Analysis Performance of *L*-PPM Infrared Wireless Communications for Indoor LOS and Diffuse Links

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Abstract- In this paper, we present the efficiency and performance of Pulse Position Modulation (*L*-PPM) for indoor wireless infrared communication system. By physical characteristic of infrared channels using intensity modulation with direct detection (IM/DD). Noise in the channel will be considered as Additive White Gaussian Noise. We evaluate power and bandwidth efficiency compared with On Off Keying (OOK). We have computed the path loss versus horizontal separation between transmitter and receiver in LOS and Diffuse link, and our results show the best average power efficiency among the modulation techniques, which are presented for 2, 4, 8, 16, 32, and 64 PPM at bit rates of 10 Mb/s to 100 Mb/s. Finally, we present Monte Carlo Simulation results to Bit Error Probability and the best Signal to Noise Ratio that *L*-Pulse Position Modulation requirement.

Keywords: *L*-PPM, LOS, Diffuse Link, IM/DD

I. INTRODUCTION

Infrared wireless communication technology has several features that are well suited to indoor wireless applications. Infrared transmitters and receivers can be built at relatively low cost, and with small size and low power consumption suitable for battery-supported operation. Typical portable devices include laptop computers, personal digital assistants, and portable telephones, while the base stations are usually conected to a computer with other networked connections, as show in Fig.1.Hopefully, this technology will provide breakthroughs that will aid the development of 3G (third generation) wireless technology, [1-3].

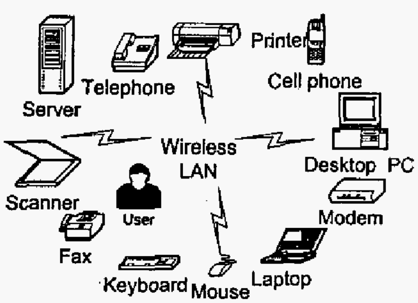


Fig. 1. Indoors wireless infrared communication system.

The different kinds of link for indoor infrared wireless communications have been classified, depending on the existence of a Line-Of-Sight (LOS) path between the transmitter, receiver and the degree of directionality. Directed links also improve power efficiency as the path loss is minimized, but this kind of system need alignment of the transmitter, the receiver, or both, making then is less convenient to use for certain application. One of the most attractive configurations is the Diffuse Link (Non directed - Non LOS). Systems working under this configuration do not require a direct line of sight, or alignment between the transmitter and receiver because the optical waves are spread as uniformly as possible in the room by making use of the reflective property of the walls and the ceilings. This kind of link has the advantage that it can operate even when barriers are placed between the transmitter and the receiver. This makes it the most robust and flexible configuration. The two basic configuration are shown in Fig.2.

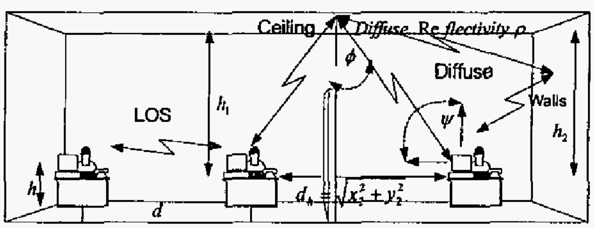


Fig. 2. Line Of Sight (LOS) and Diffuse Links system.

II. DESIGN OF POWER – EFFICIENT LINKS AND NOISE MODEL

A. IM/DD Channels

For infrared links, the most viable modulation is intensity modulation (IM), in which the desired waveform is modulate onto the instantaneous power of the carrier. The most practical down-conversion technique is direct detection (DD). The modeling of infrared channel with IM/DD is illustrated in Fig.3. We can write the photo current at receivers as

$$Y(t) = RX(t) \otimes h(t) + N(t) \qquad (1)$$

The received photocurrent Y (t) is the convolution of the transmitted optical power X (t) with a channel impulse response $h(t)$ (fixed for a given configuration of transmitter, receiver, and intervening reflectors) scaled by the photo detector responsivity R, plus an additive noise $n(t)$, which is usually modeled as white gaussian noise, and independent $x(t)$.

