

Module

2

Data Communication Fundamentals

Version 2 CSE IIT, Kharagpur

Lesson

Data and Signal

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Specific Instructional Objectives

At the end of this lesson the students will be able to:

- Explain what is data
- Distinguish between Analog and Digital signal
- Explain the difference between time and Frequency domain representation of signal
- Specify the bandwidth of a signal
- Specify the Sources of impairment
- Explain Attenuation and Unit of Attenuation
- Explain Data Rate Limits and Nyquist Bit Rate
- Distinguish between Bit Rate and Baud Rate
- Identify Noise Sources

2.1.1 Introduction

A simplified model of a data communication system is shown in Fig. 2.1.1. Here there are five basic components:

- **Source:** Source is where the data is originated. Typically it is a computer, but it can be any other electronic equipment such as telephone handset, video camera, etc, which can generate data for transmission to some destination. The data to be sent is represented by $x(t)$.

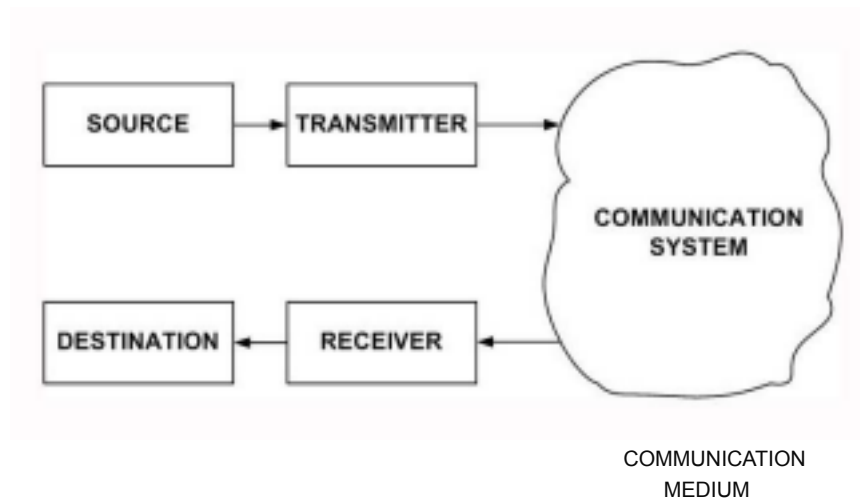


Figure 2.1.1 *Simplified model of a data communication system*

- **Transmitter:** As data cannot be sent in its native form, it is necessary to convert it into signal. This is performed with the help of a transmitter such as modem. The signal that is sent by the transmitter is represented by $s(t)$.

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- **Communication Medium:** The signal can be sent to the receiver through a communication medium, which could be a simple twisted-pair of wire, a coaxial cable, optical fiber or wireless communication system. It may be noted that the signal that comes out of the communication medium is $s'(t)$, which is different from $s(t)$ that was sent by the transmitter. This is due to various impairments that the signal suffers as it passes through the communication medium.
- **Receiver:** The receiver receives the signal $s'(t)$ and converts it back to data $d'(t)$ before forwarding to the destination. The data that the destination receives may not be identical to that of $d(t)$, because of the corruption of data.
- **Destination:** Destination is where the data is absorbed. Again, it can be a computer system, a telephone handset, a television set and so on.

2.1.2 Data

Data refers to information that conveys some meaning based on some mutually agreed up rules or conventions between a sender and a receiver and today it comes in a variety of forms such as text, graphics, audio, video and animation.

Data can be of two types; analog and digital. *Analog data* take on continuous values on some interval. Typical examples of analog data are voice and video. The data that are collected from the real world with the help of transducers are continuous-valued or analog in nature. On the contrary, *digital data* take on discrete values. Text or character strings can be considered as examples of digital data. Characters are represented by suitable codes, e.g. ASCII code, where each character is represented by a 7-bit code.

2.1.3 Signal

It is electrical, electronic or optical representation of data, which can be sent over a communication medium. Stated in mathematical terms, a signal is merely a function of the data. For example, a microphone converts voice data into voice signal, which can be sent over a pair of wire. Analog signals are continuous-valued; digital signals are discrete-valued. The independent variable of the signal could be time (speech, for example), space (images), or the integers (denoting the sequencing of letters and numbers in the football score). Figure 2.1.2 shows an analog signal.

