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Basic Elements of Optical Communication

1.1 Spectrum of Optical Waves

An optical communication system transmits analog and digital information from one place to another using high carrier frequencies lying in the range of 100–1000 THz in the visible and near-infrared (IR) region of the electromagnetic spectrum [1–15]. As for microwave systems, they operate at carrier frequencies that are 5 orders of magnitude smaller ($\sim 1\text{--}10$ GHz).

White light involves the wavelength band from the ultraviolet spectral band, passing the visible one, to the near-IR band, which has been included here since most fiber communications use carriers in the IR having lowest losses of glass fiber intrinsic surface [8–10].

There are some links in the visible band based on plastic fiber intrinsic surface and therefore having higher loss. Therefore, for the visible optical band such fiber is utilized for short paths. Thus, optical fiber systems operating in 650–670 nm bandwidths with plastic intrinsic surface have loss of 120–160 dB/km, whereas those operating in 800–900 nm bandwidth have loss of 3–5 dB/km, and those operating in 1250–1350 and 1500–1600 nm bandwidth, based on glass surface, have loss of 0.5–0.25 dB/km, respectively.

The relationship between wavelength (λ) and frequency (f) is $\lambda = c/f$, where the velocity of light in free space is $c = 3 \cdot 10^8$ m/s. As an example, a wavelength of $\lambda = 1.5 \mu\text{m}$ corresponds to a frequency of $2 \cdot 10^{14}$ Hz = $2 \cdot 10^2$ THz (a corresponding period of oscillations is $T = 0.5 \cdot 10^{-14}$ s).

A sufficiently wide frequency band has allowed an increase in the bit rate–distance product over a period of about 150 years from $\sim 10^2$ to $\sim 10^{15}$ bps/km (summarized from Refs. [7, 12, 14]).

1.2 Optical Communication in Historical Perspective

There are five generations of light communication systems, which differ from each other by wavelength, bit rate (Mbps), and the range of communication between optical terminals [7, 12, 14].

First Generation:

- started in 1980;
- wavelength is 800 nm;
- bit rate – 45 Mbps (megabit per second);
- optical terminals spacing – 10 km.

Second Generation:

- started during the 1980s;
- wavelength is 1300 nm;
- single-mode fiber optic structure;
- bit rate – 1.7 Gbps (gigabit per second);
- optical terminals spacing – 50 km.

Third Generation:

- started in 1990;
- wavelength is 1550 nm;
- single-mode fiber laser;
- dispersive-shifted fibers;
- bit rate – 2.5 Gbps (gigabit per second);
- optical terminals spacing – 60–70 km.

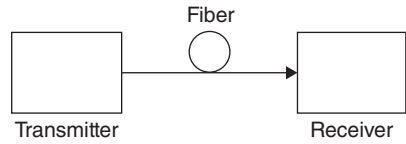
Fourth Generation:

- started in 1996–1997;
- optical amplifiers;
- wavelength-division multiplexing (WDM);
- bit rate – 5–10 Gbps (gigabit per second);
- optical terminals spacing – 60–100 km.

Fifth Generation:

- started at the end of nineties;
- solitons;
- dense-wavelength-division multiplexing (DWDM);
- dispersion compensation;
- optical terminals spacing – up to 100 km.

Figure 1.1 Scheme of optical communication link connected by fiber optics.



1.3 Optical Communication Link Presentation

Below, we will give a definition of the optical link both for fiber optical link, as a “wire” communication link, and for atmospheric link, a “wireless” communication link. Optical communications via fiber optics can be considered as a finishing optical communication system, as shown in Figure 1.1 according to Refs. [7–12]. The message passing such a link is assumed to be available in electronic form, usually as a current. The transmitter is a light source that is modulated so that the optical beam carries the message.

As an example, for a digital signal, the light beam is electronically turned on (for binary ones) and off (for binary zeros). Here, the optical beam is the carrier of the digital message. Fiber optic links usually take the light-emitting diode and the laser diode as the source. Several characteristics of the light source determine the behavior of the propagating optical waves [1–6]. The corresponding modulated light beam (i.e. the message with the carrier) is coupled into the transmission fiber.

