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Optical Transceiver Design And Geometric Loss Measurement For Free Space Optic Communication

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ABSTRACT:- This paper discuss optic transceiver design and measurement of free space optical channel characteristic in term of the geometric loss. FSO is a point to point communication system in free space using infrared LED or laser as light source. FSO is supposed to be a counterpart of existing conventional microwave radio link in the future. Its application may be prefered due to some advantages such as unlicensed operation, free of electromagnetic interference and easy to deploy where cable run is not possible. Issue, such as, noise caused by surrounding light have to be taken into acccount therefore modulation scheme is used to prevent the noise and the use of aspheric plano convex lens are also made to solve a problem of optical link range. Two designs of optical transmitter with and without lens are also investigated and analyzed to figure out their geometric losses. Test and mesurement are conducted either in the indoor and outdoor environment. The test result shows that the optical link range is achieved within 300 meters at data rate of 100 Kbps and some curves of geometric loss are also produced to help optical link attenuation calculation.

Keywords:- FSO, laser, LED, geometric loss

I. INTRODUCTION

Free Space Optics (FSO) is an exelent supplement to conventional radio link and fiber optics. It is a broadband wireless solution to solve last mile problem through metropolitant networks *[1]*. FSO design and realization was actually already conducted using LED as a pilot project to demonstrate the viability of an optical free-space visible light transceiver as a basis for indoor wireless networking *[2]*. The performance of FSO as line of sight point to point communication depends on atmospheric turbulence and weather condition.*[3] [4]*. Based on experiments made, not only the atmosphere and weather can affect the FSO performance,but also noise from the surrounding environment can also affect its performance.

In this paper has been realized the optical transceiver for FSO communication to transmit serial data over laser in duplex mode. Data format are sent with transfer data program made by Visual Basic 6. The data that are sent will be converted to TTL signal via USB to TTL converter. This signal will then drive laser diode to modulate the light using ASK modulation technique.

II. BASIC THEORIES

2.1 Light and Electromagnetic Spectrum.

The electromagnetic spectrum as demonstrated in Fig 1, can be expressed in term of wavelength, frequency, or energy. Wavelength (λ is given by expression (1) :

$$\lambda = \frac{c}{v}$$

Where c is the speed of light (2.998 × 108 m /s). The energy of the various components of the electromagnetic spectrum is given by the expression (2) :

$$E = hv$$

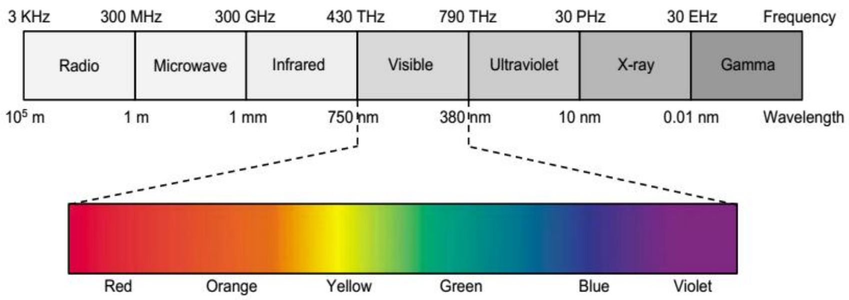

Fig. 1: The electromagnetic spectrum

Where h is Planck`s constant = 6.63 × 10-34 Joule seconds. The units of wavelength are meters with the terms microns (denoted μm and equal to 10-6 m) and nanometers (10-9 m) being used just as frequently. Frequency is measured in Hertz (Hz), with one Hertz being equal to one cycle of one cycle of sinusoidal wave per second. A commonly used unit of energy is the electron-volt. There are several transmission windows that are nearly transparent (attenuation < 0.2 dB/km),between 780 nm and 1600 nm wavelength range. These windows are located around several specific center wavelengths and characterized by low attenuation, the 850 nm window is very suitable for FSO operation [5].

2.2 Geometric Loss (GL).

The geometric path loss for an FSO link depends on the beam-width of the optical transmitter θ , its path length L and the area of the receiver aperture A_r . The transmitter power, P_t is spread over an area of π (Lθ)2 / 4. Geometric loss is the ratio of the surface area of the receiver aperture to the surface area of the transmitter beam at the receiver. Since the transmit beams spread constantly with increasing range at a rate determined by the divergence, geometric loss depends primarily on the divergence as well as the range and can be determined by the formula stated as (3):

$$\text{geometric loss} = \frac{d_2^2}{\left[d_1 + (L\theta)\right]^2}$$

Where:
*d*2 is the diameter receiver aperture (unit: m);
*d*1 is the diameter transmitter aperture (unit: m);
θ is the beam divergence (unit: mrad);
L is the link range (unit: m).