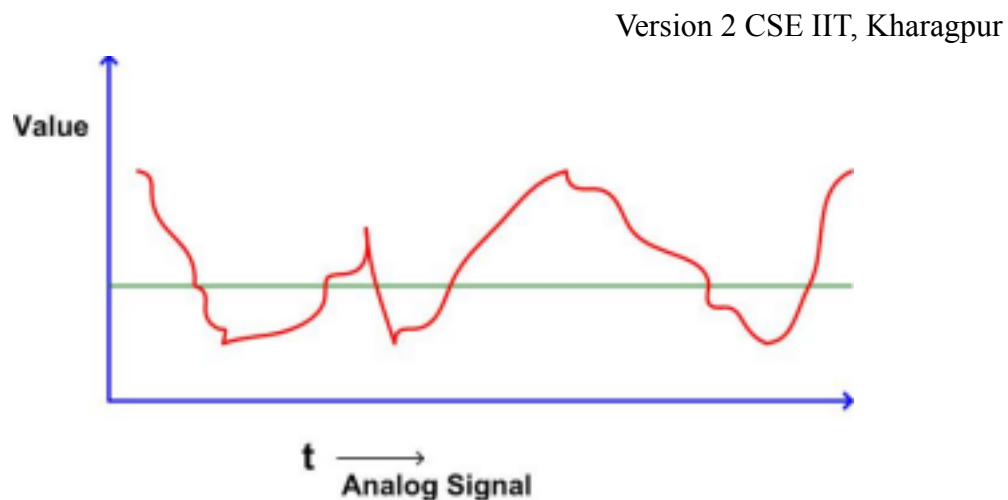


Figure 2.1.2 *Analog signal*

Digital signal can have only a limited number of defined values, usually two values 0 and 1, as shown in Fig. 2.1.3.

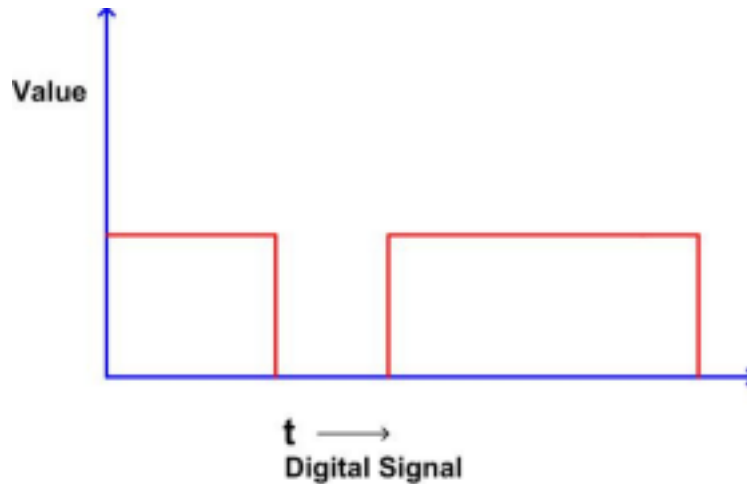


Figure 2.1.3 Digital signal

Signaling: It is an act of sending signal over communication medium **Transmission:** Communication of data by propagation and processing is known as transmission.

2.1.4 Signal Characteristics

A signal can be represented as a function of time, i.e. it varies with time. However, it can be also expressed as a function of frequency, i.e. a signal can be considered as a composition of different frequency components. Thus, a signal has both time-domain and frequency domain representation.

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2.1.4.1 Time-domain concepts

A signal is *continuous* over a period, if

$$\lim_{t \rightarrow a} s(t) = s(a), \text{ for all } a,$$

i.e., there is no break in the signal. A signal is *discrete* if it takes on only a finite number of values. A signal is *periodic* if and only if

$$s(t+T) = s(t) \text{ for } -\alpha < t < \alpha,$$

where T is a constant, known as *period*. The period is measured in seconds.

