DATA COMMUNICATION

CSE 225/233

WEEK-3, LESSON-1

DATA AND SIGNAL

Background

- To be transmitted, data must be transformed to electromagnetic signal.

Analog and Digital

Data can be analog or digital. The term analog data refers to information that is continuous; digital data refers to information that has discrete states. Analog data take on continuous values. Digital data take on discrete values.

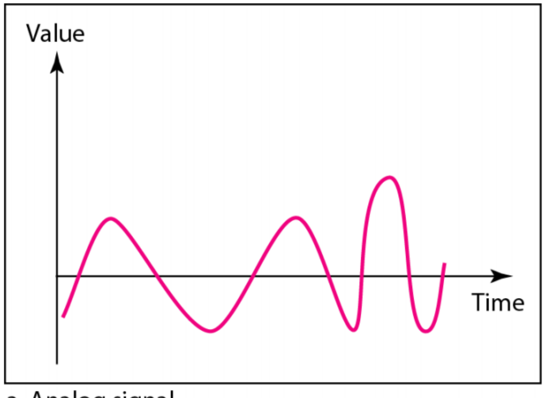
Topics discussed in this section:

Analog and Digital Data
Analog and Digital Signals
Periodic and Nonperiodic Signals

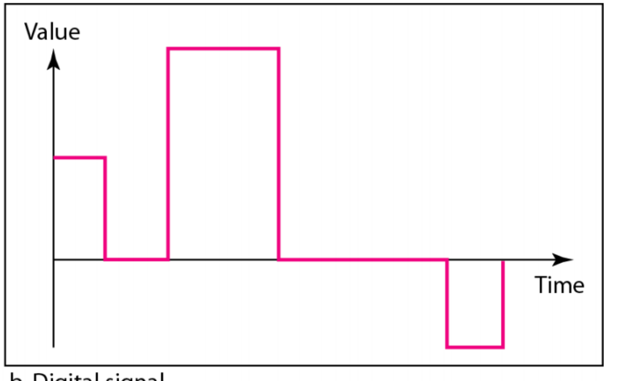
Analog and Digital (Contd.)

Data can be analog or digital. Analog data are continuous and take continuous values. Digital data have discrete states and take discrete values.

Signals can be analog or digital. Analog signals can have an infinite number of values in a range; digital signals can have only a limited number of values.



a. Analog signal



b. Digital signal

Periodic and Aperiodic signals

Both analog and digital signals can take one of two forms.

—Periodic: completes a pattern within a measurable time frame called a period and repeats that pattern over subsequent identical periods

—Aperiodic: Signal changes without exhibiting a pattern or cycle that repeats over time

In data communications, we commonly use periodic analog signals and nonperiodic digital signals.

