INTERNATIONAL JOURNAL OF ADVANCE RESEARCH, IDEAS AND INNOVATIONS IN TECHNOLOGY

ISSN: 2454-132X
Impact Factor: 6.078
(Volume 11, Issue 3 - V11I3-1151)
Available online at: https://www.ijariit.com

Application of Optical Communication in FMCW Radar

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ABSTRACT

Frequency-modulated continuous waves (FMCW) radars are long-range, frequency-modulated electromagnetic sensors that can perceive their environment in three dimensions. Recent introductions of RADARs with frequencies ranging from 60 GHz to 300 GHz have expanded their possible applications due to their improved precision in angle, range, and velocity. FMCW RADARs have a better resolution and are more accurate than narrowband and ultra-wideband (UWB) RADARs. They offer several important benefits, such as long-range perception, resistance to rain and lightning, and more, and they are less costly than cameras and LiDARs. Even yet, their outputs are less dense and noisy than those of other RADAR technologies, and their ability to measure target velocities requires the employment of specifically created algorithms.

Recently, radar sensors have become more and more common in a variety of industries, such as automotive, defense, and surveillance. This is because radar sensors can withstand a wide range of conditions, such as extreme heat, bright light, and bad weather. The simulation results were performed using Optisystem 22.0 and MATLAB (R2024b). The results demonstrate that 40 mW of power is effectively utilized for target identification, with the best technique for moving targets being direct detection.

Keywords: *RADAR, Sensors, Surveillance, Target Detection*

INTRODUCTION

A specific type of radar system known as a frequency modulated continuous wave radar, or FMCW radar system, is used to estimate the distance and velocity of moving objects. To do this, a modulating signal is used to continuously alter the frequency of the broadcast signal at a specific rate over a predefined period of time. Numerous frequency modulation techniques may be used to change the frequency pattern of the radio wave that is transmitted; sawtooth and triangle wave modulations are the most often used approaches. Additional methods include sawtooth modulation, stepped modulation, square wave modulation, sine wave modulation, and triangular modulation.

FMCW lidars are fundamentally different from the pulsed and AMCW approaches. Both pulsed lidars and AMCW rely on changing the intensity of the light. The photons are often treated as particles by the receivers of these lidars, which encode the range information in their arrival timings. However, FMCW lidars rely on the wave properties of the light. These lidars employ an interferometric detection method in their receivers, which apply the modulation to the light field frequency. Consequently, the broad frequency bandwidth of the optical domain becomes accessible and may be utilized to improve lidar performance. The light frequency of the transmitter is linearly modulated with respect to time in FMCW lidar. The echo light reaches the receiver following the round-trip delay τd.

FMCW lidars and the pulsed and AMCW approaches are fundamentally different. Changing the intensity of the light is essential for both pulsed lidars and AMCW. These lidars' receivers often encode the range information in their arrival timings by treating the photons as particles. FMCW lidars, however, rely on the wave properties of the light. The light field frequency in these lidars is modulated, and an interferometric detection method is used by their receivers. This opens up the large frequency spectrum of the optical domain, which may be utilized to improve lidar performance. In FMCW lidar, the light frequency of the transmitter is linearly modulated in relation to time. The receiver receives the echo light following the round-trip delay τd.

$$R=\frac{1}{2}c\cdot\tau_{d}=\frac{1}{2\gamma}c\cdot f_{d} \quad (1)$$

where $\gamma=(\Delta f_{max})/T$ is the frequency modulation vs. time slope, given in Hertz per second. This formula demonstrates that the range precision depends on the accuracy of regulating or understanding the modulation slope γ as well as the measurement precision of fd.

LITERATURE REVIEW

System Design

Two target detection scenarios—direct detection and coherent detection—are covered in this section. Figure 1 for coherent detection and Figure 2 for direct detection show the configurations assessed in Optisystem 22.0. The structure provides a clear representation of the parameters taken into account throughout the study. Target reflectivity, optical transmission loss, and atmospheric loss factor are all assumed to be 1 for the free space channel model. The laser provides 40mW of power, and the operating frequency is 1550nm. Direct detection methods generate short bursts of light (a few nanoseconds) using a pulsed laser. The LIDAR sensor measures the amount of time needed to receive the pulse of reflected light.

