Impact of LNA Non Idealities on the Performance of IR-UWB Non Coherent Energy Detector

M. HAJRI D. BEN ISSA
Graduate School of Engineering of Sfax, Street of Soukra 3.5Km, BP.3038, Tunisia
hajrimadihah@gmail.com, dalenda_benissa@yahoo.fr

H. SAMET
Graduate School of Engineering of Sfax, Street of Soukra 3.5Km, BP.3038, Tunisia
hekmet.samet@enis.rnu.tn

Abstract: *UWB systems are among the most exciting technologies due to their capability of transmitting data over a wide frequency spectrum with very low power and high data rates. In a UWB receiver circuit the LNA is the first stage. It is the most important noise contributor to the overall noise of the receiver.*
The performance of IR-UWB system is mainly dependent on the LNA characteristics. In this paper, we have designed a wide band LNA, implemented using Agilent's ADS software. The LNA achieves a flat gain over 12.5 dB and a low noise figure NF of 2.4 dB. A UWB OOK transceiver was designed in MATLAB/SIMULINK to evaluate their performance. Then, the effects of the LNA non idealities on the IR-OOK-UWB receiver performance were investigated. The receiver system performance was evaluated in terms of bit error rate (BER) versus signal to noise ratio (SNR).
The simulation results show that for a constant LNA gain, the change in the LNA noise figure NF of LNA directly affects the performance. A better performance is obtained with a low NF.

Key words: *IR-UWB, Receiver, Energy detector, LNA, Noise figure, BER.*

1. Introduction

The UWB technique is one of the emerging and promising technologies for high data rate, short-range communications and low data rate applications ensuring a low cost and low a power implementation. According to FCC, a UWB radio signal defined as a signal that occupies a band with larger than 20% with strict limits on its power spectral density to -41.3dBm/MHz in the range 3.1 to 10.6 GHz [1]. But in UWB communications, other potential systems allow researchers to interfere using the same band frequency. Some countries regulation require the implementation of spectrum sensing techniques, in some bands for the coexistence of licensed primary systems and secondary UWB systems, these techniques have been widely explored in the context of cognitive radios [2][3]. However, from the receiver point of view, to capture a sufficient amount of energy using coherent schemes, such as Rake receivers, a large number of correlators must be implemented, which results in a very complex hardware architecture. In this case, the channel estimation is a challenging task as it involves intensive signal processing and sampling rates[4]. Such receivers are further burdened with the problem of estimating the amplitude and delay of each multipath component. Due to these challenges, there is an urgent need for simpler receiver structures, capable of exploiting the rich UWB multipath channel diversity at an affordable cost, reasonable power consumption and low complexity.

Because of practical complexity constraints, non-coherent schemes such as transmitted reference, the energy detector (ED) is proposed for UWB systems[5]. Energy detectors have the advantage of being in simple structure and inexpensive in price. Due to the low signal to noise ratio (SNR) of the received signal in an ultra-wide Band (UWB) system, these desirable advantages can be achieved at the expense of non-trivial performance degradation. Table.1 presents a summary comparison between coherent and non coherent receivers.

Non-coherent energy detector receiver is further explored in this work due to its simple circuit architecture without need for a frequency synthesizer and a template signal for integration.

The received signal in any communication system is a delayed, attenuated and possibly distorted version of the signal that was transmitted plus noise and interference [6]. For IR-UWB systems non coherent receivers implemented either in digital or analog domains can be used for the detection of a deformed and noisy received signal. The implementation of the all-digital receiver requires high-sampling data converters (ADCs) and its high-data-rate solutions also need a large memory and high processing speeds, which makes it expensive to implement [7]. Alternatively, a full analog implementation of IR-UWB non coherent receiver can provide a simple and low-cost receiver. In practice , however, any analog circuit in the receiving chain, involving a low noise amplifier (LNA), an integrator and a mixer, has its own non idealities hence introduces some alterations in the spectrum. This causes a performance loss which in turn impacts on the signal-to-noise ratio (SNR) in input of the detector and ultimately on the bit-error-rate (BER). Therefore, it is important to study these effects in order to create a robust and efficient UWB system.

In this work, a non coherent IR-UWB energy detector was implemented with Matlab/Simulink and a wide band LNA was proposed. The BER performance of the UWB receiver with different LNA specifications and with additive white Gaussian noise (AWGN) environment was calculated to investigate the impact of the non-idealities like noise figure and gain on the BER.

The remainder of the paper is organized as follows. In Sect. 2, the system model of IR-UWBOOK is presented and ED receivers are introduced. In Sect. 3, the non idealities versus performance of TR-ED are theoretically analyzed. The system level modeling of a non coherent IR-UWB-OOK receiver is simulated in Sect.4. Performance evaluation and simulation results are presented in Sect. 5. Finally, Sect. 6 is devoted to draw our conclusions.

