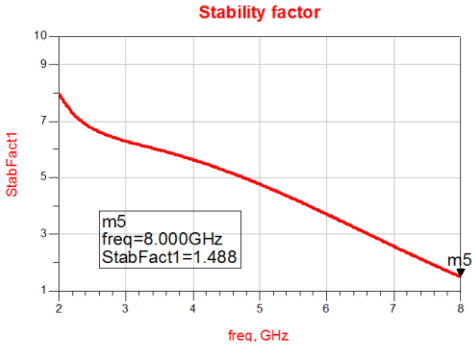
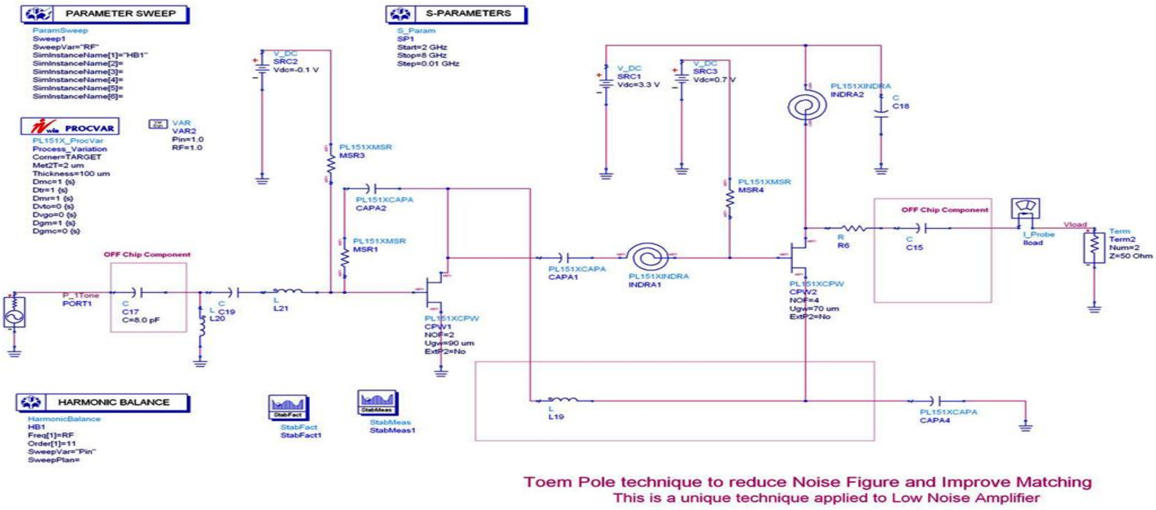


Fig 3: Stability test for transistor



Toem Pole technique to reduce Noise Figure and Improve Matching
This is a unique technique applied to Low Noise Amplifier

Fig 4: Proposed LNA schematic with Totem Pole Technique

2.3 Overview of proposed LNA schematic

The LNA is designed by using 0.15µm GaAs pHEMT process. The first stage is optimized for noise matching and the resistive shunt-feedback stage provides wideband gain and good stability [13]. First stage transistor is driving second stage along with total current. Transistor M1 is biased with drain voltage of 0.98V with gate biased at -0.1V and provides a sufficient current to drive transistor M2. A novel design is proposed here where a unique technique is applied to the LNA. Here to improve matching Totem Pole technique is used. The proposed LNA schematic is shown in Fig 4.

2.4 Matching Network

The input matching is achieved by LC network. L20 and C19 are obtained using Smith Chart Utility in ADS. To obtain desired gain and low noise figure the components are fine tuned [18]. At the other end the output matching circuit is achieved by only using a resistive network R6.

Whenever IMN and OMN circuitry is to be designed the device parasitic should be considered. The matching network is designed to get lowest noise figure along with maximum power output. There always exists a tradeoff between gain flatness, S11 and NF. [20].

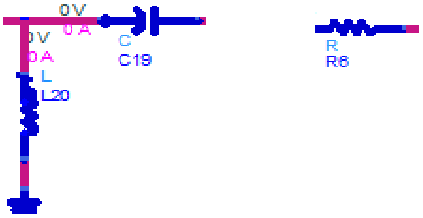


Fig 5: Input and Output Matching Network for proposed LNA

2.5 Feedback Technique

The RC feedback helps in improving amplifier stability as well as improves broadband gain. When the feedback resistor is used it helps to improve gain but degrade noise figure. Therefore feedback resistor value should be properly selected. [21]

Fig 6: Feedback circuit technique

Although Gain, Noise Figure, Stability, Linearity and input and output match are all equally important, they are interdependent and do not always work in each other's favor. High IP3 requires higher current draw although the lowest possible noise figure is usually achieved al lower current. Additional improvement of IP3 can also be achieved by proper power output matching.