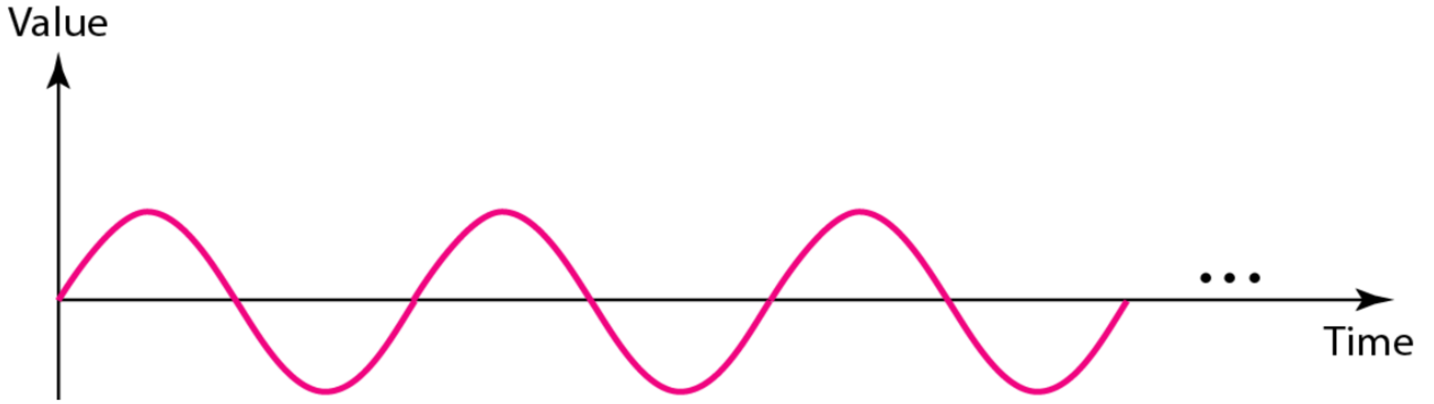
PERIODIC ANALOG SIGNALS

Periodic analog signals can be classified as simple or composite. A simple periodic analog signal, a sine wave, cannot be decomposed into simpler signals. A composite periodic analog signal is composed of multiple sine waves.

Topics discussed in this section:

- Sine Wave
- Wavelength
- Time and Frequency Domain
- Composite Signals
- Bandwidth

A sine wave



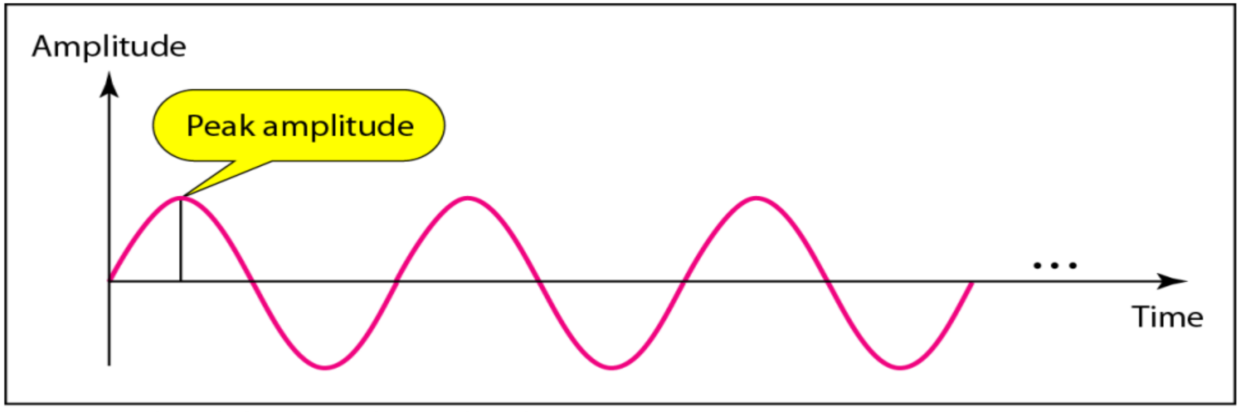
We can mathematically describe the sine wave as

$$s(t) = A \sin(2\pi f t + \varphi)$$

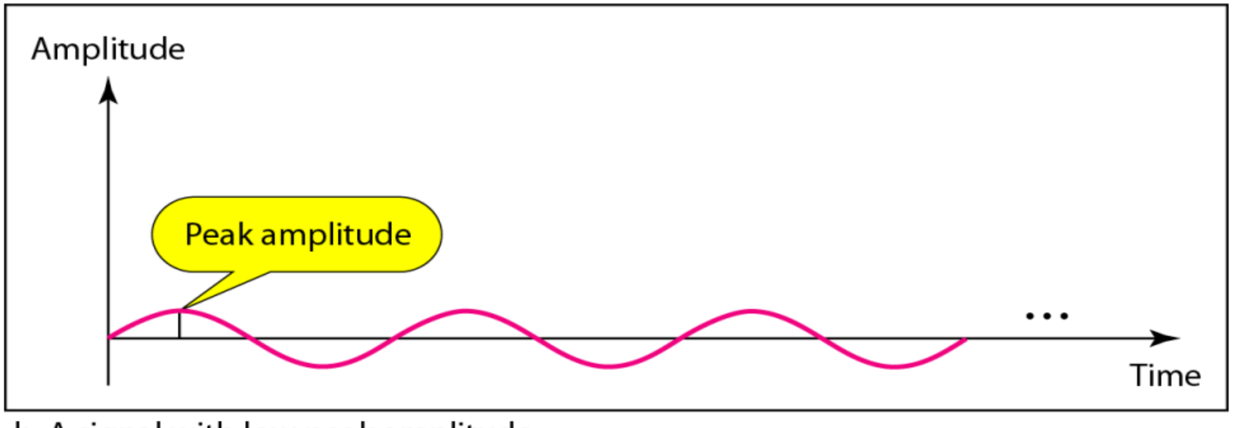
where,	s	is the instantaneous amplitude
	A	is the peak amplitude
	f	is the frequency
	φ	is the phase
	t	is the time
	π	is a constant (~3.14159)

