Performance Evaluation of Different LNA's having Noise Cancellation and Phase Linearity Characteristics for IR-UWB Systems.

Alpana P. Adsul, Shrikant K. Bodhe

Abstract— **In the UWB communication system receiver LNA is the essential module. In this paper two LNA architecture with noise cancellation and phase linearity are presented. The performance evaluation is carried out for low band UWB system having frequency range from 3 to 5 GHz and a wide band UWB system with frequency range from 3.1 to 10.6 GHz. The noise figure and the gain are major parameters considered while designing the LNA's. This paper gives the detailed analysis for both low band as well as wide band LNA. The phase linear LNA achieves gain of 12 dB, a maximum noise figure of 2.6 dB for the wideband frequency range. Whereas, the noise cancellation low band LNA achieves a gain of 11.3 dB and the noise figure of 4.04 dB. The gain of wide band phase linear LNA is flat over the band of interest as compare to the noise cancellation LNA.**

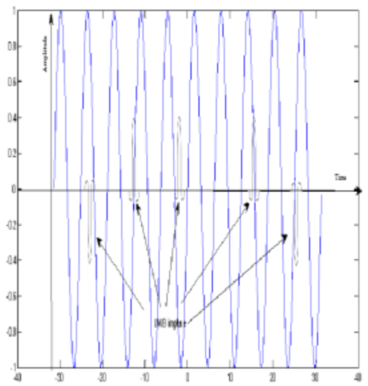
***Index Terms*—UWB, LNA, Phase linear, Noise Cancellation, ADS, Receiver.**

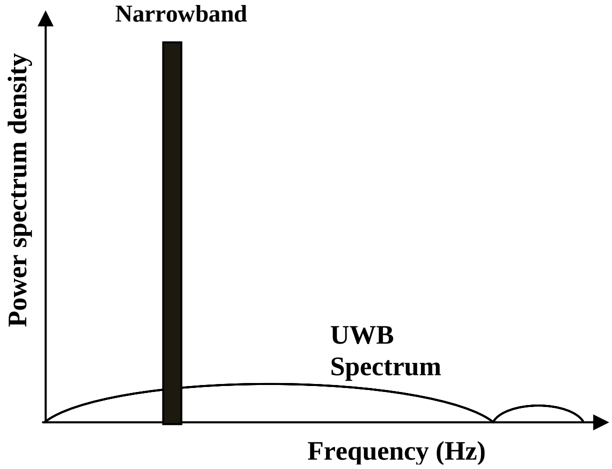
I. INTRODUCTION

Ultra-wideband (UWB) is a wireless radio technology used in high speed data transmission. The UWB technology has glorified the future of personal wireless communication applications [4]. The UWB signals carry a huge amount of data over a distance of up to 230 feet at very low power (less than 0.5mW) in very short time. Also, it has the ability to penetrate through the doors and other obstacles that have a tendency to reflect signals at more limited bandwidths and higher power densities. According to [3], historically, UWB radar systems were developed mainly as a military tool because they could "see through" trees and beneath ground surfaces, etc. However, recently, developments in UWB technology have been focused on consumer electronics and communications. The UWB system communicates with the help of short nanosecond pulses, without interfering with existing wireless systems [4]. The key characteristics of the UWB are low power, low cost, high data rates, precise positioning capability and extremely low interference [3]. Also it is having a high immunity to the multipath fading as well as ranging and communication applications.

UWB technology is defined by the federal communications commission (FCC) as any wireless scheme that occupies either a fractional bandwidth of $BW/f_c > 20$ %, where BW is the communication bandwidth and f_c is the band's center frequency, or more than 500 MHz of absolute bandwidth. For UWB communication the FCC specifies unlicensed frequency range from 3.1 GHz to 10.6 GHz at a limited transmit power of −41.3 dBm/MHz [1]. This higher bandwidth makes it possible to realize point-to-point, high speed data transmission between laptops, pocket devices and peripheral consumer handhelds within a short distance with low emission [1].

The main difference between UWB and existing narrowband WLAN system is that; the narrowband system operates by modulating data onto a continuous carrier with strong transmitted power. Fig. 1 shows the difference clearly in both time and frequency domain [4]. UWB systems are having low power spectrum density (PSD) and high resolution in time domain; due to this it is appropriate for short-to-medium range wireless communications [5].





