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Optical Repeater for free- space laser communication System

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Abstract:

The aim of this project is to design and construct an optoelectronic repeater to be utilized to extend the range of a laser free – space communication system. It consists of an optical receiver, an electronic processing unit, and an optical transmitter. This repeater is expected to extend the range of the laser communication system several folds depending on the number of the utilized repeaters.

Introduction:

Any Communication system consists of three main units, a transmitter, propagation medium and receiver. The purpose of the system, the range between the information source and its destination in addition to the cost and many other factors dictate the power requirements of the communication system. Optical communication system have many promising advantages that make them the proper choice to many applications. Laser source added powerful tool to optical communication system which increases their capability especially in free space communications including the remote sensing as a type pf indirect or passive communications.

Free – space, or unguided optical communication system have many important applications, specially, when one or both terminals (transmitter – receiver) has to be mobile is found very interesting in modern military applications since it provides a highly secured communication channels [1].

Theory:

A physical model for a laser communication system can be summarized as follows:

An information signal is coded to the modulator format (PCM, PPM, FM, AM, etc) and applied to a modulator. The modulated laser beam is collimated by an optical antenna (refracting or reflecting optics) and transmitted, through an optical wave guide (free- space, optical fiber), to a receiver unit. The receiver unit has also, its own optical antenna, but its role now is gathering and condensing the received optical power. While the transmitter optical antenna works as a collimator, especially in the free space laser communication system (FSLCS). The received optical signal is condensed on optical antenna (detector), which transforms the collected optical energy into an electrical signal. This signal is then processed and decoded to regain the original transmitted signal. In any communication system the relationship between the transmitted and received signal power is described by a communication range equation. This equation provides a characterization of propagation in the communication channel, free space propagation loss, and attenuation losses in the system components. The laser beam is therefore, utilized as a signal carrier. The power of this carrier suffers from different losses and degradation through its passage from the source to the receiver processing unit. Optical signal power losses in a laser transmitter unit can be described by the transmitter system transmittance, τ_t, which is given as

$$\tau_t = \frac{P_t}{P_L} \qquad (1)$$

Where P_L is the laser source power, and P_t is the transmitter unite optical power. The transmittance of the transmitter unite implicitly includes any losses of the laser beam power due to the units optical components. Diffraction causes beam divergence, in the far field, which is inversely proportional to the aperture diameter of the transmitter optical antenna. At a distant point (Z), assuming a uniformly illuminated circular aperture, the intensity per unite sold angle centered at

(Z), in the receiver plane, can be expressed in the term of the Bessel function of the first order as [2],

$$I(z) = \left[\frac{2J_1(u)}{u}\right]^2 * I_o \text{ ------------------------- } (2)$$

Where $u = \frac{\pi}{\lambda} d_t \alpha_t$

d_t - Transmitter aperture diameter

α_t - Half angle from center of transmitter aperture to point (Z) at the receiver plane

λ - Laser wavelength

And $I_o = \pi \left(\frac{d_t}{2\lambda}\right)^2 * P_t$

At the receiver plane, the power received about the center of the diffraction pattern, is the spatial integral of I (R) over reception angle (α_r) multiplied by the atmospheric transmittance factor (τ_a) to account for attenuation losses in the atmosphere [3]. If the receiver optical antenna diameter (dr) is located at a large distance (R) from the transmitter, and centered on the optical axis, then it can be shown that minimum power at the receiver aperture is given as

$$P_{MIN}(R) = 0.3\tau_a \left(\frac{d_r d_t}{R\lambda}\right)^2 P_t \text{ --------------------------- } (3)$$

If a photodetector , of diameter (d_p), is placed at the focal point of a receiver antenna and the optics of this antenna is assumed to be diffraction limited which produce a spot size of diameter (d_A) given as ;

$$d_A = \frac{2.44\lambda}{d_r} F_r$$

At the receiver antenna focal plane (F_r), then the carrier signal power at the detector surface is given as:

$$P_c = 0.3\tau_t \tau_a \tau_r \left(\frac{d_t d_r}{R\lambda}\right)^2 P_l \text{ ------------------------- } (4)$$

Where (τ_r) represents the receiver transmittance. This quantity includes the transmittance (or reflectance when using reflecting optics) of all optical parts of the receiver antenna and detector window. The optical detector is an energy transducer that converts the optical signal to an electrical one. The detection capability and the energy transfer efficiency of this transducer are related by several detector parameters such as the detectivity , quantum efficiency and responsivity.If the optical signal is sinusiodally modulated, and its modulation index (m=1). Then the average signal current is given by [4];

$$\langle i_s \rangle = \sqrt{2}\frac{e\eta\lambda}{hc} P_c \text{ -------------------------------- } (5)$$

Where:

η - The detector quantum efficiency

λ -the optical signal wavelength

P_c - The optical signal carrier power in (W) collected by the detector.