Two signals

Same phase and frequency, but different amplitude



a. A signal with high peak amplitude



b. A signal with low peak amplitude

Period and frequency

Period refers to the amount of time, in seconds, a signal needs to complete 1 cycle.

- Denoted by ***T***, measured in seconds.

Frequency refers to the number of periods in one second

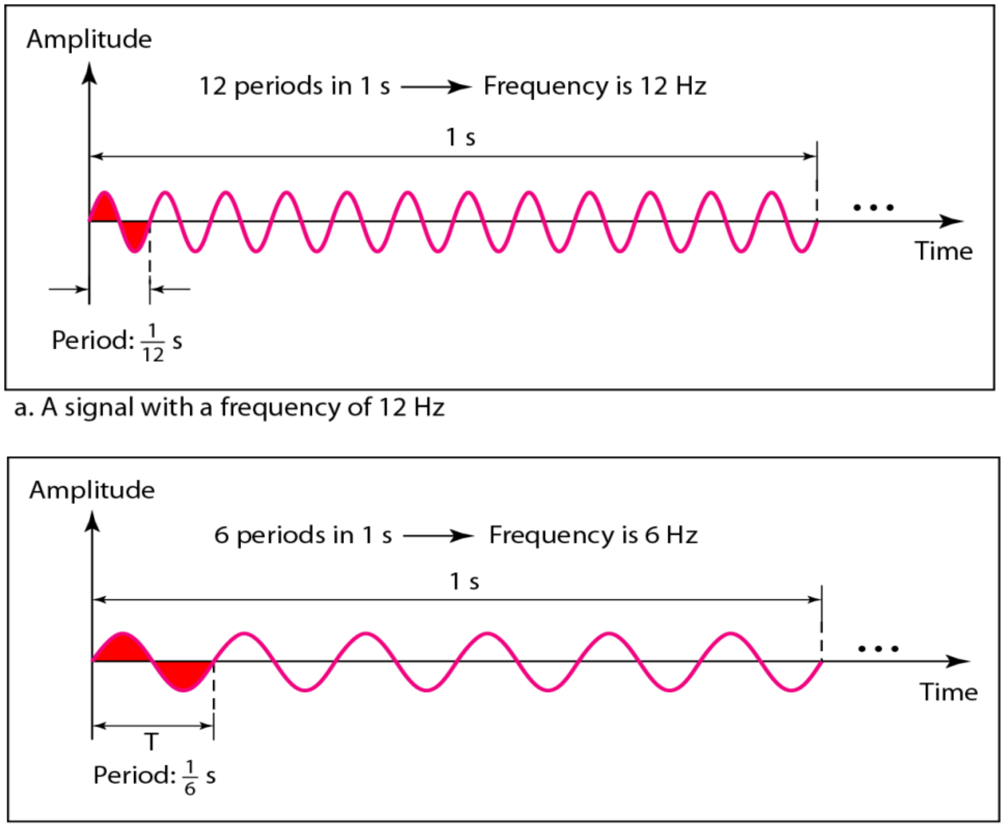
- Denoted by f, measured in Hertz (Hz)