Geometric path loss is present for all FSO links and must always be taken into consideration in the planning of any link. This loss is a fixed value for a specific FSO deployment scenario; it does not vary with time, unlike the loss due to rain attenuation, fog, haze or scintillation [5].

2.3 Modulation Scheme.

Basically the optical carrier can be modulated in its frequency, amplitude, phase. And amplitude-shift keying (2 ASK) technically is the simplest digital modulation scheme among the others. In optical systems it is referred to as on-off keying (OOK). OOK is an intensity modulation scheme where the light source (carrier) is turned on to transmit a logic ”one” and turned off to transmit a ”zero”. In its simplest form this modulation scheme is called NRZ (non-return-to-zero)-OOK. Besides NRZ also other codes exist. The most common one besides NRZ is RZ (returnto-zero) coding. The advantages of RZ compared to NRZ are its higher sensitivity and the fact that the clock frequency lies within the modulation spectrum. Both NRZ and RZ can lead to loss of clock synchronization if long strings of ones or zeros are transmitted. This can be avoided with other coding systems such as Manchester coding, which is related to RZ but amounts to state changes at the beginning or in the middle of clock cycles. With such a variant of RZ the clock of the digital signal can easily be recovered. According to Nyquist–Shannon theorem, RZ has twice the bandwidth of NRZ However RZ can also work when using the same bandwidth as for NRZ.

For OOK, the exact wavelength of the carrier and its phase are irrelevant for the demodulation. The receiver just directly detects the currently incoming power and compares it against a certain level. OOK is sensitive to amplitude distortion (fading) and propagation through different routes, while the second one is negligible for clear-sky conditions. Atmospheric obscuration e.g. in clouds can lead to significant attenuation of the received signal but is less important for FSO systems operating under clear-sky conditions.

Another modulation scheme that can be used in optical communications systems is Coherent modulation Usually, a binary coherent modulation scheme is used. For example binary phase shift keying (BPSK), where the phase of the coherent laser light is shifted between two states. Coherent receivers rely on the superposition of the received light with the light of a local oscillator. Instead of the local oscillator self-homodyne is also possible. This is used in differential phase shift keyed (DPSK) systems, which are less sensitive than BPSK systems. In BPSK systems typically some kind of optical phase-locked loop is required, which allows the local oscillator laser to be tuned exactly to the same frequency (or a frequency with a constant offset) and phase as the received carrier. The sensitivity of coherent receiver implementations is approximately one to two orders of magnitude better than the sensitivity of OOK systems, but at the cost of higher system complexity and additional sensitivity to phase distortions of the received beam [6].

III. DESIGN

Design of optical transceiver is based on the specification in table 1 and block diagram shown in Fig 2 below

Table. I: Design specification

Maximum Range	100-300 meters in line of sight condition
Data rate	100 Kbps or higher
Mode	Full Duplex
Computer interface	COM Port RS232 (Serial port)
Laser beam Modulation	On-Off Keying
Laser wavelength	650 nm
Laser power	< 5mW peak pulse power < 1mW average power
Laser Class	Class 3
Power requirements	5 VDC

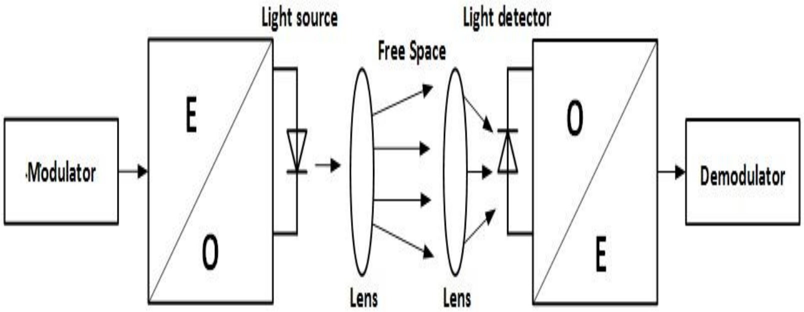

Fig. 2: Block diagram of optical transceiver

The transceiver is basically split into two section they are transmitter and receiver. Function of each block diagram are described as follows; on transmission side, serial to TTL function as a converter from serial data to TTL format. This TTL signal is then modulated with 38 KHz carrier oscillator signal to switch laser diode ON and OFF like ON-OFF Keying (OOK) modulation. Laser as light source operating on wavelength about 650 nm therefore it belongs to visible light source. Laser used is 650nm Red Laser Diode [7]. Schematic diagram of the transmitter is shown is Fig 3.