(a) (b)

Fig 1.UWB and narrowband signal characteristics in (a) time domain (b) frequency domain

The remaining paper is organized as section II gives the detailing of all three LNAs. Section III gives the results of all LNAs. Finally the paper is concluded in section IV.

II. DESIGN OF LNA

The LNA is the first block in most receiver front ends. The LNA is used to amplify the signal which will introduce a minimum amount of noise to the signal. There are different types of LNA's available, depending on the requirement the specific type of LNA is used in the receiver [6]. In UWB receivers due to limited battery life for portable wireless devices the power consumption is crucial issue [7]. According to the [7] to reduce power consumption, the common-gate (CG) input stage in addition to the current-reuse is used. The UWB system are used in two modes of operation, first is the Low band having frequency range from 3 to 5 GHz and second is the wide band having frequency range from 3.1 to 10.6 GHz. This paper proposes LNA design for both the modes with results.

A. Design of low band LNA without noise cancellation:

In this case a differential configuration is selected using source degeneration technique to provide a good noise match. In this LNA design the input impedance is considered as 50 Ω and transconductance g_m= 20 ms with degenerating inductors (L_s) connected together at the 'virtual earth'. A cascade stage is added to the source degenerated stage to provide improved gain and reverse isolation.

In case of LNA design it is very difficult to trade off between noise performance and power consumption at the same time. Classical noise matching only considers the noise performance which results in high power consumption sometimes [1]. This means that both input matching and minimum NF cannot be obtained simultaneously. In this design firstly, select the device and operating point to meet the circuit noise requirements by the preliminary noise analysis; secondly, a circuit configuration or feedback that can determine the gain, bandwidth and impedance requirements; thirdly, some modification should be done to meet all specifications, such as more stages, additional feedback or increasing the bias current of the input transistor; finally, the noise can be recalculated to see if it is still within the specification.

