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Design and Implementation of Free Space Simplex Video – Laser Communication system.

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Abstract

The optical communication system consists of a transmitter uses a laser beam of a wavelength 650 nm as a carrier in free space, and a receiver uses PIN diode as a detector . In both sides Intensity modulation (IM) technique has been used to transmit video signal of a frequency range (0~5) MHz band width. The video signal fed by camera. The transmitted signal amplified and converted to a modulated intensity of laser beam and sent to the receiver, the receiver converts the laser signal to a weak electrical signal by the detector; the signal will be amplified and converted back to an analogue signal to produce the original transmitted signal, and monitored by TV set in (black and white) . The transmission range was 5 m , that can be developed letter for longer range.

Keywords: carrier ; Intensity modulation ; video signal.

تصميم وتنفيذ منظومة اتصالات ليزر فيديوية باتجاه واحد فى الفضاء الحر

الخلاصة

تتالف منظومة الاتصالات البصرية من مرسلة تستخدم شعاع اليزري بطول موجى 650 نانومتر كناقل للمعلومات فى الفضاء الخالي ، ومستقبلة أستخدم فيها ثنائي الوصلة PIN ككاشف. ولقد أستخدمت في كلا الجانبين تقنية تضمين الشدة (IM) في تكوين ألاشارة ألمرئية بعرض حزمة تردد (0 - 5) ميكاهرتز. حيث تمت ألتغذية من خلال كاميرا. ولقد تم تضخيم الاشارة المرسلة ثم تحميلها لشعاع الليزر المضمن من قبلها ثم ارسالها الى المستلمة . قامت المستلمة بتحويل موجة الليزر الى اشارة كهربائية ضعيفة بواسطة الكاشف ثم تضخيمها وتحويلها الى اشارة مماثلة للاشارة المرسلة وعرضها من خلال جهاز تلفاز(اسود وابيض) ، كانت مسافة الارسال 5 م والتي يمكن تحسينها لاحقا الى مسافات أكبر .

Introduction

Co mmunication may be broadly defined as a transfer of information from one point to another. When the information is to be conveyed over a distance, a communication system is usually required. Within a communication system, the information transferred is frequently achieved by modulating the information on to an electromagnetic wave which acts as a carrier for the information signal. This modulated carrier is then transmitted to the

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required destination where it is received and the original information signal is obtained by demodulation. Many techniques have been developed for this process using electromagnetic carrier waves operating at radio frequencies as well as microwave and millimeter wave frequencies

However communication may also be achieved using an electromagnetic carrier which is selected from the optical range of frequencies [1].Transmission protocols can be done in a various methods: - simplex, half duplex and full duplex as shown in Figure (1).**Simplex:** means that the transmission of information occurred only in one direction (transmitter to receiver). A common exampleis broadcast radio or television [2]. This mode has been used in the present design.

Theoretical concepts

Light Sources:

In optical communication systems, optical beams generated from light sources carry the information. Laser diodes (LD) and light-emitting diodes (LED) are the most common sources, their small size and their solid structure, and low power requirements are compatible with modern solid state electronics, both are (p-n) junction semiconductors , emits light when forward biased , which cause recombination of holes and electrons that are injected in to the junction , the energy lost in the transition is converted to optical energy in the form of a photon . Photon energy and frequency are related by (E = hν) [3] . The radiated wave length is then:

$$l = \frac{hn}{Eg} \qquad \ldots (1)$$

Where λ = Wavelength of radiation or emitted laser beam . h = Blanks constant=6.626*10^{-34} J.s

ν = frequency of the radiated light .

Eg = the gap energy .

photo detectors :

A photo detector is optoelectric device that converts the received optical power into electrical power with linear response [4].

There are two types of detectors used in free space optical communication systems. Both are semiconductor devices, they are: positive intrinsic negative (PIN) and Avalanche photodiode (APD) [5]. In most application PIN is the preferred element in the receiver. This is mainly due to the fact that it can be operated from standard power supply, typically between (5-15 V); it has lower cost, lower noise, and no gain. APD devices have much better sensitivity than PIN. In fact they have high gain (5 to 10 dB) more sensitivity. However, they cannot be used on a (5V) printed circuit board. They also require a stable power supply, typically between (100-400V), this makes their cost higher. APD devices are usually found in long haul communication links .The output of the detector is a very weak signal; therefore the photo diode circuitry is followed by one or more amplification stages. This is to amplify the signal to yield an electrical signal representing the original input [6].

