

Optical Communication

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Introduction

Interest in short-range communication using wireless techniques has been growing in the recent past. The prevalence of technology has been based on the increased usage of solid-state lighting. Besides, transmission bandwidth capabilities have improved significantly. As a result, new paths for optical communication have been opened to enhance efficiency while reducing the costs and times used in modulation. Also, improved technology for modulation and encoding of optimal communication supports multiple user requests. New and advanced methodologies for processing signals have created sufficient transmission capacities (Certik & Roka, 2016). Modulation rates are on the rise, and traditional encoding and modulation approaches have a tradeoff of bit errors. The impact that the new advancements are likely to have on the environment is positive. New methods allow users to design optical systems operating optimally since it offers multiple processing alternatives. For instance, transmission ranges and data rates can be increased accordingly to promote the functionality of optical fibers.

Forward Error Correction

Forward error correction (FEC) is employed nowadays to insert additional data into the transmitted message to enable recovery at the receiver. Recovery is possible even in the presence of errors generated during transmission. FEC codes are applied in high haul transmission frameworks as well as broadcasting. The codes are divided into blocks that are processed block-by-block or convolutions that are processed bit-by-bit. Convolutional codes are used to encode a signal using an impulse response (Certik & Roka, 2016). Decoding is carried out using a Viterbi algorithm that has high reliability. The approach finds the most relevant way of decoding the

existing states of transition. Complex algorithms cause the number of states to increase during the decoding process. The approach has an advantage since it creates codes that have lower resistance that protects the system from noise.

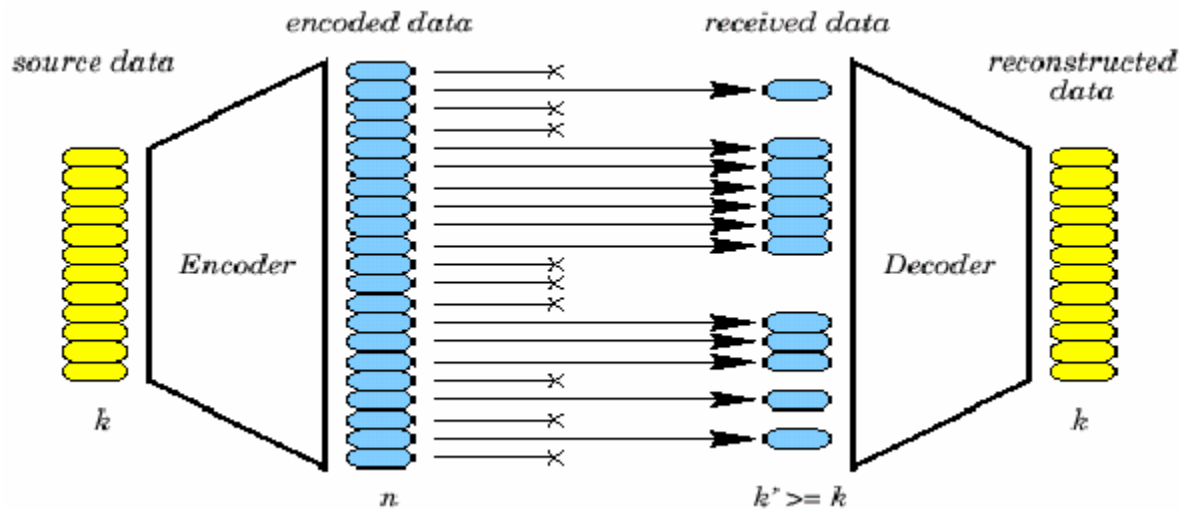


Fig. 1 Forward error correction

Binary Phase-Shift Keying

The transition to digital systems in the last few years has caused different ways of processing optical data. There have been massive breakthroughs in semiconductor technology that has enabled scaling capabilities. Semiconductor technology enables mass production of optical fibers at relatively low costs. The resultant microchips are power-efficient and highly reliable and can be integrated into an optical fiber channel. Besides, the number of internet users has increased considerably, and there is a need for high-end internet fibers that transmit data to internet-enabled electronic devices. Modulation and encoding of data signals are carried out by imprinting digital information onto optical carriers. Coding is also performed to minimize transmission errors (Winzer et al., 2009). Besides, the correction of already existing transmission

errors is possible. Binary phase-shift keying is used most for space-based communications as well as laser interactions. The approach is effective since it supports sensitive applications in the transmission of data within optical fibers.

