# PARAMETRICAL ANALYSIS OF A PULSED LASER SYSTEM

Shashank Soi
B. Tech, Electronics and Communication Engineering
Dr.B.R.Ambedkar, National Institute of Technology Jalandhar, India

***Abstract: In this paper a base for analysis of the reception of optical signals on the optical receiver is developed. In particular, the analysis is carried out by taking into consideration the quad-rant photodiode. Attention is also paid to the trans impedance amplifier as a key factor in the laser systems. The laser seeker and designator is analyzed experimentally. The laser power and reflectivity as a function of range variation is also analyzed. The simulation results are presented in MATLAB.***
***Index Terms: Designator, Seeker, QPD, TIA, Visibility***

## I. INTRODUCTION

Today laser systems play a significant role in various fields of engineering. The use of laser designator and the laser seeker allows us to determine various parameters of the laser illuminated objects, such as the distance to the object and the power received at the optical receiver. The principle of distance and power measurements is based on the laser pulses emission, which illuminates the target, whose parameters are to be determined, and their reception with the corresponding optoelectronic receiver. Various signal processing schemes allows the determination of theses parameters.

## II. WORKING PRINCIPLE OF LASER GUIDED WEAPONS

The laser guided weapon consists of a laser seeker section which is equipped with a quadrant photo detector and suitable optics, an electronic card to decode the laser code, a guidance system to analyze target's relative direction, a control section which converts guidance system commands to physical control surface deflections. For the working of the laser guided weapons, two main components are necessary: a designator and a seeker. Laser designators are special equipments which creates a very high power but short duration pulses of laser. Laser designators consist of a laser source and suitable binocular optics for the operator to aim and track the target easily. The designator is aimed at the target by means of operator optics. The laser beam strikes the target surface and gets reflected. The acquisition starts when the reflected laser energy falls on the seeker. The reflected light enters the seeker where the optics collects the incoming laser beam and directs it on the surface of the detector where the falling energy causes a current formation on the detector. Since there is a line of sight angle between the weapon and the target, when refracted by the lenses most of the energy will fall into one region of the detector, giving information about the line of sight angle between the target and weapon. Laser designators and seekers use a pulse coding system to ensure that a specific seeker and designator combination work in coordination. By setting the same code in both the designator and the seeker, the seeker will track only the target illuminated by the designator.

## III. LASER ATTENUATION IN THE ATMOSPHERE

A laser beam is attenuated as it propagates through the atmosphere. The attenuation depends on the wavelength, output power, and atmospheric conditions. Laser beams travel in the atmosphere according to Beer's law, which states that

$$T = \exp(-\sigma R) \quad (1)$$

where
T= Transmittivity
σ= Atmospheric attenuation coefficient (in 1/km)
R= Range (in km)
Atmospheric attenuation and visibility are related as:

$$\sigma = \frac{3.91}{V}\left(\frac{550}{\lambda}\right)^{q} \quad (2)$$

where
V= Visibility (in km)
λ= Wavelength of laser (in nm)
q= Size distribution of scattering particles
q=1.6 for high visibility and 1.3 for low visibility
The variations in the values of atmospheric attenuation coefficient with visibility is shown in Fig. 1

Atmospheric Attenuation Coefficient vs Visibility

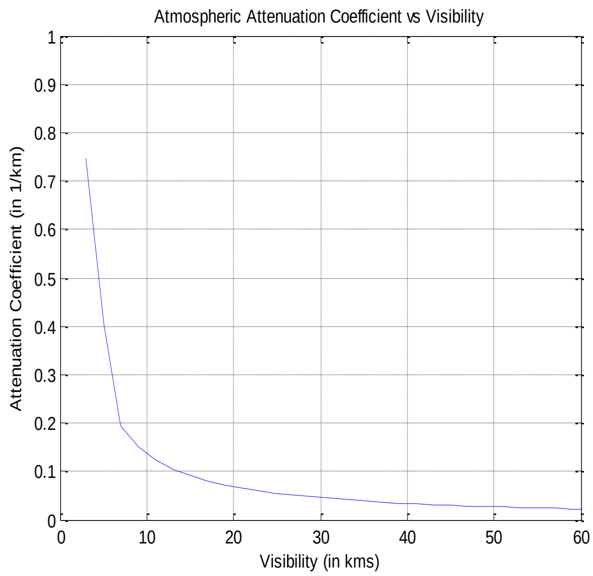


Fig. 1 Atmospheric attenuation coefficient for λ=1064 nm as a function of visibility