$\Re$ - is the detector current responsivity in $\left(\frac{A}{W}\right)$

From relation (4) & (5) the range equation can be represented as;

$$R = 585 d_r d_t \left(\frac{\eta \tau_s P_L}{\lambda \langle i_s \rangle} \right)^2 (m) \text{------------------------} (6)$$

Or

$$R = 0.65 \frac{d_t d_r}{\lambda} (\Re \tau_s \zeta_{or})^{\frac{1}{2}} (m) \text{-----------------------} (7)$$

Where:

$\tau_s = \tau_t \tau_r \tau_a$

$\zeta_{oe} \equiv \frac{P_L}{\langle i_s \rangle}$ Is the system optical – to- electronic signal transferability in ($\frac{W}{A}$).

For the case of a PIN photodiode with a FET operation amplifier, the minimum detectable signal current may be given as [5];

$$\langle i_s^{\,2} \rangle_{\min} = 2eI_p \Delta\nu + \frac{4kT\Delta\nu}{R_L} \text{---------------------------} (8)$$

Where:

$I_p = \Re P_c \tau_r$ Is the photocurrent.

$\Delta\nu$ Is the circuit bandwidth

T – Temperature

K – Boltzmanns constant

R_L – load resistor

The first term of Eqn. (8) represents the shot noise, while the second term represents thermal noise. A maximum optical communication system transferrablity can, therefore represented by

$$\zeta_{\max} = \frac{\zeta_{oe}}{\sqrt{\langle i_s^{\,2} \rangle_{\min}}} \text{-----------------------------------} (9)$$

Telecommunications systems include signal repeaters that consisted of a detector, amplifier, and a signal regenerator that restored the shape and intensity of the pulse and laser source replicates and reinforces the signal optically [6], is shown in figure (1).

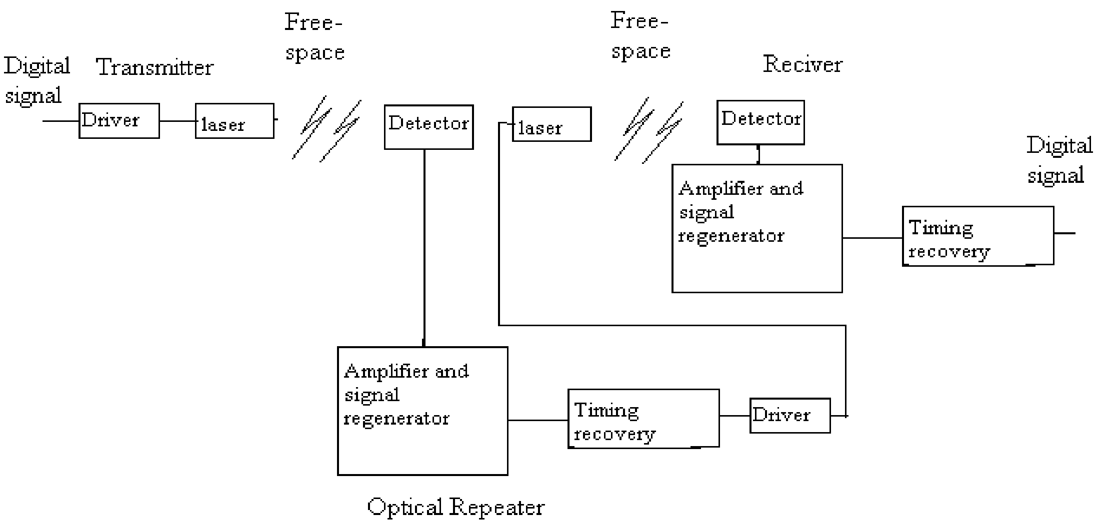


Figure (1) Schematic diagram for laser communication system with Optical repeater

Repeaters:

In the case of free space optical communication, the range between the transmitter and receiver is limited by the direct viewing within a line of signal , and for a high – capacity digital system , then repeaters are used to extend the range of the overall system. Repeaters usually designed with the same optical components as the terminal equipment, That is it consists of a detector , low noise ,an amplifier and automatic gain control gain , threshold detection and regeneration, and a laser transmitter circuitry ,as shown in the figure (2) .