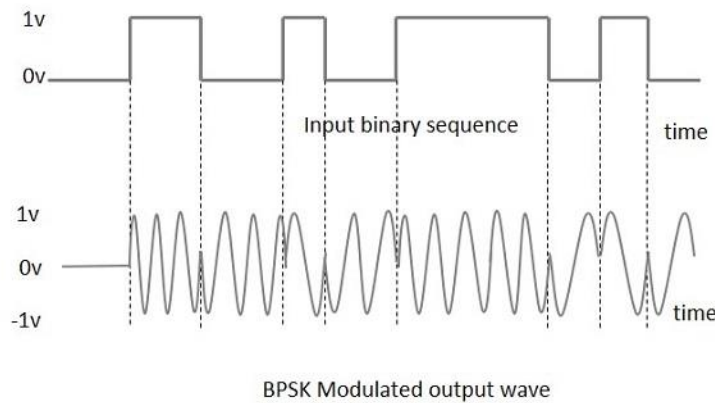


Fig. 2 Binary phase shift keying

Moreover, orthogonal modulation is carried out on signals with complex dimensions to eliminate the challenges of time slots that are not overlapping. Pulse position modulation occurs as a result of the orthogonal frequencies. M-ary frequency can also be used for shift keying signals to process optical pulses that are available at the transmission slots. The transmission channel contains slot positions that combine the data symbols to increase the bandwidth of the signal. The introduction of FEC enables the correction of codes at the detection unit of the receiver (Winzer et al., 2009). Unlike traditional modulation formats that aimed at increasing the transmission bandwidth, FEC allows capacity-constrained systems to increase the density of the packing capacity. It also enables narrow modulation spectra since signal spaces are stuck to two-dimensional signals. Using multiple levels of imaginary and real components enables the magnitude and the phase of the optical field can be obtained.

Software-Defined Optics

In addition, encoding and processing of optical signals are carried out at the transmitter side to promote optimal transmission to the receiver. Digital to analog conversion is done at the transmitter to generate waveforms on Software-Defined Optics (SDO). The resultant analog bandwidth plays an integral part in coherent detection. At the coherent detection stage, electrical signals are detected through a self-homodyne mechanism. Pre-equalizing is done to generate 4-level signals that are used to drive the IQ modulator. The process enhances the performance of high-frequency signals within the transmitted signal. The technique has a limitation of applicability in systems of up to 100-400G (Yu & Zhang, 2016). In this regard, it requires additional DSP blocks at the reception stage to remove noise fluctuations and random error bits. Time-domain synchronization is also required to ensure that the transmitted signal is averaged over the transmission duration. Systems that have limited bandwidth are post-equalized to remove narrowband impairments.

Return to Zero and Non-Return to Zero

The first step of the recent modulation formats is to determine an electrical binary data that are converted into bitstreams later. Optical pulses are confined within time slots that correspond to the condition 1. The absence of the HIGH condition shows that the bitstream is being transmitted 0 bits. The method is known as off-keying since it switches the optical signal back and forth between 1 and 0 levels—the methodology results in non-return to zero (NRZ) and return-to-zero (RZ) formats. In the RZ approach, the optical pulse that is used to represent the bitstream (1) is shorter as compared to the bit slot (Agrawal, 2016). The amplitude of a particular bit returns to zero when the duration of transmission is on the verge of completion. In the NRZ

mechanism, the generated optical pulses are maintained at 0 throughout the transmission. In this regard, the amplitude of the optical pulse does not return to 0 with regard to successive bits. NRZ is advantageous over RZ since it has smaller bitstreams since the transition of the pulse happens a fewer number of times. Optical communication systems use this format to remove the tradeoff of limited bandwidth.