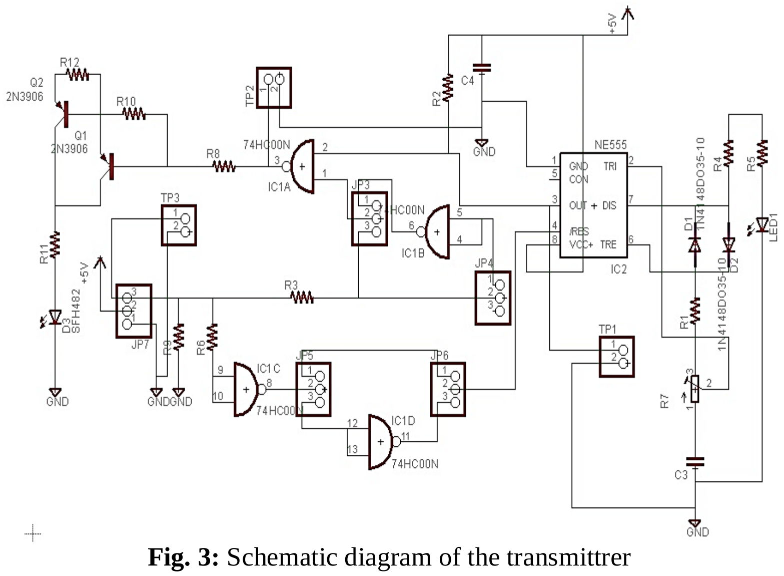

Fig. 3: Schematic diagram of the transmittrer

While on reception side, the main device is TSOP 4148 optical detector [8]. This photo diode operates from 450 – 1050 nm. It does not only receives signal from transmitter but also demodulates carrier signal. Fig 4 shows schematic diagram of the receiver.

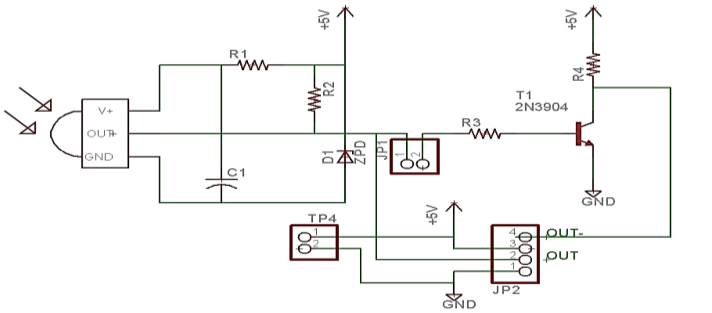

Fig. 4: Schematic diagram of the transmittrer

IV. HARDWARE REALIZATION

First of all the circuirs are experimented and tested in protoboard. And then all the circuits are realized in PCB layout like shown in Fig 5 and Fig 6.