3. SIMULATION RESULTS

The performances of the proposed LNA is summarized and compared with previous works in Table I. The proposed LNA is characterized with its flat gain, its wide bandwidth, low noise figure etc. The simulated small signal (S21) gain is between 33.4 dB to 29.7 dB from 2 GHz to 8 GHz as shown in Fig 7.The lowest gain obtained is 28.5 dB at 6.5 GHz. It's difficult to achieve high gain with single stage LNA design. The simulated input return loss (S11) is – 10dB at 2GHz and – 14.1 dB at 8GHz as shown in Fig 8. With proper input matching network we have achieved a good S11. Broadband matching technique has been used to best match the device impedance with 50Ohm input impedance using Smith chart. The output return loss is -9.542 dB at 2 GHz dB and -9.264 dB at 8 GHz as shown in Fig. 9 for the entire designed spectrum. With proper Output matching network we have achieved good S22. The device output impedance is matched with 50ohm impedance. The output series resistance used to match output impedance with 50Ohm using smith chart.The noise figure is 1.383 dB at 2 GHz and 1.391 dB at 8 GHz as indicated by marker m3 and m7[Fig 10] . Several design technique has been used to get lowest noise figure. The LNA is designed using pull down technique where first stage device is biased at lowed VDD which lower current and hence help in improved Noise Figure. The lowest noise figure is also improved using matched input impedance. The reverse gain (S12) is lower than -40 dB shown in Fig. 11 which indicates the isolation is good enough. In two stage design it is easy to get good isolation (reverse gain). Matching along with RF Choke helps improve isolation. To understand the performance of LNA few other parameters are also simulated, 1-dB compression point (P1dB) [fig 12] [fig 13], the 3r~d order Intercept point (IIP3) [fig 14], OIP3 in [fig 15]. IIP3 and OIP3 represent device linearity.

