Design and Performance Evaluation of Transmitted Reference BPSK UWB Receiver using SIMULINK

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Abstract - Ultra wideband systems find applications in indoor and high speed applications. Being baseband transmission, it exhibits properties like low power and low cost design. Especially, IR-UWB systems demonstrate such characteristics. The performance of IR-UWB system is mainly dependent on LNA design. In this paper we have designed three LNA's, a wide band and two low band. A SIMULINK based transmitter and receiver model is designed based on BPSK to evaluate the performance. The wide band LNA is phase linear and one low band LNA is noise cancellation type. Both LNA designs are tested on Agilent's ADS software for 25 micron technology. The wide band LNA gives flat gain over 12 dB. The low band LNA gives good noise figure 4.06 dB. The simulation is carried out to check the BER of BPSK transmitter and receiver. The simulation result shows the low band LNA with noise cancellation performs better than 'without' noise cancellation. The system with wideband LNA having phase linear characteristics gives good BER performance as compared to low band LNA.

Keywords— **UWB, LNA, AWGN**

I. INTRODUCTION

Ultra wideband was included in the FCC part 15 revision of August 2002, as a new category of short-range communication. This category is having a wider spectrum as compared to all other intentional radiation sections. UWB technology is based on transmission of very narrow electromagnetic pulses; having low repetition rate. Due to this reason the radio spectrum is spread over a very wide bandwidth—much wider than the bandwidth used in spread-spectrum systems. Ultra-wideband transmission is virtually untraceable by ordinary radio receivers and therefore can exist concurrently with existing wireless communications without demanding additional spectrum [1]. Due to the wide bandwidth and very low power UWB transmissions appear as background noise. So they can readily be distinguished from unwanted multipath reflections because of the fine time resolution. This leads to the characteristic of multipath immunity. UWB systems are having advantages such as low power, low cost, high data rates, precise positioning capability and extremely low interference as compared with conventional narrow-band communication systems. Also, UWB systems have high immunity to interference from other radio systems and fine range-resolution capability [2]. One of the most important benefits of the UWB communication system that has been raised is the ability of pulses to easily penetrate walls, doors, partitions, and other objects in the home and office environment. The UWB bandwidth defined by FCC is the difference between the two frequencies on both sides of the frequency of maximum radiation at which the radiated emission is 10 dB down. If f_H and f_L are the upper and lower 10 dB down frequencies respectively, then the fractional bandwidth equals $2(f_H - f_L)/(f_H + f_L)$. The centre frequency is defines as $f_C = (f_H + f_L)/2$ [1]. A UWB signal is typically composed of a train of sub nanosecond pulses, resulting in a bandwidth over 1 GHz. Though the total power is spread over such a wide range of frequencies, its power spectral density is extremely low. This minimizes the interference with the existing services that already use the same spectrum [2]. There are different schemes of UWB system such as OFDM or impulse radio UWB. In this paper impulse radio UWB system is used. A time-hopping (TH) sequence is applied in UWB system to eliminate catastrophic collisions in multiple accesses. For UWB system several modulation methods are proposed such as pulse position modulation (PPM) and variety of pulse amplitude modulations (PAMs), including binary phase-shift keying (BPSK) and on-off keying (OOK). In this work the TH-BPSK is used. The BER performance of UWB receiver with different LNA specifications and with additive white Gaussian noise (AWGN) environment is calculated. The AWGN model is important in its own right for some UWB applications. Any information in UWB system is typically transmitted using collection of narrow pulses with a very low duty cycle of about 1%. Duty cycle is the ratio of pulse duration to pulse period. A different pseudo-noise (PN) sequence is assigned to each user, which is used to encode the pulses in either position (PPM) or polarity (BPSK). The channelization is thus based on the assigned code.

The paper is organized as follows. In section II we describe the details of IR-UWB transceiver architecture. The BPSK model is described in section III. In section IV three different LNA designs are given. In section V focus on the different SIMULINK models for transmitter, receiver as well as LNA in detail. The BPSK modulation for UWB signal with AWGN channel for different LNA design is evaluated in section VI. Finally the conclusions are presented in section VII.

II. UWB TRANSCEIVER ARCHITECTURE

The IR-UWB is frequently known as carrier-less technology; in which the modulated baseband signal is directly transmitted
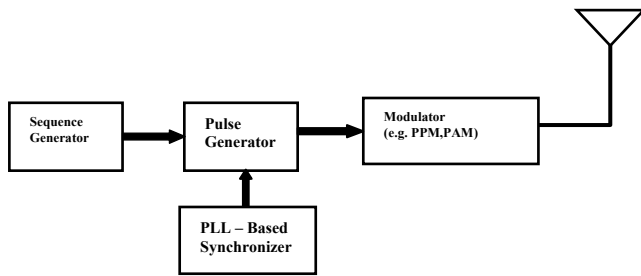
Fig 1: Block diagram of IR-UWB transmitter.

through the antenna into air. Fig. 1 shows the transmitter of IR-UWB. Due to low power emission requirement in IR-UWB transceiver the design of the transmitter side antenna pre-drivers are simple. However the narrowband transceivers use the high power PAs to commence the signal with sufficient power to the antenna [5]. In an IR-UWB system different types of modulation schemes are used with LNA.