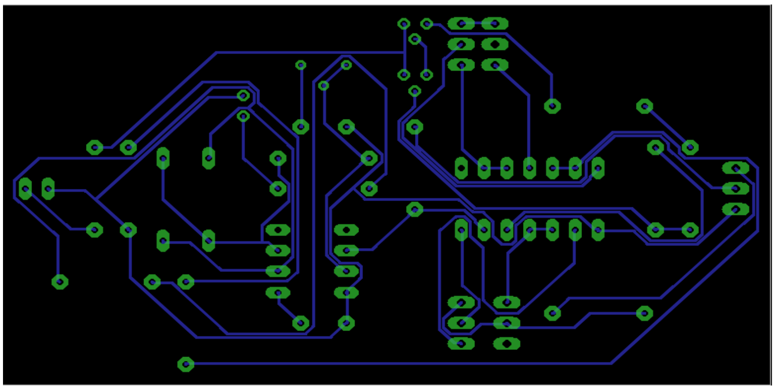

Fig. 5: PCB of the modulator

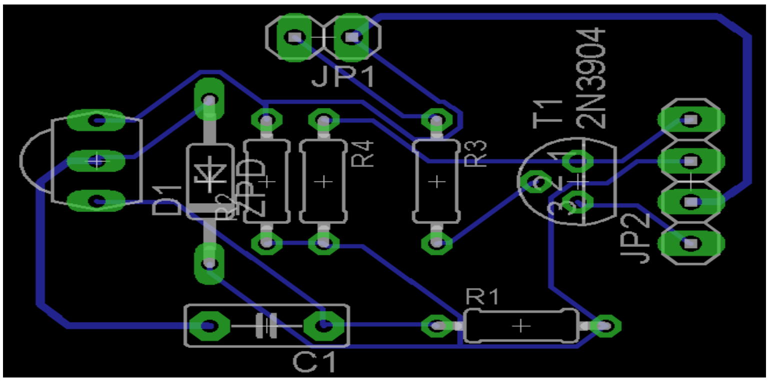

Fig. 6: PCB of the receiver

After that all the PCB's are put in plastic chassiss in which convex lens are already mounted like shown Fig 7.

Fig. 7: Chassis of optical transceiver

V. TEST AND MEASUREMENT

5.1 Optical Transceiver Test.

A test setup of the optical transceiver is illustrated in Fig.8. The heart of the transmitter is a light source. The major function of a light source is to convert an information signal from its electrical form into light. , as a light source is laser diodes. And the key component of an optical receiver is its photo detector. The major function of a photo detector is to convert an optical information signal back into an electrical signal (Photocurrent). Prior to testing the lasers has to be pointed towards the other transceiver with distance of 200 meters. And then run a communication test program written in VB 6.0. This test demonstrates data communication between transmitter and receiver. Data received at the receiver is then looped back or sent back to the transmitter to be compared with the sending data. There are two tests to be conducted to investigate whether there is no data errors are in the transmission.

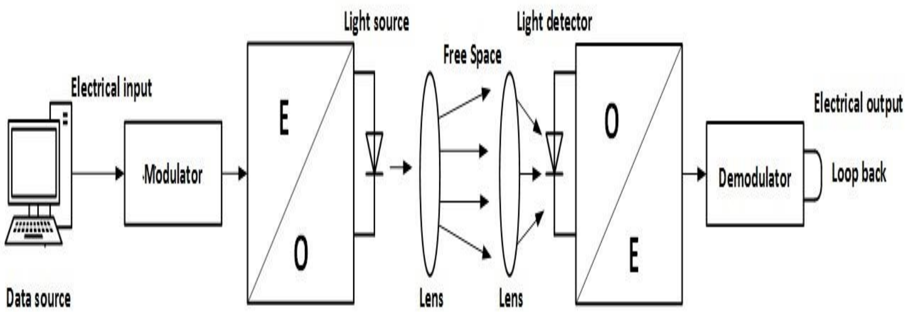

Fig. 8: Test setup

The first test is to measure bit error ratio (BER). 1024 bits are sent from the transmitter and 1024 bits have been received. So there is no bit errors or bit missing during transmission. Fi 9, 10. In the left side shows test result with no errors when the receiver and the transmitter are aligned properly. While the one in the right side shows bit errors when beam intensity and beam spread vary due to inproper alignment.

