COMPARISON OF MODULATION SCHEMES USED IN FSO COMMUNICATION

M. Rama Narmada[1], K. Nithya[2], P. Ashok[3]
[1,2,3]Prince Shri Venkateshwara Padmavathy Engineering College

Abstract
The semiconductor diode called VCSEL (Vertical Cavity Surface Emitting Laser) working at the wavelength of 863nm emits the laser beam perpendicular to its surface in a narrow and nearly circular manner. This paper has solved the rate diode equations of VCSEL using the ode45 differential equations present in the MATLAB software to obtain the steady state and transient characteristics which is used to obtain the threshold current (I_{th}), FWHM (Full Width Half Maximum) and the output power (P_0). The lowest possible FWHM can be obtained by varying the current values. The short pulse is generated by using this value of FWHM as the pulse duration which is applied to calculate the Bandwidth Efficiency and BER (Bit Error Rate) of the commonly employed modulation scheme in FSO (Free Space Optics) communication like OOK (On – Off Keying), DPIM (Differential Pulse Interval Modulation), DHPIM (Dual Header Pulse Interval Modulation).
Index Terms: Bandwidth Efficiency, BER, FWHM, FSO, Modulation, Output power, Short Pulse generation, Steady state response, Transient response, VCSEL rate equations.

I. INTRODUCTION

Free - space optical communication (FSO) also known as WOC (Wireless Optical Communication) is an optical communication technology that uses light propagating in free space to wirelessly transmit data for telecommunications or computer networking. "Free space" means air, outer space, vacuum, or something similar. This contrasts with using solids such as optical fiber cable. This technology is useful where the physical connections are impractical due to high costs or other considerations. Most importantly, Line Of Sight (LOS) is required to implement FSO in which a direct path must exist between transmitter and receiver.

FSO has limitations on the optical power so modulation schemes with a high peak-to-mean optical power ratio (PMOPR) such as the pulse position modulation (PPM) and digital pulse internal modulation (DPIM) are preferred. OOK is the most widely used scheme in FSO systems due to its simplicity.

VCSEL is used as a source to generate the input short pulses in the order of microseconds since their pulse duration is small and the analysis can be made effective.

II. CHARACTERISTICS OF VCSEL

The Laser Diode Rate Equation for VCSEL (Vertical Cavity Surface Emitting Laser) is given in equations below

$$\frac{dN}{dt} = \frac{\eta_i I}{q} - \frac{N}{\zeta_n} - \frac{G_0(N-N_0)S}{1+\epsilon S} \quad (1)$$

$$\frac{dS}{dt} = \frac{-S}{\zeta_p} + \frac{\beta N}{\zeta_n} + \frac{G_0(N-N_0)S}{1+\epsilon S} \quad (2)$$

Where the parameters and their values are given in the Table 1. The photon number is determined by S and the number of electrons is determined by N. The first term in equation 1 denotes the injected rate, the second term carrier depletion and the third term denotes the carrier depletion due to stimulated recombination. The first term in equation 2 denotes photon rate, the next term represents photon density increase due to stimulated emission, and the last term denotes the spontaneous emission.

Table 1. Parameters used in rate equation

PARAMETERS	VALUES
Q	1.60219×10^{19} (C)
$\boldsymbol{\zeta}$n	5×10^{-9}
ζp	2.064×10^{-12}
G_0	1.6×10^{4}
ϵ	5×10^{-7}
$\boldsymbol{\beta}$	1×10^{-6}
K	2.6×10^{-8}
I_{th}	1.5 (mA)
I	1.539 (mA)
N_0	1.654×10^{7}
P_0	Dynamic

A. *Steady State Response*

The steady state response is obtained by varying the input current. The main function is called with the help of ode45 function through which the rate equations are used. A for loop is used in the function to set the current as zero. Here the length of the carrier density and electron density equations are studied. Then if loop is included to determine the number of carriers and photon in the laser diode.