Table 1

A summary comparison between coherent and non coherent receivers

	Non-Coherent	Coherent
Description	Based on energy detection	Correlates the received signal with a template signal
Advantages	Low complexity, low cost, low power consumption	Optimal over AWGN and multipath channels
disadvantages	SNR degradation	High complexity

2. Overview of the OOK transceiver

The transmitted signal in the OOK scheme can be expressed as follows

$$s(t) = \sum_{i=-\infty}^{\infty} b_i \sqrt{E_w}\; w(t - i\,T_b) \qquad (1)$$

Where w (t) is the UWB pulse, Ew is the energy of w (t), Tb is the symbol time and bi {0, 1} is the binary information bits.

Signal s (t) propagates through a multipath channel with an impulse response

$$h(t) = \sum_{j=1}^{L} \alpha_j\, \delta(t - \tau_j) \qquad (2)$$

Where L is the number of multipath components [6], α_j and τ_j are the gain and delay values associated with jth multipath component according to IEEE 802.15.4 channel mode [6], and δ (.) is the Dirac delta function.

The received signal can be expressed as:

$$r(t) = \sqrt{E_w} \sum_{i=-\infty}^{\infty} b_i\; g(t - i\,T_b) + n(t) \qquad (3)$$

Where n (t) is the white Gaussian noise with a power spectral density $\frac{N_0}{2}$, and g (t) = w (t) * h (t) is the channel response to w (t) [6].

2.1. Energy detector

An energy detector is formed by a square device, an energy integrator and a threshold decision mechanism as shown in fig. 1.The decision variable in the energy detector is obtained as follows

$$Z_{ED} = \int_0^{T_i} r^2(t)\, dt \qquad (4)$$

Where T_i and r (t) are the integration interval and the received signal passing through a low noise amplifier, respectively.

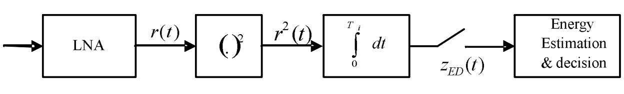

Fig.1: Energy detector structure

In OOK scheme, the demodulation stage has

$$\begin{cases} H_0 : Z_{ED} = \int_0^{T_i} n^2(t)\, dt & (\text{bit} = 0) \\ H_1 : Z_{ED} = \int_0^{T_i} (g(t) + n(t))^2\, dt & (\text{bit} = 1) \end{cases} \qquad (5)$$

Where g (t) and n (t) are the received desired signal and noise, respectively. The symbol decision in the

receiver is made by comparing Z_{ED} with the threshold value [6].
If the pulse envelope is lower than the threshold, no pulse is detected and the output signal remains at 0V, if the pulse envelope crosses the threshold, a pulse is detected and the output signal goes to 1V. The choice of the threshold voltage must then be made as a trade-off between the false alarm rate, due to the influence of noise, and the non-detection rate and so the receiver sensitivity.
Hypotheses 0 and 1 have the probability density functions (PDF) $P_0(x)$ and $P_1(x)$, respectively.
The optimum threshold value th_{opt} is obtained by the solution $P_0(x) = P_1(x)$ [6]. Therefore, the approximation of the threshold value can be calculated by solving the following equation:

$$\frac{1}{\sqrt{2\pi\sigma_0^2}}\exp\left(-\frac{(Thg-m_0)^2}{2\sigma_0^2}\right)=\frac{1}{\sqrt{2\pi\pi_1^2}}\exp\left(-\frac{(m_1-Thg)^2}{2\sigma_1^2}\right) \quad (6)$$

Where Th_g is the Gaussian approximation for the threshold value (m_0, σ_0) and (m_1, σ_1) are the mean and standard deviation values regarding Gaussian distribution for hypothesis 0 and hypothesis 1 respectively[7][8]. By taking the natural logarithm of both sides of equation (6), the following quadratic equation can be achieved

$$C_1 Thg^2 + C_2 Thg + C_3 = 0 \quad (7)$$

Where the coefficients are given by:

$$\begin{cases} C_1 = \sigma_1^2 - \sigma_0^2 \\ C_2 = -2\left(m_0\ \sigma_1^2 - m_1\ \sigma_0^2\right) \\ C_3 = \sigma_1^2\ m_0{}^2 - \sigma_0^2\ m_1{}^2 - 2\ \sigma_0^2\ \sigma_1^2\ \ln\left(\frac{\sigma_1}{\sigma_2}\right) \end{cases} \quad (8)$$