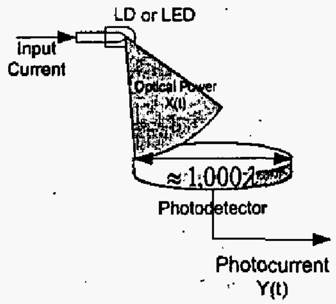


Fig.3. Transmission and reception in an infrared link with IM/DD.

The average transmitted optical power has given by

$$P_t = \lim_{T\to\infty}\frac{1}{2T}\int_{-T}^{T} X(t)dt. \qquad (2)$$

For the purpose of computing the average power *Pt* required to achieve a certain bit rate Rb and bit error probability *Pe*, only two key parameters are needed to characterize multipath IR channels: Dc gain *H*(0) and root-mean-square delay spread D. Where the *H*(0) has given by

$$H(0) = \int_{-\infty}^{\infty} h(t)dt \qquad (3)$$

H(0) is the frequency responses of infrared channels are relatively flat near dc, and the average receiver optical power has given by

$$P_{Receive} = H(0)P_t \qquad (4)$$

B. Infrared Transceiver and Eye Safety

A transmitter or source converts an electrical signal to an optical signal. The two most appropriate types of device are the light emitting diode (LED) and laser diode (LD). LEDs have a naturally wide transmission pattern, and so are suited to nondirected or diffuse links. The comparison between LEDs and LDs show in Table1, [4-5]. A receiver or detector converts optical power to electrical current by detection the photon flux incident on the detector surface. The two most appropriate types of device are the Silicon p-i-n photodiode and Avalanche photodiode. The p-i-n photodiodes are ideal for wireless infrared communications as they have good quantum efficiency in this band and are inexpensive. The comparison between p-i-n photodiode and avalanche photodiode show in Table. 2.

Table 1. Comparison of LEDs versus LDs.

Characteristic	LED	LD
Optical Spectral width	25 – 100 nm	0.1 – 5 nm
Modulation Bandwidth	10 kHz - 100 MHz	10 kHz – 10 GHz
Special Circuitry Required	None	Threshold and Temperature Compensation Circuitry
Eye Safety	Considered Eye Safety	Must be rendered Eye Safety
Reliability	High	Moderate
Cost	Low	Moderate to High

Table 2. Comparison of p-i-n Photodiode versus Avalanche Photodiode for wireless infrared links.

Characteristic	p-i-n Photodiode	Avalanche Photodiode
Modulation Bandwidth	10 MHz – 10 GHz	100 MHz - 10 GHz
Photo current Gain	1	$10^2 - 10^4$
Special Circuit Required	None	High Bias Voltages and Temperature Compensation Circuitry
Linearity	High	Low- suited to digital applications
Cost	Low	Moderate to High

The wavelength band between about 780 and 950 nm is presently the best choice for most applications of infrared wireless links. But in this wavelength band can pass through the human cornea and be focused by the lens onto the retina, where it can potentially induce thermal damage, so that the eye safety of infrared transmitter standards have governed by International Electrotechnical Commission (IEC), [3][13-14].

C. Path Loss and Noise

In Fig.2 the path loss versus horizontal separation between transmitter and receiver for LOS and Diffuse channel by considering a Lambertian radiated pattern, neglecting the contribution of indirect propagation paths, and assuming for simplicity a detector field-of-view half – angle of 90°, the loss of unshadowed line of side and diffuse link channels have computed approximately by [5].

$$LOS_{Path..Loss(Optical..dB)} = -10\log_{10}\left[\frac{A_R}{\pi}\frac{h^2}{\left(h^2+d^2\right)^2}\right] \qquad (5)$$

and

$$Diffuse_{Path..Loss(Optical..dB)} = -10\log_{10}\left[\frac{\rho A_R h_1^2 h_2^2}{\pi^2} \times \iint_{Ceiling}\frac{dxdy}{\left(h_1^2+x^2+y^2\right)^2\left[h_2^2+(x-x_2)^2+(y-y_2)^2\right]^2}\right] \qquad (6)$$