Fig. 2 shows the IR-UWB receiver block diagram. In which the first and crucial component is LNA (Low noise amplifier). The analog information is used by the correlator; which is nothing but the multiplier. The two inputs of the correlator are the input signal and template generated by the pulse generator. The product of these two input signals at the output of the multiplier is further integrated to produce a robust signal level with relatively low frequency content. This signal is fed to the ADC [5]. In this paper at the receiver side three different types of LNAs are used with BPSK modulation and AWGN channel.
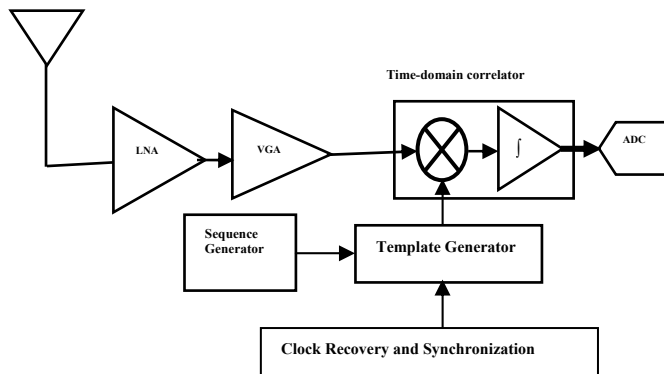

Fig 2: Block diagram of an IR-UWB receiver with a time-domain correlator.

III. BPSK SYSTEM MODEL

In case of BPSK we assume the bit stream be denoted by a sequence of binary symbols b_j (with values +1 or -1) for j = -∞, … , ∞. A single bit is represented using N_c pulses, where N_c refers to the length of the PN code c_i. For BPSK the code modulates the polarity of a pulse within each frame. The transmitted signal $s(t)$ can be written as follows for BPSK modulation in which each frame has duration T_f the duration of each bit is thus given by $N_c T_f$. Here A denote the amplitude of each pulse $p(t)$.

$$S_{BPSK}(t) = A \sum_{j=-\infty}^{\infty} \sum_{i=0}^{N_c-1} b_j c_i p(t - jN_cT_f - iT_f) \qquad (1)$$

The Fig. 3 shows the BPSK modulated pulses for UWB. This represent that the BPSK; which is also known as bi-phase modulation and is polarity dependent.
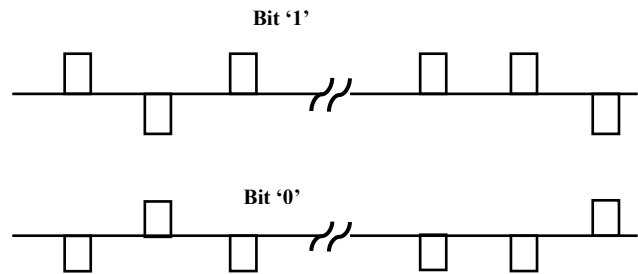

Fig 3: BPSK modulated UWB signal for the bit representation of '1'and '0'.

IV. LNA DESIGNS FOR UWB RECEIVER:

The LNA is one of the most critical components of a UWB receiver. The LNA provided to amplify the received signal with sufficient gain and as little additional noise as possible [3]. The LNA's noise figure has a major impact in deciding the system's overall noise figure [4]. LNA is having different circuit topologies; each method proposes to accommodate a wide bandwidth through input and/or output impedance matching. Such as shunt-series feedback topology is having broad band behaviour as well as good input and output characteristics. To further increase the gain and bandwidth, cascode common source architecture is there. A capacitor is used in series with feedback to avoid the effect of the output voltage on the optimum biasing point. Therefore the desired gain is achieved with low power consumption. An inductive load which improves the output noise performance as well as overcomes the gain degradation at higher frequencies is employed. Another inductor is added in series with feedback to give additional gain at higher frequencies [4]. The inductive degenerated topology had a superior performance as compared to its common gate. Also this topology provides simultaneously input matching and minimum noise figure [4].

Low noise amplifier (LNA) is the first stage of a receiver, whose main function is to provide enough gain to overcome the noise of subsequent stages. In addition to good gain and low noise, an LNA should accommodate large signals without distortion and must also present specific impedance such as 50 Ω, to the input source. To develop a design strategy that balances gain, input impedance, noise figure and power consumption, this paper gives the details of design for such type of LNA.

The LNA designs for UWB are available in two different bands of frequencies; which are known as low band LNA and wide band LNA. For low band the frequency range considered is from 3 GHz to 5 GHz and for wide band the frequency range considered is from 3.1 GHz to 10.6 GHz. In this paper three different LNA's are designed for UWB with low as well as wide band. This paper also focuses on the performance of BPSK for different LNA designs.

All LNA circuits are designed with the help of Advanced Design System of Agilent. To obtain the performance of the designed circuit we simulate it for harmonic balance and gain compression. In this simulation we have plotted the performance of the designed LNA in terms of forward gain, input reflection, output return loss, noise figure.