The results have been plotted in Table 1

  

Table 1. Atmospheric Attenuation Coefficient For Different Values Of Visibilities

| S.No. | Visibility(km) | Attenuation Coefficient (1/km) |
|---|---|---|
| 1 | 3 | 0.7469 |
| 2 | 9 | 0.1511 |
| 3 | 15 | 0.0906 |
| 4 | 21 | 0.0647 |
| 5 | 27 | 0.0503 |
| 6 | 33 | 0.0412 |
| 7 | 39 | 0.0348 |
| 8 | 45 | 0.0302 |
| 9 | 51 | 0.0266 |
| 10 | 57 | 0.0238 |

From Table 1 it is observed that there is increase in attenuation as the visibility decreases. The same result can be verified from the graph of Fig. 1.

## IV. POWER CALCULATIONS

The output power from the laser designator is taken as Pd. Since the entire laser beam is assumed to be reflected from the target's projected area, the power reflected from the target will be attenuated only by the atmosphere. The power at the target Pt, can be found by multiplying the designator output power Pd, with the transmittivity T, as depicted by Equation 3

$$P_t = P_d * T \qquad (3)$$

The average value of target reflectivity γ is between 0.2 and 0.5. The reflected power Pr from the target can then be found using Equation 4

$$P_r = P_t * \gamma \qquad (4)$$

Fig. 2 shows the plot of power magnitudes for different values of visibility for designator power of 5MW.

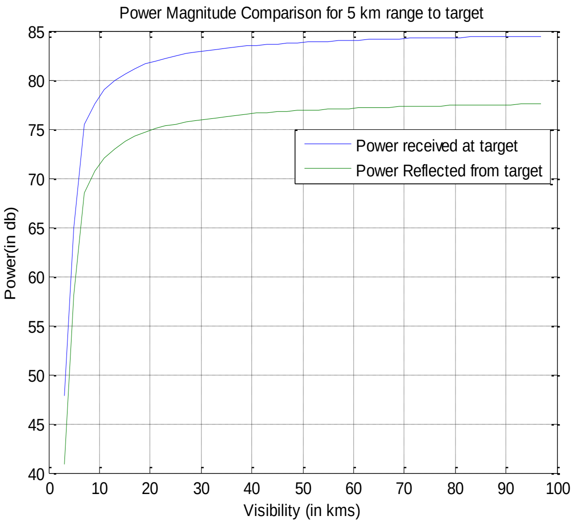


Fig. 2 Plot of Received and Reflected Powers from the Target for designator power of 5MW as a function of visibility

Table 2 shows the results obtained from Fig 2.

Table 2. Power Magnitude Comparison For Different Values Of Visibilities

| S.No. | Visibility (km) | Power Received at Target (in dB) | Power Received at Target (in dB) |
|---|---|---|---|
| 1 | 3 | 116.9043 | 109.9728 |
| 2 | 9 | 146.6919 | 139.7605 |
| 3 | 15 | 149.7149 | 142.7835 |
| 4 | 21 | 151.0105 | 144.0790 |
| 5 | 27 | 151.7303 | 144.7988 |
| 6 | 33 | 152.1883 | 145.2568 |
| 7 | 39 | 152.5054 | 145.5739 |
| 8 | 45 | 152.7379 | 145.8065 |
| 9 | 51 | 152.9158 | 145.9843 |
| 10 | 57 | 153.0561 | 146.1247 |

Fig. 3 shows the variations of Power received at the target for different values of visibility as a function of distance between the target and designator.