Frequency and period are the inverse of each other.

$$f = \frac{1}{T} \quad \text{and} \quad T = \frac{1}{f}$$

Two Signals

Same amplitude and phase, but different frequencies



a. A signal with a frequency of 12 Hz

b. A signal with a frequency of 6 Hz

Units of period and frequency

Unit	*Equivalent*	*Unit*	*Equivalent*
Seconds (s)	1 s	Hertz (Hz)	1 Hz
Milliseconds (ms)	10^{-3} s	Kilohertz (kHz)	10^{3} Hz
Microseconds (μs)	10^{-6} s	Megahertz (MHz)	10^{6} Hz
Nanoseconds (ns)	10^{-9} s	Gigahertz (GHz)	10^{9} Hz
Picoseconds (ps)	10^{-12} s	Terahertz (THz)	10^{12} Hz

Example (1)

The power we use at home has a frequency of 50 Hz. The period of this sine wave can be determined as follows:

$$T = \frac{1}{f} = \frac{1}{50} = 0.02 \text{ s} = 20 \times 10^{-3} = 20 \text{ ms}$$

Example (2)

The period of a signal is 100 ms. What is its frequency in kilohertz?

Solution

First, we change 100 ms to seconds, and then we calculate the frequency from the period (1 Hz = 10^{-3} kHz)

$$100 \text{ ms} = 100 \times 10^{-3} \text{ s} = 10^{-1} \text{ s}$$

$$f = \frac{1}{T} = \frac{1}{10^{-1}} \text{ Hz} = 10 \text{ Hz} = 10 \times 10^{-3} \text{ kHz} = 10^{-2} \text{ kHz}$$

More about frequency

Frequency is the rate of change with respect to time. Change in a short span of time means high frequency.

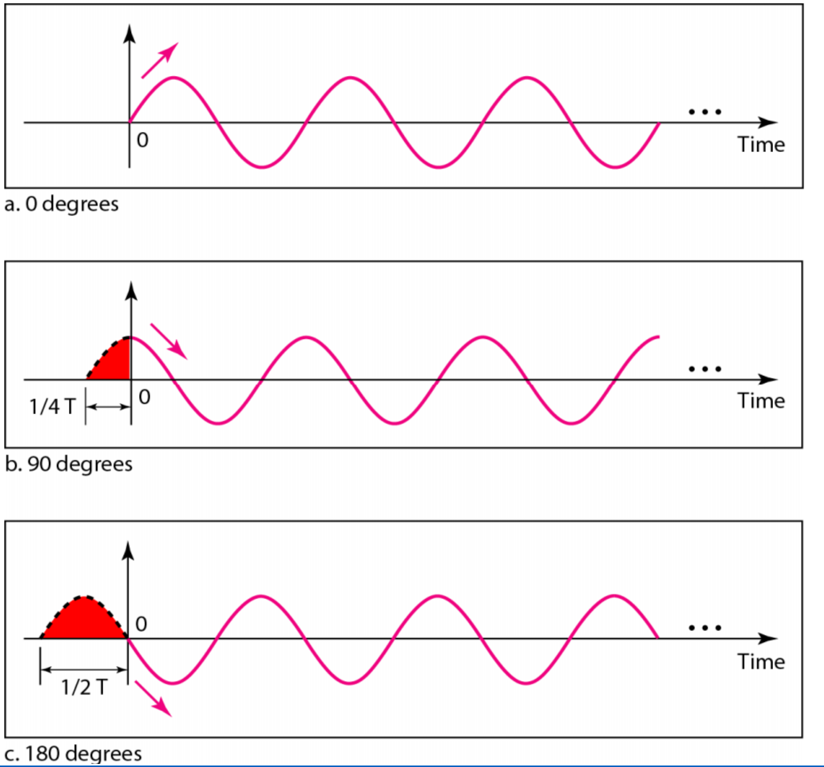
Change over a long span of time means low frequency.