A. Wide band LNA (Phase Linear) design with results

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 [7]. This LNA design gives good power and phase linearity performances, which is suitable for both OFDM and IR-UWB system applications. Also impedance matching is very important in LNA designs. In most cases, the source impedance of the LNA is 50 Ω. Since the input impedance of the MOS transistor is almost purely capacitive, providing a good match to the source without degrading noise performance is a challenge. At the beginning of LNA design, it is necessary to give a thorough analysis of the low noise FET.
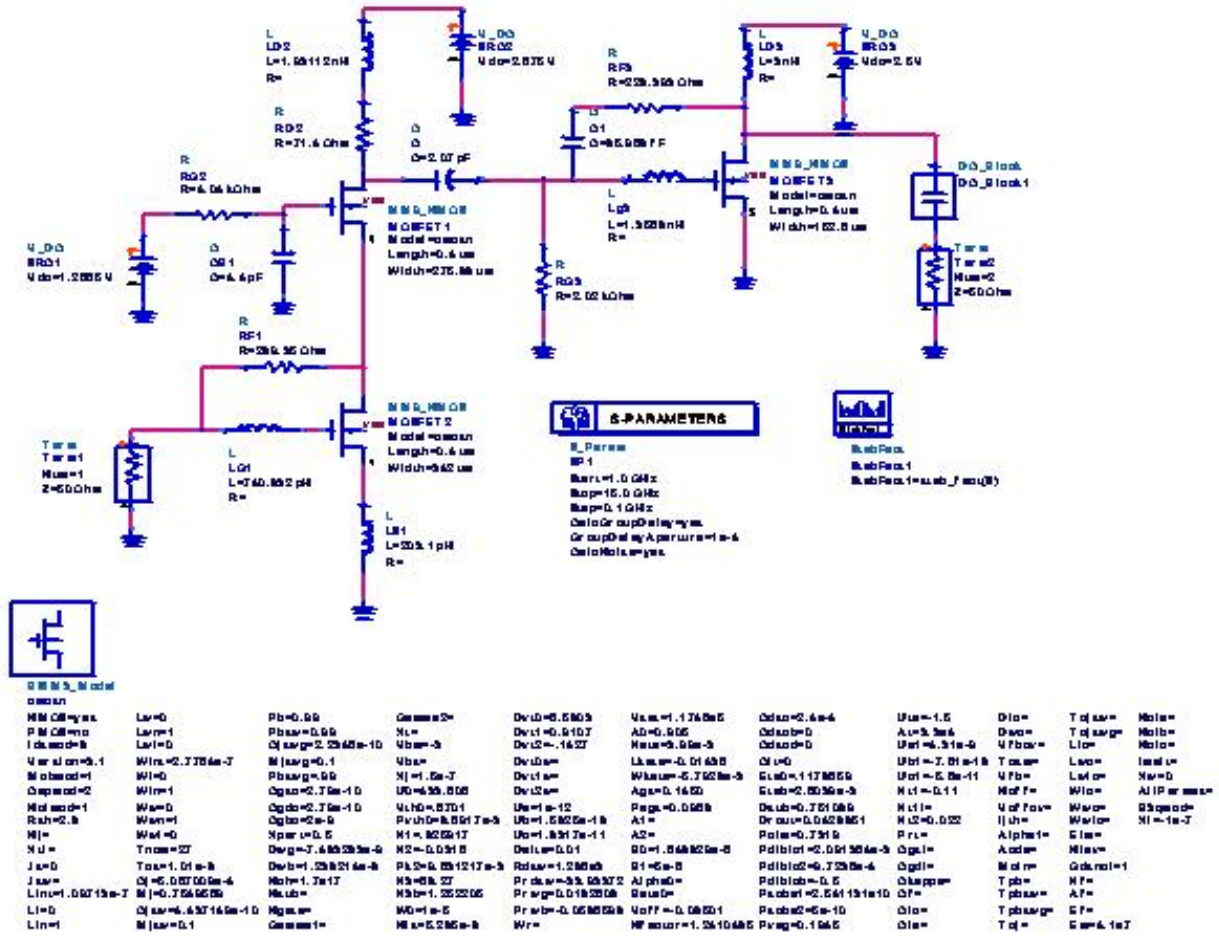

Fig 4: Complete schematic for Wide band Phase Linear UWB LNA.

In this source degenerative low band LNA value of parameters are as follows:

The Gate-Source Capacitance evaluated as follows

$$C_{gs} = \frac{1}{R_s \omega_0 Q} \qquad (2)$$

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

In this design the degeneration inductor L_s is calculated with the help of Gate-Source Capacitance C_{gs} as follows

$$L_s = \frac{R_s C_{gs}}{g_m} \qquad (3)$$

The value of gate inductance L_g i is calculated as

$$C_{gs} = \frac{1}{\omega_0^2 (L_s + L_g)} \qquad (4)$$

Fig. 4 shows the complete schematic for the wideband UWB LNA. As shown in the figure, to achieve sufficient gain, this LNA is composed of a cascode input stage and common-source output stage. According to the methodology in [7] 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_m

simultaneously the input impedance and noise matching is achieved.

The Fig. 5 shows the gain of the LNA. According to figure 5, UWB LNA is having high and flat gain (S_{21}) which is greater than 12 dB. The gain remains flat from 3.1GHz to 10.6 GHz in the band of interest. The peaking inductance in this design helps to increase the forward gain (S_{21}). The Figure 6 shows the noise figure measured in low band LNA. The noise figure achieved with the designed LNA is 3.3 ~ 2.7 dB over the band of interest.
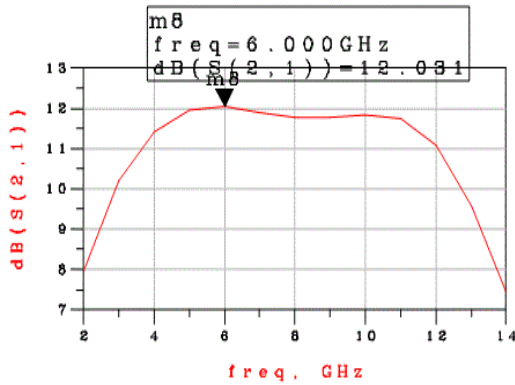

Fig 5: The measured S_{21} versus frequency characteristics of 3.1 -10.6 GHz
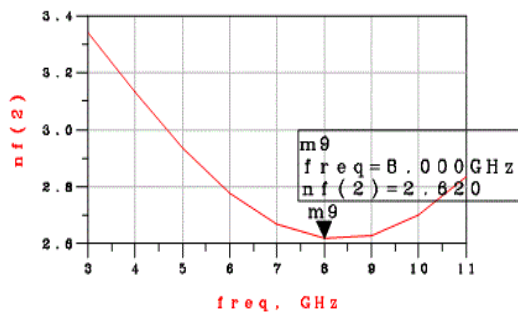

Fig 6: The measured NF.

