Def Sci J, Vol 34, No 1, January 1984, pp 79-84

Modulation Method of Laser for Underwater Communication

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Received 16 January 1984

Abstract. Due to very high absorption of light in the water it is necessary to use high energy pulsed bluegreen lasers for underwater communication systems. However, these lasers do not have high repetition rates, sufficient enough to support high data rate signals. The pulse interval modulation method is one of the prospective methods of sending large bandwidth data using low frequency (500 to 1000 pulses per second) pulsed laser. This method appears to be more promising for underwater communication system with likely development of fast PIM coder/decoder.

1. Introduction

There has been attempts to achieve underwater communications using blue-green[1] high power lasers due to their transmission characteristics[3] through the ocean water.

An underwater laser communication system requires a laser source[L] capable of producing short high peak power pluses, which could be focussed into a narrow beam, source optics for scaling and imaging, transmitter modulator, coder, decoder, receiver detector, data processing and control circuits etc.

According to sampling theorem condition, the carrier should have high repetition rate at least twice the bandwidths of the signal for effective transmission of high data rate information. But high repetition rate laser sources are limited in the peak power. Hence for effective transmission of high data rate signal on low repetition rate laser carrier, a suitable modulation format is required. The conventional methods are not suitable for high data rate transmission. A modulation format i.e., Pulse Interval Modulation (PTM) (M-Ary) has been discussed in the paper and requirements and limitations of laser sources for underwater application have been studied.

2. Requirements of Laser Sources

Tn order to have efficient modulation formats, the laser source should meet the following requirements :

(i) Controlled pulsing, (ii) Short pulses, (iii) High peak power, (iv) High repetition rate, (v) Inter pulse time control, (vi) High power efficiency, and (vii) Narrow Bandwidth.

It appears from the above requirements that the continuous wave laser in general does not fulfill (ii), (iii) and (vi) requirements. Hence a pulsed or high repetition rate mode locked laser is ideal for this type of communication. Present day pulsed laser having very high peak power, have the repetition rates in the range of 500 pps., however using mode locking it is possible to produce high repetition rate pulses, as an example is quoted data of spectra Physics Mode[4] Locked Laser. (ion) are as follows :

$P_w = 5$ ps

$P_{av} = 80$ mW

$P_{pk} = 200$ W

Pulse rate = 80 MHz

The laser is tunable in 540 to 690 nm using R6G, R110 and DCM dyes.

3. Modulation Methods

Before analysing the PIM method, we first review in short the different modulation methods commonly used in laser communication. These are : (i) Pulse Gates Binary Modulation (PGBM), (ii) Pulse Polarisation Binary Modulation (PPBM), and (iii) Pulse Position Modulation (PPM).

3.1. *Pulse Gates Binary Modulation*

This is equivalent to CW Binary PCM except that the laser is operating at low duty cycle with fixed large inter pulse time. A mode locked laser is ideal for this mode of modulation with a gated receiver. The waveform of PGB is shown in Fig. (la).

3.2. *Pulse Polarisation Binary Modulation*

In this case the polarisation of laser pulse is rotated to produce 0 & 1 Bit. Hence, signal is always present at the receiver and the detector has dual channel. detecting both polarisation. The waveform is shown in Fig. (Ib).

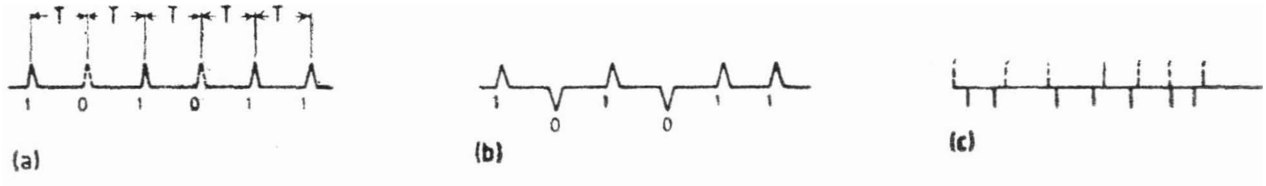

Figure 1. (a) Waveform of PGBM, (b) Wave form of PPBM, (c) Waveform of PPM

3.3. Pulse Position Modulation

It is generally used for direct analog information input. The waveform is shown in Fig. (lc). It is important to mention that all the above modulation methods require high repetition rate, at least twice the bandwidth of the signal according to sampling theorem condition.

3.4. *Pulse Interval Modulation* (M-Ary)

Now we analyse the method of modulation which is of particular interest for under-water communication applications. In ***PZM,*** the inter-pulse time of laser is divided into M discrete time-slots and only one pulse is sent in this time interval in a definite slot, which represents a code symbol. (Fig. 2).