Atmospheric Attenuation

In general, attenuation is the relation between transmitted signal power and received signal power as follow [7].

$$Attenuation = 10\log\frac{P_{transmitted}}{P_{received}} \quad (dB) \quad \dots (2)$$

However, atmospheric attenuation may be described by the exponential law of attenuation. The transmittance path through the atmosphere can be expressed as follow [8].

$$\tau = \exp(-\alpha R) \quad \dots \quad (3)$$

Where τ : is the atmospheric transmittance, Range is the atmospheric transmission path length, and α is the coefficient, which is equal to sum of the absorption coefficient (α_β) and scattering coefficient(α_s) $\alpha = \alpha_\beta + \alpha_s$ ... (4)

Geometrical Attenuation Loss:

The geometrical loss of the free space optical system can be calculated for transmitted beam as follows [7].

$$P_{geom.} = 20 \log (Div.\ R/d)\ dB.. \quad (5)$$

$$d_1 = Div. * R + d_2 \quad \dots \quad (6)$$

Where: d_1 is the laser beam diameter reaching the receiver optics, while d_2 is the laser beam diameter at output aperture of the transmitting device .The divergence angle of transmitted beam, and angle of received beam, is shown in Figure (2)

Consequently equations (2), (3), (5) the total power of the received signal through the earth's atmosphere can be calculated by:

$$P_{scat.} = P_{transmitted} \times \frac{A_{receiver}}{(Div. \times R)^2} \times t \dots \quad (7)$$

$$A_{receiver} = p\left(\frac{D^2}{4}\right) \quad \dots \quad (8)$$

Where: $A_{received}$ is the receiver optics area and D is the receiver diameter.

Optical Receiver Noise

In free space optical communication system, as any communication system, the spontaneous fluctuations are limitted of the transmission information. There are two types of the noise source presented in the optical receiver [9].Firstly, the internal noise is created by the optical receiver itself such as thermal noise, and dark current noise. Where the thermal noise current (I t) due to the load resistance (R_L) can be calculated by the following formula [10]:

$$I_t = \frac{[4 \times K \times T \times BW]^{1/2}}{R_L} \quad \dots \quad (9)$$

Where I_t : is the thermal noise current (Ampere), K : is Boltzmann's constant, T : is the absolute temperature (K)

BW : is the system bandwidth (Hz) and R_L : is the load resistance of the optical receiver (Ω).

While the dark current noise is generated when no optical power incident on the optical receiver, small reverse leakage current flows from the device terminals. Thus, the dark current noise is given by [9].

$$I_d = [2 * e * BW * i_d]^{1/2} \quad \text{... (10)}$$

Where I_d: is the dark current noise (Ampere), e: is the charge of the electron and i_d : is the dark current. Secondly, the External noise is created by the radiation sources available such as the sun, moon, stars, and sky. The background radiation may cause serious problems in the communication system performance .

Also the signal-to-noise (SNR) can be calculated according to i_s: signal current, and i_n : noise current by the following formulae [11]:

$$S/N = 20 \log (i_s / i_n) \text{ dB} \quad \text{.. . (11)}$$

The main Advantages of Wireless Optical Communication Channels Are:

- Low price of the equipment, quick installation.
- The speed of information transmission (10-100) Mbps.
- No license to use the radio frequency is needed.
- Complete Secrecy of transmitting information is guaranteed by direct radiation and receiving.
- High resistance to hindrances, absence of hindrances during simultaneous work of several systems.
- Ecologically safe [12] .

Modulation

The term modulation refers closely to any technique that systematically alter the shape of the waveform by bending its graph a parameter of carrier wave according to the variation of message signal. Modulation is an important process in any communication system. The purpose of using modulation is:

a) Multiplexed operation of a transmission path.
b) Transfer of signal into a frequency band favourable for signal transfer.
c) Obtaining favourable signal - to - noise ratios when source and noise power are given [13] .

Direct Modulation

AM/IM Sub carrier Modulation

Conventional amplitude modulation places the message on a carrier whose frequency is much greater than any of the frequency contained in the base band. Amplitude modulation (AM) means that the amplitude of the carrier wave is proportional to the amplitude of the carried wave. The resulting waveform has a spectrum that surrounds the carrier frequency.

Intensity modulation (IM) means the intensity of the laser light is proportional to the amplitude of the sub carrier which depends on the modulation signal (such as audio wave). In essence, (AM) shifts the base band to anew region of the electromagnetic spectrum [14].

System Design

Optical video link using laser beam in free space is shown in Figure (3). The optical transmitter (OT) converts the camera signal (through the 75Ω coax cable) into proportional light variations which are sent through the free space. The optical Receiver (OR) converts the modulated laser light back into a video signal which is sent to the monitor (TV set) through the (75Ω) coax cable.

Optical Video Analogue Transmitter Driver Circuit

Optical transmitter requires electronic circuitry called the driver circuit; Figure (4) to control the electrical input to its light source .
Driver Circuits can be driven by different types of signals:DC., AC. and pulse. Power and speed (switching speed) are important characteristic of optical – transmitter driver circuit .Without overheating, a driver circuit must apply enough electrical power to a light source so enough optical power is produced for the system .A driver must also be fast enough to pass a signal with minimum distortion. There are two basic types of driver circuits that are commonly used for optical transmitters, series and shunt as in Figure (5).

The most common driver circuits use a transistor to control the forward current through an LD light source. A series driver circuit has its active device (transistor) connected in series with the light source (LD). A shunt driver circuit has its active device (transistor) connected in parallel with the light source (LD). The series driver circuit is a simple voltage switch that only draws significant supply current when the LD is ON, this reduces the average power supply current . The shunt (parallel) driver is a simple current switch that draws significant current when the (LD) is off, because current is drawn by the driver even after it turns the (LD) off, there is a relatively constant load on the power supply, and the constant load reduces power supply and improves circuit response time.