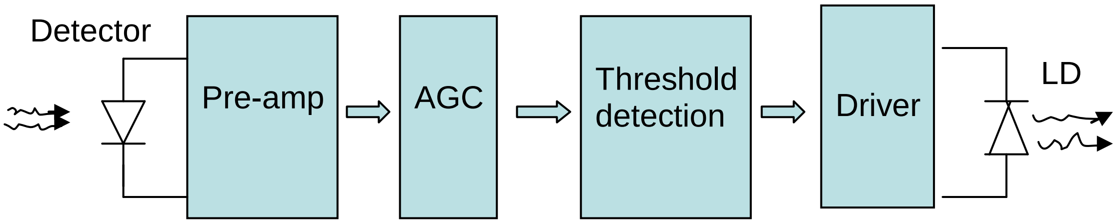


Figure (2) Schematic diagram for Optical repeater

The attenuate an dispersed optical pulse train is detected and amplified in the receive unit. This consists of a photodiode followed by a low noise preamplifier . the electrical signal thus acquired is given a further increase in power level in a main amplifier prior to reshaping in order to order to compensate for the transfer characteristic of propagation medium and the amplifier using an equalizer. Depending on the photodiode utilized, automatic gain control (AGC) may be provided at this stage for both the photodiode bias current and the main amplifier. Accurate timing (Clock) information is then obtained from the amplified and equalized waveform using a timing extraction circuit such as a reining circuit on phase locked loop. This enables within he bit intervals of the original pulse train. This function of the repeater circuit is to reconstitute the originally transmitted pulse train , ideally without error.

Laser Transmitter:

Electrically, a semiconductor laser behaves as a diode with a voltage turn-on knee greater than 1 V. When the laser is biased with a sufficient current so that lasing occurs, a further increase in injected current results in a proportional increase in laser optical output. For representative laser diodes, the frequency response of optical power output due to a change in laser current is flat out to a resonance at a very high frequency [7]. This resonance is due to laser relaxation processes. In this paper, the diode is to be operated at a maximum modulation frequency of a few megahertz, with a rise time (depending on laser current set-point) of approximately 15 ns. The laser current is modulated between two pre-set values I_{th} and I_{pk} .The threshold current I_{th} bias the laser to a point where is just begins lasing. I_{pk} is the current necessary to generate a given optical output power. For a 1 Watt at temperature 25^oC semiconductor laser, representative values for and are 300 mA and 1.2 A, respectively. to maintain constant optical power output, it is desirable to make the injected laser current independent of temperature. Therefore, the laser is driven with a high impedance current source. The laser is also fitted with a thermo-electric (TE) cooler so as to maintain constant laser chip temperature so that optical power remains constant at constant current and the wavelength constant at 810 nm. The circuit in figure (3) is capable of delivering 1200 mA to a laser load at full optical power modulation frequencies of 10 MHz, related the input signal it have amplitude about 30μA.