By analyzing the time it takes for light to reach and return to the target, it calculates the distance to objects in the surrounding area.

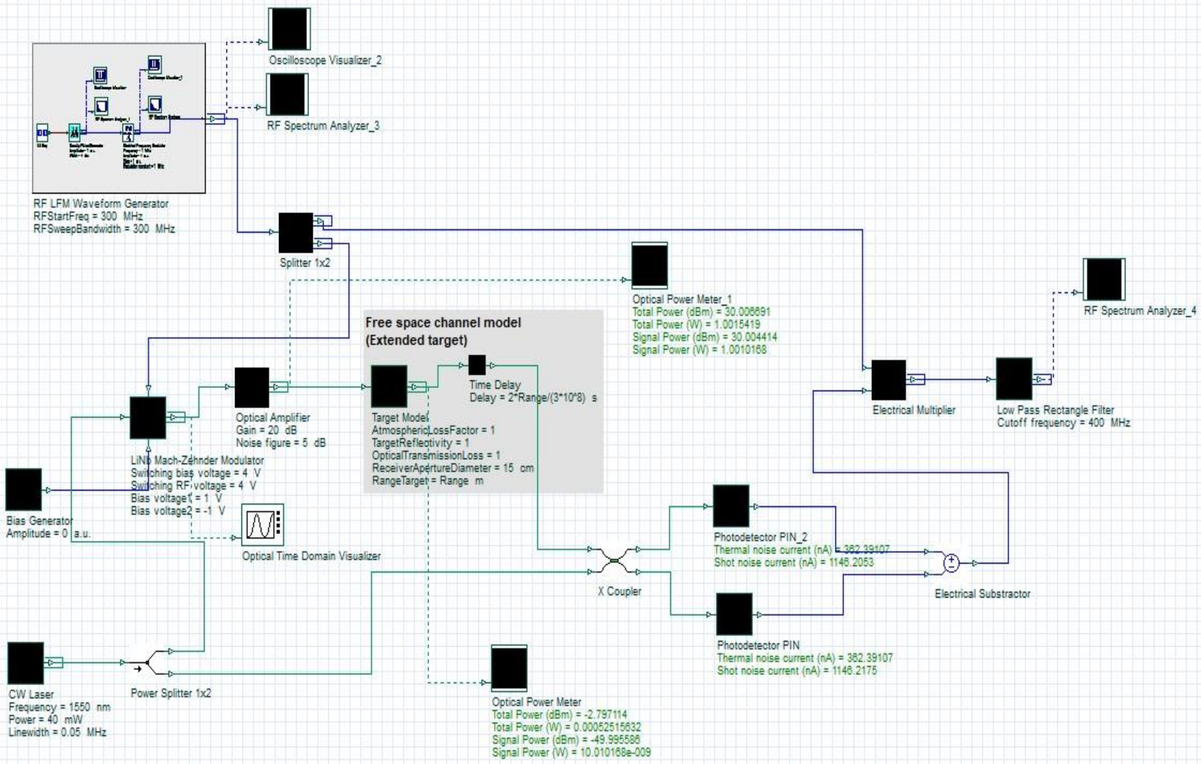


Fig.1 Optisystem Layout for Lidar Coherent detection

In coherent detection, a modulated laser is active for a long time after the return signal is optically coupled with a sample of the transmitted photodetection (also known as the local oscillator) before photodiode detection. This optical mixing causes the received signal to be amplified by the local oscillator. By utilizing a sample of the send signal, it is possible to ensure that the phase connection between the transmit and receive channels is preserved (or coherent). Similar to direct detection, distance is calculated using the time gap between photon transmission and reception.

