Experimental Investigation of a Laser Wireless Video Communication System Using Intensity Modulated /Direct Detection Technique

Hani J. Kbashi

College of Science, Department of Physics, University of Baghdad, Baghdad, Iraq

Abstract: In this work Laser wireless video communication system using intensity modualtion direct detection IM/DD over a 1 km range between transmitter and receiver is experimentally investigated and demonstrated. Beam expander and beam collimeter were implemented to collimete laser beam at the transmitter and focus this beam at the receiver respectively. The results show that IM/DD communication sysatem using laser diode is quite attractive for transmitting video signal. In this work signal to noise ratio (S/N) higher than 20 dB is achieved in this work.

Introduction

Laser wireless, also known as free space optics is a method of communication that involves using a light source, usually a laser, to transmit information through space or the atmosphere to a receiver. Optical wireless communication is an effective high bandwidth communication technology serving commercial point –to- point link in terrestrial last mile application, such as air-to-air, satellite-to-submarine, air- to- satellite, and satellite-to-satellite links, have several attractive characteristic such as dense spatial rescue, low power usage license free band of operation, and relatively high bandwidth[1,2,3]. Optical wireless communications (OWC) have attractive attention from many researchers worldwide for their potential advantages over radio links. These advantages include the availability of huge unregulated bandwidth; theoretically 200 THz. Optical wireless links also offer high data rates, immunity to electromagnetic interference, and relative security since it does not penetrate walls [4, 5]. The schematic structure of a basic OWC system is shown in Figure 1. In optical communication systems, the information signal may be used directly to modulate the optical carrier signal using intensity (amplitude), phase or frequency, or the information is modulated. Almost all practical optical wireless system (Indoor and Outdoor) employ some form of electrical modulation in conjection with the intensity modulation with direct detection (IM/DD) for its simple implementation and low cost. [6]. At the transmitter, a laser beam is generated by an electrical to optical process, expanded and directed by a transmitting telescope. After propagation through the atmosphere, it is collected by a receiver telescope, optically filtered and concentrated onto the focal plane detector, and, finally converted into electric current by a reverse optic-to-electric process. With the emerging communication technology, size of signals such as a video and high resolution images is growing tremendously causing an increasing demand for modulation schemes with lower bandwidth requirement. Asynchronous amplitude modulation scheme is an alternative to ON-OFF keying for a wireless video laser communication.

The optical power loss of the propagating laser beam through the earth's atmosphere is mainly due to absorption and scattering losses by the molecular species [7, 8].
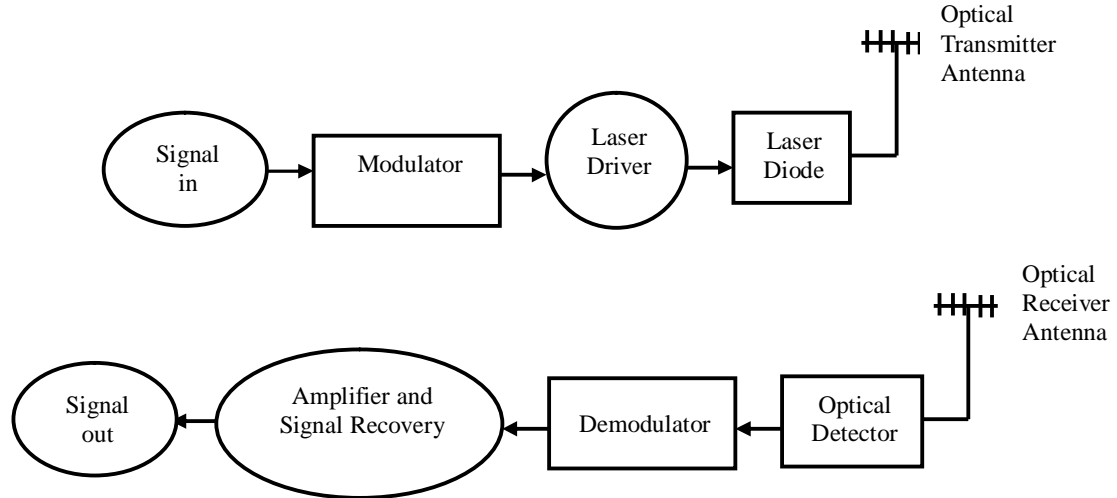
Fig. (1): Block diagram of the wirelles communication system

Theoretical Work

The transparency of the atmosphere for the laser radiation is one of the most important parameters in the calculating the attenuation. This depends on the weather state and path length (range). Atmospheric attenuation effect upon the irradiance may be described as in the following equation [9]

$$E = E_o \exp(-mR) \qquad (1)$$

where,

$E_\circ$ is the emergent beam irradiance at zero range, R is the path length in km, and μ is attenuation coefficient expressed in km^{-1}, μ is the sum of the scattering d and absorption coefficients a .