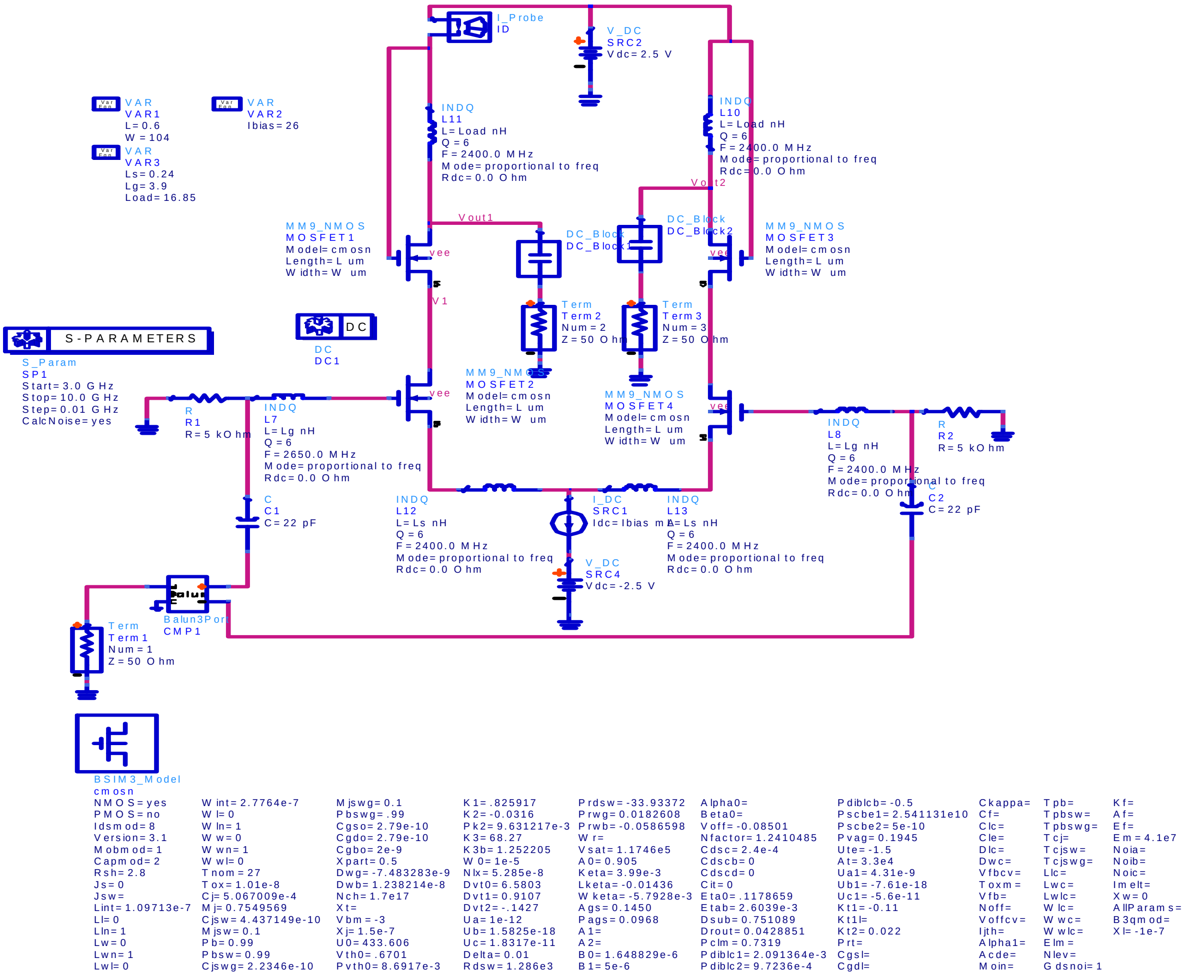


Fig. 2: Complete schematic for Low band UWB LNA without noise cancellation

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Fig. 2 shows the schematic for low band UWB LNA without noise cancellation. The LNA is designed for low band which is having frequency range from 3 GHz to 5 GHZ. In this design of LNA the input impedance of the transistor M_1 is given by [11]

$$Z_{in1} = j\omega\left(L_g + L_s\right) + \frac{1}{j\omega C_{gs1}} + \frac{g_{m1} L_s}{C_{gs1}} \qquad (1)$$

Where g_{m1} and C_{gs1} are the transconductance and the gate-source capacitance of M_1. Inductors L_s and L_g are the source degeneration inductor and the gate input inductor. The real part of the input impedance in (1) is given by;

$$Re\{Z_{in1}\} = \frac{g_{m1} \cdot L_s}{C_{gs1}} \qquad (2)$$

By setting the source degeneration inductor L_s accordingly; the desired impedance to match to R_s (usually 50 Ω) can be obtained with given values of g_{m1} and C_{gs1}. The imaginary part of the input impedance can be compensated with an input matching inductance L_g the corresponding resonance frequency is approximated by;

$$\omega_0 \approx \sqrt{\frac{1}{\left(L_s + L_g\right) C_{gs1}}} \qquad (3)$$

In the UWB LNA without noise cancellation the input impedance is much better due to the source degeneration inductor L_s.

B. Design of wide band LNA with phase linear characteristics.

In the IR-UWB system good phase linearity is required as an alternative in order to keep the shape of the pulse when receiving RF-signals from an antenna [9]. This LNA design gives good power and phase linearity performances, which is suitable for both OFDM and IR-UWB system applications. For impedance matching is very important to give a thorough analysis of the low noise FET. In this source degenerative low band LNA value of some parameters are computed as follows.

In this design the value of degeneration inductor L_s is fairly arbitrary but is ultimately limited on the maximum size of inductance allowed by the technology, which is typically about 10 *nH*.