Here, h is the vertical separation between transmitter and receiver (m), d is their horizontal separation (m), A_R is a detector area (cm^2), and ρ is a Lambertian reflector of reflectivity. In diffuse system assume the transmitter and receiver have located respectively at coordinate (0,0) and (x_2, y_2) in the horizontal x,y plane, h_1 and h_2 represent the transmitter-ceiling and receiver - ceiling vertical separation respectively. In Fig.3 the noises N (t) induce in p-i-n photodiode can be broken into three components: ambient light noise, receiver circuit or thermal noise, and periodic noise. The ambient light noise is due to background light source, such as sunlight, fluorescent lamp, and incandescent lamp light. The total noise in system can be described by [6-7].

$$i_{total\ noise} = i_{receiver\ noise} + i_{sun+fluores+incan..\ noise} \quad (7)$$

$$i^2_{receiver.noise} = i^2_{shot..noise} + i^2_{thermal..noise} \quad (8)$$

$$i_{shot..noise} = \sqrt{2q\left(I_d + I_{Ph}\right)B_W} \quad (9)$$

$$i_{thermal..noise} = \sqrt{\left(4k_B T / R_L\right)B_W} \quad (10)$$

$$i_{sun..noise} = A_R R_A H_B \quad (11)$$

$$i_{fluorescent..noise} = \frac{i_{sun..noise}}{A_2}\sum_{i=1}^{20}\left[b_i\cos\left(2\pi\left(100i-50\right)t+\varphi_i\right) + c_i\cos\left(2\pi\cdot 100it+\varphi_i\right)\right] \quad (12)$$

$$i_{incandescent..noise} = \frac{i_{sun..noise}}{A_1}\sum_{i=1}^{\infty} a_i\cos\left(2\pi\cdot 100it+\phi_i\right) \quad (13)$$

Where q = Electron charge ($1.6x10^{-19}$ coulombs)

I_d = Dark current (A)

I_{Ph} = Photo current (A)

B_W = Bandwidth (Hz)

k = Boatman's constant, $1.38x10^{-23}$ (J/k)

T = Temperature (k)

R_L = Feedback resistance amplifier (Ω)

H_B = Average background irradiance

A_R = Photo detector active area (cm^2)

R_A = Responsivity of the photo detector

$b_i and \varphi_i$ = Amplitude and Phase of the odd harmonica of AC 50 Hz

$c_i and \phi_i$ = Amplitude and Phase of the even harmonica of AC 50 Hz

$A_1 and A_2$ = Constant that relates the interference amplitude with $i_{sun..noise}$

III. L-PPM MODULATION AND MONTE CARLO SIMULATION TECHNIQUES

In infrared wireless systems, a limited transmitter complexity and small power consumption are of utmost importance. Pulse Position Modulation based on intensity modulation and direct detection, is a very suitable modulation scheme, because it easy multiplexing of sensor signals, the probability for data compression and error correction, and small duty-cycle pulse transmission (Low power transmitter). The format waveform pulse position modulations and On Off Keying are show in Fig.4, [7-8].

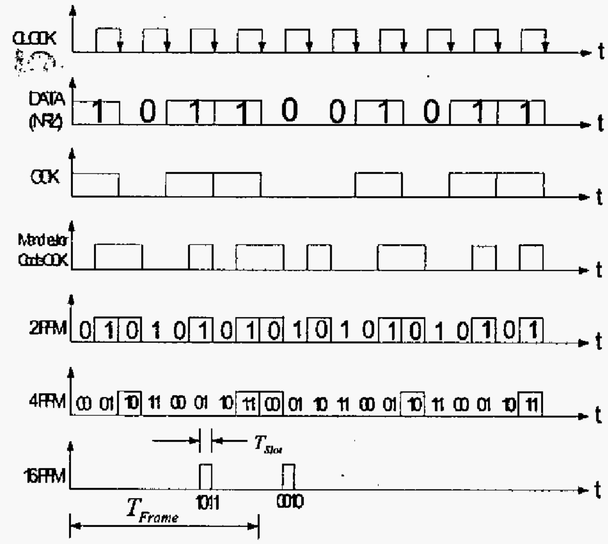


Fig. 4. 2, 4, 16 PPM and OOK Waveform.