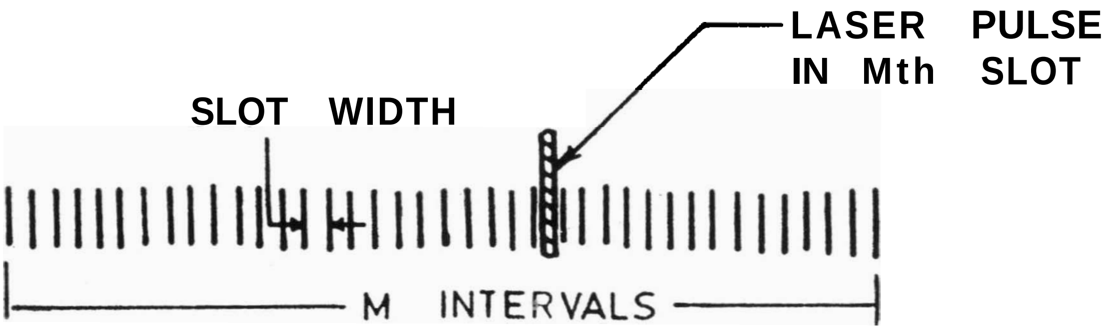

Figure 2. Pulsé interval modulation (PIM) waveform.

The number of bits transmitted per pulse is therefore Lg_2 M. Hence by using low duty cycle pulses, many time slots are possible in a given time interval, thereby giving many bits per pulse.

4. Noise Discrimination Efficiency of PIM

The probability of receiving m photo-electrons in time interval t is given by

$$P_t(m) = a^m e^{-a}/m\,!$$

Where a is average number of photo-electrons received in the time interval t.

Detailed analysis shows that following relations exists between optimum threshold for each combination of signal, non signal and laser duty cycle :

$$n_{opt} = \bar{n}_s + \log\,[\,P\,(O)/\,P\,(1)]/\log\,(1+\bar{n}_s+\bar{n}_b). \qquad (1)$$

n_{opt} = Optimum threshold value defined as reducing the likelihood of an error to minimum

P (O) = Probability of transmitting no signal

P (I) = Probability of transmitting signal

$\bar{n}_b$ = Average no. of total background photo-electrons/sec

$\bar{n}_s$ = Average no. of photo-electrons/sec in pulse

When the signal is present, then we have

$$a = \bar{n}_b t + \bar{n}_s$$

An equal weighing of errors, i.e. false detection costs as much as—error of no detection is assumed in the above equation. Now, if the *PIM* system has *M* slots of time period *t* and one pulse is sent in M periods. (M-ary system), the probability of transmitting a zero will be $(1-1/M)$ and for $M>>1$ this will essentially be unity.

When we are making a decision every *t* Eqn. (1) can be written as

$$n_{opt} + n_s + \log M/\log [1 + (ns\, M + nb\, T)]$$

This shows a very important feature of PIM modulation which is that reducing the likelihood of error to minimum, is function of number M, the slots. Hence a short pulse (large *M*) will produce fewer false detections because of enormous gain in signal detection capability. Thus making this mode of modulation is more suitable for underwater communication using high peak power lasers.

Figure 3 shows the small signal increase necessary to attain the same error probability per pulse for much larger *M* values. This improves the error rate per bit in comparison to long duty cycle case since many bits per pulse can be conveyed.

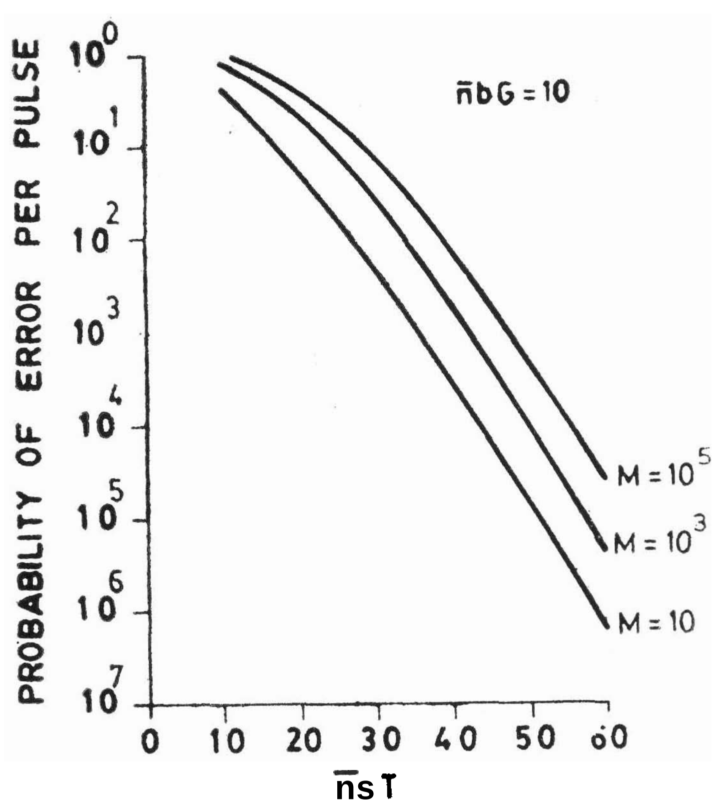

Figure 3. Error probability per pulse for different M values.