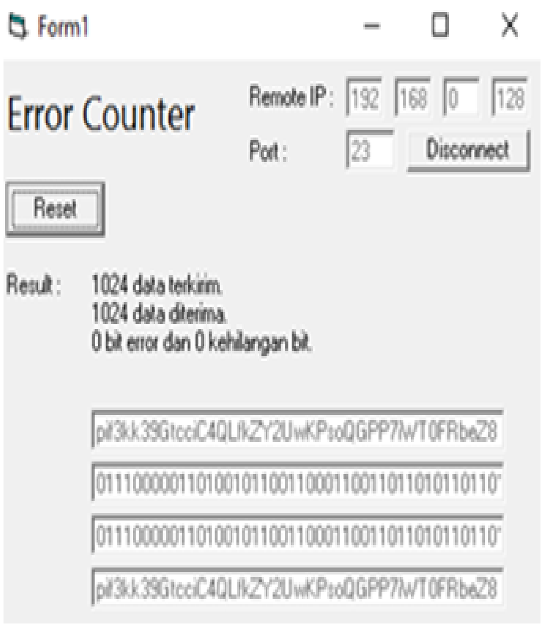

Fig. 9: Transmission with no errors

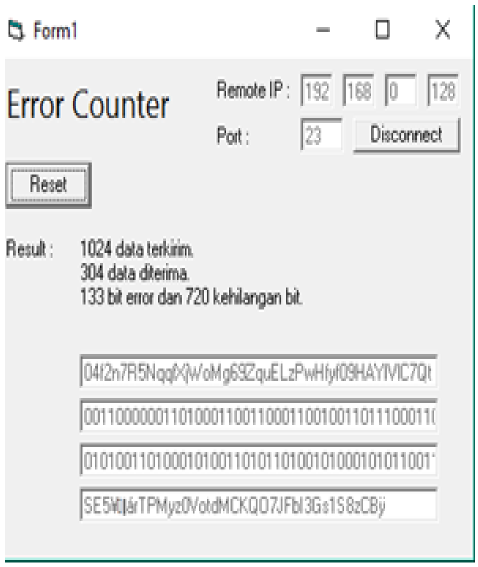

Fig. 10: Transmission with errors

The second test is to send text “polban juara” . The results show the text sent is similar to the received one like shown in Fig 11 and Fig 12.

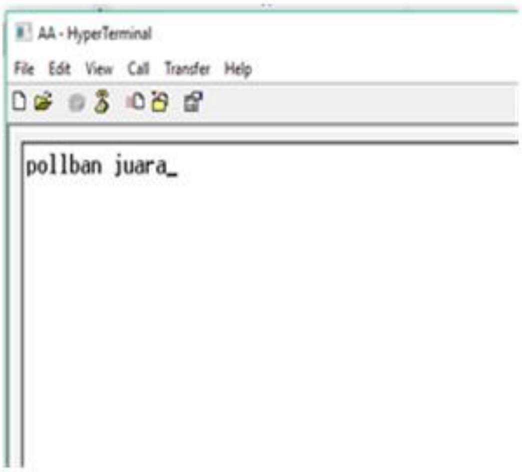

Fig. 9: Sending text data

Fig. 10: Receiving text data

5.2 Geometric Loss Measurement.

The geometric loss measurement is intended to investigate performance of light source, namely laser diode. the light source shall be tested with and without 40 Jmm diameter aspheric-Plano-Convex lens. Let us call design 1 without lens and design 2 with lens. Using quick method, the focal length of the optical element is moved horizontally back and forth until a sharp image of the light source is projected on the wall (surface of other things that can be used as a screen) [9]. Small angles – divergence angle and spot size between transmitter and receiver are presented in Fig. 13.

1° ≈ 17 mrad → 1 mrad ≈ 0.0573°
θ is a divergence angle between transmitter and receiver FSO units.

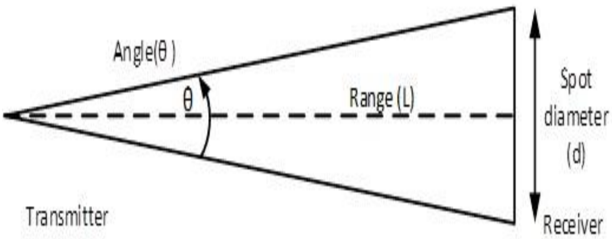

Fig. 11: Small angles – divergence and spot size between transmitter and receiver.

To find out divergence angle we can use trigonometric identities as stated in (4) :

$$\frac{1}{2}\theta = tan^{-1}\left(\frac{\frac{1}{2}d2}{L}\right)$$

To convert degrees to radian units one can use this formula (5) :

$$A = \theta \; x \; \frac{\pi}{180}$$

Where: A (radian)
θ (degree)

Fig 14, 15 ilustrate setup diagram to measure receiver aperture diameter and divergence angle to figure out the geometric loss without lens and with lens repectively. And table 2,3 show certain measurement condition. and calculation.