In a PPM modulator, an input word consisting of several bits is converted into the position of a pulse within a frame; this is show in Fig. 4. The frame, with duration (T_{frame}) is divided into L slots with duration T_{slot} and only one of these slots contains an optical pulse. Since L possible pulse positions are used to code $\log_2 L$ bits of information, the bit rate follows as $R_b = \log_2 L / T_{frame}$. Initially we assume the pulse to be rectangular. A model circuit is also presented which further phase locks the recovered word clock (T_{frame}) to the slot clock (T_{slot}) and therefore corrects the phase error in the word clock (T_{frame}) is show in Fig.5.The PPM can be viewed as the rate $\log_2 L / L$ block code consisting of all binary L-tubules having unity Hamming weight. A PPM signal can be expressed by [8-9].

$$X(t) = LP\sum_{K=0}^{L-1} C_K\, p(t - KT_{frame}/L) \quad (14)$$

Where [$C_0, C_1, ... C_{L-1}$] is the PPM codeword, and where $p(t)$ is a rectangular pulse of duration T_{frame}/L and unity height. All of the signals are equidistant, with:

$$d^2 = 2LP^2\frac{\log_2 L}{R_b} \quad (15)$$

Therefore, the average power requirement between P_{OOK} and P_{PPM} is approximately by equation

$$\frac{P_{PPM}}{P_{OOK}} \approx \frac{d_{OOK}}{d_{\min}} = \sqrt{\frac{2}{L\log_2 L}} \qquad (16)$$

From (16) we see that, for any L greater than 2, PPM requires less optical power than OOK.In principle, the optical power requirement can be made arbitrarily small by making L suitably large, at the expense of increased bandwidth; the bandwidth required by PPM to achieve a bit rate of Rb is approximately the inverse of one chip duration by

$$Bw_{PPM} = \frac{L}{T_{slot}} = \frac{LR_b}{\log_2 L} \qquad (17)$$

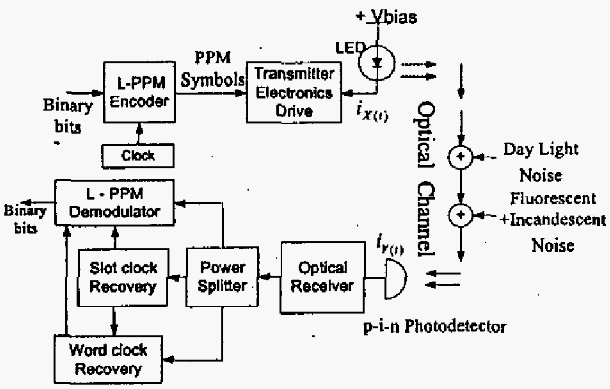


Fig.5. Genera tic Simplex of L-PPM Infrared Wireless Communication System.

In Fig.5 ideal photon counting channel the photocurrent produced by the photo detector is given by [4][7].

$$i(t) = \frac{\eta q}{h\nu} P_{Receive}(t) = RP_{Receive}(t) \qquad (18)$$

For most practical communications applications, the magnitude of the photocurrent as a function of electrical frequency is well approximated by

$$i_{photo}(\omega) \cong RP_{rcvd} G \frac{1}{\sqrt{1+\left(\frac{\omega}{\omega_C}\right)^2}} + i_d + noise \qquad (19)$$

Where ω = Electrical frequency (Hz)

ω_C = Bandwidth of the photo detector (Hz)

P_{rcvd} = Received optical signal power (w)

$R = \frac{\eta q}{h\nu}$ = Responsivity of the p-i-n photodiode

G = Grain = 1 for a p-i-n photodiode

η = Photo detector quantum efficiency

h = Planck's constant ($6.626x10^{-34} J/S$)