Where the threshold is:

$$Th_{g,i} = \frac{-C_2 \pm \sqrt{C_2^2 - C_1\ C_3}}{2\ C_1} \quad ;i = 1,2 \quad (9)$$

3. Non idealities versus performance

In the RF system, signal processing is achieved through cascaded stages as shown in fig 1. RF system performance of depends on various factors such as channel characteristics, interferences from surrounding radio, and internal non ideal circuit effects. The RF front end non idealities limit the overall performance. Therefore, it is important to know how performance is affected by the non linearity of each stage. In the UWB context, the study of the block level non-idealities effect on the overall receiver chain has become a must since the received signals are often weak in order of -79dBm[9].
To be able to receive a similar weak signal, a good sensitivity of the UWB receiver is urgent. Such sensitivity is often restricted by the noise figure.

3.1. Noise analysis

Noise analysis plays a major role in choice of high level RF receiver specifications such as sensitivity. In RF circuits, noise affects directly the high level system performance like SNR, BER.
Noise is defined as an undesired signal interfering with desired processed signals or unwanted signal produced by a device itself. This noise is further degraded as it goes through the receiver chain preceding stages. As a result, the signal strength degrades as it passes through each stage. The amount of noise degradation caused by each stage of RF front end is quantified by a parameter called noise figure.

3.2. Noise Figure

Noise Figure defined as a ratio of SNR at input to SNR at output. In other words, the noise figure is a measure of how much degradation is incurred on the SNR signal as it goes through each stage.

$$\text{Noise Figure} = \frac{SNR_{in}}{SNR_{out}} \quad (10)$$

$$P_{sig} = P_{RS}.NF.SNR_{out}$$

Where Psig denotes input signal power, PRS source resistance noise power, both per unit BW.

$$P_{sig,tot} = P_{RS}.NF.SNR_{out}.B \quad (11)$$

Where Psig,tot is the overall signal power distributed across the channel bandwidth B. In other words, it is known as sensitivity. The radio sensitivity can be defined as the minimum detectable signal (MDS) level at the antenna with acceptable signal to noise ratio.
The receiver sensitivity expressed in dBm as

$$P_{in,min}\big|dBm = P_{RS} + NF + 10\log B + SNR_{min} \quad (12)$$

Where $P_{in,min}$: minimum received signal level that achieves SNR_{min}, SNR_{min}: minimum acceptable SNR at receiver output, which is a function of Minimum required BER at the demodulator output. B: bandwidth in Hz, P_{RS}: source noise power: -174dBm/Hz.
The first three terms on the right side of the above equation (12) represents noise floor. The thermal noise referred to the input of a radio system is also called noise floor. Consequently, the noise power which appears at the receiver input is determined by the voltage divider between the receiver input resistance (Rin) and the antenna source resistance (Rs).

$$P_{noise} = \frac{\overline{V_{in}{}^2}}{R_{in}} = \frac{R_{in}R_S}{(R_{in}+R_s)^2}.4\,K\,T\,Bw \qquad (13)$$

Most receivers are designed for a maximum power transfer from the antenna to the receiver input, in which case, $R_s=R_{in}=R$ the above equation becomes

$$P_{noise} = 4\,K\,T\,Bw$$

In the RF circuit design, power levels are commonly referred to in decibels referenced to 1mW (or) 0dBm. At 300 K, the noise power in dBm for a target channel bandwidth from 3GHz to 5GHz is

$$p_{noise} = 10*\log_{10}\left(1.38e^{-23}*290*\frac{1e^{3}mW}{w}\right)+10*\log_{10}(BW)$$

$$p_{noise} = -174+10*\log_{10}2e^{9} = -81dBm \qquad (14)$$

The equation can be rewritten as

$$SNR_{in,dBm} = P_{mds,dBm} - NF - P_{noise,dBm} \qquad (15)$$

From this equation, it is clear that NF affects the receiver sensitivity since SNR_{in} is dependent on the tolerable bit error rate of the target application.

3.3. NF System level consideration

The received signal by the antenna spreads through different blocks before it reaches the digital back-end in the receiver path. During this process, each block induces noise to the signal characterized by a noise figure. The overall noise figure of the receiver depends on the noise contributed by each block as well as the gain of the preceding stages. Naturally, larger signal are less prone to noise, and this is why a large gain of one stage causes the noise inflicted by the next stage to be less. Finally, from Friis' equation[10], the overall NF of the cascade system shown in Fig.2 is given by equation (16).