The switching speed of these two driver circuits can be improved by adding the resister and diode shown in above Figure (6).These improvements allow the (LD) and transistor
junction capacitance to change up before the (LD) is switched ON. The technique is known as pre-biasing or “priming” the (LD). The maximum bandwidth of these circuits even further by adding RC current–peaking circuitry, as shown in Figure (7).

The forward current waveform is frequency compensated by the current–peaking circuitry to improve the wave shape of the optical output signal. Maximum bandwidth can be obtained by selecting R and C values for optimum current –peaking .The Analog Video Transmitter shown in Figure (8), Uses a buffer amplifier in its driver circuit as a voltage - to - current converter , and R_2. The circuit also uses feedback. The Feedback Maintains a stable bias voltage at the amplifier input that is equal to the (LD) forward voltage . An A.C. input voltage creates an A.C. current through the (LD) that modulates the emitted optical power. The low cutoff frequency for the analog transmitter is determined by a high –pass filter consisting of C_1, and R_1 in union with low –pass filter C_2 .The input signal at point (A) is fed through capacitor C_1 to the input of the voltage-to-current converter Q_1, this point include feedback, from Q_2 that maintains stable bias at the amplifier input.

Figure (9) is Video Optical Transmitter Circuit Diagram .

Optical Video Analogue Receiver

Optical receiver circuit consists of a light detector, and an output circuit, as shown in Figure (10).

Light detector

The light detector converts on optical signal delivered by free air space to an electric current signal. The light detector is usually a photodiode or phototransistor, both of these devices use radiant power (light) to control their current (photocurrent

Output Circuit

The output circuit converts the light detector signal into a format compatible with other system components.

The Optical Analogue Receiver uses a PIN photodiode

The Analogue Receiver light detector converts changes in light power, representing the message intelligence, into voltage changes. A coupling capacitor (C) as shown in Figure (11) passes voltage changes to the receiver output circuit, while blocking D.C., Blocking D.C. at the optical receiver output circuit eliminates D.C. bias drift.

The analogue receiver output is an inverting amplifier that corrects the signal amplitude, impedance, phase, and bandwidth as shown in Figure (12).

Figure (13) is Optical Video Receiver Circuit diagram .

Results and Discussion :

Determining the (I-V) characteristic of laser Diode :

The circuit in Figure (14) can be used to have (I-V)Characteristic of laser diode , the curve of the forward current as a function of forward voltage in presented in Figure (15)

Pre bias current and (Q-point) :

Its possible to fix the per bias current for the laser diode on (I-V) for the diode characteristic and fixed the (Q-point), in the middle of the linear portion of the tangent line to the curve as shown in Figure (16)

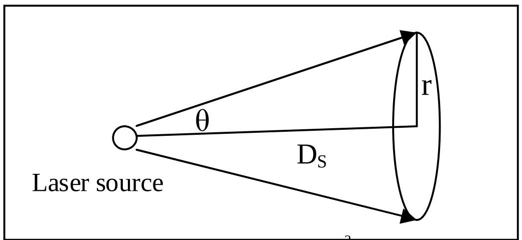
Laser Diode Divergence Angle Measurements

The laser beam has been transmitted from a distance point; the radius of the laser beam spot was measured at different locations from laser diode to the target. The result is shown in Figure (17), Illustrates the relation between the radii of laser spot with the distance from the laser diode to the recever .In this work, a laser beam was transmitted from distinct point, and the radius of the laser beam spot was measured at many distances from the system starting with (1 m) distance to 5 m, which the laser beam was measured . A typical FSO system will have half angle divergence equal to (θ).

This results a cone radius of (r).

A typical shape of the laser spot will be elliptical of minor axis 2r

Adopting ($^1/_{e^2}$) intensity region the beam divergence (θ) can be given by :



$$q = \tan^{-1}\left(\frac{r}{D_S}\right) = \tan^{-1}\left(\frac{7.5\times10^{-3}}{5}\right) = \tan^{-1}(1.5\times10^{-3})$$

$$= 0.0859$$

$$= 0.00149\,rad$$

$$= 1.49\,mrad$$

where D_S : is the distance

Measurement of Intensity with the Distance

The laser diode intensity inversely proportional to the distance, this means that the laser intensity is reduced rapidly when the distance increased.

The most important factor on the intensity of laser beam is the solar radiation background noise. The results are taken at daytime, where the background noise is at maximum value. It is possible to reduce this effect by taking the measurements at night . Figure (18) shows the relation between the intensity and distance .