In other words, a signal is a *periodic signal* if it completes a pattern within a measurable time frame. A periodic signal is characterized by the following three parameters.

Amplitude: It is the value of the signal at different instants of time. It is measured in volts.

Frequency: It is inverse of the time period, i.e. $f = 1/T$. The unit of frequency is Hertz (Hz) or cycles per second.

Phase: It gives a measure of the relative position in time of two signals within a single period. It is represented by ϕ in degrees or radian.

A sine wave, the most fundamental periodic signal, can be completely characterized by its amplitude, frequency and phase. Examples of sine waves with different amplitude, frequency and phase are shown in Fig. 2.1.4. The phase angle ϕ indicated in the figure is with respect to the reference waveform shown in Fig. 2.1.4(a).

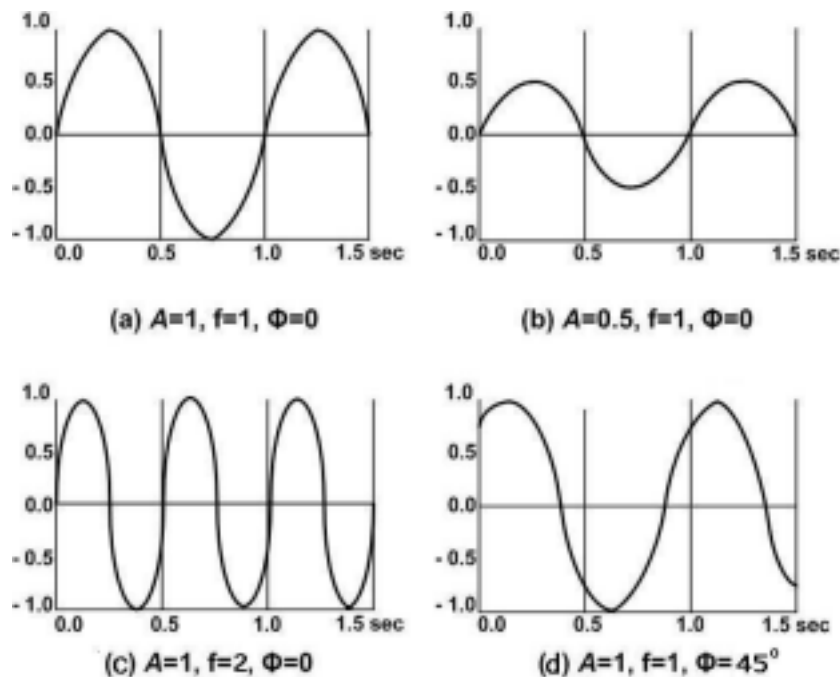


Figure 2.1.4 Examples of signals with different amplitude, frequency and phase

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An *aperiodic signal* or nonperiodic signal changes constantly without exhibiting a pattern or cycle that repeats over time as shown in Fig. 2.1.5.

a). Analog aperiodic signal b). Digital aperiodic signal

Figure 2.1.5 Examples of aperiodic signals

2.1.4.2 Frequency domain concepts

The time domain representation displays a signal using *time-domain plot*, which shows changes in signal amplitude with time. The time-domain plot can be visualized with the help of an oscilloscope. The relationship between amplitude and frequency is provided by frequency domain representation, which can be displayed with the help of *spectrum analyser*. Time domain and frequency domain representations of three sine waves of three different frequencies are shown in Fig 2.1.6