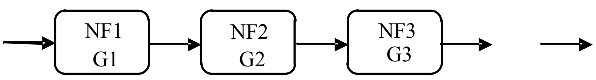

Fig.2. Cascade chain of RF front end

$$NF_{rx} = NF_1 + \frac{NF_2}{G_1} + \frac{NF3}{G_1G_2} + ... \qquad (16)$$

Where NF_i and G_i are the NF and available power gain of i-th stage respectively. Assuming that G_1 is a larger value, then, NF_1 is the dominant term in the above equation. It is clear that the first stage dominates the overall NF of the receiver. From *q*.3.2, it is clear enough that the first stage is the most important noise contributor to the overall noise of the receiver. Since, it adds up directly, it is important to keep the noise figure of first stage as low as possible. Extra care has to be taken while determining specifications of first stage. This leads to stringent requirements like low NF and high gain on the first stage, which usually involves the LNA.

3.4. Need of LNA as the first stage block

The power of the received signal is also calculated from

$$P_{rx} = P_{tr} + G_t + G_r - P_{loss} \qquad (17)$$

Where P_{rx} : available power of the received signal

P_{tr} : Transmitted signal power

G_t : Transmission antenna gain

G_r : Receiver antenna gain

P_{loss} : Path loss power dependent on the distance separating the transmitter and the receiver

Since UWB systems use spread spectrum techniques to avoid interferences with nearby radios by distributing power across the entire bandwidth. They acquire substantial gains. The processing gain is defined as a relation of the spread bandwidth over the information signal bandwidth at the receiver output.

$$PG = 10\log_{10}(B/r) \qquad (18)$$

Where B: Bandwidth

r: bit rate of the system

PG is also one of the parameters that influence the SNR_{min} requirement to maintain a desired performance. Other parameters involve the type of modulation, multiple access technique, detection mechanism and number of users that share the channel.

For UWB systems, the equation (12) can be rewritten as shown below

$$P_{in,min}\big|dBm = -174 + NF + 10\log B + SNR_{min}(PG/NU) \qquad (19)$$

It suggests that NF, Bw, PG can be traded off to get the required sensitivity for a specific SNR. The channel bandwidth of the system is defined by the UWB pulse bandwidth, by antennas frequency response. Therefore, the PG depends on the bit rate and the pulse repetition rate, which are parameters that depend on the target application.

Consequently, the only improvement that can be achieved from the architectural viewpoint is to reduce the overall NF. As the transmitted power is very limited (in order to -9 dBm) in UWB radio and also

due to high path losses the received signal is very weak for further processing at the receiver.
Hence in order to improve the system sensitivity and match the SNR specifications, it is recommended that the LNA always be the first stage immediately followed by a square law device and RF front end.

3. OOK transceiver implementation

Fig.3 presents the simulink model for the OOK UWB transceiver. The transmitter has two inputs: Gaussian doublet pulse as a reference pulse and the data signal.

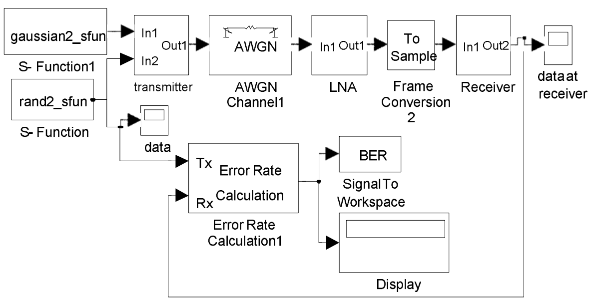

Fig.3. Block diagram of the OOK receiver

3.1. Pulse generation

A wide range of pulse shapes have been explored for a UWB communication system from rectangular to Gaussian. The most adopted pulse-shaping function is the Gaussian pulses and their derivatives in order to gain more flexibility in the frequency domain[11]. These shapes are generated with simple circuits. The equation for the time domain Gaussian pulse is defined as

$$\frac{1}{2\pi\sigma^2} e^{\frac{-(t-\mu)^2}{2\sigma^2}}$$

Where σ^2 is the variance and μ is the mean. A scaled version of this equation with zero mean and variance equal to $\frac{\tau^2}{4\pi}$ is given by:

$$p(t) = -e^{-2\pi\left(\frac{t}{\tau}\right)^2} \qquad (20)$$

The first and the second order Gaussian pulses are given by:

$$p'(t) = \frac{d\,s(t)}{dt} = \frac{4\pi t}{\tau^2} e^{\frac{-2\pi t^2}{\tau^2}} \qquad (21)$$

$$p''(t) = \frac{d^2 s(t)}{dt} = -4\pi\, e^{\frac{-2\pi t^2}{\tau^2}} \left(\frac{-\tau^2 + 4\pi t^2}{\tau^2} \right)$$

The MATLAB program involves a pulse generation with the help of Gaussian 2nd derivative which can be shown in figure 4. In this figure, a sequence of T_f = 1ns duration frame is shown. The generated wave form has a duration T_p= 2ns

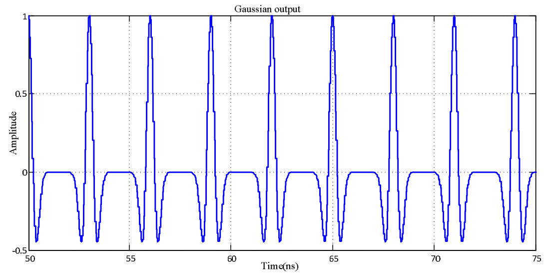

Fig .4. Time domain representation of the Gaussian pulse Generator output.