Fig. 7 and Fig. 8 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 ~ -10 dB were achieved over the 3.1GHz to 10.6 GHz band of interest.
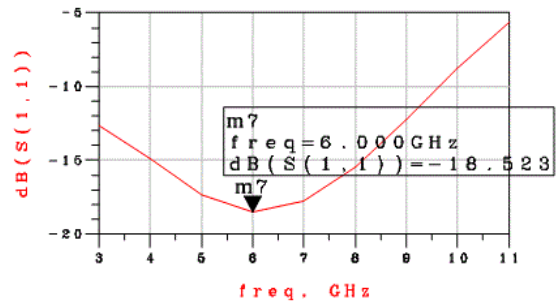

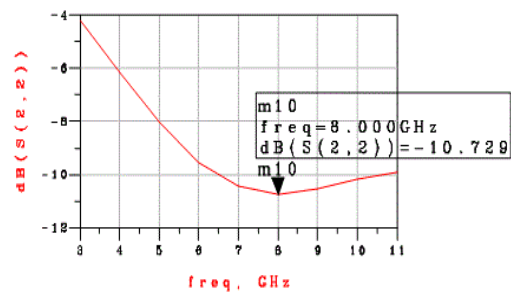Fig 7: The measured S_{11} versus frequency characteristics of the 3.1 -10.6 GHz

Fig 8: The measured S_{22} versus frequency characteristics of the 3.1 -10.6 GHz

B. Low band LNA without noise cancellation design with result

The LNA is designed for low band frequency range. This design is for differential LNA using source degeneration technique to provide a good noise match. The differential amplifier is in fact the single LNA design. In this LNA design the input impedance is considered as 50Ω and tranconductance g_m = 20ms with degenerating inductors (L_s) connected together at the 'virtual earth'. In this design a cascade stage was added to the source degenerated stage provide improved gain and reverse isolation.

In LNA 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 so in that power consumption is quite high sometimes [5]. This means that both input matching and minimum NF cannot be obtained simultaneously. In LNA 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 can be determined to meet 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. 9 shows the schematic for low band UWB LNA without noise cancellation. The LNA is designed for low band

BSIM3_Model
cmosn

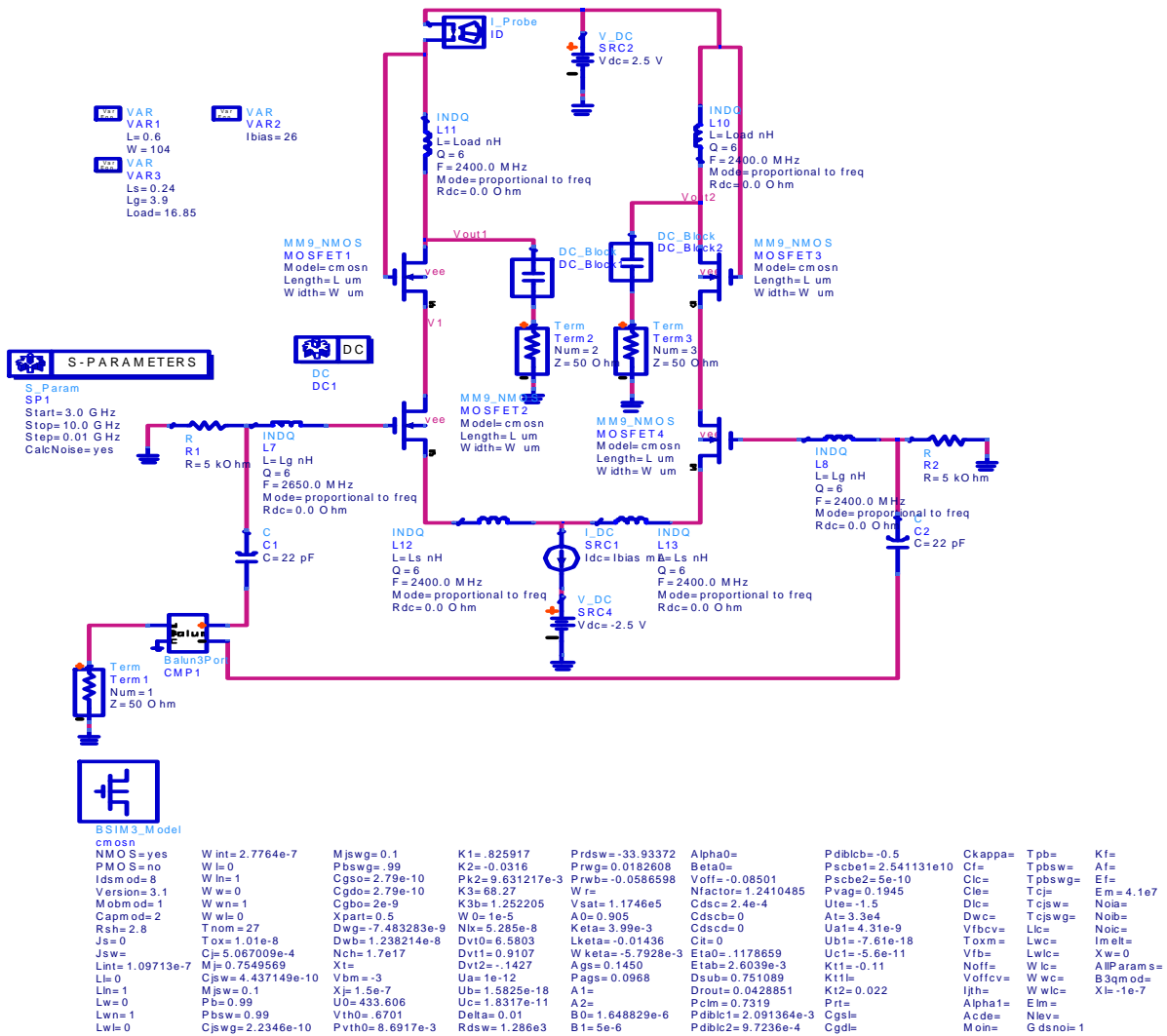|									
NMOS=yes	W int=2.7764e-7	M jswg=0.1	K1=.825917	Prdsw=-33.93372	Alpha0=	Pdiblcb=-0.5	Ckappa=	Tpb=	Kf=
PMOS=no	W l=0	Pbswg=.99	K2=-.0316	Prwg=0.0182608	Beta0=	Pscbe1=2.541131e10	Cf=	Tpbsw=	Af=
Idsmod=8	W ln=1	Cgso=2.79e-10	Pk2=9.631217e-3	Prwb=-0.0586598	Voff=-0.08501	Pscbe2=5e-10	Clc=	Tpbswg=	Ef=
Version=3.1	W w=0	Cgdo=2.79e-10	K3=68.27	W r=	Nfactor=1.2410485	Pvag=0.1945	Cle=	Tcj=	Em=4.1e7
Mobmod=1	W wn=1	Cgbo=2e-9	K3b=1.252205	Vsat=1.1746e5	Cdsc=2.4e-4	Ute=-1.5	Dlc=	Tcjsw=	Noia=
Capmod=2	W wl=0	Xpart=0.5	A0=0.905	Cdscb=0	At=3.3e4	Dwc=	Tcjswg=	Noib=
Rsh=2.8	Tnom=27	Dwg=-7.483283e-9	Nlx=5.285e-8	Keta=3.99e-3	Cdscd=0	Ua1=4.31e-9	Vfbcv=	Llc=	Noic=
Js=0	Tox=1.01e-8	Dwb=1.238214e-8	Dvt0=6.5803	Lketa=-0.01436	Cit=0	Ub1=-7.61e-18	Toxm=	Lwc=	Imelt=
Jsw=	Cj=5.067009e-4	Nch=1.7e17	Dvt1=0.9107	W keta=-5.7928e-3	Eta0=-.1178659	Uc1=-5.6e-11	Vfb=	Lwlc=	Xw=0
Lint=1.09713e-7	Mj=0.7549569	Xt=	Dvt2=-.1427	Ags=0.1450	Etab=2.6039e-3	Kt1=-0.11	Noff=	W lc=	AllParams=
Ll=0	Cjsw=4.437149e-10	Vbm=-3	Ua=1e-12	Pags=0.0968	Dsub=0.751089	Kt1l=	Voffcv=	W wc=	B3qmod=
Lln=1	Mjsw=0.1	Xj=1.5e-7	Ub=1.5825e-18	A1=	Drout=0.0428851	Kt2=0.022	Ijth=	W wlc=	Xl=-1e-7
Lw=0	Pb=0.99	U0=433.606	Uc=1.8317e-11	A2=	Pclm=0.7319	Prt=	Alpha1=	Elm=	
Lwn=1	Pbsw=0.99	Vth0=-.6701	Delta=0.01	B0=1.648829e-6	Pdiblc1=2.091364e-3	Cgsl=	Acde=	Nlev=	
Lwl=0	Cjswg=2.2346e-10	Pvth0=8.6917e-3	Rdsw=1.286e3	B1=5e-6	Pdiblc2=9.7236e-4	Cgdl=	Moin=	G dsnoi=1	