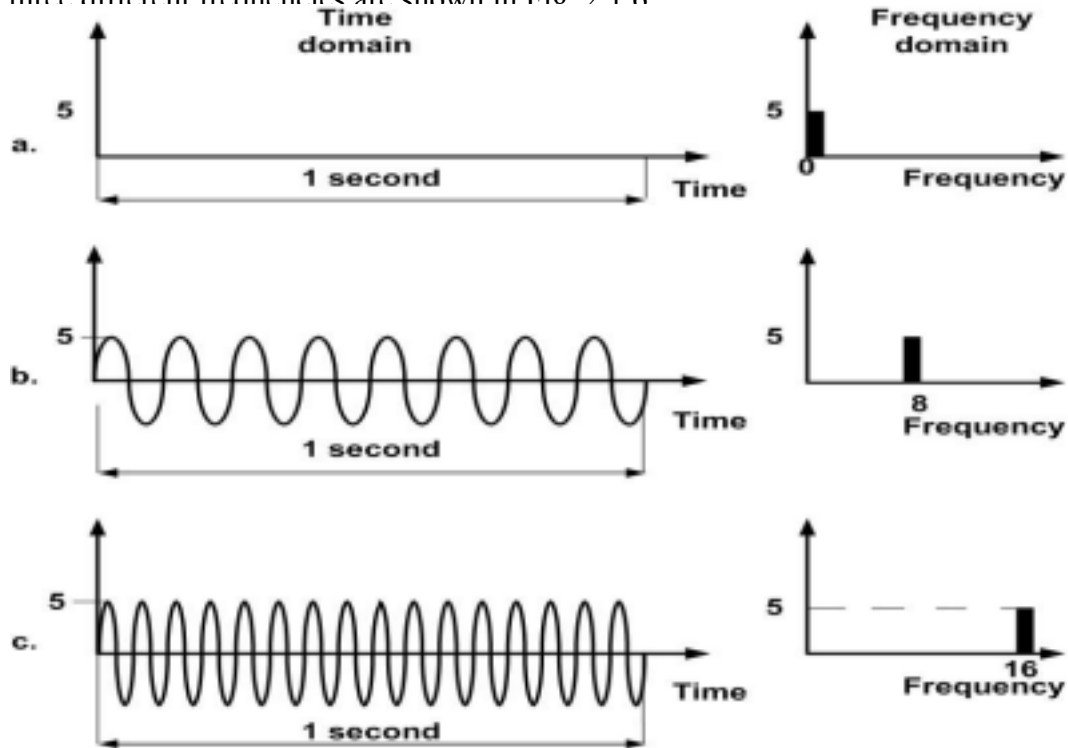


Figure 2.1.6 Time domain and frequency domain representations of sine waves

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Although simple sine waves help us to understand the difference between the time domain and frequency domain representation, these are of little use in data communication. Composite signals made of many simple sine waves find use in data communication. Any composite signal can be represented by a combination of simple sine waves using Fourier Analysis. For example, the signal shown in Fig. 2.1.7(c) is a composition of two sine waves having frequencies f_1 , $3f_1$, shown in Fig. 2.1.7 (a) and (b), respectively and it can be represented by

$$s(t) = \sin \omega t + \frac{1}{3} \sin 3\omega t, \text{ where } \omega = 2\pi f_1.$$

The frequency domain function $s(f)$ specifies the constituent frequencies of the signal. The range of frequencies that a signal contains is known as its *spectrum*, which can be visualized with the help of a spectrum analyser. The band of frequencies over which most of the energy of a signal is concentrated is known as the *bandwidth* of the signal.