The amount of the received power is proportional to the amount of power transmitted and the area of the collecting aperture. It is inversely proportional to the square of the beam divergence and square of the link length. It is also inversely proportional to the exponential of the product of the atmospheric attenuation coefficient (km^{-1}) and the link length [9].

The received power through the earth's atmosphere can be calculated as:

$$P_{rec} = P_t \frac{A_{rec}}{(q * R)^2} \exp(-mR) \qquad (2)$$

and,

$$A_{rec} = p \, (D^2 / 4) \qquad (3)$$

where,

A_{rec} is the receiver optics area, D is the receiver optics diameter and θ is the divergence of the laser beam in radians.

The SNR for a PIN photodiode receiver in optical communication system is given by :

$$S \, / \, N \, (dB \,) = 10 \, \log \, \frac{P_{rec}}{P_N} \qquad (4)$$

The P_N represents the noise power in watts.

Experimental Work

In this work the experimental setup of the laser video communication system was designed and constructed containing three major units, the transmitter with transmitter telescope, the channel which is represented by the atmosphere and the receiver with receiver telescope.

In the transmitter unit, the electric signal comes from a collar CCD camera or TV signal, which converts the video signal into electrical signal. Transistor type BC109 is used as a preamplifier after biasing it with a suitable resistance and capacitors as shown in Figure 2.
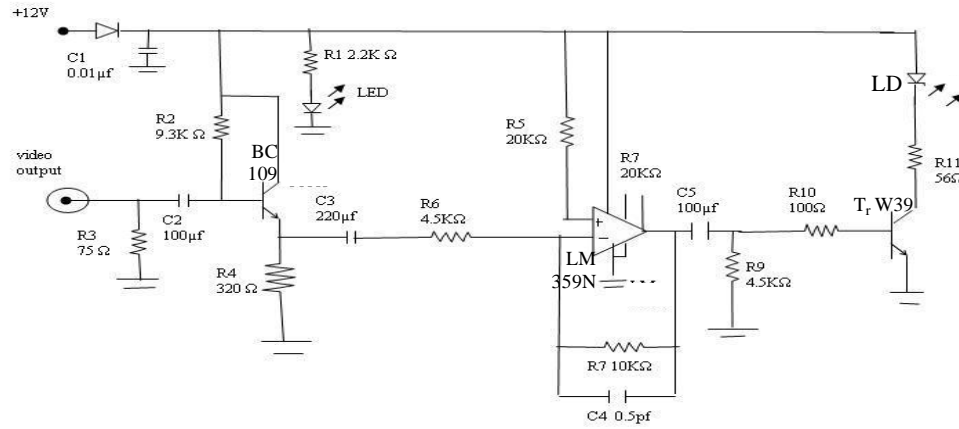
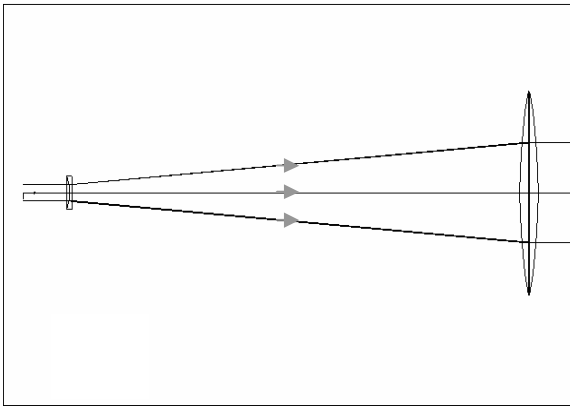**Fig. (2):** The circuit diagram of the transmitter unit

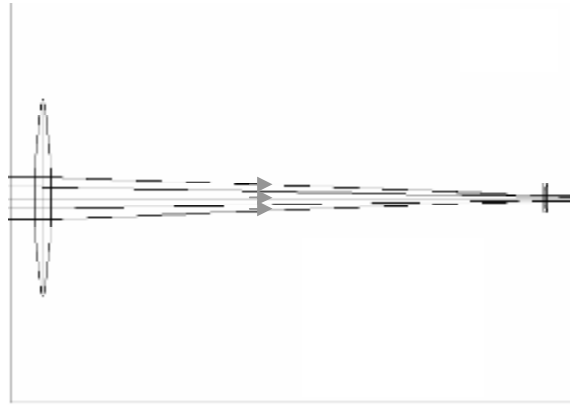**Fig. (3):** The optical design of the transmitter telescope.