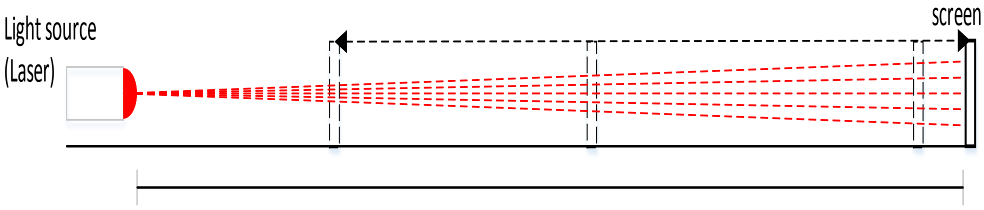

Fig. 12: Setup diagram to measure geometric loss without convex lens

Table. II: Measurement condition and calculation without lens

Jarak Layar (cm)	Diameter *aperture* pengirim (mm)	Diameter bayangan pada layar (mm)	Sudut Divergensi (mrad)
200	1,5	31	1

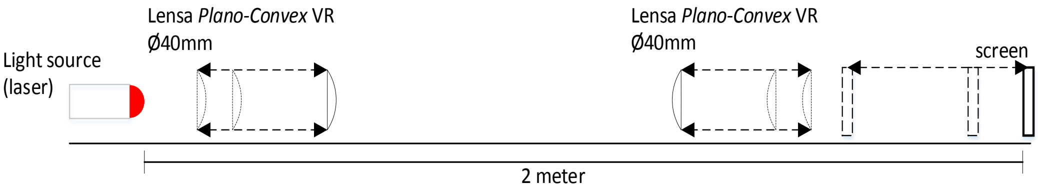

Fig. 13: Setup diagram to measure geometric loss with convex lens

Table. III: Measurement condition and calculation with lens

Range (cm)	Focal lenght (mm)	Transmittrer aperture diameter (mm)	Spot diamter on the screen (mm)	Receiver aperture diameter (mm)	Divergence angle (mrad)
200	56	40	19	40	0,16

To measure and calculate geometric loss with respect to distance, transmitter aperture, receiver aperture and divergence angle use expression (3) by making one factor becomes variable, for intance distance, while the other ones stay the same. Fig 16,,17,18,and 19 show curves of the geometric loss measurement and calculation with repect to different variables , i.e distance, the diameter of transmitter and receiver apertures and laser beam divergence. There are a number of parameters that control geometric loss: transmission range, the diameter of transmitter and receiver apertures and laser beam divergence. These parameters also contribute to the design of FSO system, so that it is suitable during bad weather conditions. From Fig 15, geometric loss is proportional to link range, which shows that the link range increases with the increases of geometric loss. Fig16 demonstrates the geometric loss versus the transmitter aperture diameter. This figure shows that thetransmitter aperture diameter rises with increases of the geometric loss. That means the small transmitter aperture diameter is suggested to minimize in the geometric loss effect on FSO systems.