Signal-to -noise Ratio Calculations:-

Indoor SNR Calculations:-

The total signal to noise ratio (S/N) at optical detector can be calculated according to eq's.(11) and (12) current from the average value, can be calculate: $i_s = P_r \times R_\lambda$ A/W ... (12)

Where P_r: is incident optical power on the photodiode, and R_λ is the responsively .Since the responsivity (R_λ) of detector system is (0.4 A/W) at the peak spectral response (650 nm)

(i_S) at a range of (5 m), which is according to eq.(12) is :- i_S = 344.4 μW × 0.4 A/W = 137.76 μA

Where (i_n): can be calculated according to equation (13): $i_n = i_d + I_t$ … (13)

I_t: is the thermal noise current which calculated according to eq. (9):Also the bandwidth (BW) of the link can be calculated as follows BW = 2 × B = 2× 115 Kbps = 230 kHz. R_L = 50 Ω and i_d = 5 nA from data sheet, thus:-

$I_t = \sqrt{4\times1.38\times10^{-23} \times300\times230\times10^{3} / 50}$ = 8.727 nA thus. i_n = 8.727 +5 =13.727 nA .Thus, the ratio (S/N) can be calculated with range = 5m as follows:-

SNR = 20 log 137.76/ 13.72 = 80 dB

Video Signal Waveform

Figure (19) illustrates the signal waveforms and the live picture (video) which is send from the camera to the TV set via the optical system . The video picture received by the TV set wasn't obvious because of the noise sources
(internal noise and external noise) .

Conclusions

The following points summarize the conclusions :

1. The possibility of transmitting video life picture is presented in this work rather simple , cheap and available elements .
2. The designed system using (IM) modulation technique in simplex mode
Indoor was achieved , it is possible to us
duplex mode by employing the same
design .
3. The (FSO) distance (range) indoor
between a working transmitter and receiver is (5) meters , thus the designed
system acts as a demonstration system
which uses the benefits of the wireless
laser communication .
4. The produced picture wasn't obvious
because of the noise sources (internal
noise and external noise) .
5. The signal – to – noise ratio was about
(80 dB) with (5) meter range .
6. The divergence angle used laser diode
was (1.49) mrad .
7. To increase the range of communication
system , it is possible to use beam
expander , more powerful laser and/or
more sensitive detector .
8 . The designed system is up to our
knowledge is the first project in our
university .

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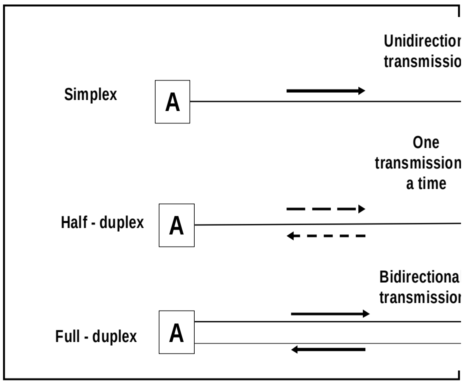

Figure (1): Different Communication Modes. [2]

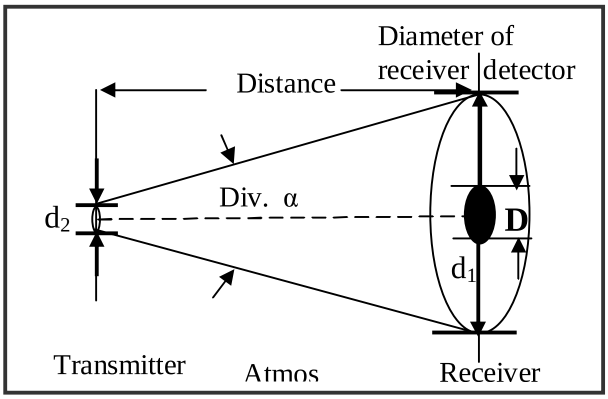

Figure (2): The Geometric of the System [7]

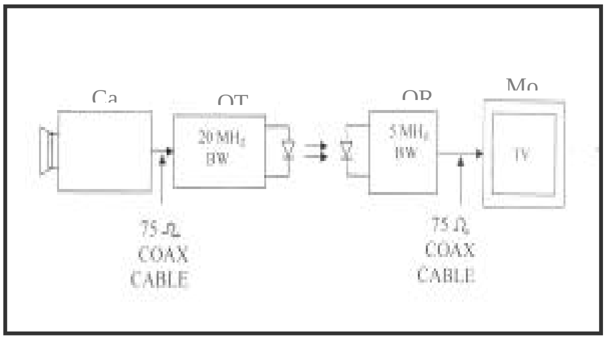

Figure (3) Analog Communications Optical Video Link in free space.

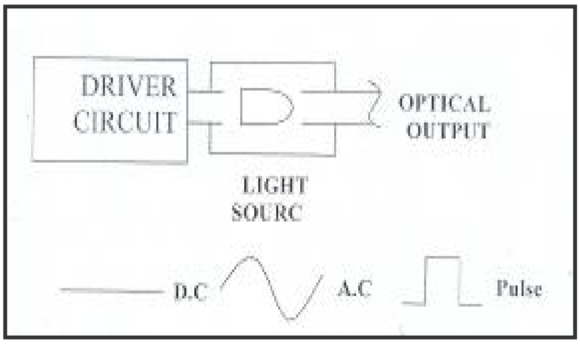

Figure (4): Optical transmitter driver circuit.