ν = Infrared frequency (Hz)

From (4) so that $i_{LOS..system} = i_{photo} x H(0)_{LOS..system}$ (20)

and $i_{Diffuse..system} = i_{photo} x H(0)_{Diffuse..system}$ (21)

By $H(0)_{LOS..system}$ and $H(0)_{Diffuse..system}$ are LOS channel dc gain and Diffuse Link channel dc gain respectively. When L-PPM is transmitted over multipath channels (Diffuse), .the nonzero transmitted chips can induce interference in chips both within the same symbol (intrasymbol interference) and intersymbol interference (ISI) induced by a multipath channels $h(t)$ .The multipath channel h(t) is the channel root-mean-square (rms) delay spread D. The delay spread of a channel is a remarkably accurate predictor of ISI-induce SNR (Signal to Noise Ratio) penalties, independence of the particular time dependence of the channel's impulse response. The delay spread is computed from the impulse response using: [1-2][5].

$$D = \left[\frac{\int_{-\infty}^{\infty}(t-\mu)^2 h^2(t)dt}{\int_{-\infty}^{\infty} h^2(t)dt}\right]^{1/2} \qquad (22)$$

Where the mean delay μ is given by

$$\mu = \frac{\int_{-\infty}^{\infty} t h^2(t)dt}{\int_{-\infty}^{\infty} h^2(t)dt} \qquad (23)$$

The impulse response $h(t)$ and delay spread D can be considered to be deterministic quantities, in the sense that as long as the positions of the transmitter, receiver and intervening reflectors are fixed, $h(t)$ and D are fixed. A threshold detection based receiver for L -PPM samples the incoming signal at the slot rate, and assigns a 'one' or a 'zero' depending on whether the received signal is above or below the threshold level at the sampling instant. A symbol is then assigned depending on which of the L samples is a 'one'. If the block of L samples consists entirely of 'zero', we assume that a slot is chosen at random to receive the 'one'. If the correct slot has been assigned a 'one', but there is one or more other slots in the block of L slots which are also 'one', one of the slots containing a 'one' is chosen at random. Let P_{01} denote the probability that a correct pulse is not detected and P_{10} denote the probability that a pulse is detected in a slot, which should be empty. The probability of symbol error for a PPM system using threshold detection, $P_{Symbol..error}$, is given by [9-10].

$$P_{symbol..error} = 1 - \left[\frac{1}{L}P_{01}(1-P_{10})^{L-1} + \sum_{n=1}^{L}\frac{1}{n}\binom{L-1}{n-1}(1-P_{01})P_{10}^{n-1}(1-P_{10})^{L-n}\right] \qquad (24)$$

The first term gives the probability that no pulses are detected and the randomly assigned pulse is placed in the correct slot. When $n=1$, the second term gives the probability that a pulse is detect in the correct slot and no other pulses are detected. When $n>1$, the second term gives the probability that the correct pulse is detect along with $n-1$ in correct pulses and the correct pulse is chosen from the detected pulses. Assuming an equal probability of error receiver, i.e. $P_{01}=P_{10}$. If the threshold level is set to half the amplitude of the received PPM pulses at the sampling instant, then the slot error is given as:

$$P_{01}=P_{10}=\frac{1}{2}Erfc\left[\frac{LP_{rcvd}R\sqrt{T_{slot}}}{2\sqrt{2qi_{total..noise}}}\right] \qquad (25)$$

In simulation systems,we analysis performance of 2,4,8,16,32 and 64 PPM by Monte Carlo Simulation scheme that show in Fig.6, [11-12].