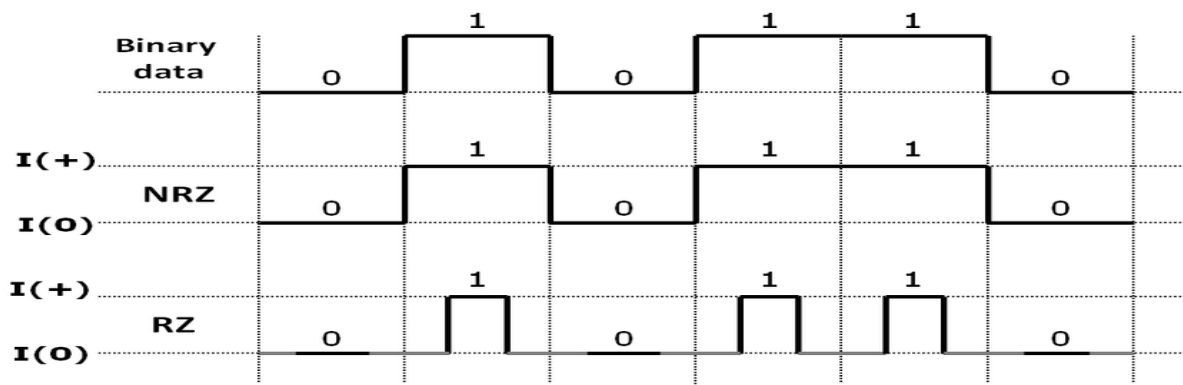


Fig. 3 Non-return to zero



Fig. 4 Return to zero

Pulse Width Modulation

Also, there is an intra-pulse insertion at the modulation stage for optical pulses. In this approach, compensation symbols are inserted into the optical pulses to enhance matching with

the light data being transmitted. From the perspective of Pulse Width Modulation (PWM), optical pulses are varied with regard to the dimming target. The duty cycle of the pulses changes as the binary symbols are switched ON and OFF within the transmission period (Lee, Jung, & Kwon, 2015). In the ON cycle, symbols of the same width are inserted on every pulse being transmitted. Consequently, the message is modulated to ensure sufficient dimming abilities for the dimming targets. The technique has a tradeoff since visible bandwidth typically has minimum bandwidth that restricts symbol insertion. As a result, the data rate is limited, creating a phenomenon known as pulse padding to provide compensation of the optical pulse. The symbols within the message are arranged in such a way that they provide 50% matching for the dimming target.

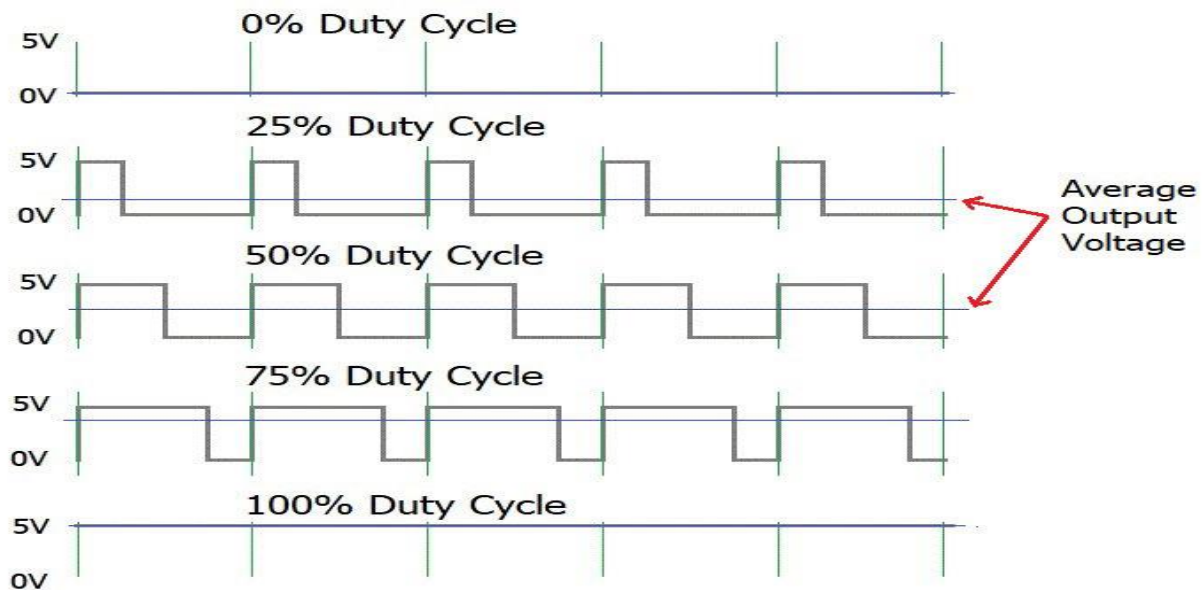


Fig. 5 pulse width modulation

Additionally, in the time-domain, time slots are assigned to each optical user and transmitted via optical carriers. Complex algorithms are used to assign bandwidths and used to generate packets that are not vulnerable to collision. Multiplexing of the signal is done in such a