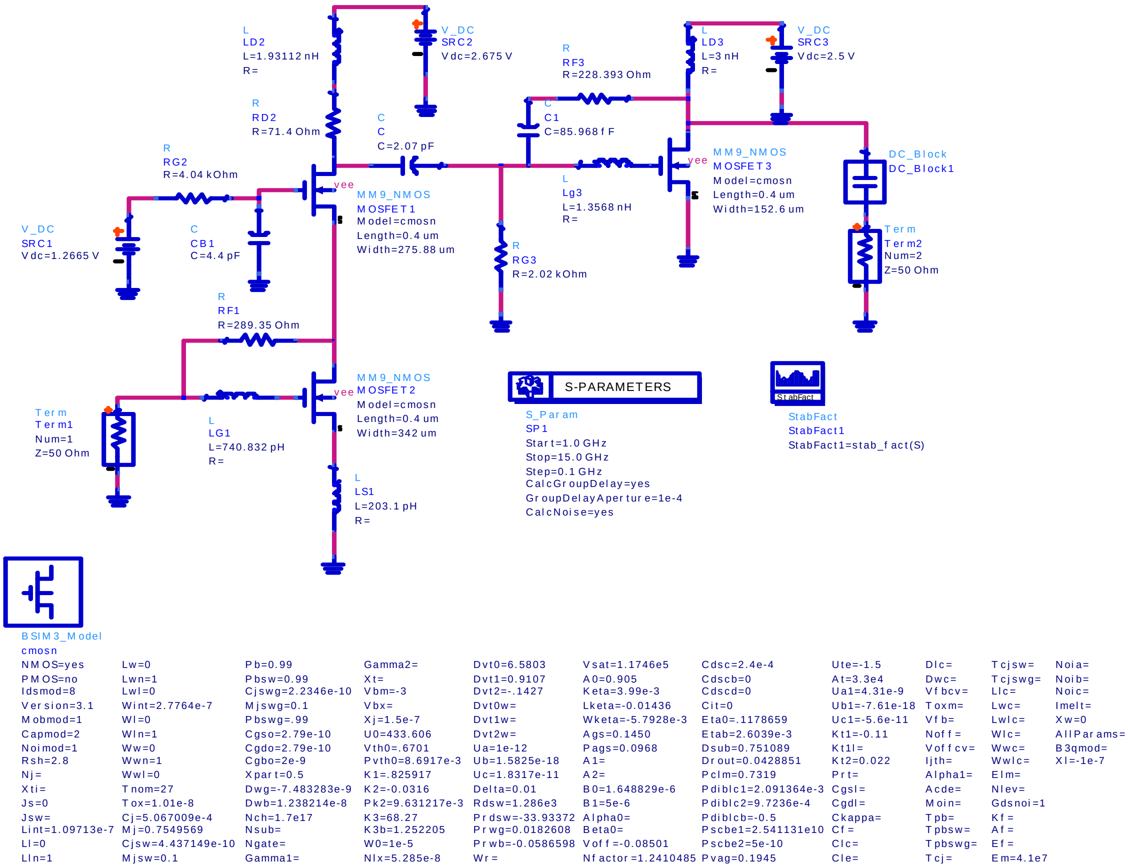

Fig. 3: Complete schematic for Wide band Phase Linear UWB LNA

Excessive source inductance can lead to LNA oscillations because of gain peaks at higher frequencies. For this design we assumed the values of 1.0 *nH*. The degeneration inductor L_s is calculated with the help of Gate-Source Capacitance C_{gs} as

$$L_s = \frac{R_s C_{gs}}{g_m} \qquad (4)$$

The Gate-Source Capacitance is evaluated as

$$C_{gs} = \frac{1}{R_s \omega_0 Q} \qquad (5)$$

Where f_0 is the center frequency, R_s is source resistance.

The value of gate inductance L_g is calculated using equation (6).

$$C_{gs} = \frac{1}{{\omega_0}^2 (L_s + L_g)} \qquad (6)$$

Fig. 3 shows the complete schematic for the wideband UWB LNA. As shown in the figure to achieve sufficient gain, this LNA is composed of a cascoded input stage and common-source output stage. According to the methodology in [9] by appropriately selecting the values of L_{G1}, L_{S1}, R_{F1} and the size and bias of the input transistor M_1, i.e. C_{gs1} and g_{m1} simultaneously the input impedance and noise matching is achieved.

C. Design of low band LNA with noise cancellation.

The LNA must meet several severe requirements, such as input matching, sufficient gain with wide bandwidth and low noise figure (NF), etc. In this design inductive series and shunt peaking techniques are used for noise cancellation [10]. In this LNA two common matching techniques are used. First is known as common gate and second is known as resistive shunt feedback.