If a signal does not change at all, its frequency is zero.
If a signal changes instantaneously, its frequency is infinite.

Phase

Phase describes the position of the waveform relative to time 0.

Following figure shows the Same amplitude and frequency, but different phases.



a. 0 degrees

b. 90 degrees

c. 180 degrees

Example

A sine wave is offset 1/6 cycle with respect to time 0. What is its phase in degrees and radians?

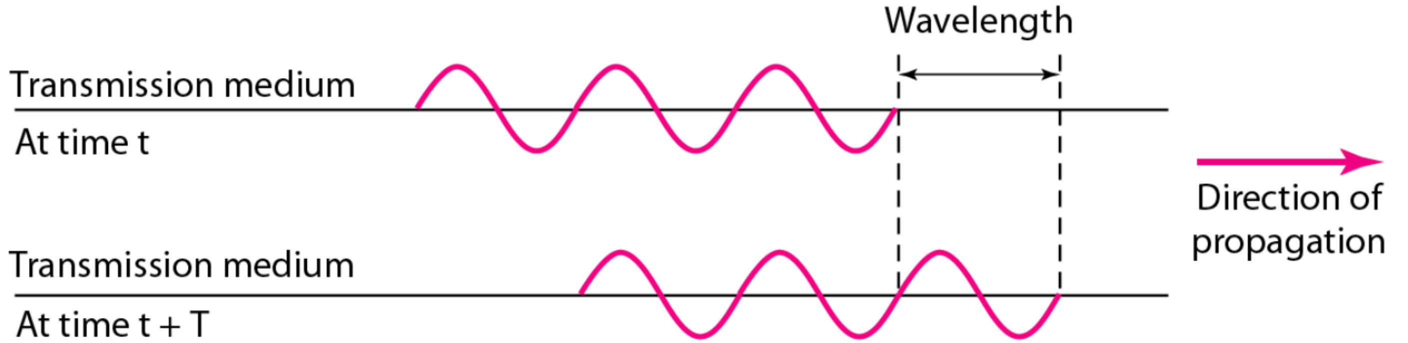
Solution

We know that 1 complete cycle is 360°.
Therefore, 1/6 cycle is

$$\frac{1}{6} \times 360 = 60° = 60 \times \frac{2\pi}{360} \text{ rad} = \frac{\pi}{3} \text{ rad} = 1.046 \text{ rad}$$

Wavelength and Period

- Wavelength is another characteristic of a signal traveling through a transmission medium.
- The wavelength depends on both the frequency and the medium.
- The wavelength is the distance a signal can travel in one period.