way that it enables bandwidth-sharing. As a result, users are able to access burst-experience features such as emailing, browsing, and file-sharing (Muciaccia, 2014). A continuous stream of data creates a traffic topology that enables the scalability of the optical communication system. However, the process requires the usage of more fiber material and these results in increased manufacturing costs. Wavelength division multiplexing offers logical connections for every user within the network. The technique enables sharing among multiple users since it has a passive infrastructure that consists of optical pulses of minimum bandwidth.

Amplitude Shift-Keying

Moreover, Amplitude-Shift-Keying (ASK) is a modulation technique used in transmitting optical pulses. In this method, the message signal is inserted into an optical carrier that is characterized by high frequency. The carrier frequency signal is modulated with the message signal to create a binary signal. Binary 1 is transmitted during the ON state, and binary 0 is propagated during the OFF state (Jawla & Singh, 2013). The two states relate with each other, and this results in an extinction ratio that has values that depend on the generated signal. The ratio is limited due to the presence of an external modulator within the system. ASK leads to the generation of signals that are easy to detect and decode. In this regard, the technique enhances demodulation since the optical energy is easily converted into electrical energy that extracts the original pattern of the waveform. ASK is nowadays used in advanced communication systems that enable channels that use this approach to achieve more than two binary levels. As a result, the transmission capacity of the system is improved significantly. The technique leads to multilevel signaling.

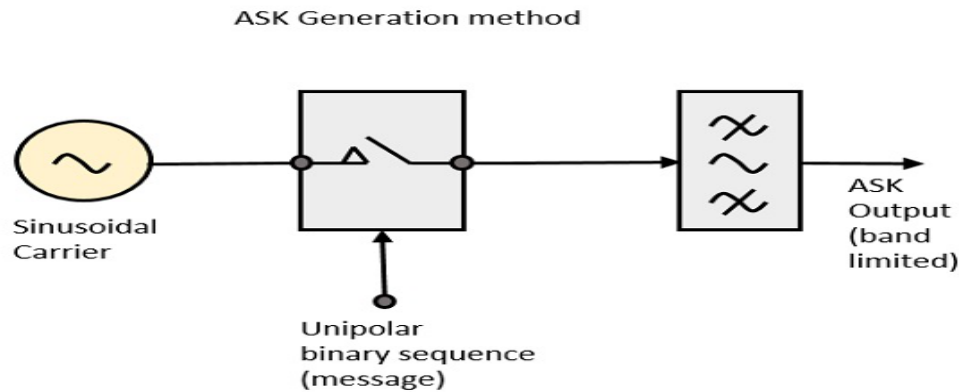


Fig 6 Amplitude shift keying

Frequency Shift Keying

Also, frequency shift keying (FSK) is used in the modulation of the optical pulse, and it involves enveloping the signals. Enveloping ensures that the signal does not vary; therefore, improving efficiency as compared to ASK. Also, it eliminates the tradeoffs of ASK since it reduces the complexities of generating signals. Besides, the reception of the signal at the receiver stage is improved. The modulation index for the signal is defined. The modulation occurs when the value is varied accordingly. Small changes in the modulation values result in compact optical spectra. In this modulation format, transmission parameters should be modified to ensure that they match.