If we send on average F pulses per second, we have bit rate R

$$R = F \log_2 M \text{ bps}$$

If t = pulse time interval, then $F = 1/Mt$

hence $R = 1/Mt \log_2 M$ bps

Signal energy $E_s = h\nu\bar{n}_s$

Average signal power $P_{av} = E_s F$

If $\lambda = 1\ \mu m$, we get

$$\frac{\text{Bit rate}}{\text{Average signal power}} = R/P_{av} = 5 \times 10^{18} (\log_2 M/\bar{n}_s) \text{ bit}/J$$

The plot of this equation as a function of duty cycle $1/M$ keeping bit rate and non signal power fixed is shown in Fig. 4.

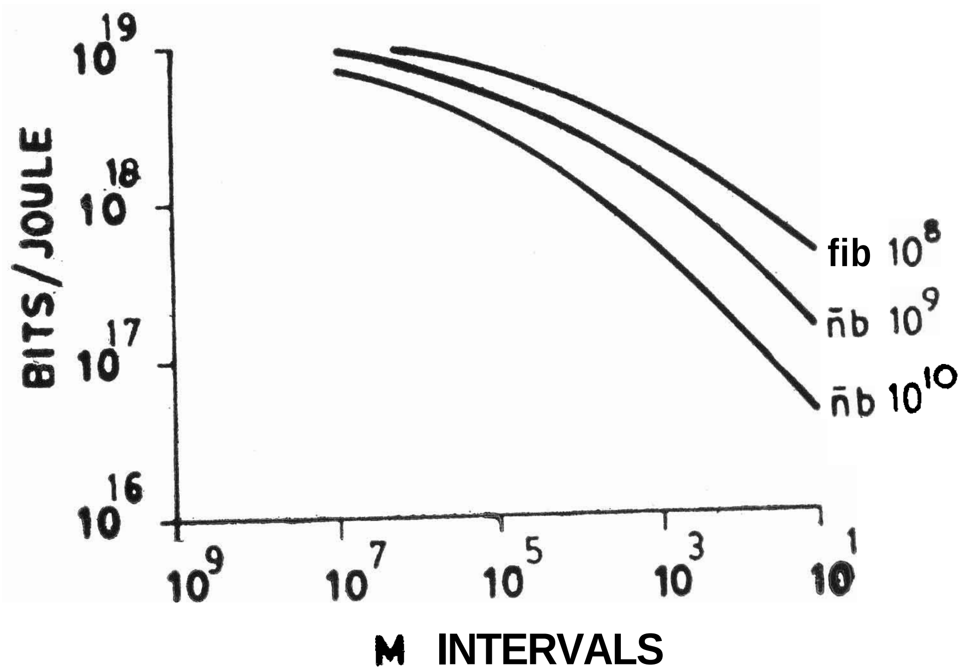

Figure 4. Information efficiency as a function of duty cycle for PIM, Bit rate = 1.3×10^{16} bps, error rate/bit = 10^{-4}, background received power = 2×10^{-9} nb watts.

Table 1. PIM relationship of pulse interval, duty cycle and bits/pulse[a]

Intervals	Duty cycle[b]	Bits/pulse
M	$1/M$	
10^4	10^{-4}	13.3
10^5	10^{-5}	16.6
10^6	10^{-6}	20.0
10^7	10^{-7}	23.3
10^8	10^{-8}	26.6

a = Bits/pulse = $\log_2$ M

b = Tt is assumed the pulse width Tequals the pulse intervals t

This shows that requirement of fixed error rate will force n_s to change as a function of duty cycle that is more signal power is required for large duty cycle system. Hence for *PIM* short duty cycle high energy pulsed laser is ideal (Tabie 1).

The advantages of pulse interval modulation are :

(a) Low repetition rate high peak power laser can be used.

(b) There is a improvement in pulse detection probability due to small time period measurement.

(c) It has many bits per pulse information.

5. Conclusion

Experiments in short pulse optical communication have been performed at high data rate (10^7 bps) with M-Ary modulation format and using sub nanosecond internally gated receiver. In an experiments[6] on TV picture transmission by M-Ary as many as 12 bits/sec were transmitted using 4095 digitally selected one ns time-slots.

The relationship in laser power and data transmission rate leads one to conclude that for Pulse Interval Modulation, short duty cycle—high energy pulse is ideal.

Acknowledgements

The authors arc thankful to Dr. R. Hradaynath, Director, IRDE, Dehra Bun for his valuable suggestions and guidance.

References

1. Ferguson, G. D., ***SPIE*, 64.**
2. ***Duntley. S. Q., JOSA, A 53* (1963), 214.**
3. E. J. Schimitschck, ***SPIE*,** 160, Ocean ***Optics*** V (1978).
4. ***Laser Focus*. June 1982.**
5. **Monte Doss, 'Laser Applications' Vol. 1 (Academic Press, New York), 1971.**