Generally speaking, each optical wireless communication system, wired or wireless, comprises three main blocks: (i) the transmitter, (ii) the channel, and (iii) the receiver (Figure 1.2). The input to the transmitter is an electronic signal, which carries the information, and the output of the transmitter is an optical signal from a light source such as a light-emitting diode (LED) or laser [6, 12] (see also Chapter 8).

The optical signal carries the information presented in digital form as shown in Figure 1.3.

The reader will find full information on the types of digital information presentation in Chapters 3–5. Now we will briefly describe the basic elements of the optical communication channel, including the transmitter, as a source of light, and the receiver, as the detector of light. These elements of the optical communication channel will be discussed in detail in Chapter 8.

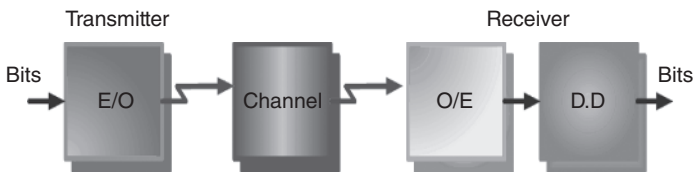


Figure 1.2 Optical wired or wireless system scheme.

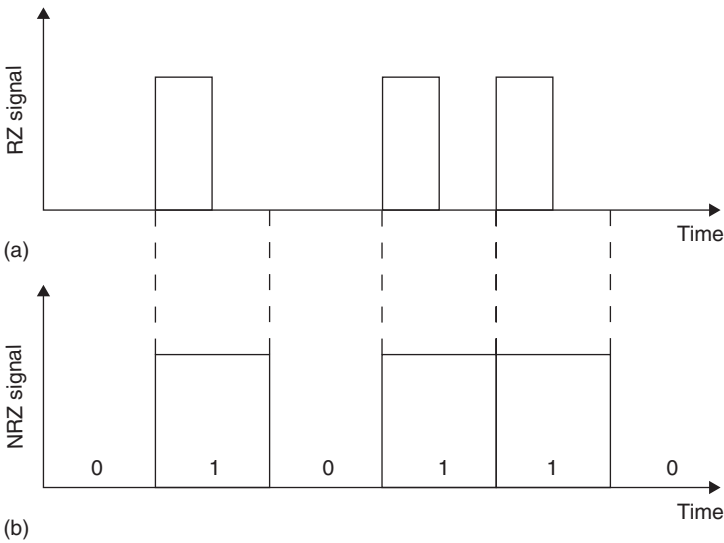


Figure 1.3 Presentation of digital information in the form of (a) return-to-zero (RZ) and (b) non-return-to-zero (NRZ) pulses.

The input to the channel is the optical signal from the transmitter and the output of the channel is the input to the receiver. The receiver receives the optical signal from the output of the channel, amplifies the signal, converts it to an electronic signal, and extracts the information. At the receiver, the signal is collected by a photodetector, which converts the information back into electrical form. The photodetectors do not affect the propagation properties of the optical wave but certainly must be compatible with the rest of the system (see Chapter 8).

The transmitter includes a modulator, a driver, a light source, and optics (Figure 1.4). The modulator converts the information bits to an analog signal that represents a symbol stream. The driver provides the required current to the light source based on the analog signal from the output of the modulator. The light source is an LED or a laser, which is a noncoherent or a coherent source, respectively. The source converts the electronic signal to an optical signal [6, 12]. The optics focuses and directs the light from the output of the source in the direction of the receiver.

The receiver includes optics, a filter, a polarizer, a detector, a trans-impedance amplifier, a clock recovery unit, and a decision device (see Figure 1.5). The optics concentrates the received signal power onto the filter.

Only light at the required wavelength propagates through the filter to the polarizer. The polarizer only enables light at the required polarization to propagate through to the detector. The detector, in most cases a semiconductor

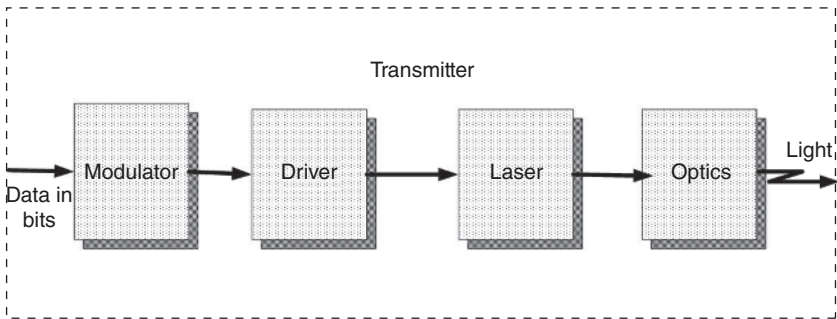


Figure 1.4 The transmitter scheme.