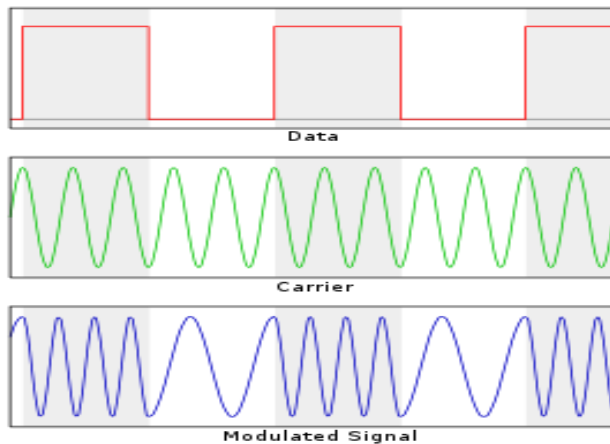


Fig 7 Frequency shift keying

Phase Shift Keying

In addition, phase-shift keying (PSK) is used to modulate optical signals by varying their phases while keeping the amplitude and frequency constant for specific transmission duration. Binary data is modulated with regard to their phases and coupled with the carrier signal. As a result, a narrow and constant envelope is generated for the optical pulses; this reduces nonlinear tolerance within the transmission system. Optical signals are very sensitive to changes in phase and reduce quality when multiple channels are used for modulation. The resultant signal that has been modulated has high receiver sensitivity (Jawla & Singh, 2013). Therefore, it can be decoded easily due to the reduced rate of bit errors. Differential phase-shift keying (DPSK) is another format for PSK that has gained interest in the recent past. In this encoding format, phase changes occur by differentially changing two successive optical bits. The encoded optical data is coupled with a carrier signal using a phase modulator. Coherent detection is utilized at the receiver stage to enable the extraction of the message from the carrier signal. In the face of challenges of implementing PSK, DPSK is often used to improve the efficiency of the optical

fiber. In DSPK, four different phases are obtained to encode the data differentially. The technique is often applied in the development of high-speed communication systems.

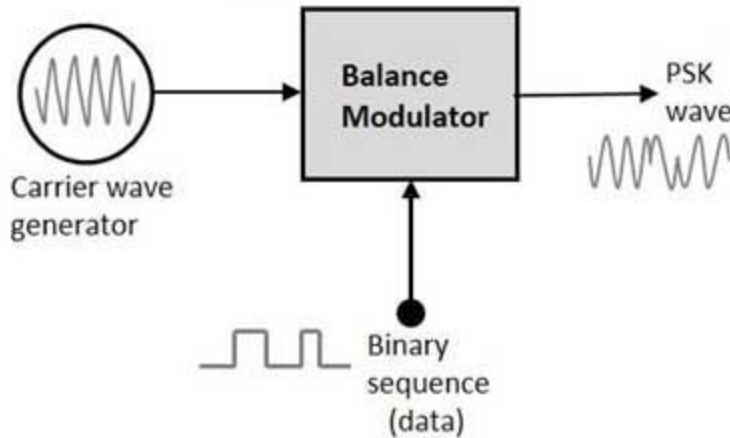


Figure 8 Phase shift keying

Polarization Shift Keying

Also, polarization shift keying (PoSK) is another fascinating modulation format for optical signals. Two polarization states result from this method. The states exist between the polarized signals that have been switched to generate a signal. The system envelope, in this case, is constant, and this condition helps reduce nonlinear tolerance. Also, it helps improve the efficiency of the system since it utilizes better bandwidth ranges. The technique also allows greater freedom for the transmission parameters; therefore, reducing disturbances within the transmission line. Cumulatively, the infrastructure of the system increases the data rate within the communication channel. However, the method has a con of polarization-mode dispersion that creates non-linearity within a system. Another version of PoSK known as differential PoSK can be used to encode the data both in polarization and phase mode for multilevel signals. Direct

detection is used to recover the original message; therefore, nonlinear polarization dispersion is eliminated.