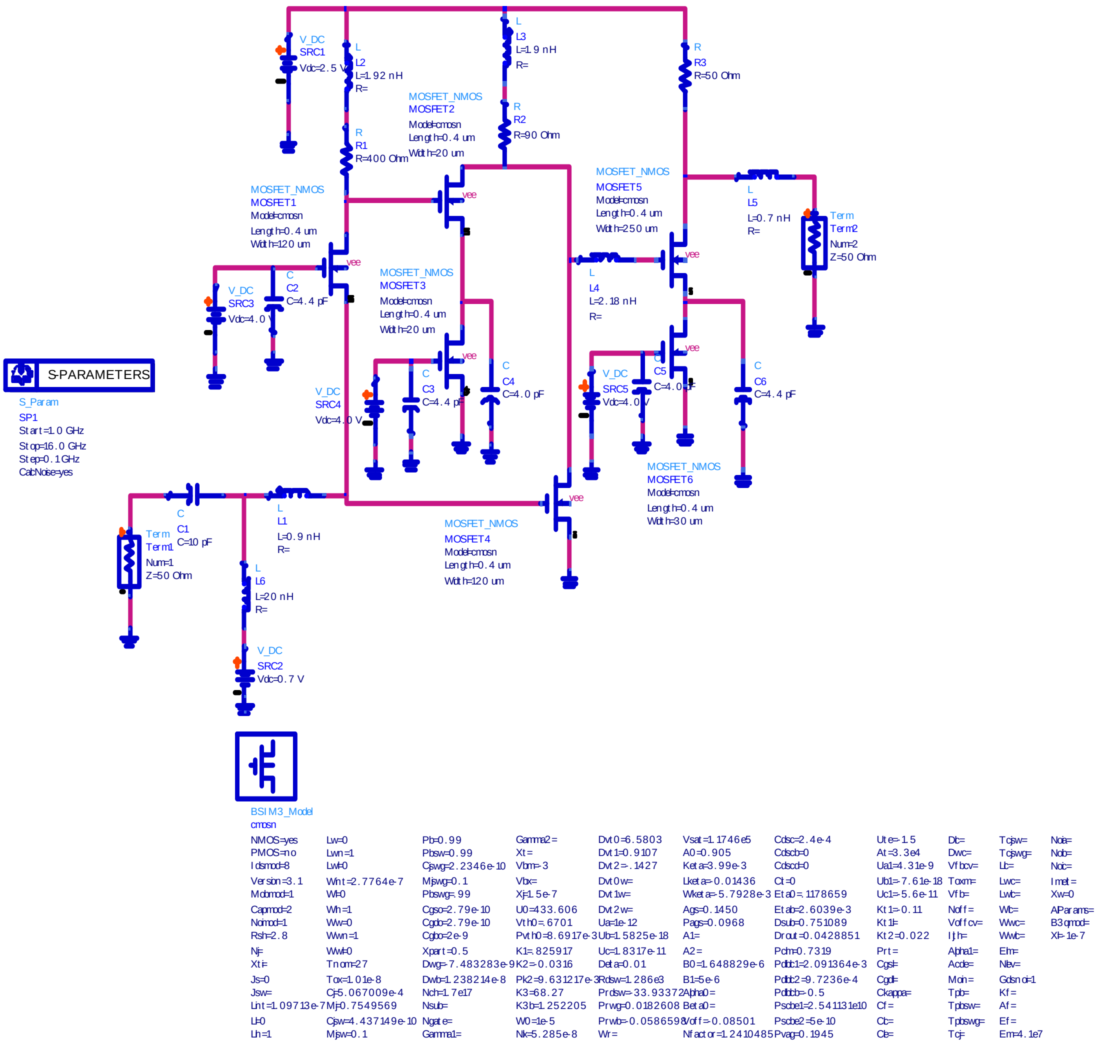

Fig. 4: Complete schematic for Low band UWB LNA with noise cancellation

With common gate topology by increasing the value of R_{L1} the bandwidth hardly exceeds 10 GHz but makes the noise figure worse. In resistive shunt feedback; the input impedance is the parallel combination of C_{in} and $[(R_F + R_{L1})/(1 + g_{m1}R_{L1})]$, where the latter must be set to 50 Ω for matching [10]. With this the noise figure obtained is about 4 dB. In this it is assumed that the dominant noise source of a MOFET is its thermal noise, which has a power spectral density of $4\kappa T\gamma g_{d0}\Delta f$ where $g_{d0}$is the channel conductance for $V_{DS} = 0$ and γ exceeds 1 in saturation and may become 2-3 under some biasing conditions [10].
The purpose of noise cancellation is to decouple the input matching with the NF by cancelling the output noise from the matching device [10].

Fig. 4 gives the complete schematic of UWB LNA with noise cancellation. In which inductor L_1 and L_2 are used for shunt peaking without any high-Q requirement efficiently extends the bandwidth [10]. The series inductor L_3 resonate with the input capacitance of M_4, resulting in a large bandwidth.