In the case of coherent detection, on the other hand, modulation is applied to the continuously (or quasi-continuously) transmitted signal. The echo timing is determined via appropriate demodulation, which requires more signal processing than direct detection because the laser is continually transmitting. Instead of following target movement over many frames like direct detection does, coherent detection enables us to compute velocity immediately and instantaneously by distinguishing the frequency change of the returned signal caused by Doppler. The following parameters were used for coherent detection:

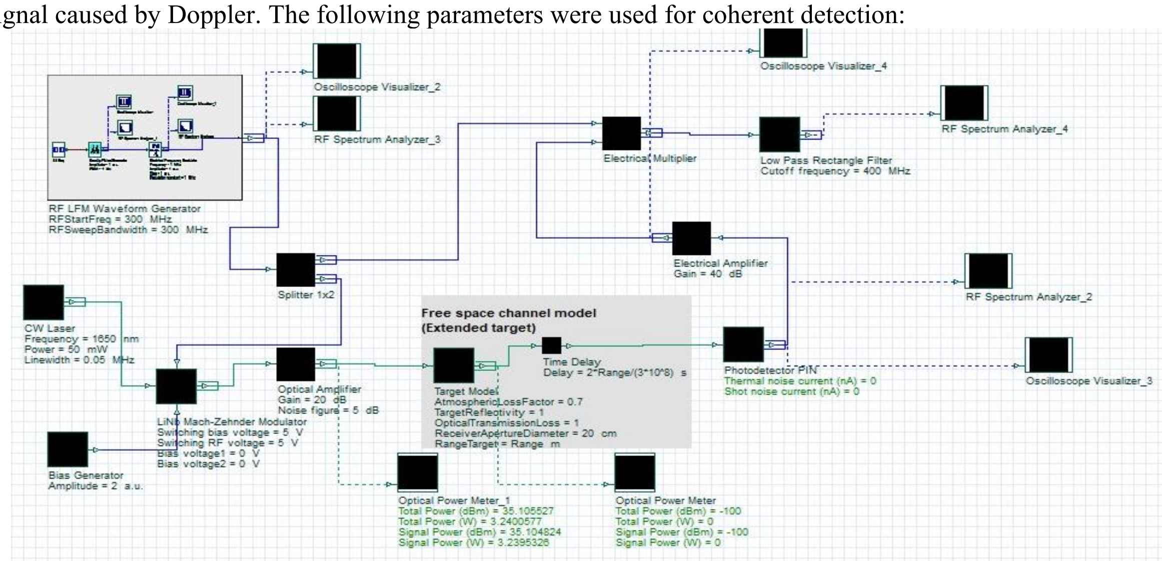


Fig.2 Optisystem Layout for Lidar Direct detection

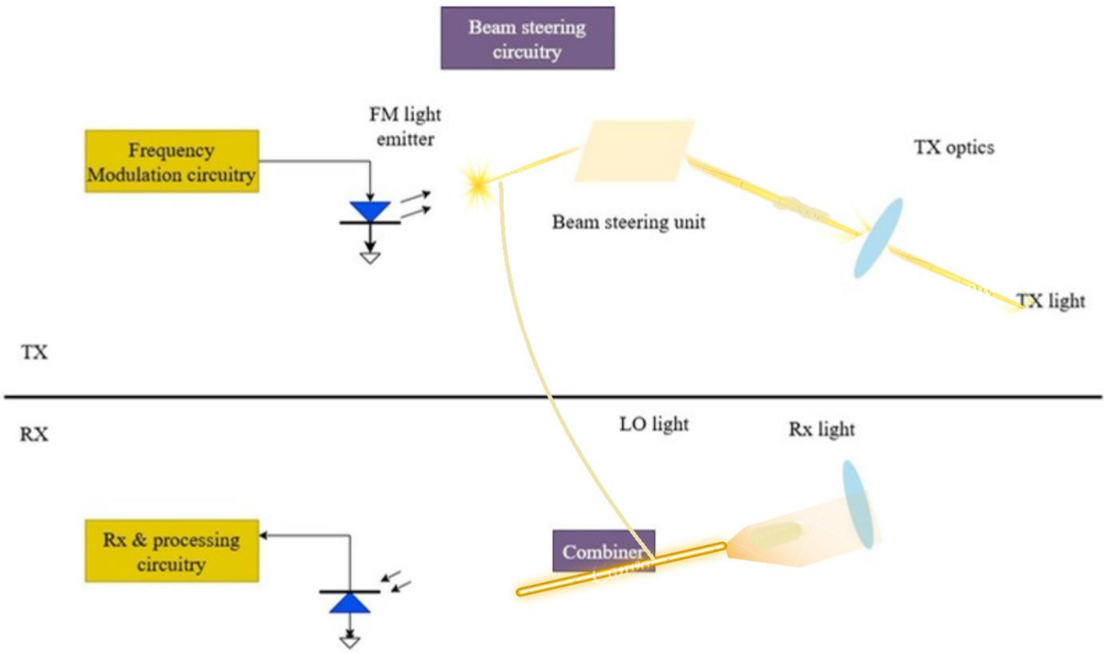


Fig.3 Concept of Optical target detection

As seen in Fig. 3, a LIDAR system emits photons and calculates how long it takes for them to reach and return from a target. While there are many considerations when developing a LIDAR system, including scanning technique, wavelength to use, and interference management, the choice of how to detect returning photons affects almost all other system decisions. Since LIDAR has become a popular issue in the sensor sector, there is a debate about whether direct-detection (or time-of-flight) or coherent (e.g., frequency modulated continuous wave) photon detection is preferable. The term "best" actually depends a lot on the application.

Through a discussion of the many aspects of direct and coherent detection, this study aims to educate researchers and empower them to make educated system decisions.

Results & Discussion

The improvement in performance parameters following the simulation of the two layouts was covered in this section. The eye diagram, quality factor, and spectral power of the developed system are examined. One of the fundamental measures for assessing channel designs in digital systems is an eye diagram. This involves overlaying a time domain sampling trace, such as an oscilloscope, with the rising and falling edges of a bitstream. A signal integrity simulator may be used to perform the same type of signal level superposition. By superimposing the rising and decreasing edges, it is easy to understand how variable the signal behavior is.

When successive signals interfere with one another due to problems with signal integrity, this is known as intersymbol interference. Examining intersymbol interference brought on by succeeding bits might help identify specific problems in a digital channel. Oscilloscope visualizer2 displays the signal waveform for both setups in Fig. 3. Fig. 4 provides a good illustration of the power distribution in the various frequency components of the optical signal.