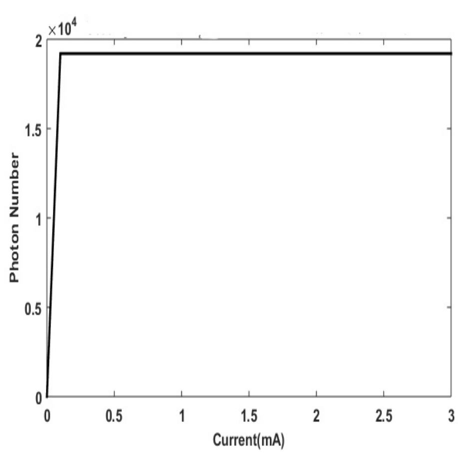

Fig 1. Input Current (mA) Vs Photon Density (S)

The number of carrier and electrons will remain zero if it goes negative, since there is no negative number of carriers and photons. Then the end value of the electron density was obtained to plot the graph. For transient response the carrier density curve will goes constant after some oscillations to reach the peak value. In steady state response the curve will go constant after reaching the threshold current. Similarly, the photon density is also obtained in the same way. Fig 1 shows the response of the photon density, as it remains zero till 1.5mA and it goes on increasing.

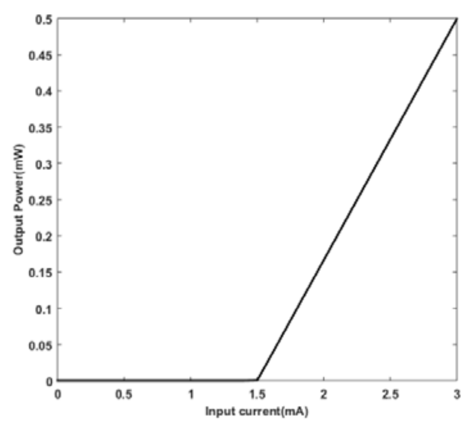

Fig 2. Input Current (mA) Vs Output Power (Po)

The photon density and the power of the laser diode were obtained to be same since they are proportional to each other. From these values the graphs are plotted and so the threshold current was obtained. The threshold current is obtained to be 1.5mA. Threshold current is defined as the current after which the power starts to increase. Thus, the power is increased by decreasing the threshold current. The output power response is shown in the Fig 2. As the power remains zero and it goes on increasing after 1.5mA.

B. *Transient Response*

In transient response, the curve is obtained by varying the time. Here a loop (t=0…1xe^{-6}) was used for generating various time sequence. For single value of current the photon density and the carrier density are obtained. The transient function is defined in the main module in which the options and ode45 are used to call the differential equations by using the similar parameters. Thus the solution for the differential equations will return their the main module. By using these values, the photon number and the electron number are obtained. These functions will be determined with respect to the loop of time.

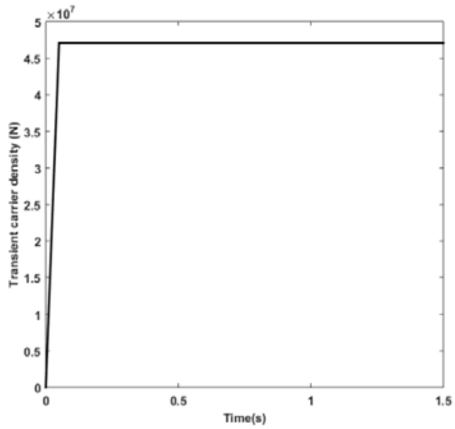

Fig 3. Time(s) Vs Transient Carrier Density (N)

Here the loop is used to obtain the number of photon and electron, in which the number of photon and electron should be greater than zero as the number of photon and electron could not be negative and if their values are found to be less than zero, the photon number and the electron number are equated to zero. Fig 3 shows the carrier density increases to the peak and it goes constant after 0.5 seconds

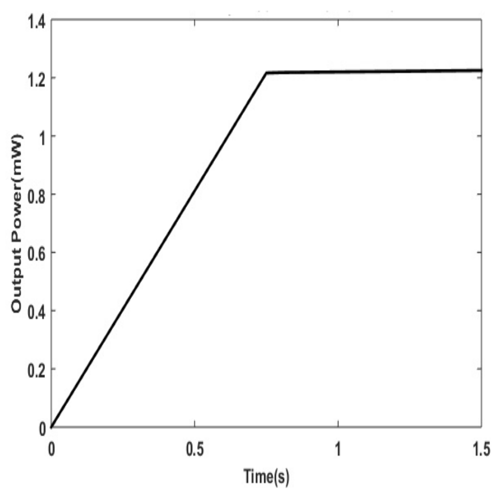

Fig 4. Time(s) Vs Output Power (Po)

The output power is directly proportional to the photon density. Thus, it is given as,

Output Power=Scaling factor(k) x No of Photons(S) (3)

With the help of the equation (3) the output power of the laser diode is obtained and so the transient response curve for output laser is plotted. Fig 4 shows the transient response of the output power.