3.2. Emitter design

The TR-UWB-OOK emitter block diagram is presented in figure 5. It consists of several components such as the multiplier and the transition rate. In order to modulate the signal with binary data, a Rand-function is added to the emitter structure. Simulation results of the transmitted signal are presented in figure 6.

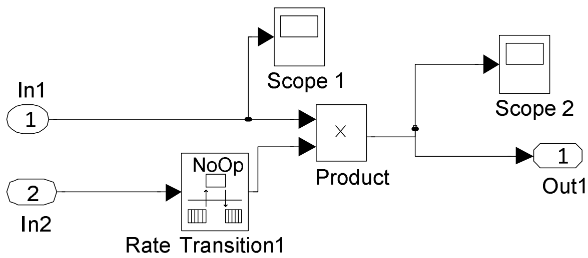

Fig.5. Block diagram of the OOK emitter

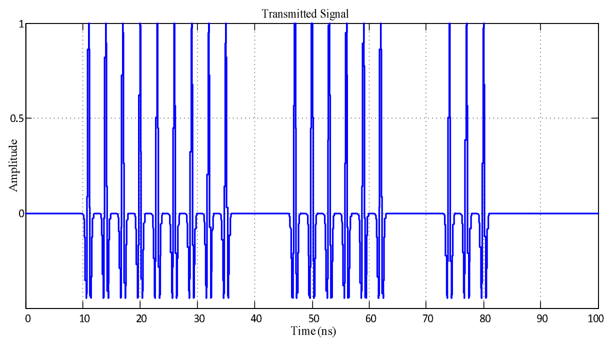

Fig.6: Time domain representation of the OOK transmitted signal

3.3. Receiver design

The IR-UWB-OOK receiver block diagram is shown in figure 7. The received signal is initially passed through a low noise amplifier (LNA) to be amplified with enough gain and low noise. The amplification value must be high enough to enhance the process of the weak received signals. Then, an ideal wide-band pass filter (BPF) with a 3.1-10.6 GHz band, equal to the received signal band width, filters the received signal to remove the interfering signals from nearby narrow band devices. Then, a square amplifies the RF signal to the desired base band frequencies. Then, this signal filtered by an LPF with 1.8 GHz band width. An integrator collects energy of base band signal over desired band width. After this energy detector/comparator converts the received pulse energy into a binary "1" or "0" based on the threshold energy value. Simulation results of IR-UWB-OOK receiver are presented in figure 8.

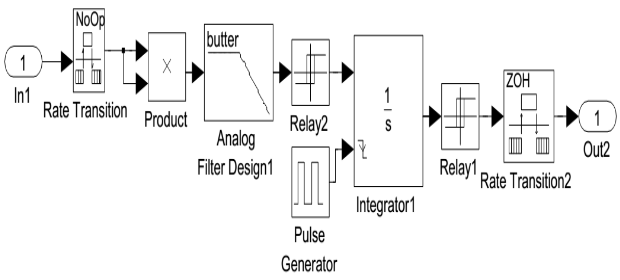

Fig.7.Block diagram of a UWB-OOK-receiver

A. LNA circuit

The LNA is one of the most critical components of UWB receivers. The LNA is provided to amplify the received signal with sufficient gain and as little additional noise as possible[12] .

The LNA's noise figure has a major impact on the systems overall noise figure. The LNA may have different circuit topologies; each method proposes to accommodate a wide bandwidth with a good input/output impedance matching, high gain, low noise figure and low consumption. The low noise amplifier whose role is to provide sufficient gain to overcome the noise of subsequent stages is the first stage of the receiver. This paper gives the design details of a wideband LNA having a linear phase property. The linear LNA design results in a good flat gain of 12.5 dB and a noise figure of 2.4 dB. Figure 9 shows the complete schematic for the wideband UWB LNA. It consists of a two stage form with a common source (CS) topology, and an overall cascode architecture design. The main advantages of the cascode architecture are its high, flat gain and low noise figure, but it suffers from a serious problem, specifically, a high power consumption. Therefore, a current reuse technique is used to solve this problem in this LNA circuit [13].