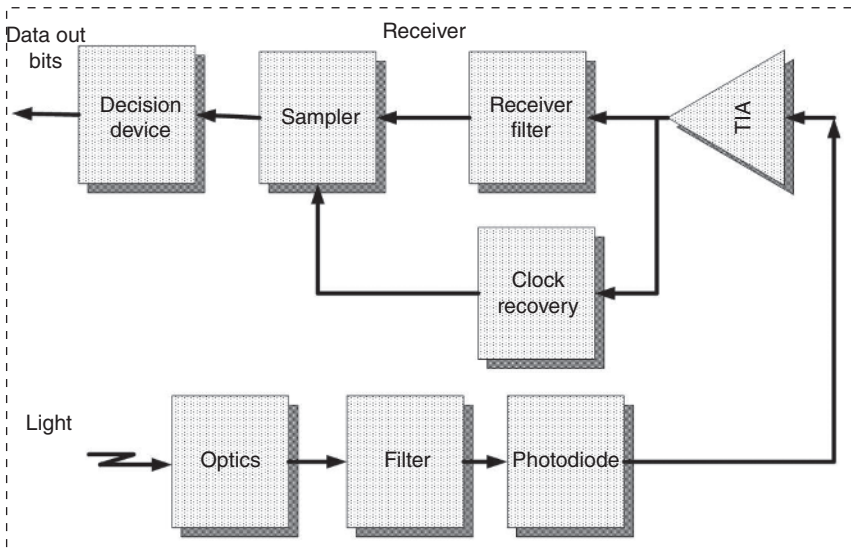


Figure 1.5 The receiver scheme.

device such as a positive intrinsic negative (PIN) photodiode, converts the optical signal to an electronic signal (see Chapter 8). The trans-impedance amplifier amplifies the electronic signal from the detector. The clock recovery unit provides a synchronization signal to the decision device based on the signal from the output of the trans-impedance amplifier. The decision device estimates the received information based on the electronic signal from the trans-impedance amplifier and synchronization signal.

The atmospheric (wireless) channel attenuates the power of the optical signal and widens and spreads it in the spatial, temporal, angular, and polarization domains (see Figure 1.6) [13, 15].

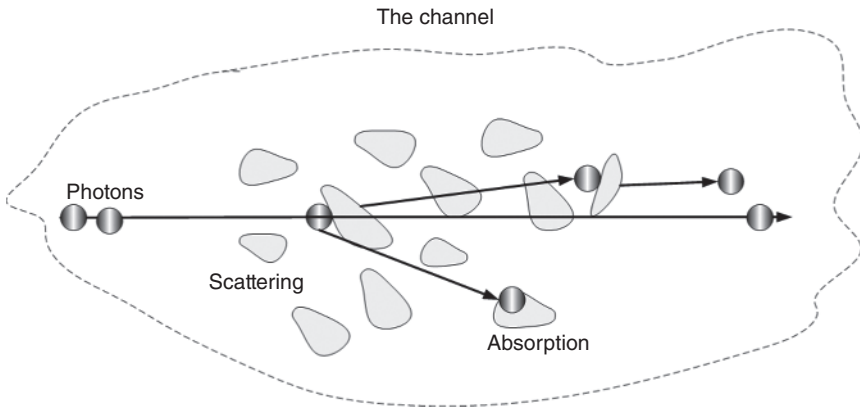


Figure 1.6 The atmospheric optical channel.

The attenuation, widening, and spreading are stochastic processes, resulting from the interaction of light with atmospheric gases, aerosols, and turbulence. The atmospheric gases mostly absorb the light while the aerosols absorb and scatter the light. The turbulence gives rise to constructive and destructive interference, which cause fluctuations in received power, or scintillations, as well as beam bending in the detector plane, as described in Chapters 10 and 11.

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