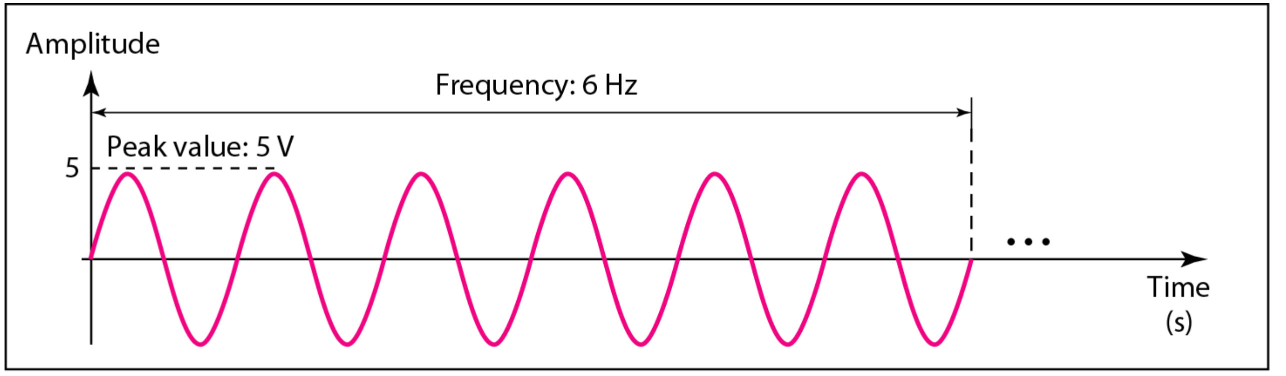
$$\lambda = c/f$$

where, λ is the wavelength

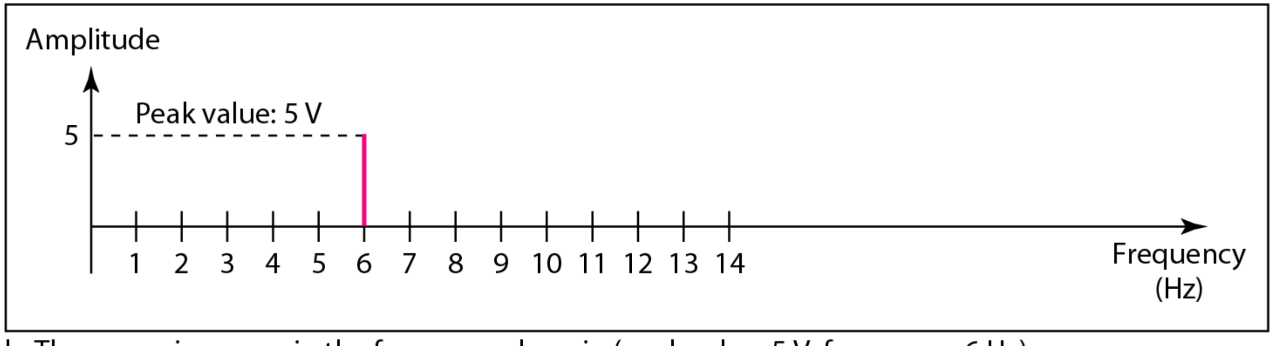
c is the speed of light (~3×10^8 m/s)

f is the frequency

The time-domain and frequency-domain plots of a sine wave



a. A sine wave in the time domain (peak value: 5 V, frequency: 6 Hz)

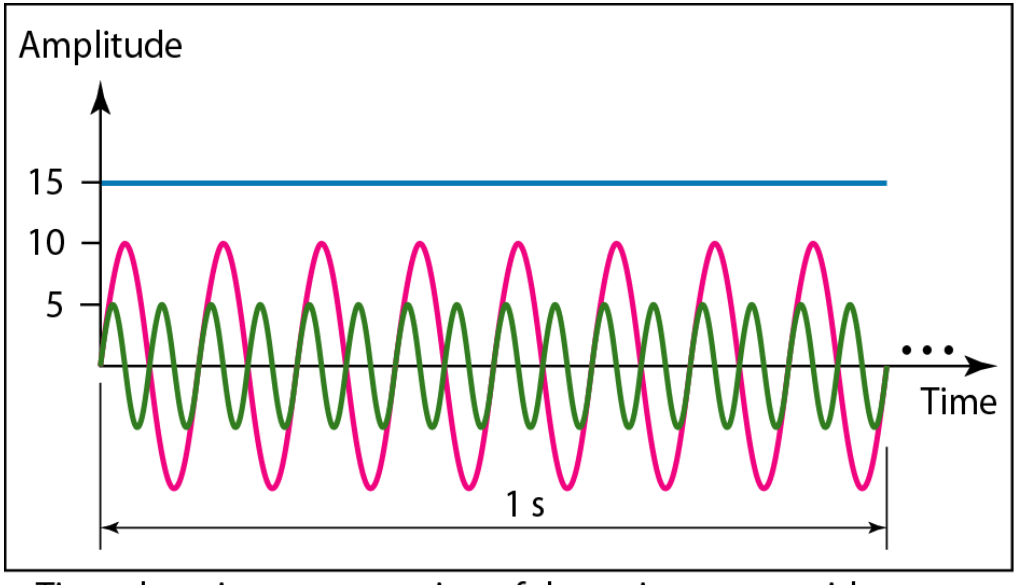


b. The same sine wave in the frequency domain (peak value: 5 V, frequency: 6 Hz)