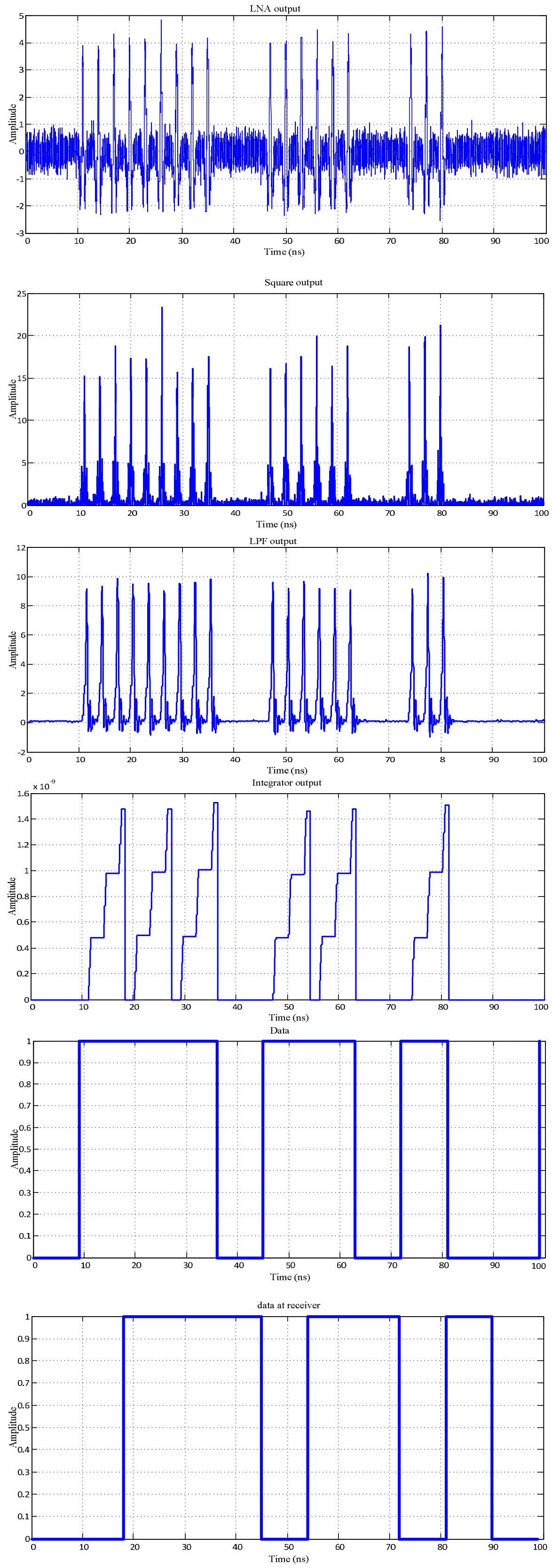

Fig.8. Simulation results of the TR-OOK-receiver

According to the methodology in [13], [14] , [15] by appropriately selecting the values of the first CS stage R_{FB} , L_{S1}, L_{G1} and the channel of M_1 transistor, the input impedance matching and noise figure are achieved simultaneously. However, the second CS stage, M_2 provides a high and flat gain by selecting the appropriate values of the channel of M_2 transistor, drain inductor L_{D2} , gate inductor L_{G2} and resistor R_{D2}. Fig 10 shows the simulated gain power, noise figure, the input impedance matching and the output impedance matching versus frequency characteristics of the UWB LNA. This LNA is incorporated into SIMULINK model of the UWB receiver as shown in figure 11.