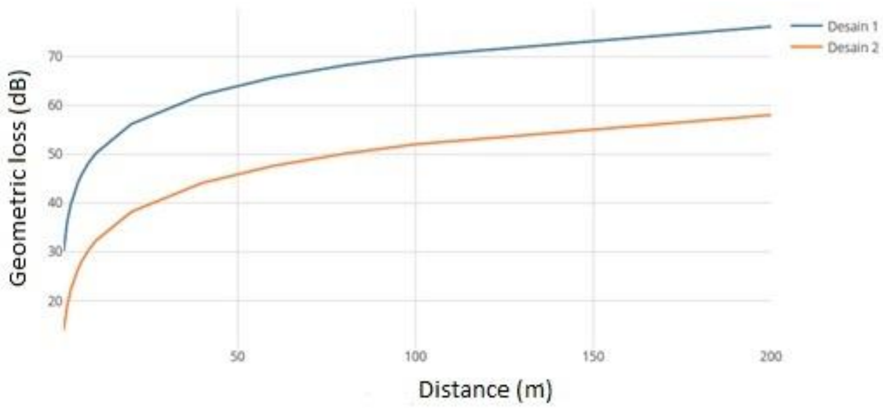

Fig. 14: Geometric loss vs distance

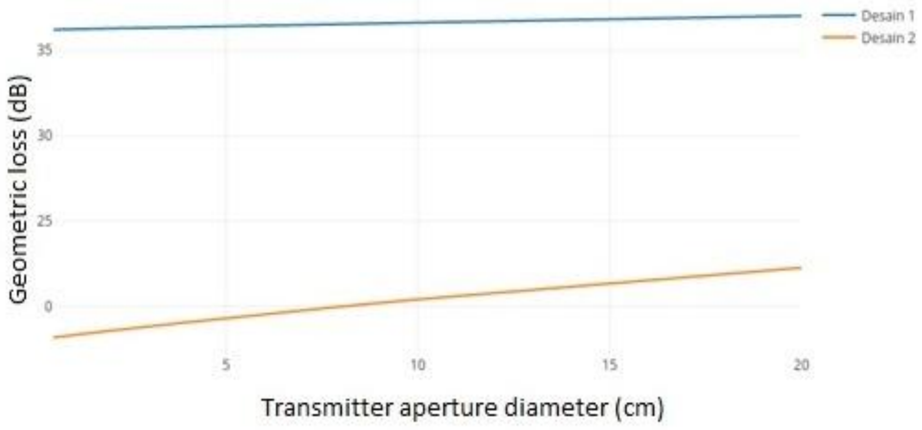

Fig. 15: Geometric loss vs transmitter aperture

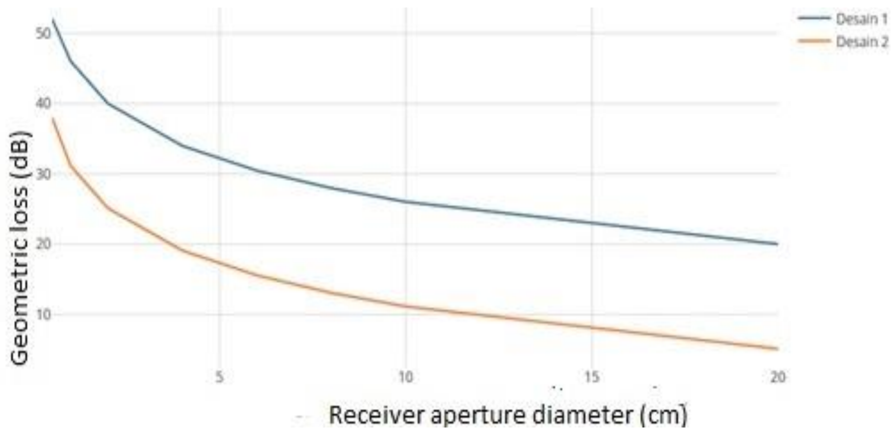

Fig. 16: Geometric loss vs Receiver aperture

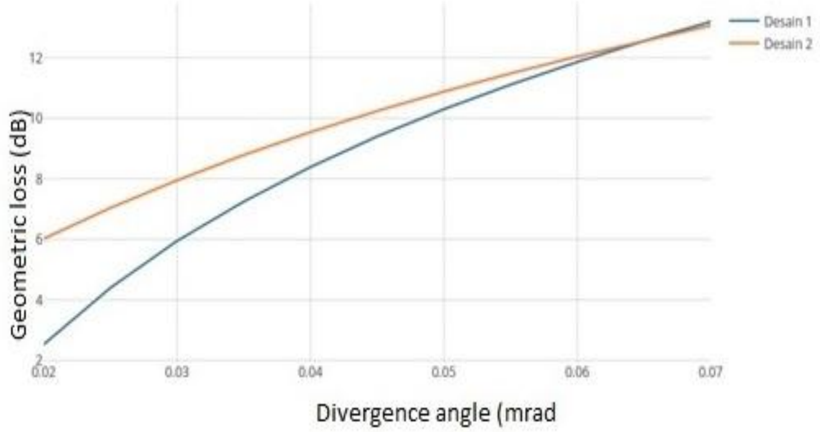

Fig. 17: Geometric loss vs Divergence angle

Fig 17 indicates the geometric loss versus the receiver aperture diameter. When the receiver aperture diameter increases, the geometric loss decreases. Fig18 shows that Geometric loss is proportionalto divergence angle, which suggest that when the divergence angle increases, geometric loss. That means by using a small divergence angle of laser beam in FSO systems, geometric loss effect is minimized.

VI. CONCLUSION

Optical transceiver modul for free space communication (FSO) system has been successfully built. It can handle serial data communication in full duplex mode at speed of 100 kbps with optimal distance of 200 meters. Data errors may occur as the distance become longer and longer. With proper alignment of the laser beam and the use of ASK modulation will improve the performance of the transceiver due to the interference of the surounding light. And the use of convex les in this design will also extend the link range so it reduces the geometric loss.

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