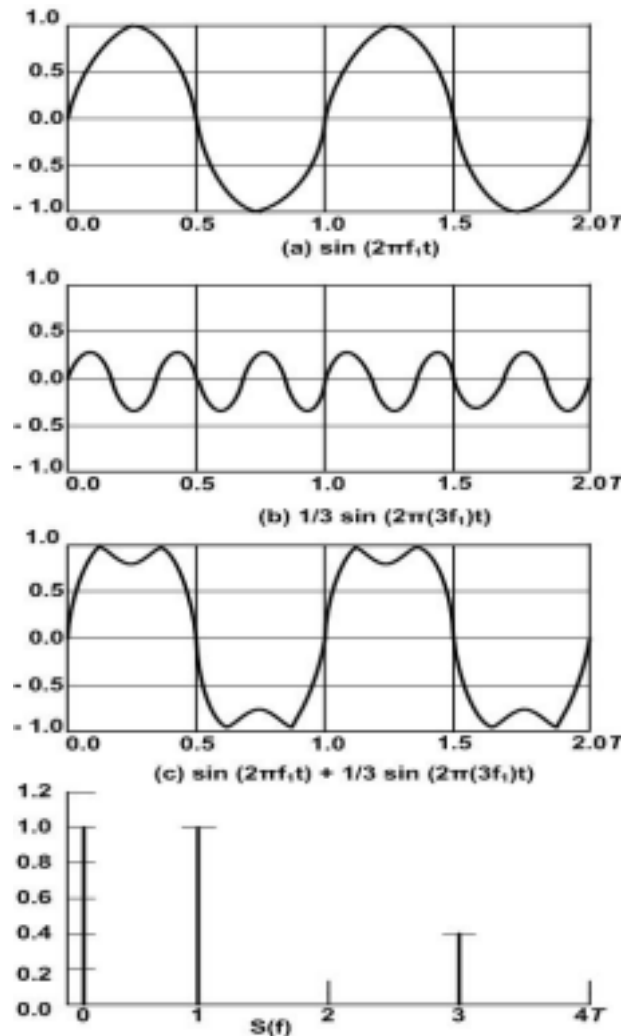


Figure 2.1.7 Time and frequency domain representations of a composite signal Version 2 CSE

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Many useful waveforms don't change in a smooth curve between maximum and minimum amplitude; they jump, slide, wobble, spike, and dip. But as long as these irregularities are consistent, cycle after cycle, a signal is still periodic and logically must


2.1.4.3 Frequency Spectrum

Exam of sin^A

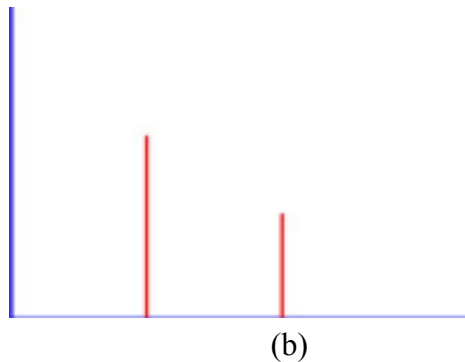
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The graph shows a square wave (red line) oscillating between positive and negative values. The x-axis is labeled t and has markers for T , $2T$, and $3T$. The wave has a period of T .



Bandwidth: The range of frequencies over which most of the signal energy of a signal is contained is known as **bandwidth** or effective bandwidth of the signal. The term ‘most’ is somewhat arbitrary. Usually, it is defined in terms of its 3dB cut-off frequency. The frequency spectrum and spectrum of a signal is shown in Fig. 2.1.9. Here the f_l and f_h may be represented by 3dB below $(A/\sqrt{2})$ the maximum amplitude.

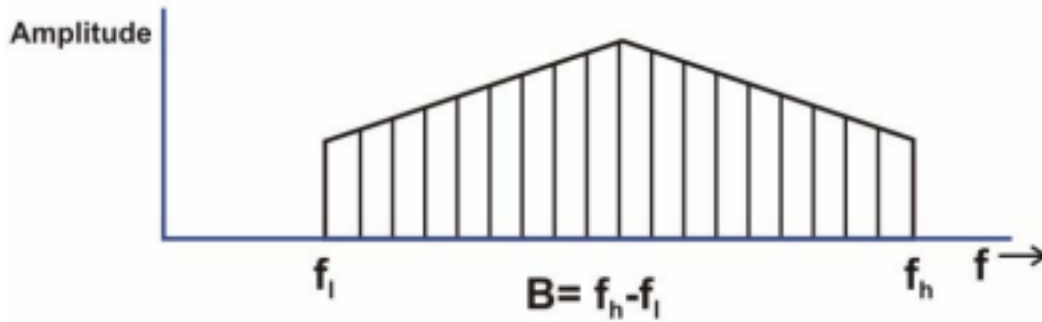
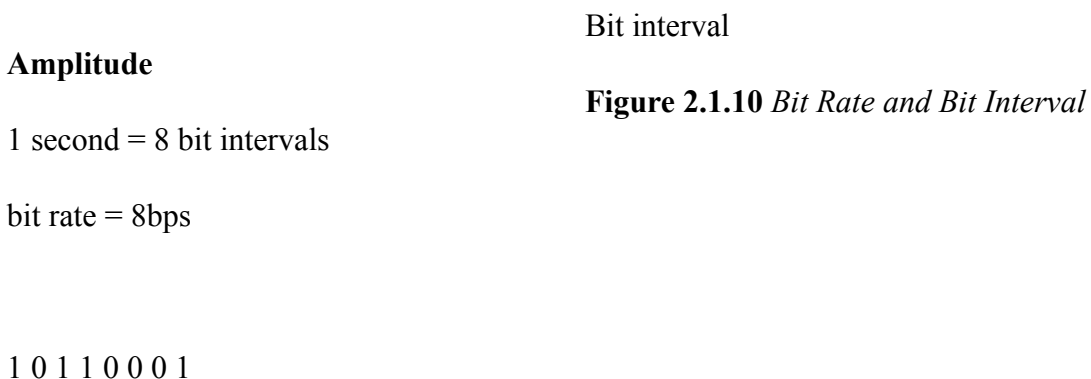