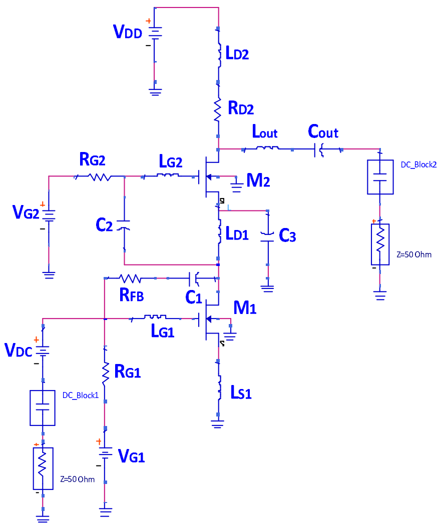

Fig.9. UWB LNA

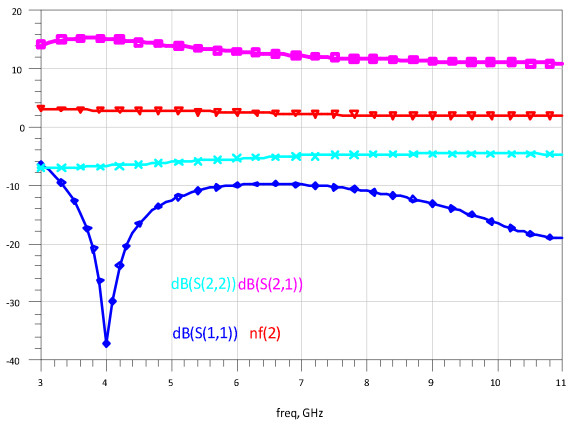

fig.10.Simulated results of UWB LNA

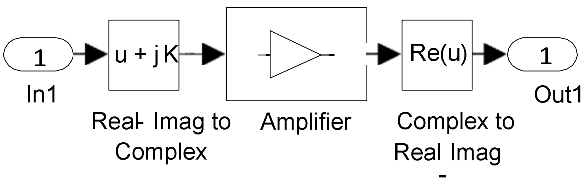

Fig.11. SIMULINK model for UWB LNA

4. Results and discussion

The simulation results for the BER performance of the IR-UWB energy detector receiver under different conditions were discussed in details in this section. All the simulations were carried out using Matlab/Simulink. To evaluate the performance of the UWB-OOK energy detector versus LNA non idealities, an LNA SIMULINK model was devised and incorporated in its receiver. The simulation was performed for 2000 iterations for SNR values of -10-0 dB in a pace of 2. The block diagram under simulation is shown in figure 3. The different values of the simulation parameters are selected in such a way that the whole system meets some standard regulations and acquires practical applicability. The various parameters and their values used during the simulation are described below in table 2.

Table 2
Different parameters and their values used during the simulation

Parameters for Gaussian signal	
Pulse repetition value	1ns
Pulse width	2ns
modulation	OOK
Pulse shape	2^{sd} order Gaussian
Parameters for the AWGN channel	
Initial seed	1000
mode	Signal to noise ratio (SNR)
Input signal power (watts)	0.314
Parameters for the wide band LNA	
Method	linear
Gain (dB)	12.5
Noise figure	2.4
Initial seed	1234

The performance analysis of BER versus SNR of the receiver with and without LNA is shown in figure 12. From this figure, the receiver with LNA achieves 0 of BER with SNR= 2dB However, receiver without LNA achieves 0.5 of BER with SNR = 2dB. It’s clear that the wide band LNA gives a better performance. At 8 dB, the UWB receiver BER performance with a wide band LNA is approximately the double of that ‘without’ LNA.

Afterwards, the receiver was simulated to analyze the effect of the LNA key parameters like gain and NF on its performance by keeping the rest of the receiver system as an ideal one. As we see from figures 13 and 14, it is clear that only gain variation (keeping other parameters constant) of LNA of LNA doesn't affect the BER performance. However, for the constant LNA gain, the change in the LNA noise figure directly affects the performance. A better performance is obtained for low noise figure as shown in figure 14.

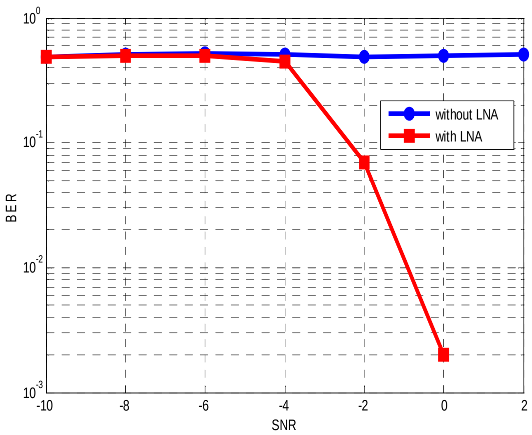

Fig.12. LNA effect on BER

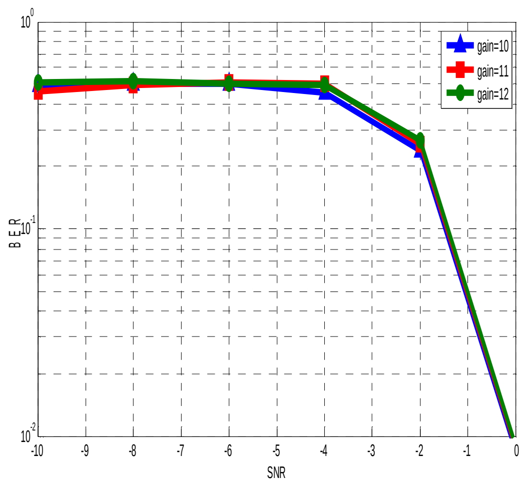

Fig.13. LNA gain effect on BER

5. Conclusion

In this paper, 3-10 GHz non-coherent UWB-OOK receiver was designed in SIMULINK. OOK modulation was chosen because of its low complexity and low power consumption. A comparison has been made between UWB-OOK energy detection 'with' and 'without' LNA. In order to achieve the design of a UWB receiver, a UWB LNA was designed with Agilent ADS system. The simulation results of the UWB LNA achieved a flat gain of 12.5 dB and a low noise figure of 2.4 dB.