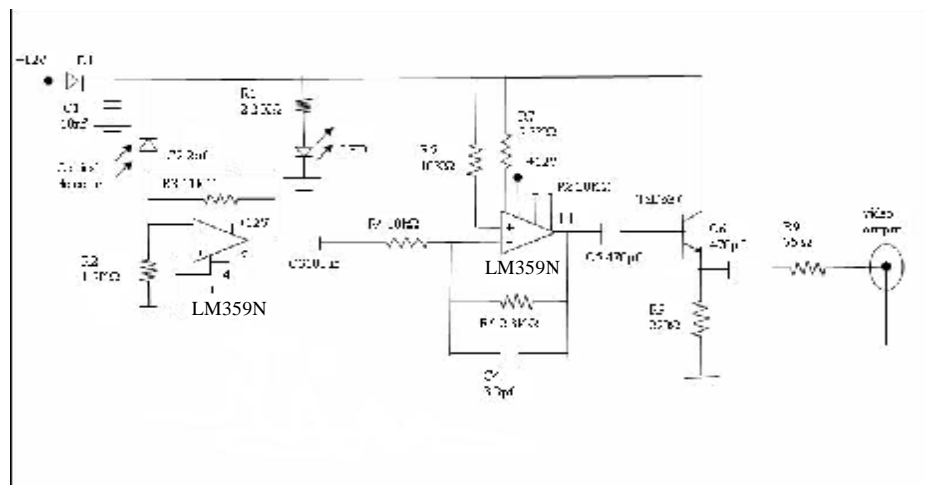**Fig. (4)**: The optical design of the receiver telescope.

Fig. (5): The circuit diagram of the receiver unit.

The high speed operational amplifier LM359 is used to provide high gain bandwidth produced with stable operation. The output of LM359 is amplitude modulated and then converted into optical signal through the optical source with driver circuit. The optical source used in this work is a laser diode that emits optical radiation at 650 nm, with maximum optical output power of 1 mw. The maximum current that passes through the laser diode is 120 mA during the driver circuit (Tr W39) with current limiter (R) which gives a power output of 1 mw. Transmitter telescope was implemented as shown in Figure 3. It includes a couple of two plano-convex lenses for 1 km range with beam divergence of 0.6 mrad. These optical signals then pass through the atmosphere towards the optical receiver. The receiver telescope shown in Figure 4 consist of two lenses used to focus the laser beam into the optical detector. The optical receiver, which is responsible for converting these optical pulses into electrical equivalent pulses and removing the effects of the different noise current sources through transmission and obtaining an exact replica of the transmitted signal, contains an

PIN photodetector type BPX 65 with a rise time of 12 nsec and a peak responsivity of 0.55 A/W. The circuit diagram of the receiver unit is shown in Figure 5. Output signal from optical detector should be amplified by a preamplifier. A dual, high speed LM 359 is used for this purpose. Each stage is designed to amplify the signal 10 times. The final stage in the receiver unit is the low pass filter (Tr D637) then the video signal is fed to a monitor.

Results and Discussion

The results of the free space laser video link includes measurement of the beam divergence of the laser diode, calculating optical power received at the detector, and the signal to noise ratio at optical receiver after the atmospheric attenuation. The average value of the full divergence angle for a laser beam is 0.6 mrad measured at the receiver telescope. The parameters of the transmitter telescope and receiver telescope are listed in the Tables 1 and 2 respectively.

Table (1): Parameters for the designed beam transmitter

Lens type	Left side radius of curvature of lens R1 (mm)	Right side radius of curvature of lens R2 (mm)	Focal length f (mm)	diameter D (mm)	Thickness (mm)
eye	-10	∞	-20	7	0.5
Objective	120	-120	120	42	4

Table (2): Parameters for the designed beam receiver.

Lens type	Left side radius of curvature of lens R1 (mm)	Right side radius of curvature of lens R2 (mm)	Focal length f (mm)	diameter D (mm)	Thickness (mm)
eye	-12	∞	-24	7	0.33
Objective	140	-140	140	45	4

In this work, the calculated and experimented results of the received optical signal of the system are presented. The maximum output power for laser diode pointer is 1mw and the measured laser beam divergence is 0.6 mrad, A_{rec} of the optical receiver is 0.0028 m^2, the attenuation coefficient is 0.478 km^{-1} for 650 nm wavelength was measured experimentally by measuring the transmittance for this wavelength. The values of the optical power received were substituted in equation 4. The calculated and experimental values of S/N for the system that was designed and constructed is shown in Figure 6, where the noise power (P_N) is 100 nW due to thermal noise, shot noise and background noise.