Fig 9: Complete schematic for Low band UWB LNA without noise cancellation

which is having frequency range from 3 GHz to 5 GHZ. With this LNA the noise figure obtained is 2.6 dB. The LNA performance is measured with help of S parameters. The Figure 10,11,12,13 shows the value of different parameters of LNA. The Figure 10 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 11 the noise figure is 2.54 dB. The figure 12 and figure 13 shows the output return loss and input return loss. As shown in the figures these values are much better. 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 in this type of LNA 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 approximately by $1/gain_{LNA}$ [6].

m1
freq=5.710GHz
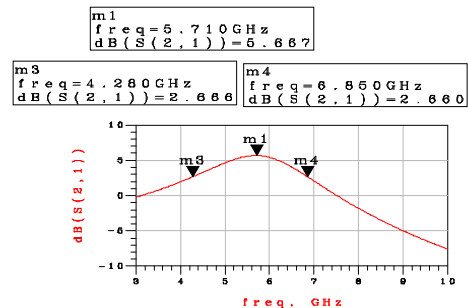dB(S(2,1))=5.667

m3
freq=4.280GHz
dB(S(2,1))=2.666

m4
freq=6.850GHz
dB(S(2,1))=2.660

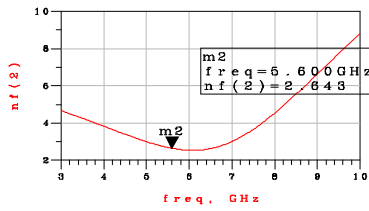Fig. 10: The measured S_{21} versus frequency characteristics of the 3 -5 GHz
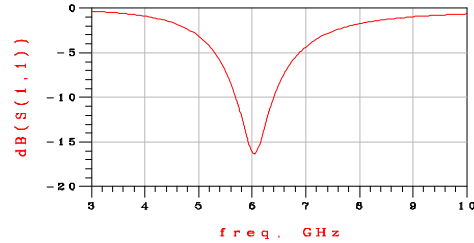
Fig. 11: The measured NF.

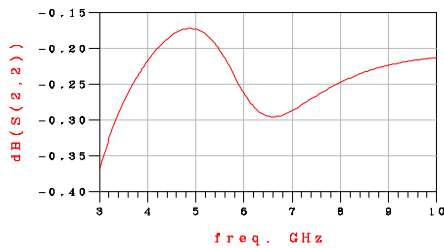Fig 12: The measured S_{22} versus frequency characteristics of the 3 -5 GHz