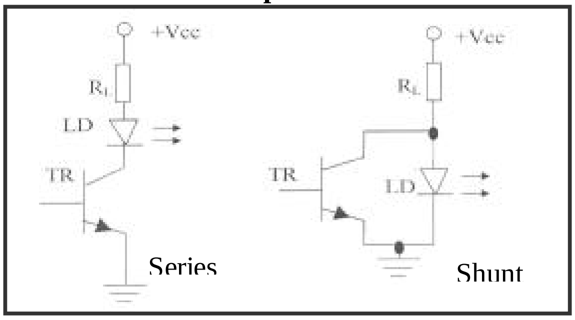

Figure (5): series and shunt driver circuits.

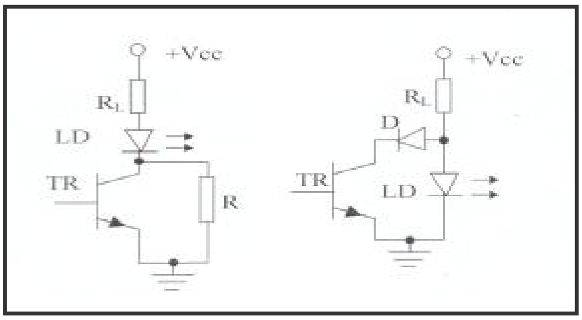

Figure (6) : Switching speed improvement.

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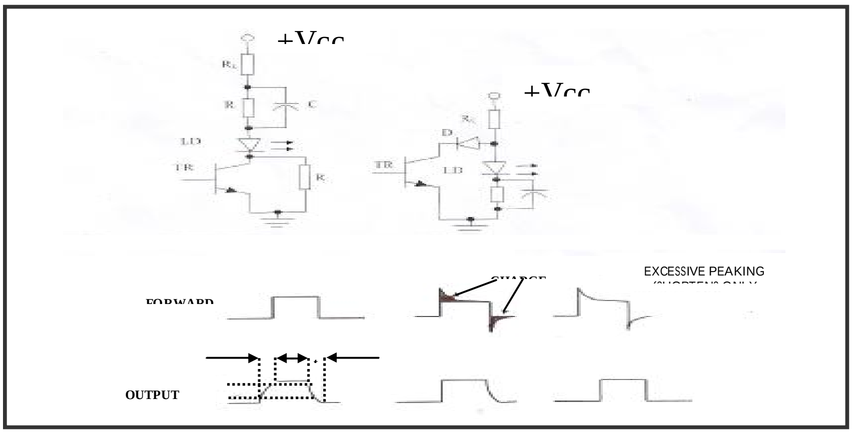
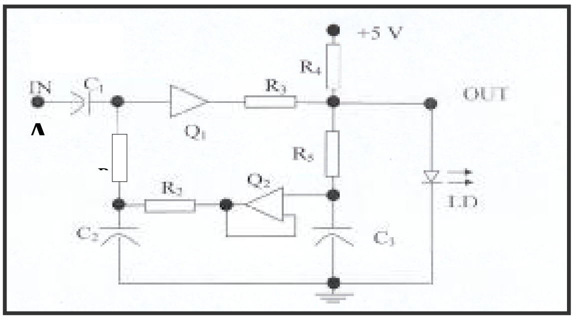


Figure (7): Maximum bandwidth.



Figure(8):Optical Video Analogue Transmitter.

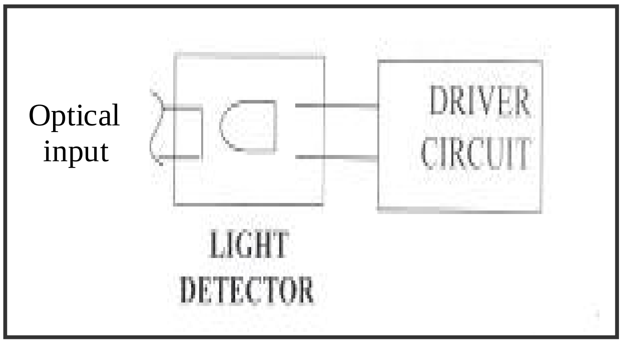


Figure (10): Optical Analogue Receiver Output Circuit.

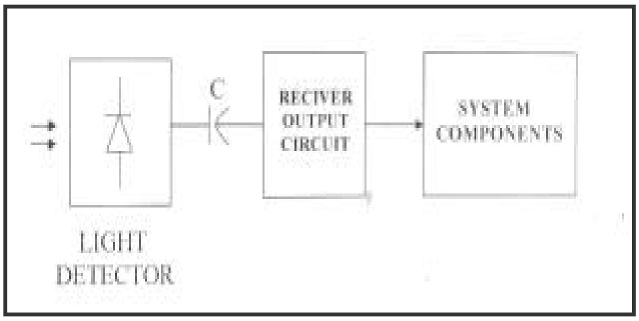


Figure (11): Optical Analogue Receive Block diagram.