III. RESULTS.

The LNA performance is measured with help of S parameters. This section gives the values of different parameters of all LNAs.

A. *Low band LNA without noise cancellation*

The Fig. 5,6,7,8 shows the value of different parameters of LNA. The Fig. 5 gives the gain of the LNA. The gain is increased by increasing the value of gate inductance (L_g). The obtained gain for this LNA is 5.6 dB. According to figure 6 the noise figure is 2.54 dB. The Fig. 7 and Fig. 8 shows the output return loss and input return loss and these values are satisfactory.

In this type of LNA by adjusting the current, W/L ratios and device inductances (i.e. L_g and L_s) it is possible to achieve the required design goals for gain and noise. Also gain is increased by adding simple C-S stages with inductive loads and decoupled on the output by small value capacitor. The increased gain also improves the noise figure of the receiver as the noise of the second stage will be reduced by a factor of $1/\mathrm{Gain}_{\mathrm{LNA}}$ [8].

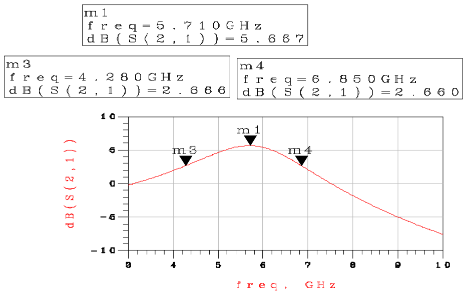

Fig. 5: The measured S_{21} versus frequency characteristics of the 3 -5 GHz

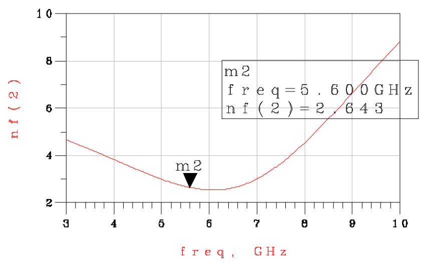

Fig. 6: The measured NF.

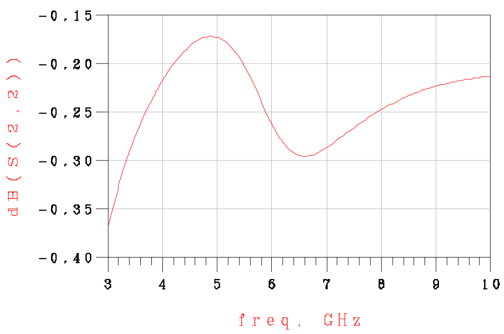

Fig. 7: The measured S_{22} versus frequency characteristics of the 3 -5 GHz

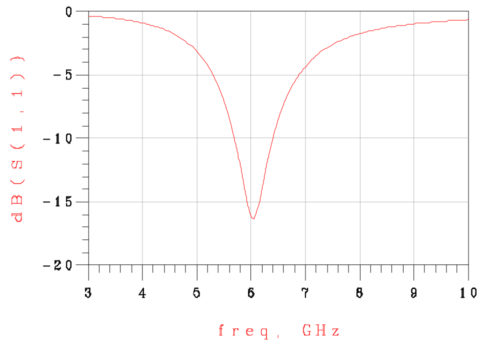

Fig. 8: The measured S_{11} versus frequency Characteristics of the 3 -5 GHz

B. Wide band LNA with phase linear

The Fig. 9 shows the gain of the LNA. By observing Fig. 9 we can state that this design results in high and flat gain (S_{21}) which is greater than 12 dB. The gain remains almost flat from 3.1 GHz to 10.6 GHz which is band of interest. The peaking inductance in this design helps to increase the forward gain (S_{21}). The Fig. 10 shows the noise figure measured in wide band LNA. The noise figure achieved with this design is 3.3 to 2.62 dB over the band of interest.