III. SHORT PULSE GENERATION

In optical communication, a short pulse of light is an electromagnetic pulse whose time duration is of the order of a microsecond (10^{-6} second) or less. Such pulses have a broadband optical spectrum, and can be created by mode-locked oscillators. They are commonly referred to as ultrafast events. They are characterised by a high peak intensity (or more correctly, irradiance) that usually leads to nonlinear interactions in various materials, including air.

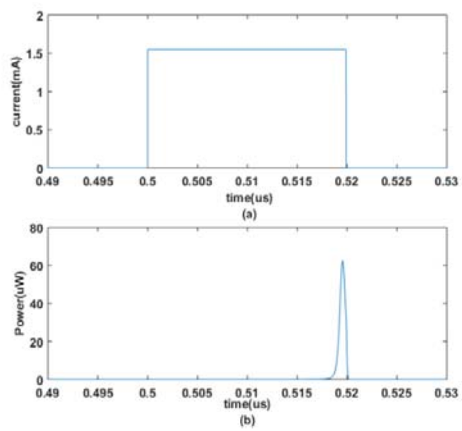

Fig 5. (a) Input pulse (b) short pulse

A square pulse with the minimum possible width of 0.0199 microseconds without disturbing the actual shape of short pulse is given as the input. The short pulse is generated from the given input pulse by using the laser diode rate equations. The short pulse is shown as a plot between varying power values with respect to the time. It must be noted that the current values must always be greater than the threshold value of 1.5 mA according to gain switching concept. Here the amplitude of current is set to 1.026 times greater than of that the threshold current.

A. *Short Pulse Characteristics*

The shortest pulse for the given input pulse can be identified in terms of its Full Width Half Maximum (FWHM), Current (I) and Output Power (P_0). For this reason, various plots for Current versus FWHM, Current versus Power and FWHM versus Power has been shown below.

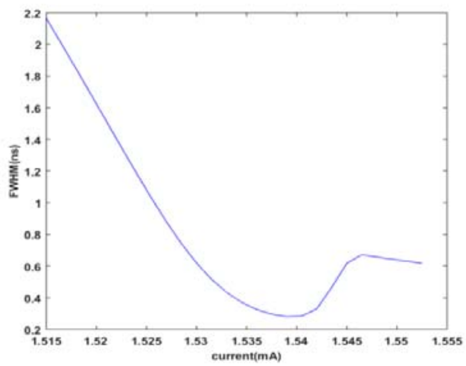

Fig 6. Current Versus FWHM

In fig 6, The range of current values with lower values of FWHM without changing the actual shape of short pulse is considered.

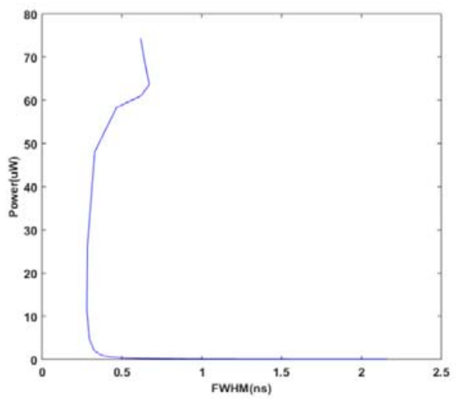

Fig 7. FWHM versus Peak Power

In fig 7, The range of lower values of FWHM in the order of nano seconds and corresponding values of peak power in the order of microwatts is considered. It should be noted that the value of FWHM must be smaller than the actual pulse width of 0.0199 microseconds. The lowest value of FWHM (28 nano seconds) is considered to be the bit duration of short pulse.