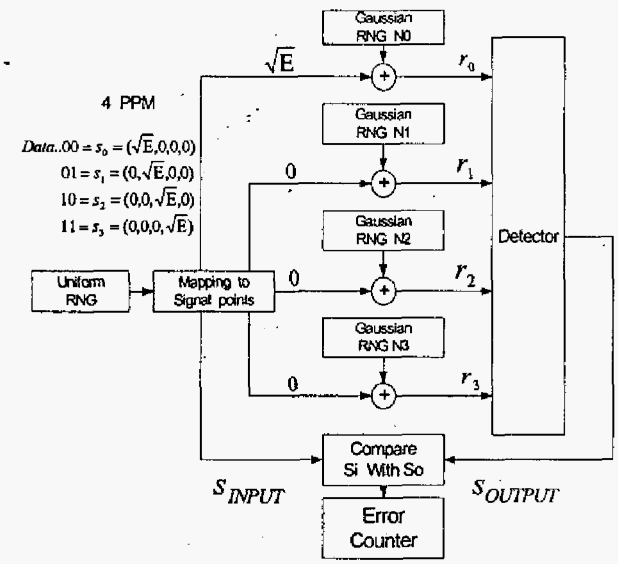


Fig. 6. Example 4-PPM Monte Carlo Simulation.

IV. SIMULATION RESULTS

In Fig.7 shows the average photocurrent of p-i-n photodiode in LOS system versus distant between Tx to Rx, at distant from 1 to 6 m. that the unit of current on detector had mA, but at the distant over 6 m. the unit of detector has μA. And Fig.8 shows the power efficiency comparisons of PPM and OOK in dB, we can see that the PPM has better power efficiency than OOK, and the 2PPM has been the same power efficiency as OOK. And in Fig. 9 we see that for order L greater than 2 the bandwidth of PPM has been increate. And the path loss versus horizontal separation between transmitter and receiver for LOS and Diffuse links show in Fig.10.The probability of bit error from L= 2,4,8,16,32 and 64 PPM show in Fig.11 (a) and (b). Where a function of the SNR per bit, Eb/No is the energy per bit: By No is the Gauss Noise generator, are having a mean zero and variance σ^2= No/2. In Fig.11 (a) we see that the 4-PPM is a maximum efficiency than other PPM in our simulation scheme at the same probability of error in Monte Carlo Simulation.

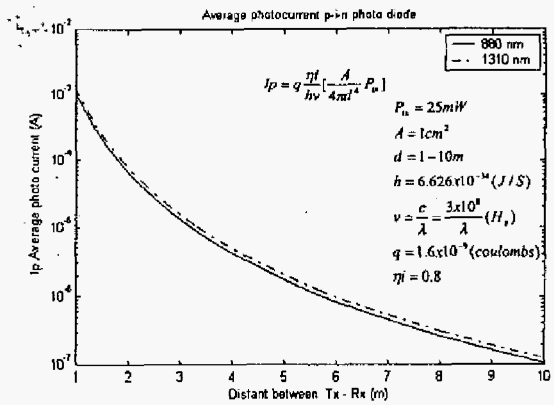
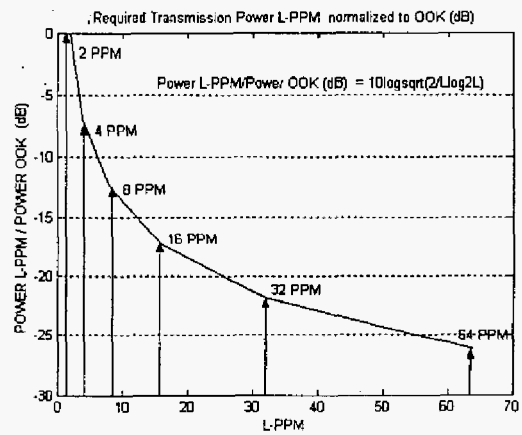


Fig. 7. Average photocurrent p-i-n photodiode versus distant Tx-Rx



(b)

Fig. 8. Required transmission power 2,4,8,16,32 and 64 PPM Normalized to OOK (dB).