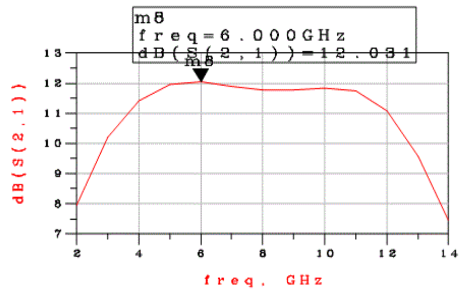

Fig. 9: The measured S_{21} versus frequency characteristics of 3.1 -10.6 GHz

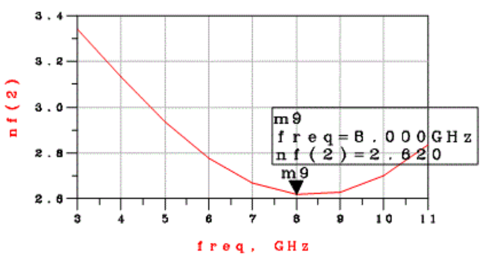

Fig. 10: The measured NF.

Fig. 11 and Fig. 12 shows the measured S_{11} and S_{22} versus frequency characteristics of the UWB LNA, respectively. The scattering parameter S_{11} measures the input reflection coefficient, and thus the quality of the LNA input impedance match. The input feedback resistor and the gate capacitance at the input stage changes the input return loss. The minimum value of gate capacitance and input feedback resistor minimizes the input return loss S_{11}. The output stage drain and gate inductance affects the value of output return loss S_{22}. The minimum value of input return loss S_{11} is of the order of -18.5 dB and S_{22} in the range of -5.85 to -10 dB were achieved over the 3.1 – 10.6 GHz band of interest.

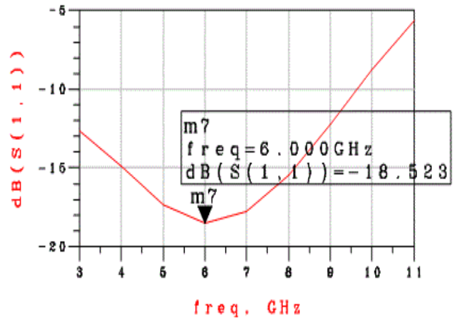

Fig. 11: The measured S_{11} versus frequency characteristics of 3.1 -10.6 GHz

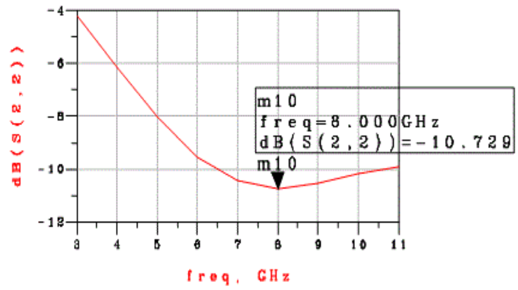

Fig. 12: The measured S22 versus frequency Characteristics of 3.1 -10.6 GHz

C. Low band LNA with noise cancellation

The Fig. 13 shows the measured power gain having maximum value of 11.3 dB at 5.5 GHz. The noise figure obtained with noise cancellation is better than other type of LNA due to the source inductance L_s. The noise figure value obtained using Agilent's Advanced Design Systems (ADS) is 4.044 dB at 5.5 GHz.

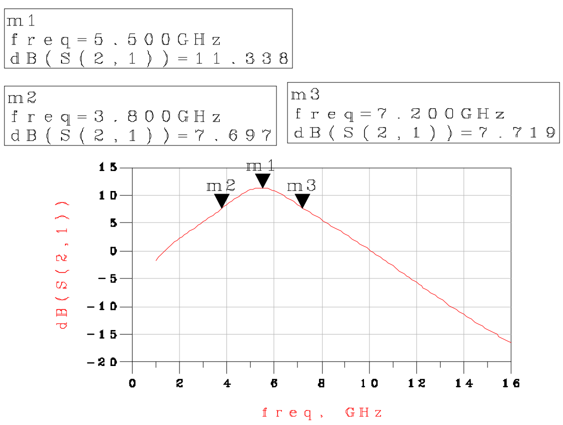

Fig. 13: The measured S_{21} versus frequency characteristics of 3 -5 GHz

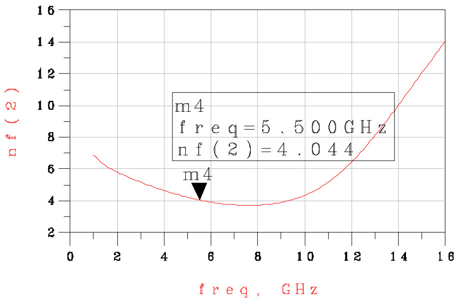

Fig. 14: The measured NF.