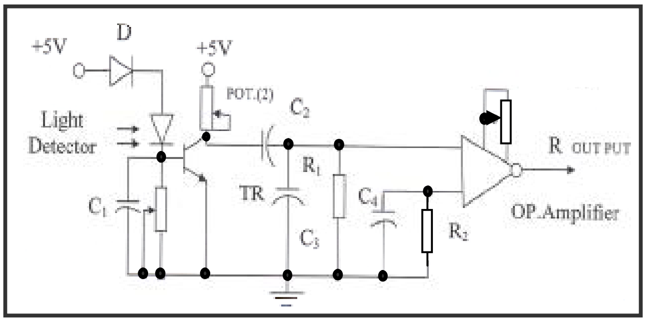


Figure (12): Optical Analogue Rece

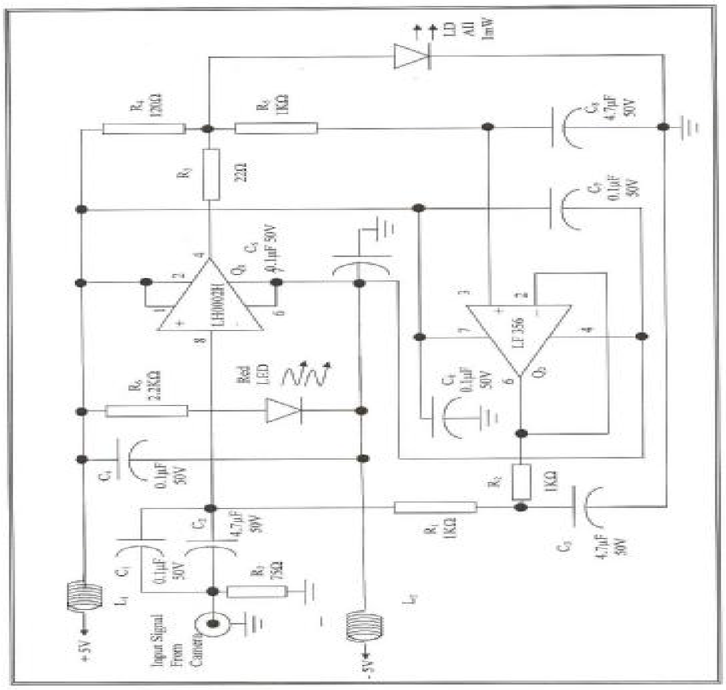


Figure (8) Video Optical Transmitter Circuit Diagram

Figure (9) Video Optical Transmitter Circuit Diagram

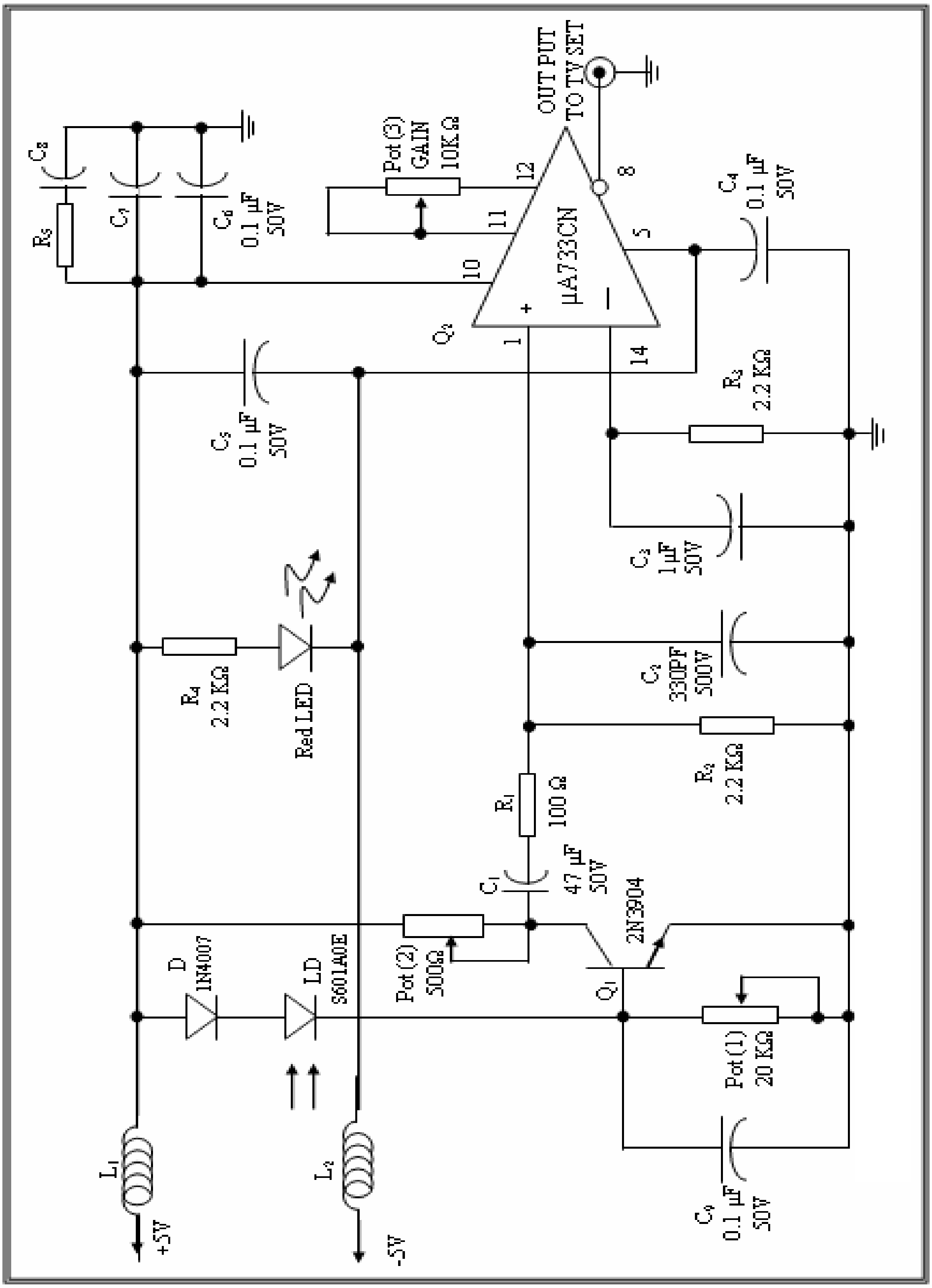


Figure (13) Illustrate Video Optical Receiver Circuit Diagram

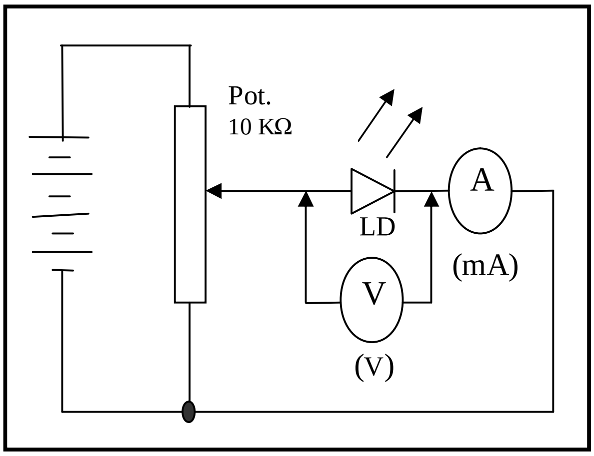


Figure (14) illustrates the circuit diagram used to determine (I-V) characteristic curve of laser diode.