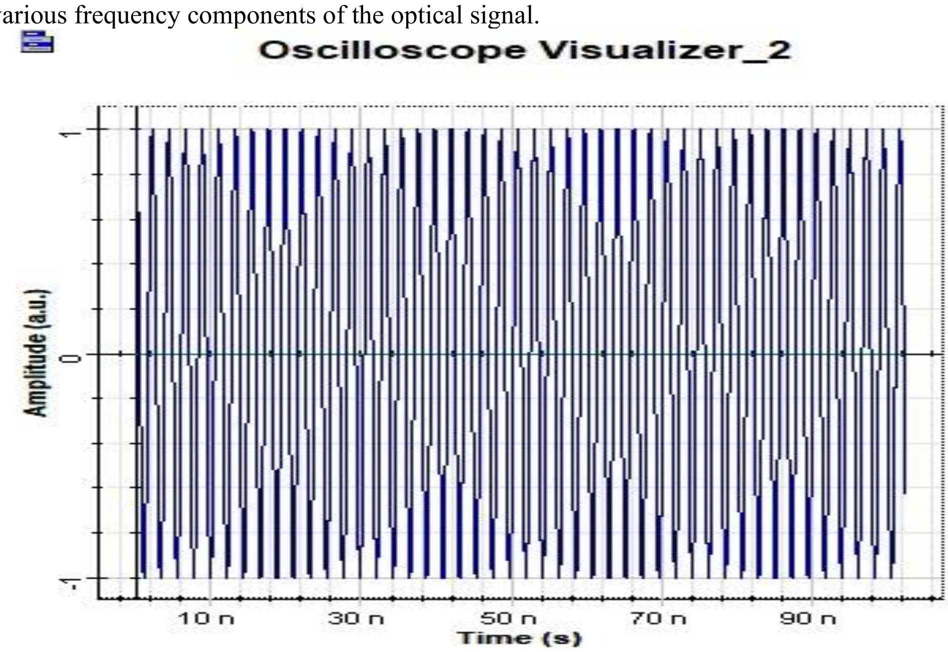


Fig.3 Signal waveform from RF LFM waveform generator

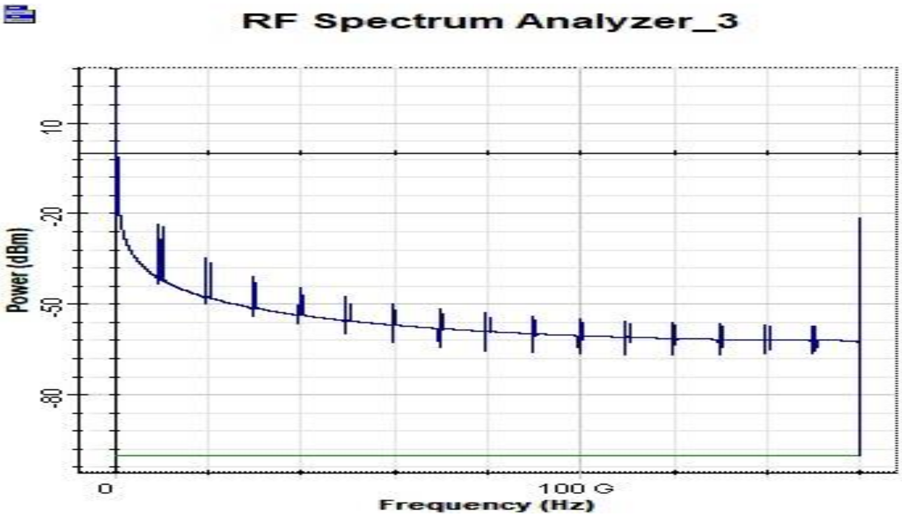


Fig.4 Spectral power curve for input signal

Power spectral density can be used to characterize random, broadband signals. By examining the frequency composition of signals, this feature aids in guiding the development of relevant filters in signal processing