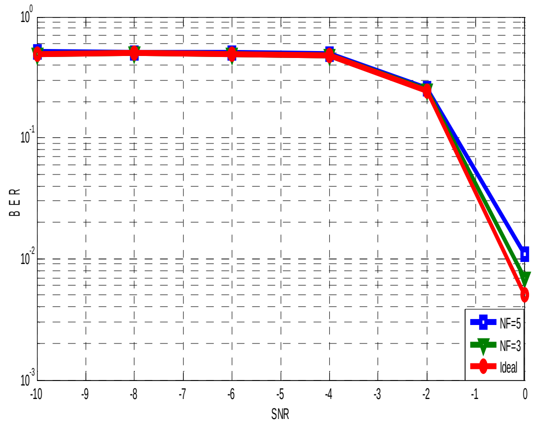

Fig.14. LNA NF effect on BER

These parameters specification are incorporated into a Simulink model of a UWB receiver. The BER performance of the receiver with LNA is better than that without LNA. Then, BER performance analyses by iteration simulation of a UWB-OOK receiver for different LNA gain and noise figures were proposed. For the constant LNA gain, the change in the LNA noise figure directly affects performance. Better performance is obtained with low noise figures.

References

1. T. R. Navineni, "Impact of non-idealities and integrator leakage on the performance of IR-UWB receiver front end," no. February, 2012.
2. I. Paper and R. W. Brodersen, "Cognitive Technology for improving Ultra-Wideband (UWB) Coexistence," pp. 253–258, 2007.
3. S. Erküçük, L. Lampe, and R. Schober, "Joint detection of primary systems using uwb impulse radios," *IEEE Trans. Wirel. Commun.*, vol. 10, no. 2, pp. 419–424, 2011.
4. D. Abbasi-Moghadam, A. Mohebbi, and Z. Mohades, "Performance analysis of time reversal uwb communication with non-coherent energy detector," *Wirel. Pers. Commun.*, vol. 77, no. 3, pp. 2291–2303, 2014.
5. D. Abbasi-Moghadam and V. Vakili, "A SIMO one-bit time reversal for UWB communication systems," *EURASIP J. Wirel. Commun. Netw.*, vol. 2012, no. 1, p. 113, 2012.
6. J. Taghipour, "Comparison of Kurtosis and Fourth Power Detectors with Applications to IR-UWB OOK Systems," *Int'l J. Commun. Netw. Syst. Sci.*, vol. 05, no. 01, pp. 43–49, 2012.
7. M. E. Şahin, I. Güvenç, and H. Arslan, "Joint parameter estimation for UWB energy detectors using OOK," *Wirel. Pers. Commun.*, vol. 40, no. 4, pp. 579–591, 2007.
8. J. Taghipour, V. T. Vakili, and D. Abbasi-Moghadam, "Estimation of the Threshold in Energy

and Kurtosis Detectors for IR-UWB OOK Systems," *Wirel. Pers. Commun.*, vol. 78, no. 2, pp. 1511–1526, 2014.

9. Z. Zou, F. Jonsson, L. R. Zheng, and H. Tenhunen, "A digital back-end of energy detection UWB impulse radio receiver," *2009 Norchip*, pp. 6–9, 2009.
10. H. a. Wheeler, "The Radiansphere around a Small Antenna," *Proc. IRE*, vol. 47, no. 8, 1959.
11. V. Yajnanarayana, S. Dwivedi, A. De Angelis, and P. Händel, "Spectral efficient IR-UWB communication design for low complexity transceivers," pp. 1–13, 2014.
12. A. Adsul and S. Bodhe, "Performance Comparison of BPSK, PPM and PPV Modulation Based IR-UWB Receiver Using Wide Band LNA," *Int. J.*, vol. 3, no. August, pp. 1532–1537, 2012.
13. a N. Ragheb, G. a Fahmy, I. Ashour, and a Ammar, "A 3 . 1-10 . 6 GHz Low Power High Gain UWB LNA," pp. 7–10, 2011.
14. W. D.-R. L. C. Wideband, Y. Lin, S. Member, C. Chen, H. Yang, C. Chen, J. Lee, G. Huang, and S. Lu, "Analysis and Design of a CMOS UWB LNA," vol. 58, no. 2, pp. 287–296, 2010.
15. M. Hajri, D. Ben Issa, and H. Samet, "New design of 3-10 GHz low noise amplifier for UWB receivers," pp. 7–11, 2015.