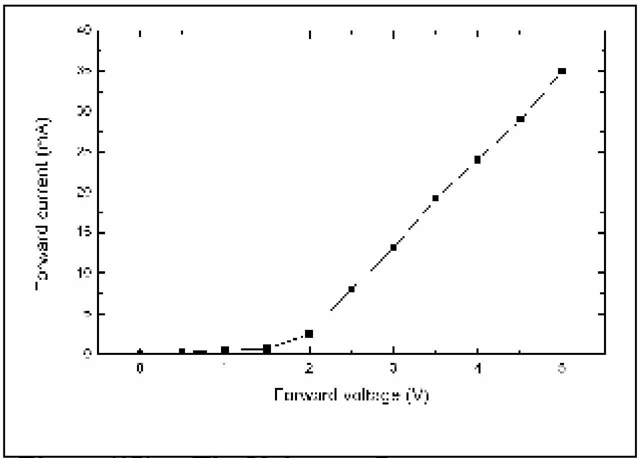


Figure (15) : The Voltage – Current characteristics of the forward bias of laser diode

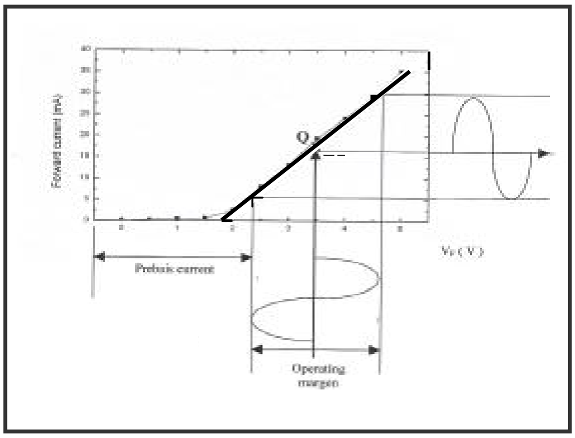


Figure (16): Illustrates the pre bias current and the Q-point on (I-V) characteristic curve of laser pointer.

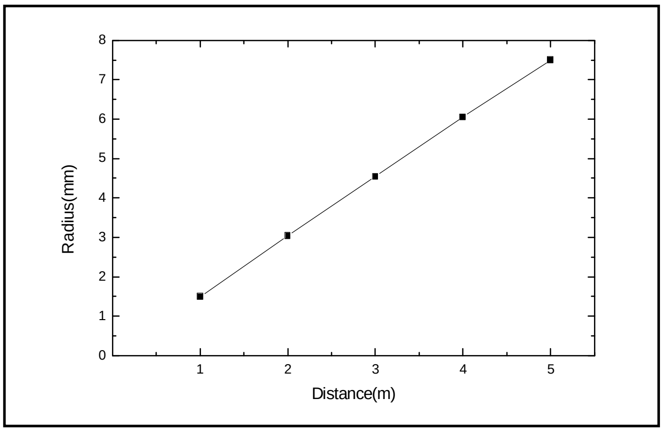


Figure (17): The radiuses of laser spot with the distance from the laser diode.