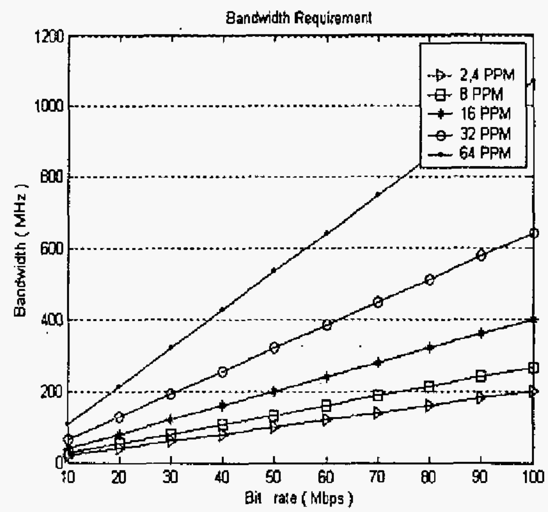


Fig.9. Bandwidth requirement of other PPM.

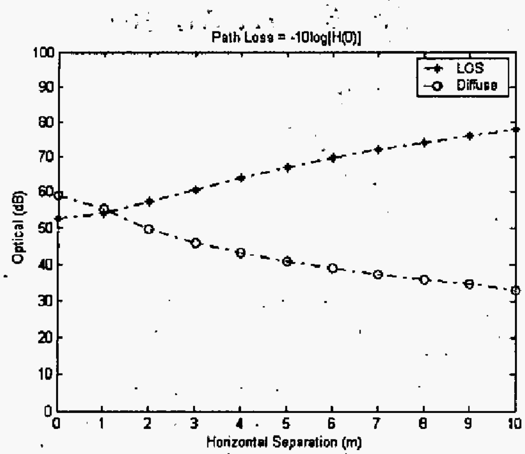
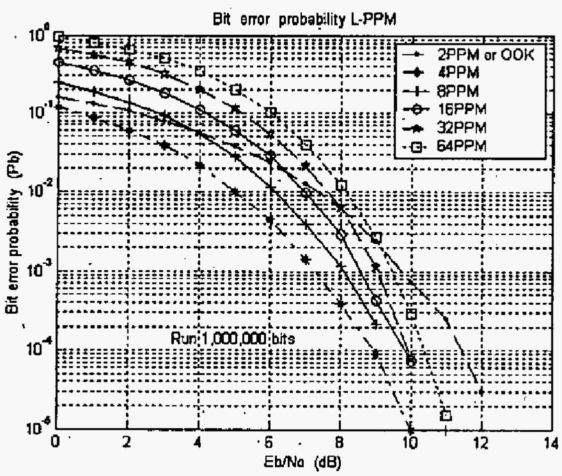
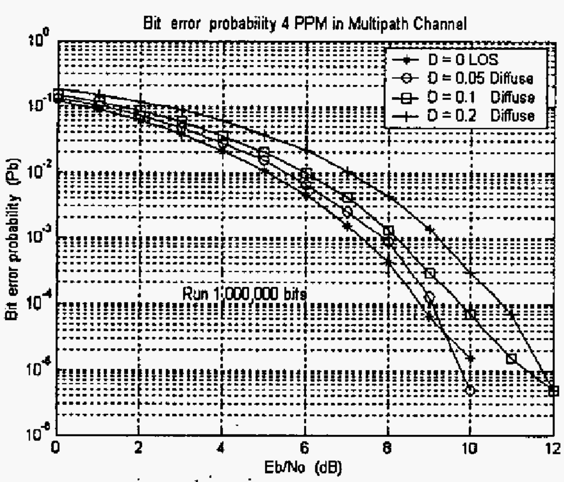


Fig. 10. Path Loss (Optical dB).



(a)



(b)

Fig.11. (a) and (b) Bit error probability of PPM from Monte Carlo Simulation Scheme.

V. CONCLUSIONS

PPM is a promising modulation scheme for high -speed wireless indoor infrared communication. For any L greater than 2, PPM requires less optical power than OOK, but the bandwidth increases as well follow the L order. The bit error probability for 2,4,8,16,32 and 64 - PPM orthogonal signals from a Monte Carlo Simulation for the transmission of 1,000,000 bits, the 4-PPM is the most efficient on the AWGN channels.

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