applications. In telecommunications, the PSD enables the analysis of interference signals, noise characterisation, and bandwidth usage. For sonar and radar applications, PSD is quite useful for tracking signals and targets of interest. Fig. 5 shows the graph for the same.

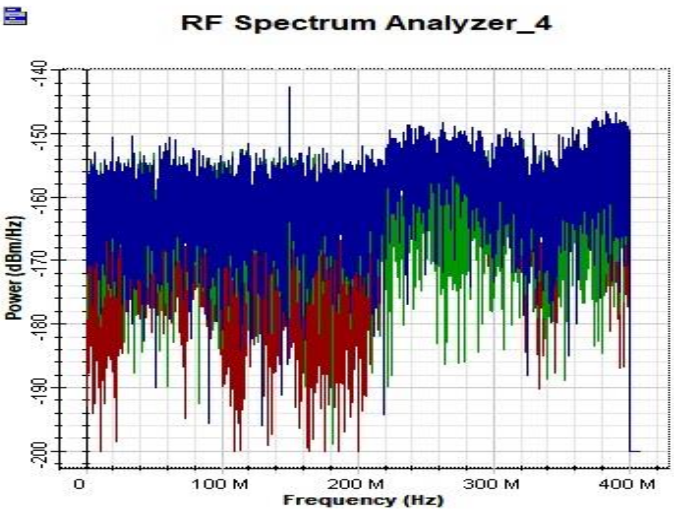
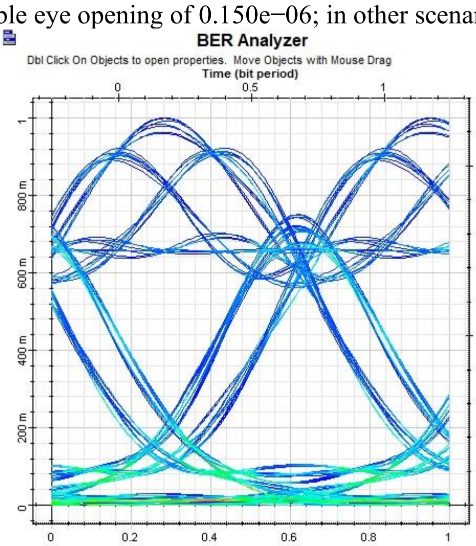
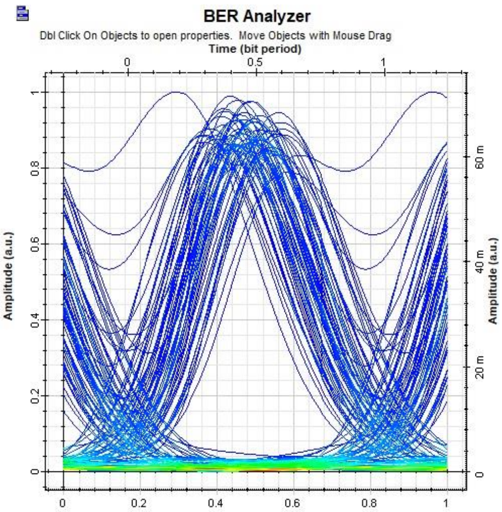