S_{11}, S_{22} specifies values of input return loss and output return loss; which indicates the mismatch between the input impedance of an amplifier and the characteristic impedance of the transmission line.

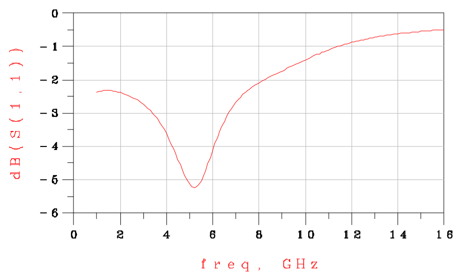

Fig. 15: The measured S_{11} versus frequency characteristics of the 3 -5 GHz

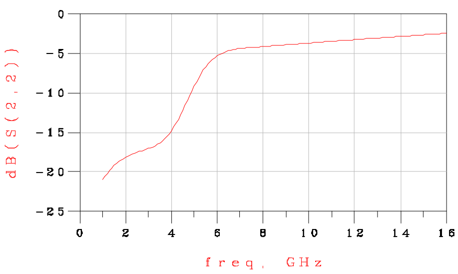

Fig. 16: The measured S_{22} versus frequency characteristics of the 3 -5 GHz

IV. CONCLUSION

The wide band as well as low band CMOS LNA for UWB system is presented. The wide band phase linear LNA achieves input impedance and noise matching simultaneously. Due to inductive peaking technique high and flat forward gain (S_{21}) and good phase linearity is achieved. These results reveal that wide band UWB LNA is suitable for both OFDM system and UWB pulse-radio system applications.

The low band UWB LNA for noise cancellation gives better noise figure. The noise figure achieved with this LNA is 4.04 dB; while other performance such as matching and gain is separately optimized. It is proposed to use the designed LNA's in IR-UWB with BPSK, PPM and PPV modulation schemes in the future research.

REFERENCES

[1] Aminghasem Safarian, Broadcom Corporation, Irvine, CA, USA, Payam Heydari University of California, Irvine, CA, USA "Silicon-Based RF Front-Ends for Ultra Wideband Radios" ISBN: 978-1- 4020-6721-1e-ISBN: 978-1-4020-6722-8

[2] Stephen Wood,Intel Corporation; Dr Roberto Aiello, Staccato Communications "Essentials of UWB" ISBN-13978-0-511-41517-3

[3] M. Ghavami ,King's College London, UK, L. B. Michael, Japan, R. Kohno, Yokohama National University, Japan, "Ultra Wideband Signals and Systems in Communication Engineering" John Wiley

[4] Ivan Siu-Chuang Lu "Design and Analysis of An Integrated Low-Power Ultra-Wideband Receiver" The University of New South Wales 2006 pg.no.2, 3

[5] K. Siwiak,"Ultra-Wide band radio, introducing a new technology," IEEE Vehicular Technology Conference, pp. 1088-1093, May 2001.

[6] John Rogers,Calvin Plett "Radio Frequency Integrated Circuit Design", ISBN 1-58053-502-x; 2003.

[7] Chang-Ching Wu, Xuening Sun, Alberto Sangiovanni-Vincentelli, and Jan M. Rabaey "A 2.2mW CMOS LNA for 6-8.5GHz UWB Receivers"

[8] J P Silver;RF, RFIC & microwave theory design "MOS Differential LNA Design Tutorial"

[9] Chang-Zhi Chen,Jen-How Lee, Chi-Chen and Yo-Sheng Lin, "An Excellent Phase-Linearity 3.1-10.6 GHz CMOS UWB LNA using Standard 0.18μm CMOS Technology" Proceeding of Asia - Pacific Microwave Conference 2007, IEEE

[10] Chih-Fan Liao, Shen-Iuau Lin, "A Broadband Noise Cancelling CMOS LNA for 3.1-10.6GHz UWB Receivers." IEEE Journal of Solid-State Circuits, Vol.42, No.2, Feb-2007

[11] S.-K. Wong and F. Kung "DESIGN OF 3 TO 5GHz CMOS LOW NOISE AMPLIFIER FOR ULTRA-WIDEBAND (UWB) SYSTEM " Progress In Electromagnetics Research C, Vol. 9, 25-34, 2009

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