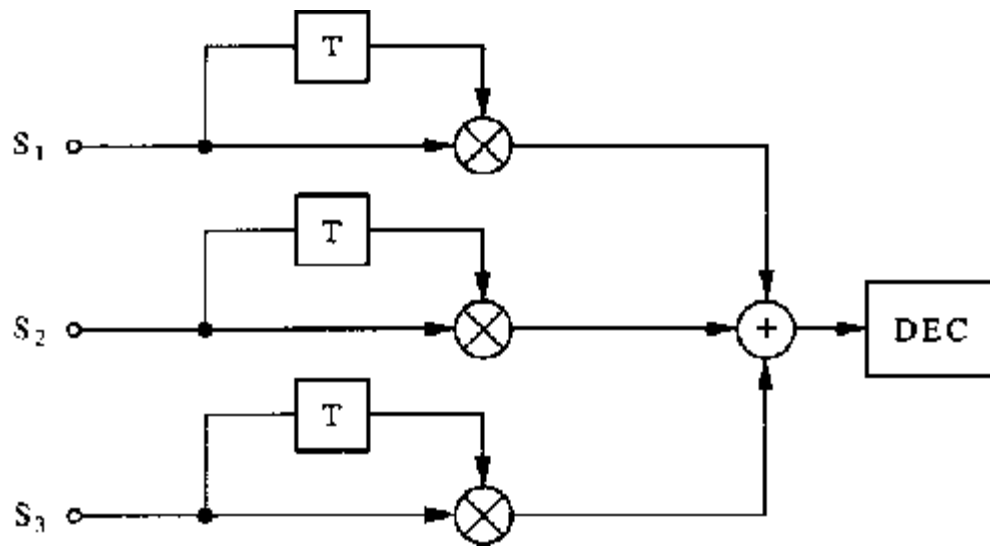


Figure 10 polarization shift keying

On-off Keying

In the recent past, on-off keying (OOK) has been used to module optical signals. In this format, light is represented as either present or absent for a specific period of time. The binary information obtained during sequencing is mapped to optical pulses in the transmitter. Mapping is done based on the cannon that for bits that are 1, information is transmitted as laser pulses. On the other hand, the bits are 0; the information is not transmitted. The 1 bit corresponds to the data stream, and the light pulses generated within the transmitter.

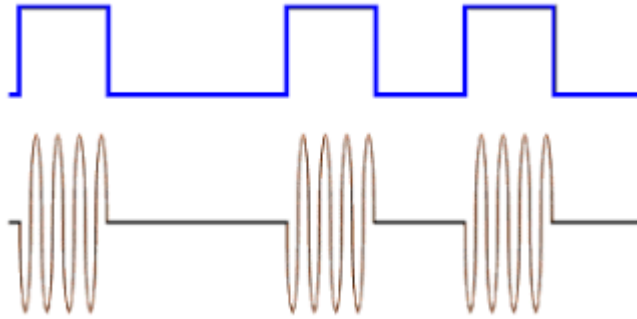


Figure 11 on-off keying

Pulse Position Modulation

Additionally, pulse-position modulation (PPM) is another reliable laser modulation technique that is used in mode-locking, Q-switching, and cavity-dumping. In this modulation format, low average power is required to attain efficient binary information. The data obtained is resistant to radiation; therefore, enabling efficient transmission of the message to the users within the system. The technique uses eight slots to assign each symbol with 3 bits (Dolinar et al., 2018). The general format comprises a fixed number of data symbols that have equal duration. The mapped information can be viewed one by one from the assignment of slot symbols. The mapped information is represented sequentially at different slots. At the reception end, symbol and slot synchronization are performed to result in average signal energy for the transmitted data.