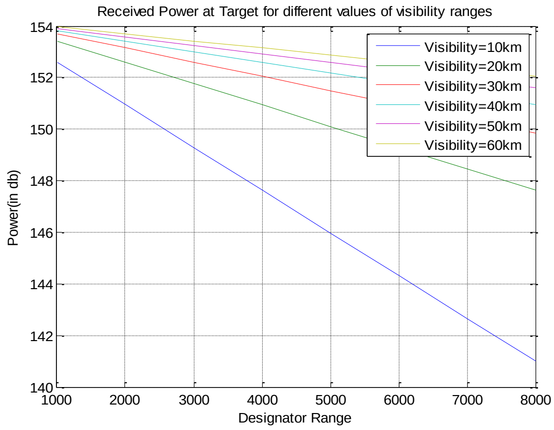


Fig. 3 Plot of Received Power at Target (in dB) vs Designator Range for different values of visibility

From Fig. 3 it is observed that the power received at the target decreases drastically as the visibility decreases as well as the designator range.

## V. RECEIVED OPTICAL POWER AT THE SEEKER

Assuming a dominant diffuse reflection from all target surfaces, the reflected power is radiated uniformly into a hemi-sphere and a fraction of this power is sensed by the seeker. The power collected by the seeker Ps, is equal to reflected power from the target Pr multiplied by the atmospheric transmission, and the ratio of the seeker optics to the area of a hemisphere with a radius equal to range. Mathematically, Power received at the optical sensor is given by Equation 5 which is

$$P_s = \frac{P_r * T * D^2}{8 * R_m^{\;2}} \qquad (5)$$

where

D= receiving optics diameter

Rm=distance between optical sensor and target (seeker range) The geometry of laser and receiving optics is shown in Fig. 4

  

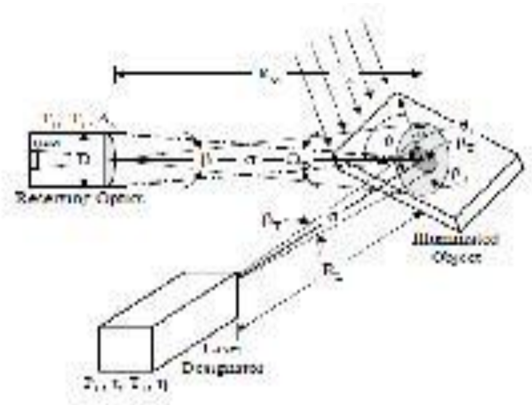


Fig. 4 Geometry of Laser and Receiving Optics

Fig. 5 shows the plot of received optical power at the optical receiver for different values of reflected powers as a function of seeker range. The results of the plot in tabulated form are given in Table 3.

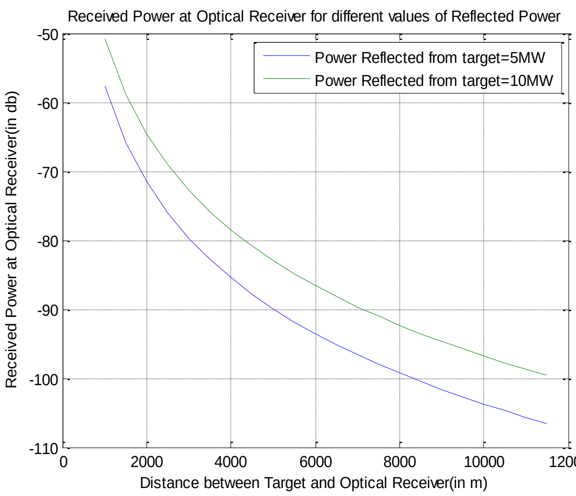


Fig. 5 Received Optical power at the optical Receiver vs Seeker Range

Table 3. Power Magnitude Comparison Vs Range for Different Values of Reflected Power

| S.No. | Distance between Target and Optical Receiver (in m) | Power Received (in dB) for 5 MW Reflected Power | Power Received (in dB) for 10 MW Reflected Power |
|---|---|---|---|
| 1 | 1000 | -57.6832 | -50.7517 |
| 2 | 2000 | -57.6832 | -64.6146 |
| 3 | 3000 | -79.6554 | -72.7239 |
| 4 | 4000 | -85.4090 | -78.4776 |
| 5 | 5000 | -89.8719 | -82.9404 |
| 6 | 6000 | -93.5183 | -86.5869 |
| 7 | 7000 | -96.6014 | -89.6699 |
| 8 | 8000 | -99.2720 | -92.3405 |
| 9 | 9000 | -101.627 | -94.6962 |
| 10 | 10000 | -103.734 | -96.8034 |
| 11 | 11000 | -105.6411 | -98.7096 |

Inspecting Fig. 5 and Table III it can be concluded that as the distance between the target and the optical receiver increases the power received at the optical receiver decreases.