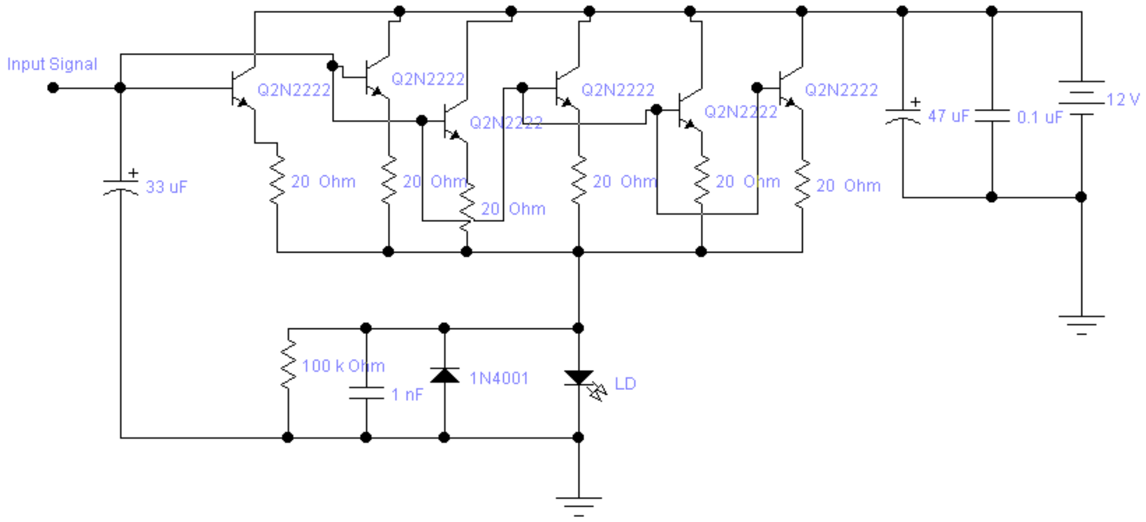


Figure (3) Laser transmitter circuit.

Laser receiver:

As a detector for the laser pulses an avalanche photodiode (61288) is employed in the receiver unite, (see figures (4, a and b)). It works as an envelope detector and converts the laser light pulses into electrical pulses . When the photons is incident , the hole -electron Pairs that is forming in the depletion region . Average value of such inner gain depends on the receiver avalanche photodiode supply voltage .Receiver avalanche photodiode (61288)represents a current generator [8]. The generated current pulse is led to the load resistor of the receiver avalanche photodiode (R_2=3.9 k ohm) where the voltage pulse is obtained.

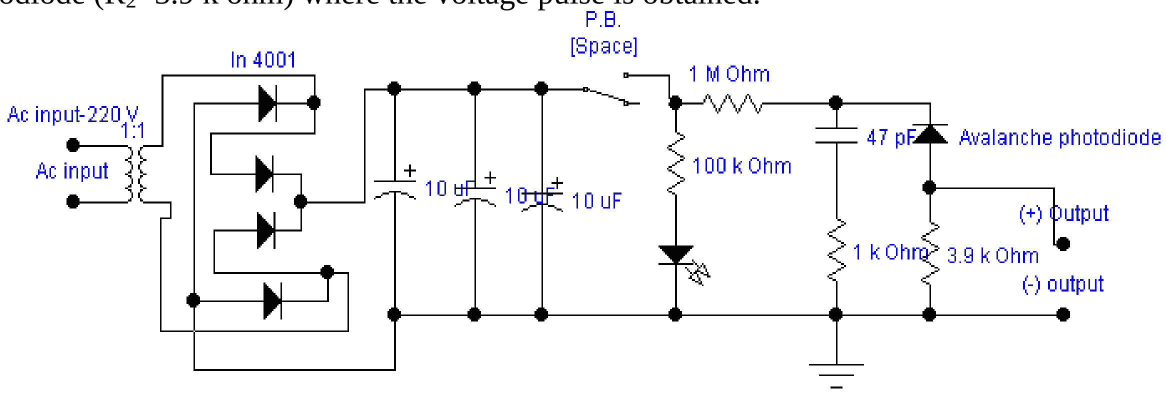


Figure (4,a), circuit of Receiver unit.

Figure (4,b) Over view of the Receiver unit

Simulation Results:

1- The figure (5) shows the signal modulated on laser diode with specification, Pulse duration = 50 ns , PRT = 100ns Vp= 4.5 v Ip =1250mA.