Fig.5 Spectral power curve for Target detection

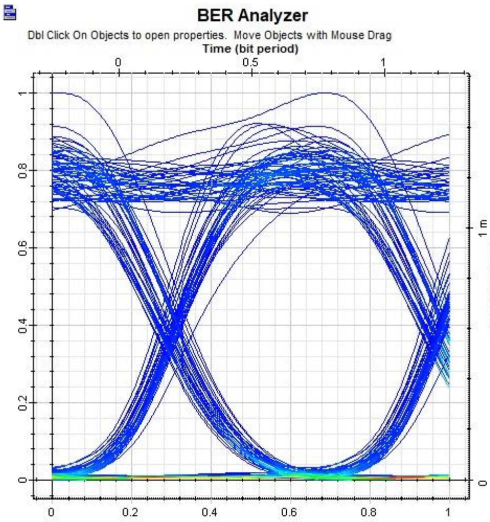
The communication system's eye diagram, which is shown in Fig. 6, specifies the signal's integrity and quality by displaying a clearer waveform for the system, ensuring less inter-symbol interference. For 40 mW power, it exhibits a very low BER of -6.5 dB and a very acceptable eye opening of 0.150e−06; in other scenarios, the BER is bigger (-6.6 dB) and the eye opening is less.



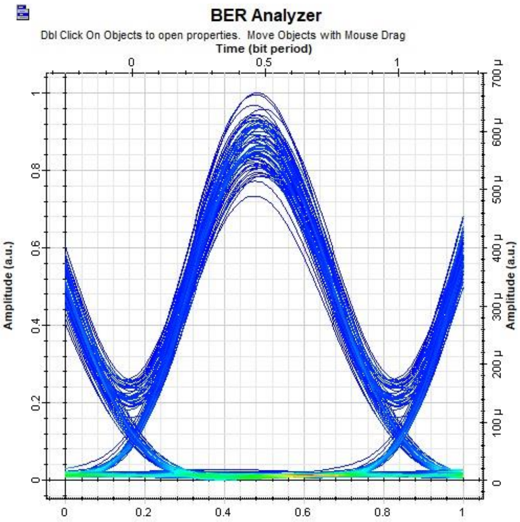
(a)



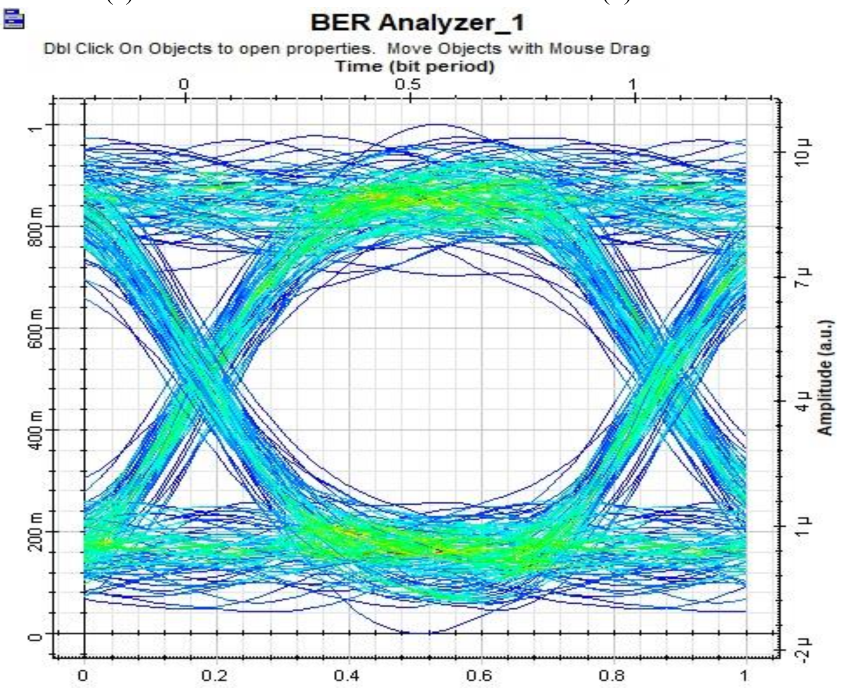
(b)