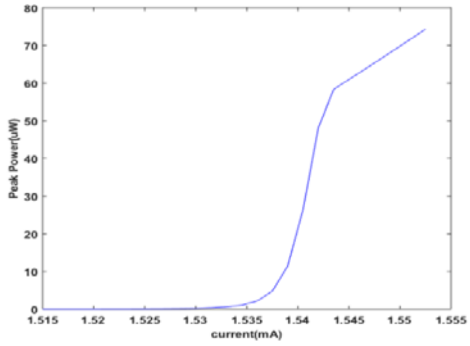

Fig 8. Current Versus Peak Power

The fig 8 shows the plot between various ranges of current values and its corresponding peak power. It must be noted that the current values must always be greater than the threshold value of 1.5 mA according to gain switching concept.

IV. BANDWIDTH EFFICIENCY

Bandwidth Efficiency is defined as the information rate that can be transmitted over a given bandwidth.

$$\eta_b = \left({R_b}/{B} \right) \quad (3)$$

It has no unit. An ideal modulation scheme must have the bandwidth efficiency to be high.

Bandwidth efficiency is the optimized use of spectrum or bandwidth so that the maximum amount of data can be transmitted with the fewest transmission errors. In a cellular telephone network, bandwidth efficiency equates to the maximum number of users per cell that can be provided while maintaining an acceptable Quality of Service (QoS). Bandwidth efficiency is essential to determine the throughput of a computer network.

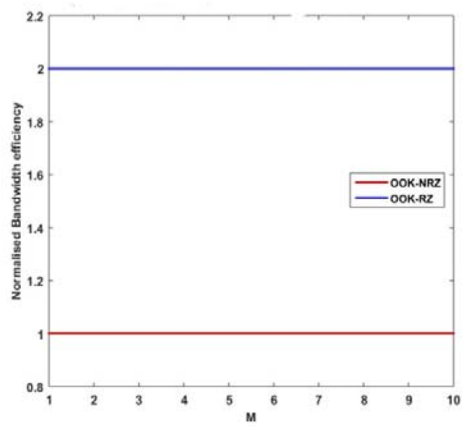

Fig 9. Normalised Bandwidth efficiency of OOK-NRZ and OOK-RZ

The fig 9 shows the comparison of normalised bandwidth efficiency of OOK-NRZ and OOK-RZ computed with the value of T_b as 0.28ns. The bandwidth efficiency is normalised with respect to R_b since it depends directly on R_b. It may be observed that the OOK-NRZ has bandwidth efficiencies lower than OOK - RZ for the same M values varying from 1 to 10. So OOK – RZ is preferred.

V. BER

Bit Error Rate (BER) is defined as the ratio of number of erroneous bits to the total number of bits. It has no unit. BER should be low as much as possible to ensure reliable data transmission. Similar to SNR analysis in wired network, BER analysis is done in wireless network. BER should be very low for any wireless data communication technique.

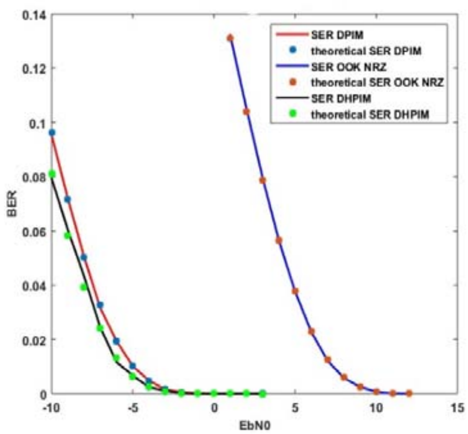

Fig 10. BER of DPIM, OOK - NRZ and DHPIM

The fig 10 shows the comparison of BER of OOK -NRZ, DPIM and DHPIM computed with the value of T_b as 0.28ns. Each modulation scheme has its SER (Slot Error Rate) computed using the theoretical formula and practical cases. It may be observed that, the practical values does not deviate much from the theoretical values. The DHPIM possess the lowest possible BER among these three schemes.

VI. CONCLUSION

Thus, the rate diode equation of the laser diode was solved using the MATLAB software. The transient and the steady state curves were plotted for the VCSEL laser diode. The minimum threshold current and minimum FWHM for the short pulse was obtained by varying the rate equation parameters. This short pulse duration was applied to calculate the parameter values like Bandwidth efficiency and BER of commonly used modulation schemes in FSO like OOK, PPM, DPIM, DHPIM. It may be observed that OOK – RZ has the highest bandwidth efficiency and DHPIM has the lowest BER making it suitable for use in FSO related applications. Generally, OOK-RZ is preferred due to its simplicity.

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