Figure 2.1.9 Frequency spectrum and bandwidth of a signal

2.1.5 Digital Signal

In addition to being represented by an analog signal, data can be also be represented by a digital signal. Most digital signals are aperiodic and thus, period or frequency is not appropriate. Two new terms, *bit interval* (instead of period) and *bit rate* (instead of frequency) are used to describe digital signals. The bit interval is the time required to send one single bit. The bit rate is the number of bit interval per second. This mean that the bit rate is the number of bits send in one second, usually expressed in bits per second (bps) as shown in Fig. 2.1.10.



Bit interval

Figure 2.1.10 Bit Rate and Bit Interval

1 second = 8 bit intervals

bit rate = 8bps

1 0 1 1 0 0 0 1

Time

A digital signal can be considered as a signal with an infinite number of frequencies and transmission of digital requires a low-pass channel as shown in Fig. 2.1.11. On the other hand, transmission of analog signal requires band-pass channel shown in Fig. 2.1.12. Version 2

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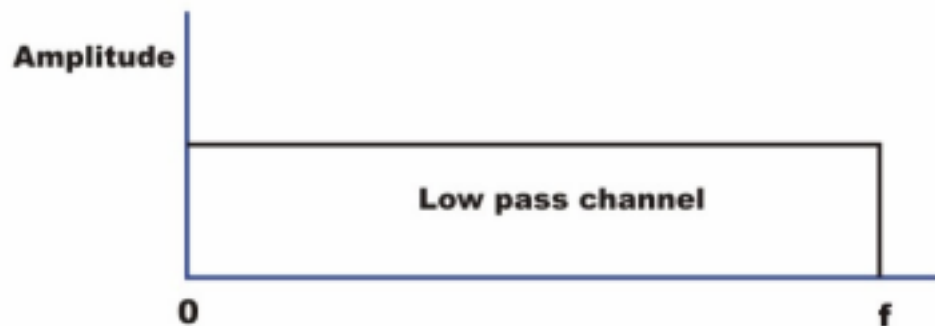


Figure 2.1.11 Low pass channel required for transmission of digital signal

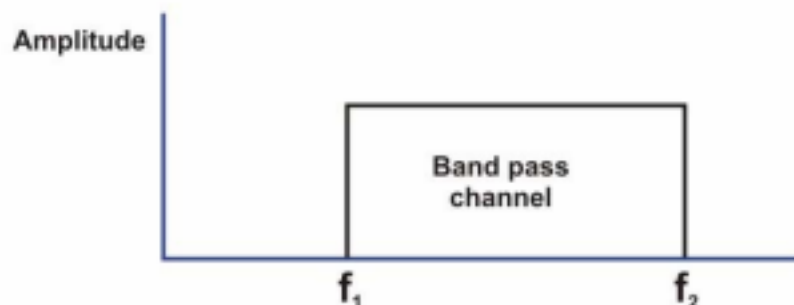


Figure 2.1.12 Band pass channel required for transmission of analog signal

Digital transmission has several advantages over analog transmission. That is why there is a shift towards digital transmission despite large analog base. Some of the advantages of digital transmission are highlighted below:

- Analog circuits require amplifiers, and each amplifier adds distortion and noise to the signal. In contrast, digital amplifiers regenerate an exact signal, eliminating cumulative errors. An incoming (analog) signal is sampled, its value is determined, and the node then generates a new signal from the bit value; the incoming signal is discarded. With analog circuits, intermediate nodes amplify the incoming signal, noise and all.
- Voice, data, video, etc. can all be carried by digital circuits. What about carrying digital signals over analog circuit? The modem example shows the difficulties in carrying digital over analog. A simple encoding method is to use constant voltage levels for a "1" and a "0". Can lead to long periods where the voltage does not change.
- Easier to multiplex large channel capacities with digital.
- Easy to apply encryption to digital data.
- Better integration if all signals are in one form. Can integrate voice, video and digital data.

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2.1.6 Baseband and Broadband Signals

Depending on some type of typical signal formats or modulation schemes, a few terminologies evolved to classify different types of signals. So, we can have either a base band or broadband signalling. *Base-band* is defined as one that uses digital signalling, which is inserted in the transmission channel as voltage pulses. On the other hand, *broadband* systems are those, which use analog signalling to transmit information using a carrier of high frequency.

In baseband LANs, the entire frequency spectrum of the medium is utilized for transmission and hence the frequency division multiplexing (discussed later) cannot be used. Signals inserted at a point propagate in both the directions, hence transmission is bi-directional. Baseband systems extend only to limited distances because at higher frequency, the attenuation of the signal is most pronounced and the pulses blur out, causing the large distance communication totally impractical.

Since broadband systems use analog signalling, frequency division multiplexing is possible, where the frequency spectrum of the cable is divided into several sections of bandwidth. These separate channels can support different types of signals of various frequency ranges to travel at the same instance. Unlike base-band, broadband is a unidirectional medium where the signal inserted into the media propagates in only one direction. Two data paths are required, which are connected at a point in the network

called *headend*. All the stations transmit towards the headend on one path and the signals received at the headend are propagated through the second path.

Fill In the blanks:

- (a) A signal is a _____, Electromagnetic or _____ coding of data. (b) The four parameters that are used to characterize a signal in time domain concept are amplitude, _____, _____ and _____.
- (c) With the help of _____, we can find out the different frequency components of a signal, and these components are visualized with the help of _____.
- (d) _____ gives a measure of the span of the spectral components of a signal. (e) The noise created by the agitation of electrons of the transmission channel is termed as _____.
- (f) The noise created by bunching several cables together is known as _____.

Short Answers Questions:

Q-1. Distinguish between data and signal.

Ans: Data is an entity, which conveys some meaning. On the other hand, the signal is a representation of data in some electric, electromagnetic or optical form. So, whenever

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data needs to be sent, it has to be converted into signal of some form for transmission over a suitable medium.

Q-2. What do you mean by a “Periodic Signal”? And what are the three parameters that characterize it?

Ans: A signal is *periodic signal* if it completes a pattern within a measurable timeframe. A periodic signal is characterized by the following three parameters.

Amplitude: It is the value of the signal at different instants of time. It is measured in volts.

Frequency: It is inverse of the time period, i.e. $f=1/T$. The unit of frequency is Hertz (Hz) or cycles per second.

Phase: It gives a measure of the relative position in time of two signals within a single period

Q-3. Distinguish between time domain and frequency domain representation of a signal.

Ans: Whenever a signal is represented as a function of time, it is called time domain representation. An electromagnetic signal can be either continuous or discrete. It is represented as $s(t)$.

Whenever a signal is represented as a function of frequency, it is called frequency domain representation. It is expressed in terms of different frequency components and represented as $s(f)$.

Q-4. What equipments are used to visualize electrical signals in time domain and frequency domain?

Ans: Cathode Ray Oscilloscope is used to visualize electrical signals in time domain and Spectrum Analyser used to visualize electrical signals in frequency domain.

Q-5. What do you mean by the Bit Interval and Bit rate in a digital signal?

Ans: The bit interval is the time required to send one single bit. The bit rate is the number of bit intervals per second. This means that the bit rate is the number of bits sent in one second, usually expressed in bits per second (bps).