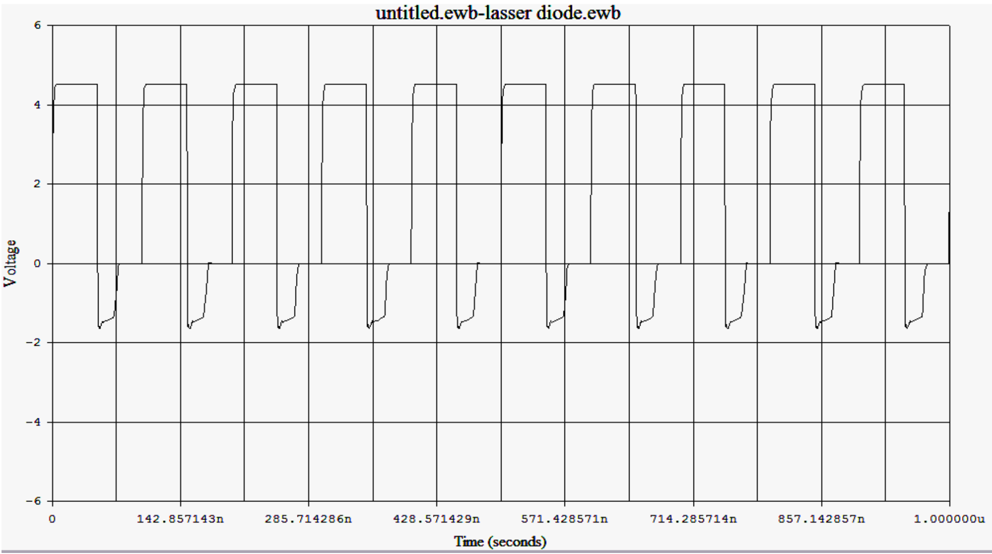
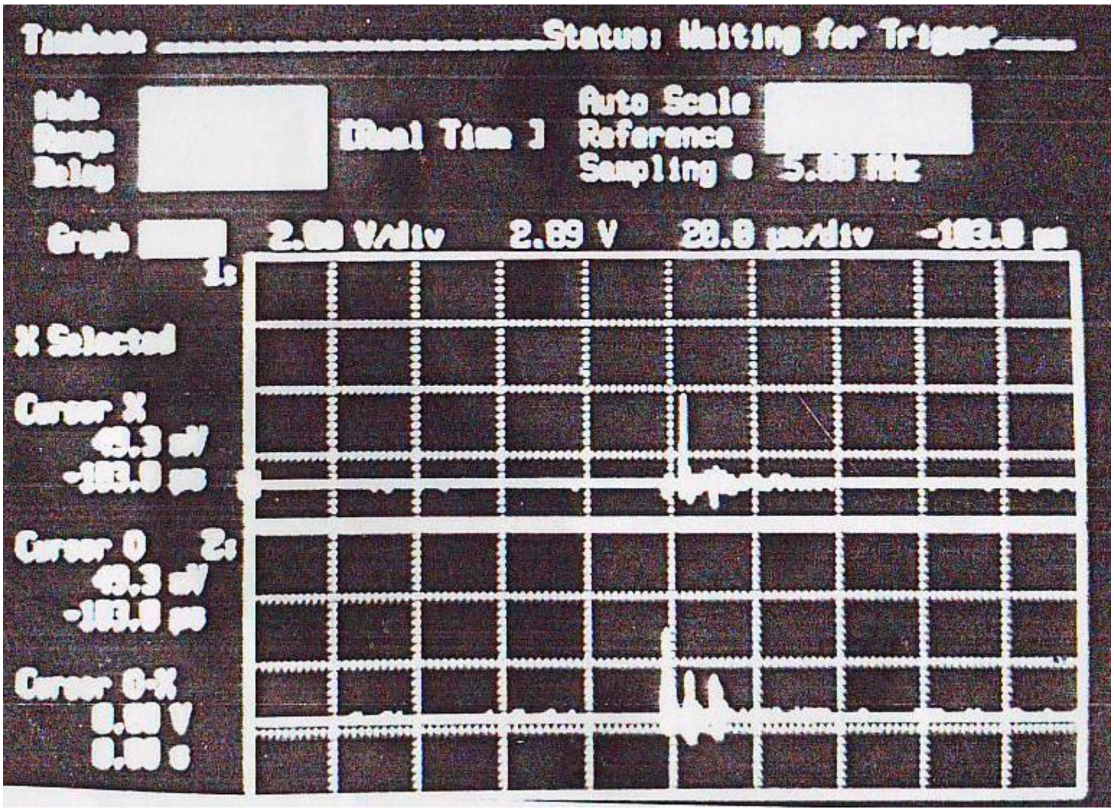


Figure (5) modulating signal

Empirical Result:

The figure (6)shown the synchronization between the optical signal of main laser source and the optical signal regeneration from optical repeater in Laboratory, the delay time between singles results from electrical components delay time and the time generated new optical signal.



The figure (6) the synchronization between optical signal

Conclusions:

This circuits demonstrates the successful application of Receive optical signal ,processing this signal and driver high power laser diode (1W) at modulated frequency (10 MHz).

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