Fig. 13: The measured S_{11} versus frequency characteristics of the 3 -5 GHz

C. Low band LNA with noise cancellation design and result:

The LNA must meet several severe requirements, such as input matching, sufficient gain with wide bandwidth and low noise figure (NF), this type of LNA gives better noise figure. Inductive series and shunt peaking techniques are used for the noise cancellation [7]. In this LNA two common matching techniques are used. First is known as common gate and second is known as resistive shunt feedback. With this the noise figure is obtained near about 4 dB
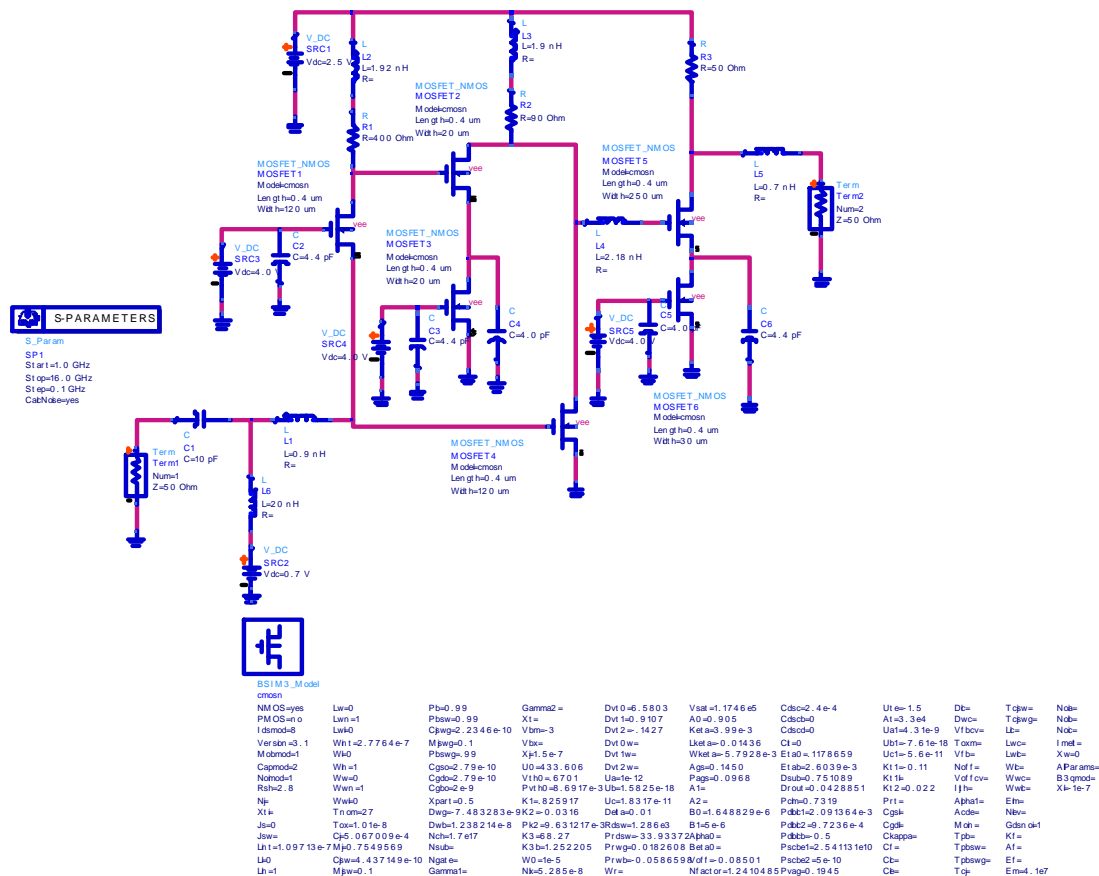
Fig. 14: Complete schematic for Low band UWB LNA with noise cancellation.

Fig. 14 gives the complete schematic of UWB LNA with noise cancellation. In this LNA inductor L_1 and L_2 are used for shunt peaking, without any high-Q requirement efficiently extends the bandwidth [7]. The series inductor L_3 resonates with the input capacitance of M_4, resulting in a large bandwidth.
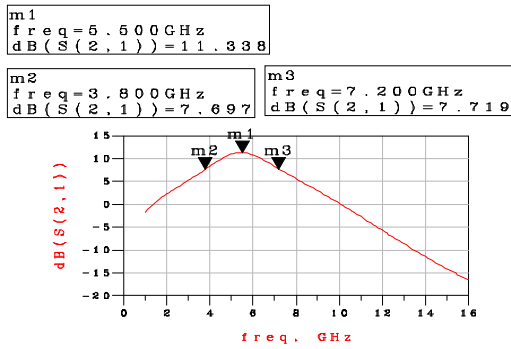

Fig. 16: The measured NF.

m1
freq=5.500GHz
dB(S(2,1))=11.338

m2
freq=3.800GHz
dB(S(2,1))=7.697

m3
freq=7.200GHz
dB(S(2,1))=7.719

Fig. 15: The measured S21 versus frequency characteristics of the 3 -5 GHz
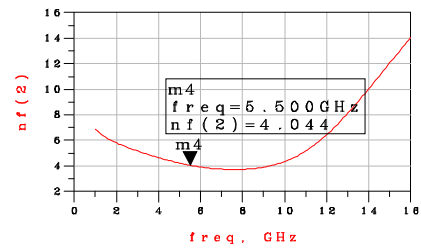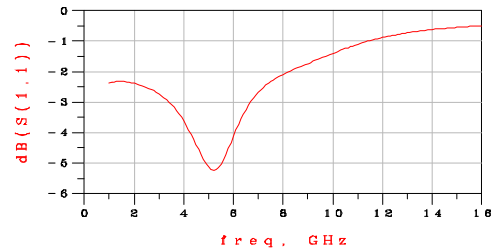

Fig. 17: The measured S_{11} versus frequency characteristics of the 3 -5 GHz

V. DESIGN OF SIMULINK MODEL.

The Figure 18 highlights the SIMULINK model for transmitter as well as receiver of BPSK based UWB receiver.