(c)

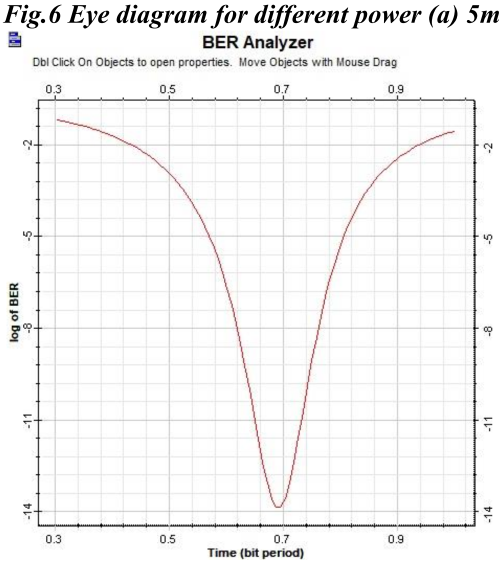


(d)

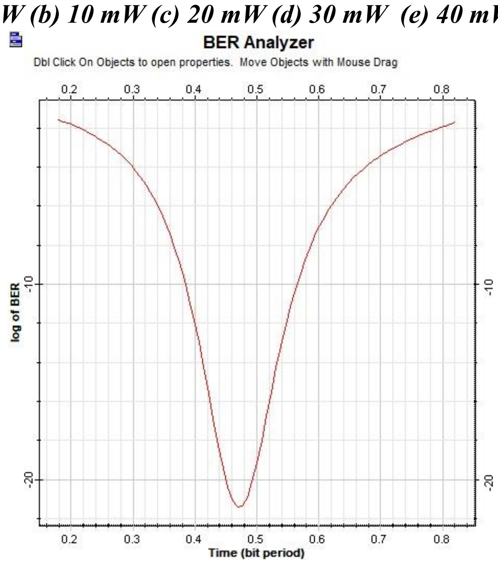


(e)

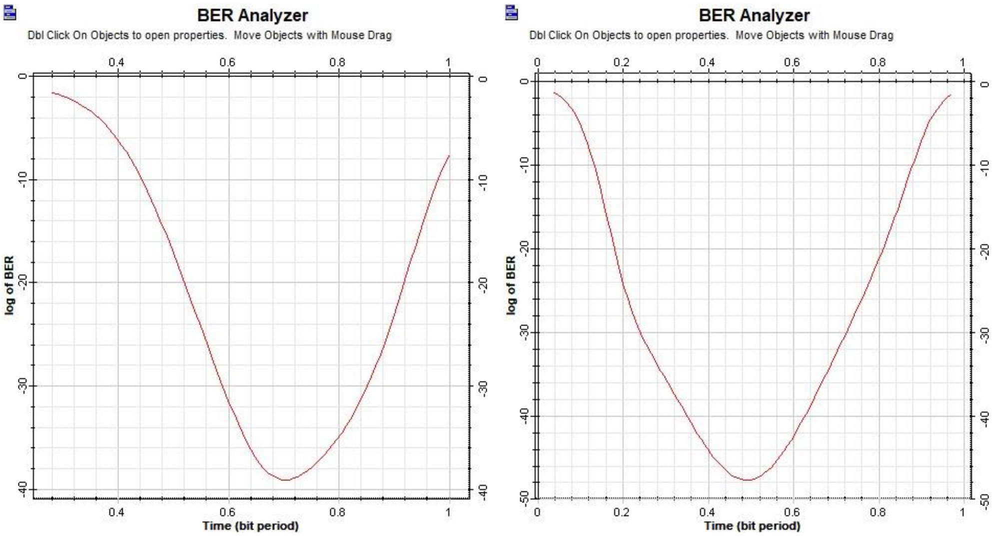
Fig.6 Eye diagram for different power (a) 5mW (b) 10 mW (c) 20 mW (d) 30 mW (e) 40 mW



(a)



(b)