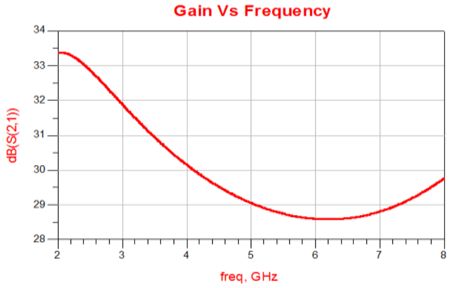


Fig 7: Gain(S21) versus Frequency

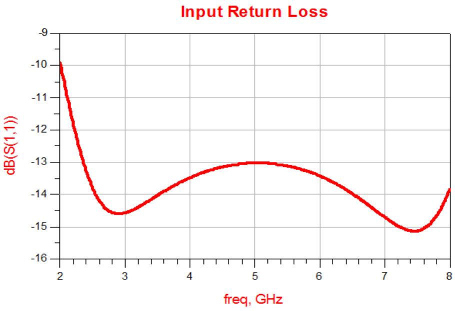


Fig 8: Input Return Loss(S11) versus Frequency

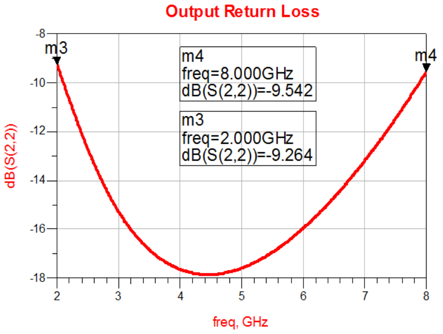


Fig 9: Output Return Loss (S22) versus Frequency

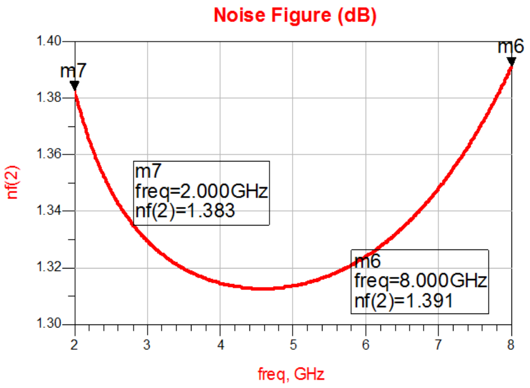


Fig 10: Noise Figure Versus Frequency

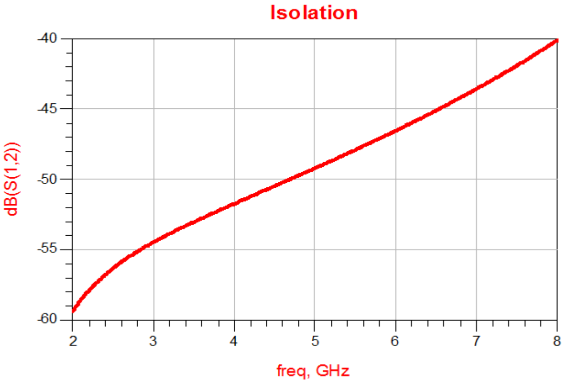


Fig 11: Isolation(S12) Versus Frequency

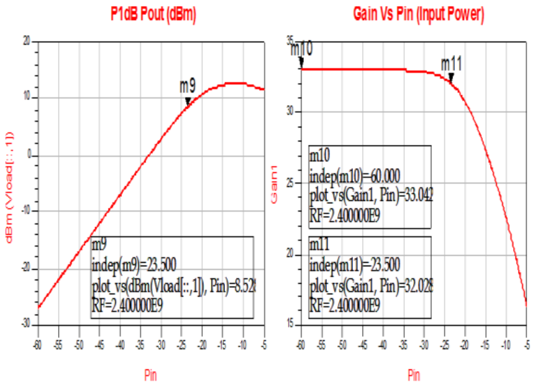


Fig 12: P1 dB @ 2.4 GHz

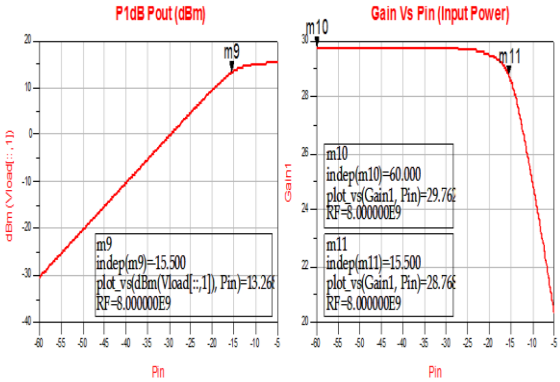


Fig 13: P1 dB @ 8 GHz

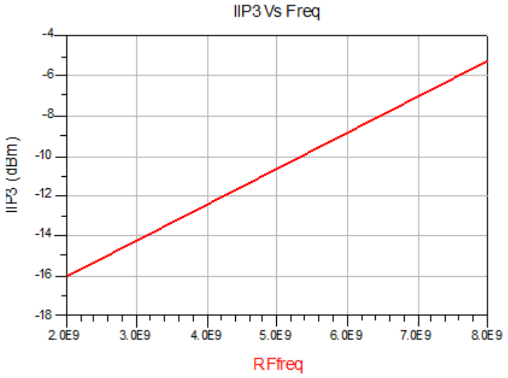


Fig 14: IIP3 versus Frequency

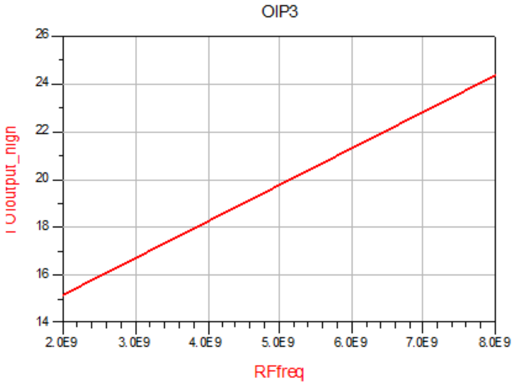


Fig 15: OIP3 versus Frequency

Table 1. Comparison of recently reported LNA with this work

Ref	Technology (GaAs pHEMT)	Frequency (Ghz)	S21 (dB)	S22 (dB)	Noise Figure (dB)
1	0.15µm	8-18	21	-	1.5
16	0.15µm	3-10	12	< -17.5	< 6.7
20	0.25µm	1.5-6	17.5	-	1.5
This Work	0.15µm	2-8	33.4-29.7	< -18	< 1.4

4. CONCLUSION

In this paper a UWB two stage LNA design is proposed for low noise figure and high gain. The LNA is analyzed and simulated in ADS tool. The resistive feedback network is used to provide wide band matching and low noise figure. The LNA is designed in standard 0.15µm GaAs technology. The simulation results verify the concept of the LNA. The peak gain of LNA is 33.4 dB, and the maximum noise figure is 1.391. The overall performance of this amplifier is compared to the other UWB LNAs and shows it is suitable for Ultrawideband applications. Future work may include improvement in bias network, reduction in power supply requirement, further improvement in input return loss and output return loss.

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