Figure (6) gives us a high quality received video signal, when the distance between the transmitter and the receiver is about 1 km while in other studies such as that of E. Woldit and M. Yong the ratio of the voice signal was less than that[10].
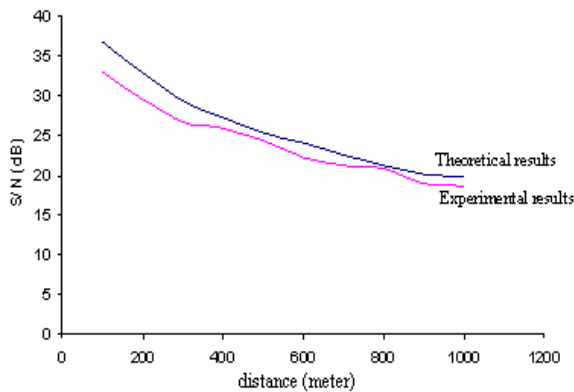

Fig. (6): The system quality (S/N) of the video signal as a function of the distance

Conclusions

A high quality wirelees video communication system for 1 km optical length was achived expermintally using IM/DD with a simple impementation and low cost. Laser wireless system using IM/DD offers a method to transmit high quality video signals over a wide range distances. To measure the transmission quality with respect to noise, the S/N of video signal transmitted over a link is calculated and measured expermintally . Results show that an increase in the laser power leads to increasing the maximum distance for transmitting optical power. Experimental results proved the development in video transmission using laser diode over a 1 km range with signal to noise ratio of 20 dB.

References

1. Akella J., Yukse M.l, and Kalyanaraman S. " Error analysis of multi-Hop free space optical communication" IEEE, **7**, No. 5, 2005.
2. Zhu X. and Kahn J. "free space optical communication through atmospheric turbulence channels" IEEE Transaction on Communications, **50**, August 2002.
3. Heatley D., Wisely D. Neild I., and Cochrane P. " Optical Wireless: the story so far" IEEE Communications, Vol. **36**, December 1998, pp 72-74.
4. Kahn J. and Barry H. "Wireless infrared communications" Proc. of the IEEE, **85**, No. 2, 1997, pp. 265-298.
5. Dickenson R. and Ghassemlooy Z. "A Feature extraction and patteren recognition receiver employing wavelet analysis and artificial intelligence for signal detection in diffuse optical wireless communications" IEEE Wireless Communication, 2003, pp. 64-72.
6. Ghassemlooy Z. and Aldibbiat N. "Multi level digital pulse interval modulation scheme for optical wireless communications" ICTON, 2006, IEEE, Tu. D3.3, pp.149-153.
7. Manor H. and Amon S. "Performance of an optical wireless communication system as a function of wavelength" Applied optics, **42**, No. 21, 2003.
8. Editorial G. "Indoor optical wireless communication systems and networks" International Journal of communication systems **18**, 2005, pp. 191-193.
9. Saba A. "Design of optical communication portable full duplex system" M.Sc thesis in Technology University, applied Science, 2005.
10. Woldeit E., Yong M. "Designed and constructed free space amplitude modulation laser communication system" EE 488-Laser Electronic,1996

الكشف التجريبي لنظام الأتصال المرئي اللاسلكي الليزري باستخدام الشدة المضمنة / تقنية الكشف المباشر

هاني جاسم كباشي

قسم الفيزياء ، كلية العلوم ، جامعة بغداد ، بغداد ، العراق

الخلاصة   في هذا البحث تم الفحص و الاختبار عملياً لنظام اتصال لاسلكي ضوئي باستخدام تقنية تضمين الشدة/الكشف المباشرلنقل اشارة فديو بمسافة أكبر من 1 كم بين المرسلة والمستلمة. موسع الحزمة و مجمع الحزمة نفــذ لتوسيع اشعة الليزر عند المرسلة ولتجميع هذه الاشعة عند المستلمة مباشرة. اوضحت النتائج ان نظام الاتصال باستخدام تضمين الشدة / الكشف المباشر باستخدام الدايود الليزري هو ملائم وجذاب لنقل الاشارة الفديوية. كما اوضحت قيمة نسبة الاشارة الى الضوضاء هي اكبر من 20dB.