## VI. OPTICAL RECEIVER: QUADRANT PHOTO DIODE

The optical receiver used is a photo detector, which generates a current in correspondence to the received optical power. There are various types of photo detectors. Since most laser guided weapons use 4-quadrant photodiodes, therefore it is discussed here. The principle of QPD positioning is simple. Incoming light is focused on the detector as a spot. Comparing of the output currents received from each of the four quadrants, the position of the spot on the surface can be determined. Thus, in general, photo-detection system can be functionally divided into two main parts: a sensing stage and a post-processing one. In the second one, the signal post-processing stage, the standard approach difference of the sum of signals coming from left- and right-side quadrant for horizontal and the difference of the sum of signals coming from upper- and down-side quadrants for vertical displacement. The geometry of light falling on the photodiode is shown in Fig. 6

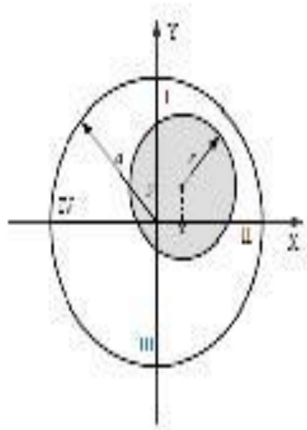


Fig. 6 Geometry of light spot on the quadrant photo detector

## VII. CURRENT CALCULATION AT PHOTO DETECTOR

The power received at the optical receiver is directly proportional to the current generated at the optical receiver. The constant of proportionality is known as the responsivity of the detector given by Rλ. Equation 6 describes this relation-ship.

$$I_p = R_\lambda * P_s \qquad (6)$$

where
IP= Photo detector current
Rλ= Responsivity (in A/W)
Ps= Received power at the detector

## VIII. I/V CONVERTER: TRANSIMPEDANCE AMPLIFIER

As the first stage, in the analog signal processing from the photodiode, the transimpedance amplifiers (TIA) have two main functions. The first is to filter the noises at their inputs and the second function is to amplify the current signals. The current signals at the photodiode are converted into voltage signals, as shown by Equation 7. A basic TIA circuit is shown in Fig. 7

  

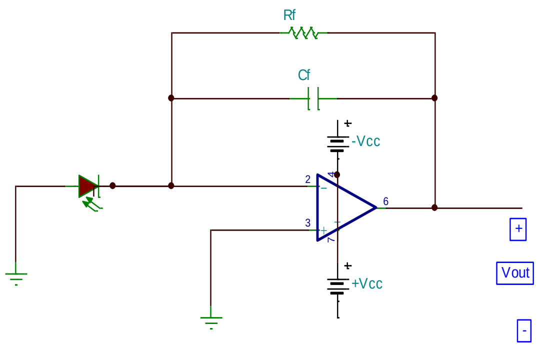


Fig. 7 Basic TIA circuit

The TIA circuit takes the input as current generated proportional to the light intensity falling on the photo detector. The corresponding output voltage generated is given by the expression.

$$V_{OUT} = -I_p * (R_F \parallel C_F) \quad (7)$$

i.e.

$$V_{OUT} = \frac{-I_p * R_F}{1 + sC_F R_F} \quad (8)$$

## IX. CONCLUSION

One of the important results of this study is the knowledge gained about the characteristics of laser designators and laser seekers. This paper aims to develop a base for the analysis of optical receivers for laser tracking systems, and in particular investigates the effects of several parameters on the performance of the optical receiver. In modelling the optical receiver, its behavior in various atmospheric conditions is investigated. It is seen that the reflected energy from a target is heavily affected by the designator’s output power, atmospheric visibility and reflectivity of the target surface. The analysis of the Transimpedance Amplifier is also presented.

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