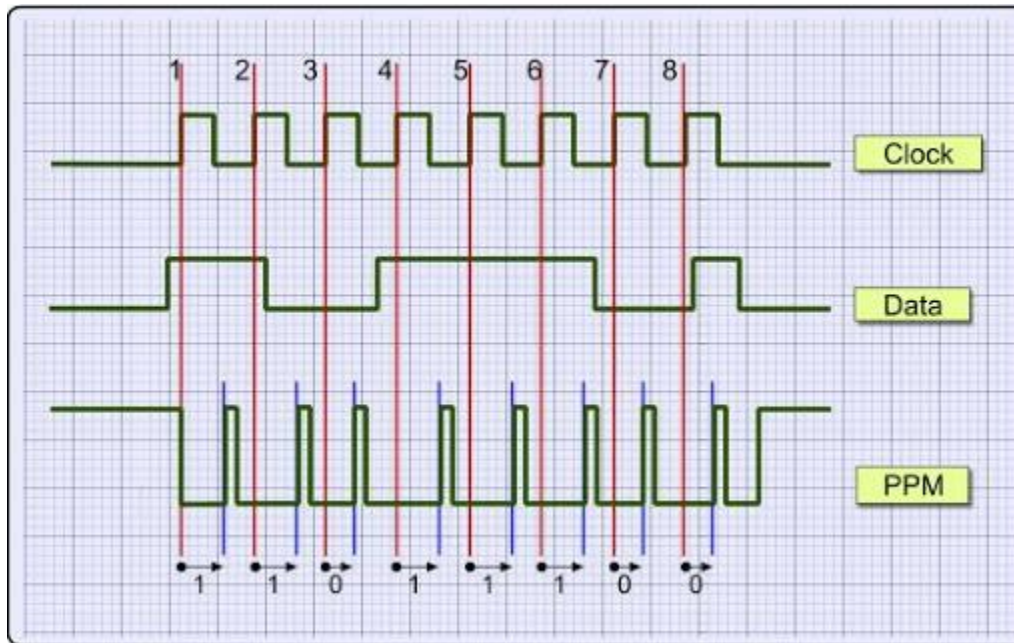


Figure 12 pulse position modulation

Differential PPM

Besides, differential PPM (DPPM) can be applied by adding another slot for the pulse signal. In this format, the non-pulsed slots that occur after the PPM symbol are flushed. Flushing causes a synchronization challenge due to the variation symbol length. Besides, error propagation is likely to occur during reception and decoding. From a positive standpoint, the technique enhances per unit time of the signal by a factor of 2. In this regard, symbols are averaged by half as compared to the original PPM. Q-switching is possible since large pulse energy is combined with the PPM on a narrow transmission slot (Dolinar et al., 2018). The challenge associated with the process mentioned above is that a delay or dead time occurs. The phenomenon causes the laser to recharge. The limitation can be eliminated by following every frame within the system with regard to their periods to determine the pulses that are not being transmitted. Even though it affects the format of modulation, it is less complex and has a high

throughput. Implementing this kind of format for variable-rate schemes is challenging due to the difficulties of adapting the decoding algorithms. Another issue is that there is a likelihood of a massive error during propagation due to the loss of the transmission frames after synchronization. The limitations can be mitigated by buffering and performing detection algorithms sequentially.

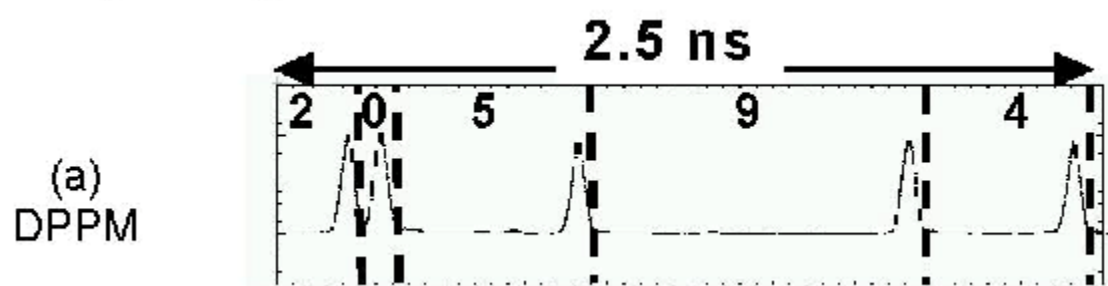


Figure 13 differential PPM

Overlapping PPM

Notably, overlapping PPM (OPPM) is also used for the general purposes of optical signal modulation. In this modulation format, the length of T is divided into a different number of chips for the specific duration (Dolinar et al., 2018). Pulses are assigned specific chips and are restrained within their respective symbol epoch. The technique requires thorough synchronization, and synchronizing codes are used for this purpose.