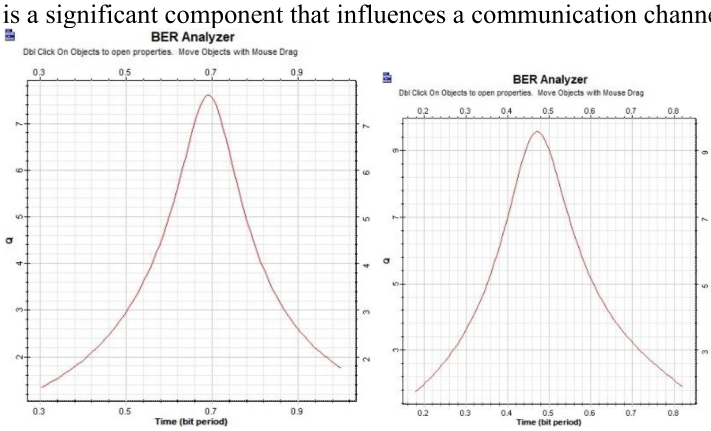


(c) (d)

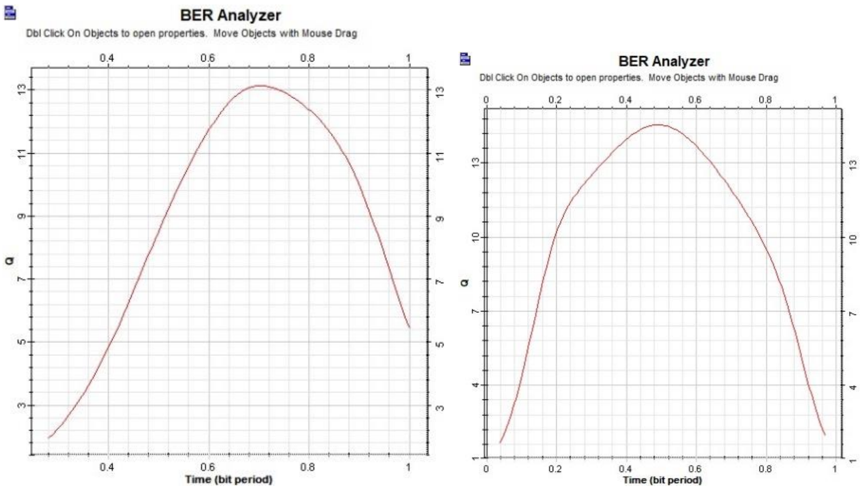
Fig.7 BER for different power (a) 10mW (b) 20 mW (c) 30 mW (d) 40 mW

The ratio of mistake-containing bits to all received bits in a transmission is known as the bit error rate, or BER, in telecommunications. For example, a transmission with a BER of 10-6 means that one bit out of every million bits sent was wrong. The BER shows how frequently data needs to be retransmitted because of a mistake. Because the BER may be reduced, requiring fewer packets to be present, a too high BER may indicate that, for a given amount of data sent, a slower data rate may actually result in a shorter transmission time (as illustrated in Fig.7).

The speed at which data is transmitted and received is determined by the signal's Quality (Q); the greater the Q number, the higher the signal quality. The Quality Factor measures the noise level of a pulse for diagnostic purposes. The Q Factor number is often displayed in a report generated by the eye pattern oscilloscope. The Q-Factor suggests the minimum signal-to-noise ratio (SNR) required to attain a specific BER for a given transmission. OSNR is measured in decibels. As bit rate increases, so does the required OSNR ratio. The Q component is a significant component that influences a communication channel's performance (Fig. 8).



(a) (b)



(c) (d)

Fig.8 Quality factor for different power (a) 10mW (b) 20 mW (c) 30 mW (d) 40 mW

CONCLUSION

Using the principles of photonics, optical lidar has emerged as a potentially revolutionary technology that revolutionizes remote sensing and target recognition. The protocol has been the subject of much speculative conjecture and criticism over its practicality, particularly in relation to Lidar. This research provides a thorough evaluation and performance enhancement of direct detection and coherent detection systems in the region, with a focus on radar and its potential as an underlying scheme for optical target detection. MATLAB (R2024b) and Optisystem 22.0 are the tools used to perform the simulation results. The findings show that 40mW of power is efficiently used for target detection, with direct detection being the most effective method for moving targets.

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