The transmitter is having two inputs Gaussian doublet pulse as a reference pulse and another pulse is the data signal.
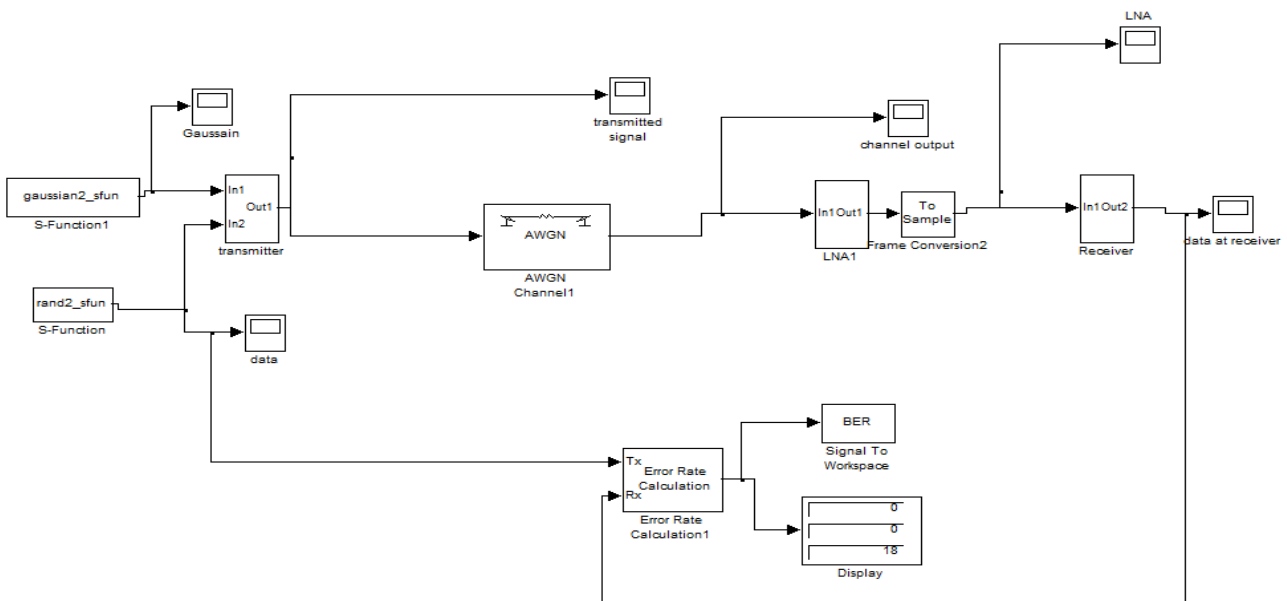

Fig.18: The SIMULINK model for TR-UWB BPSK transceiver

A. BPSK based UWB transmitter:

As shown in the Figure 19 the transmitter of the BPSK based UWB consists of different components. Such as the phase shifter, multiplier, adder as well as the rate transition is also used. The phase shifter block accepts a complex signal at the port labelled I_n which is nothing but the Gaussian doublet pulse. The output is the result of shifting this signal's phase by an amount specified by the real signal at the input port labelled P_h. The P_h input is measured in radians, and must have the same size and frame status as the I_n input. The Rate Transition block transfers data from the output of a block operating at one rate to the input of another block operating at a different rate. After adjusting the rates for the reference as well as the data input pulse multiplier and adder are used to have the '1' and '0' combination.

B. AWGN channel:

The channel used for this UWB system is AWGN (Additive White Gaussian Noise). In this the AWGN Channel block adds white Gaussian noise to a real or complex input signal. For the real input signal, this block adds real Gaussian noise and produces a real output signal. When the input signal is complex, this block adds complex Gaussian noise and produces a complex output signal. This block inherits its sample time from the input signal. Changing the symbol period in the AWGN Channel block affects the variance of the noise added per sample, which also causes a change in the final error rate.

$$NoiseVariance = \frac{signalPower \times SymbolPeriod}{SampleTime \times 10^{\frac{E_s/N_0}{10}}} \quad (5)$$

C. BPSK based UWB Receiver:

In the receiver of UWB LNA is the essential component. In this paper design of three types of LNA are proposed. The LNA implementation is done with ADS software. By using this specification of three different types of LNA the receiver architecture is studied. The figure 20 shows the detailed blocks used in the UWB receiver. Which uses component such as filter, integrator, adder etc. the input from the LNA is provided to this block.
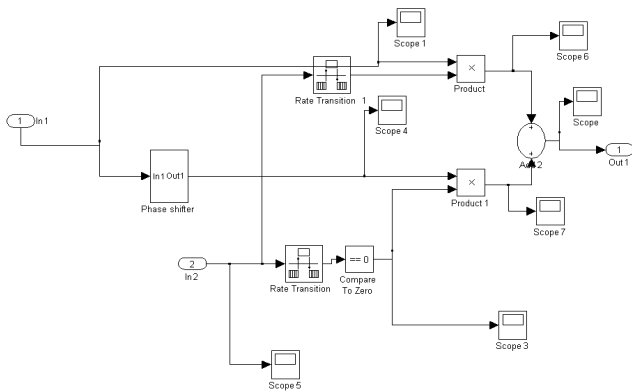