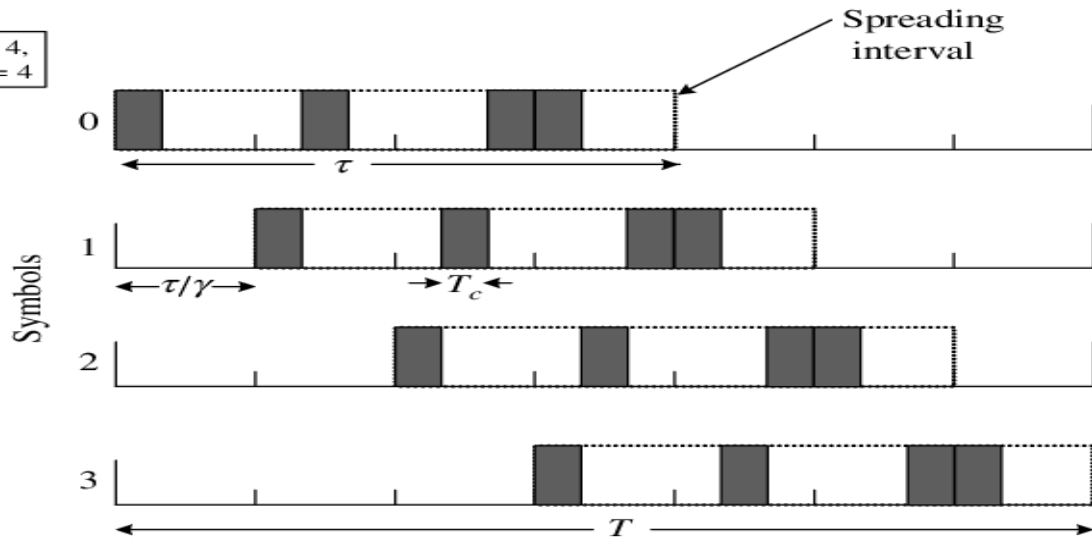


Fig 14 overlapping PPM

Wavelength Shift Keying

Furthermore, wavelength shift keying (WSK) can be used in spite of being similar to PPM. However, this modulation format requires the placement of a single pulse of the optical signal that has a specific wavelength to one of the existing time slots. A single laser pulse takes up the disjointed wavelength of the slot that it is assigned. Besides, PPM and WSK can be combined to increase the linearity of average laser power. The data rate attribute of this format is that of WSK (Dolinar et al., 2018). The laser pulse is restricted to only a single time slot; as a result, it can take a number of wavelengths so that to average the original PPM. In this regard, the low-power characteristics of the PPM are maintained. Also, the data rate of the optical signal is increased.

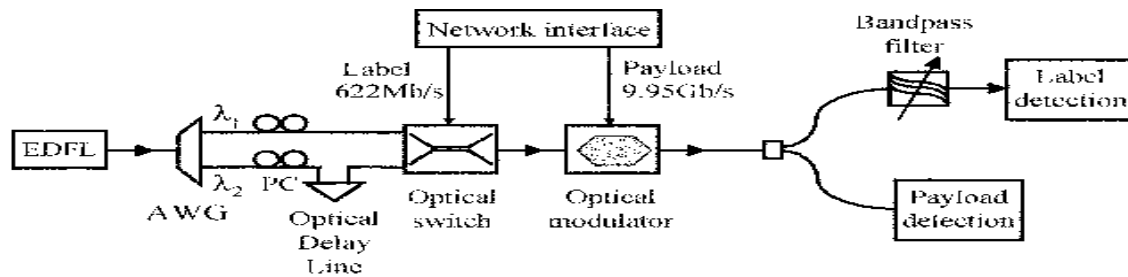


Fig. 1. WSK encoded pulses for optical labeling applications.

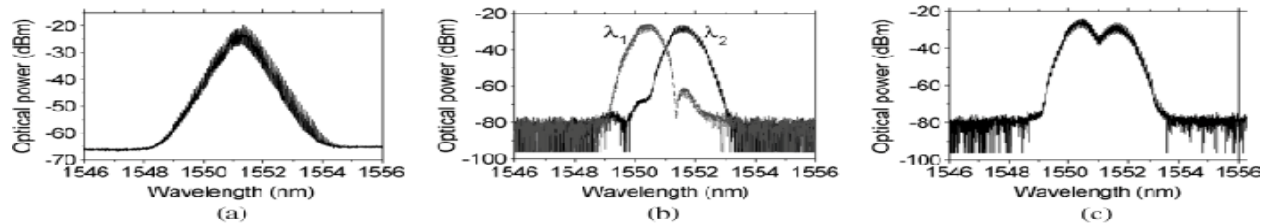


Fig. 2. (a) Optical spectrum of the output pulses from the EDFA; (b) optical

Fig 14 wavelength shift keying

All in all, the modulation techniques mentioned above shows multilevel coded signaling. Multilevel coded modulation aims at exploiting unequal errors and applying the different transmission parameters at different rates within the time slots. The block distance is optimized using different parallel channels. Binary information is mapped onto a scheme of different layers that create frames that allow easy exploitation of the codes. Corresponding distances are determined to ensure linearity within the layers. The first layer of an encoded block is used to decode the signal at the receiver. Decoding is carried out independently of other subsequent layers. This kind of decoding is known as sequential decoding and is consistent throughout the transmission line. The techniques are suitable for multistage transmission of optical signals since they reduce complexities within the system. Also, Trellis coded modulation (TCM) is another technique that partitions parallel channels to increase the system's transmission capacity (Beygi, 2010). The first layers within the channel have relatively low capacities. The initial pulse information is split into two a group of layers under the protection of the convolutional code.

Lastly, bit-interleaved coded modulation (BICM) entails the addition of interleaves between the mapping unit and the encoder. As a result, information is transmitted in the form of bits on the selected channels.

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