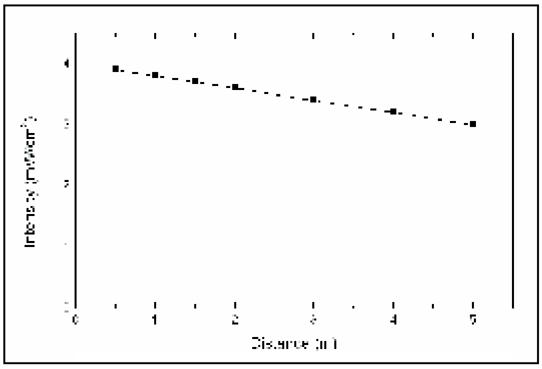


Figure (18) The laser beam intensity with the distance from diode laser

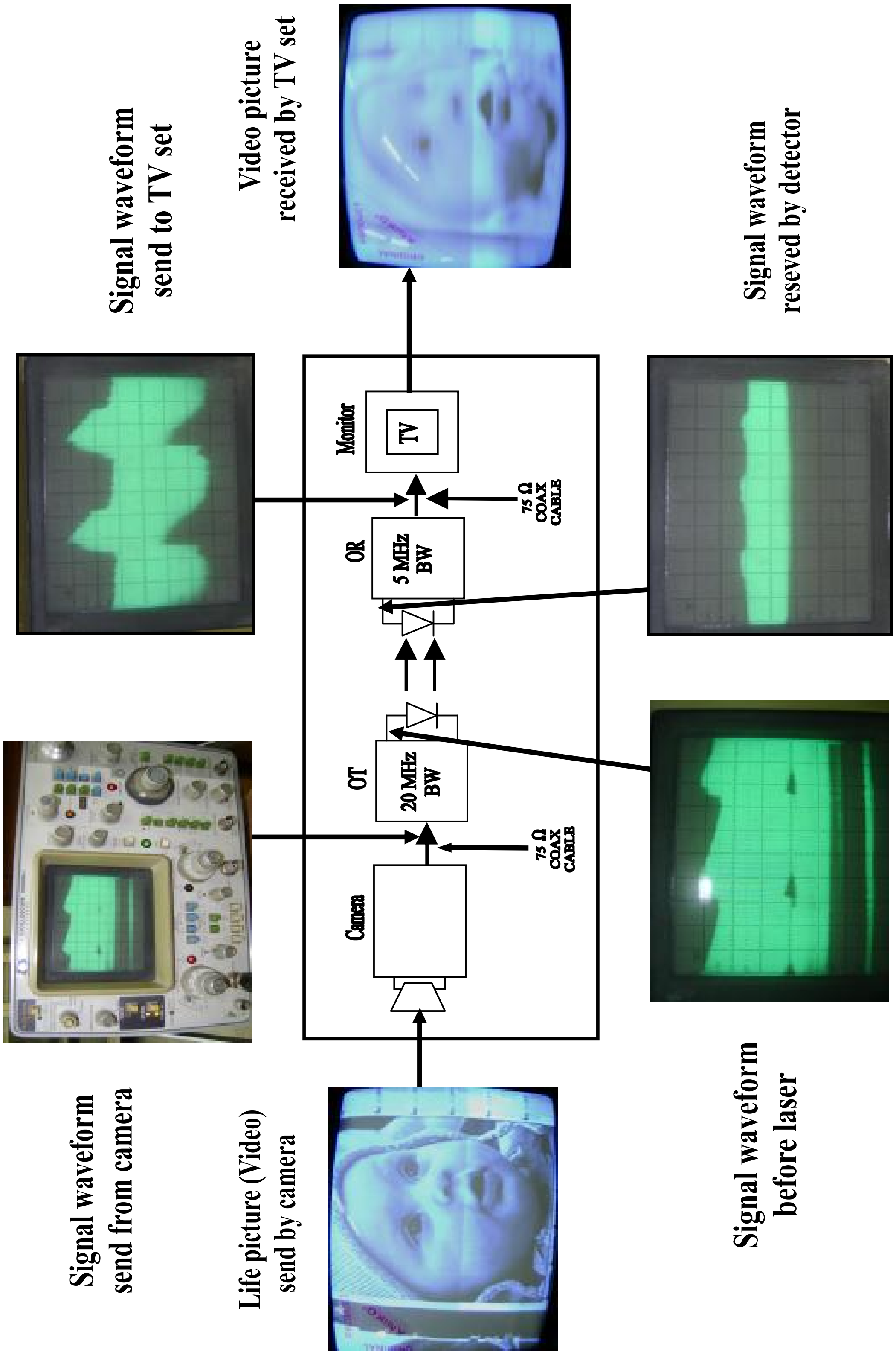


Figure (19) illustrates signal waveforms in optical video link