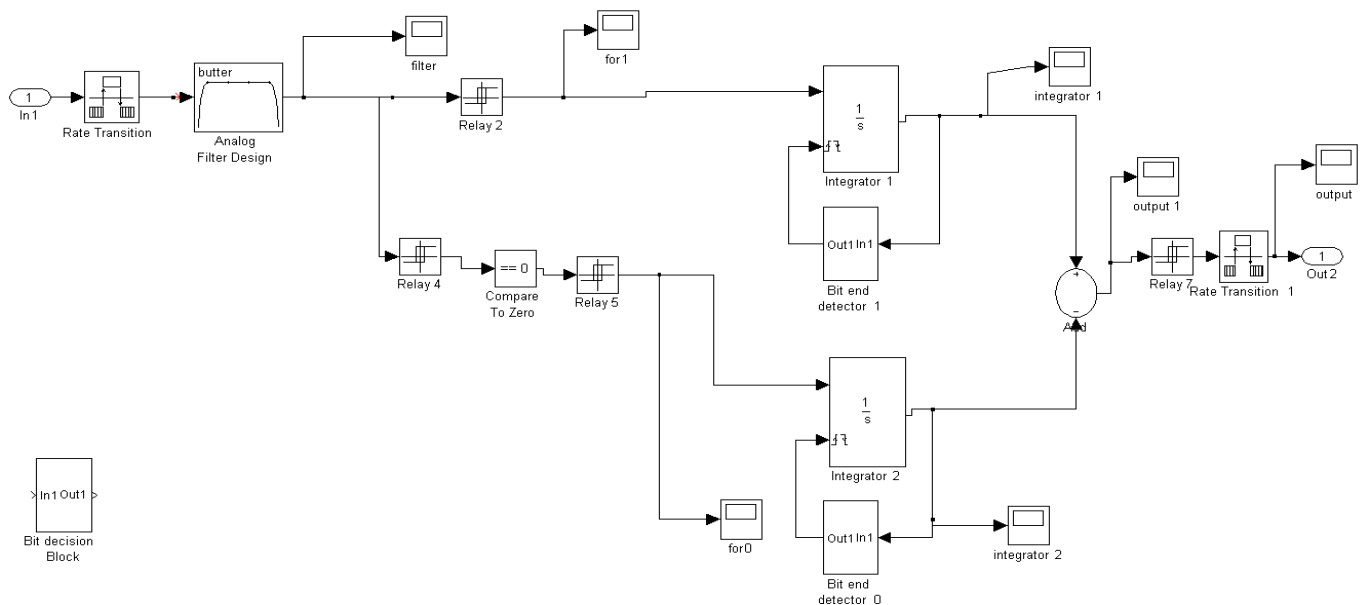Fig. 19: BPSK based UWB transmitter SIMULINK model

Fig. 20: BPSK based TR-UWB receiver SIMULINK model

The Fig. 21 gives the detailed block of LNA. In this block the different amplifier parameters are set according to the requirement. This amplifier is design for noise figure is 2.64 dB and gain is set as 5.6 dB.
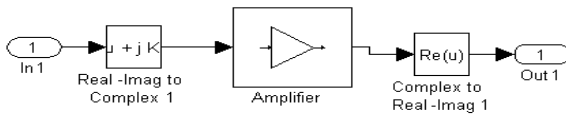

Fig. 21: LNA for TR-UWB

These are the specification of LNA without noise cancellation according to the Fig. 10 and Fig. 11. Likewise the remaining two LNA type's specifications are included in the amplifier and the performances of all LNA are plotted in Fig. 22.

VI. RESULT AND DISCUSSION

To evaluate the performance of designed LNA we devised a SIMULINK model for LNA and is incorporated in receiver's SIMULINK model. To compute BER performance an AWGN channel is used. The simulation is carried out for 3000 iteration for SNR values of 0-16 dB in steps of 2. Figure 22 shows the result of simulation and Table 1 list the numerical values of BER performance. From Table and graph we can state that wide band LNA gives better performance above 6 dB SNR, whereas low band LNA 'with' and 'without' noise cancellation performances better than wide band for SNR between 0 – 6 dB. The noise cancellation LNA performs better as compared to 'without' noise cancellation LNA. BER performance for wide band LNA at 8 dB is approximately double than LNA 'without' noise cancellation. At 10 dB SNR the BER performance of wide band LNA is good by a factor of 67 times than 'without' noise cancellation. Whereas, low band LNA 'with' noise cancellation enhances BER by a factor of 3.71 times than 'without' noise cancellation LNA.
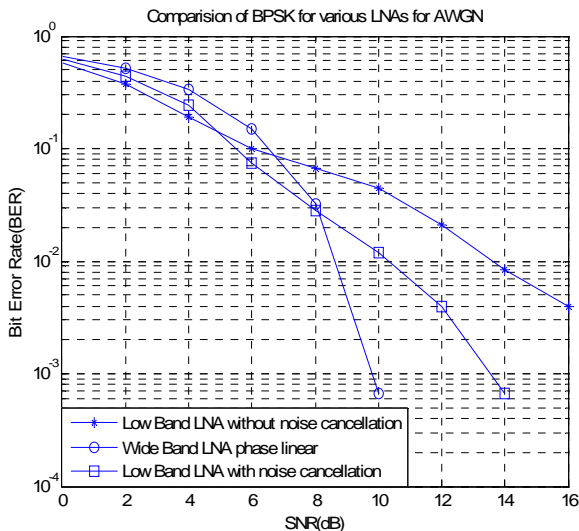

Fig. 22: The performance evaluation of BPSK for all three types of LNA.

TABLE 1
BER performance values for different SNR with variation in LNA

SNR(dB)	BER Performance		
	Low Band LNA without noise cancellation	Wide Band LNA phase linear	Low Band LNA with noise cancellation
0	0.5821	0.6667	0.6287
2	0.3764	0.5237	0.4437
4	0.1933	0.3403	0.2433
6	0.0995	0.1503	0.0737
8	0.067	0.032	0.0283
10	0.0446	0.0006666	0.012
12	0.021	0	0.004
14	0.0085	0	0.0006666
16	0.004	0	0

VII. CONCLUSION

The Agilent ADS system is used to design low noise amplifiers with phase linear and noise cancellation characteristics. A comparison has been made between 'without' noise cancellation and 'with' noise cancellation LNA. To achieve versatile design of UWB receiver, we have designed a wide band LNA having phase linear property. The linear LNA design results into a good flat gain of 12 dB and noise figure of 2.6 dB. These LNAs are incorporated into SIMULINK model of UWB receiver. The BER performance of noise cancellation LNA is 26 % better than 'without' noise cancellation LNA at 6 dB SNR and 80 % better at 12 dB SNR. The performance of wide band LNA up to 6 dB is poor than low band LNA but for SNR greater than 7 dB it is more than 100 times better. A low band LNA with noise cancellation is recommended for the use in BPSK based IR-UWB system.

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