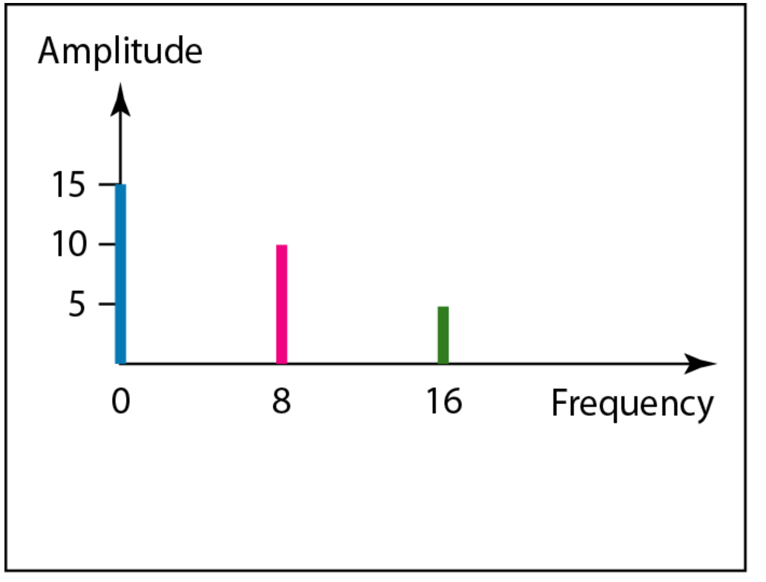
A complete sine wave in the time domain can be represented by one single spike in the frequency domain.

Example

The frequency domain is more compact and useful when we are dealing with more than one sine wave. For example, Figure 3.8 shows three sine waves, each with different amplitude and frequency. All can be represented by three spikes in the frequency domain.



a. Time-domain representation of three sine waves with frequencies 0, 8, and 16

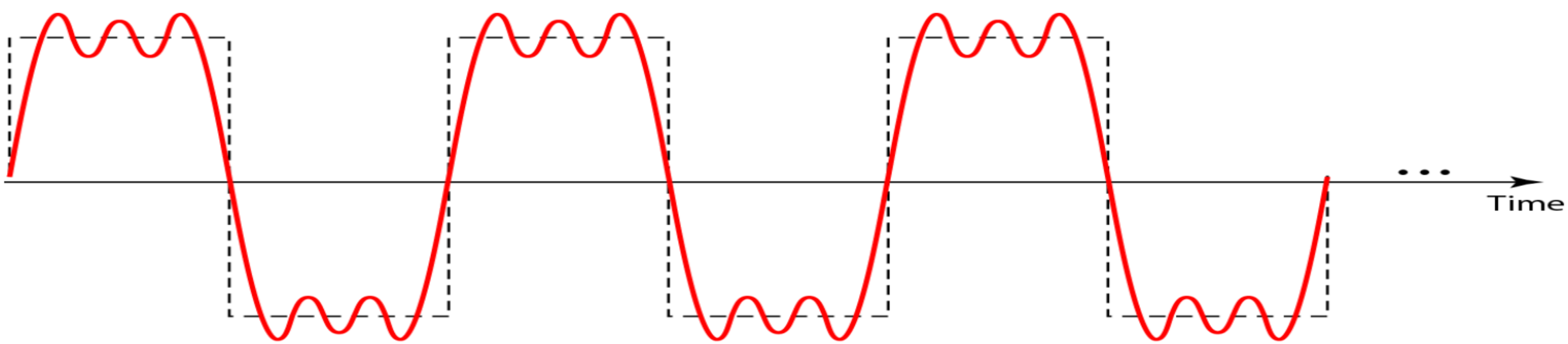


b. Frequency-domain representation of the same three signals

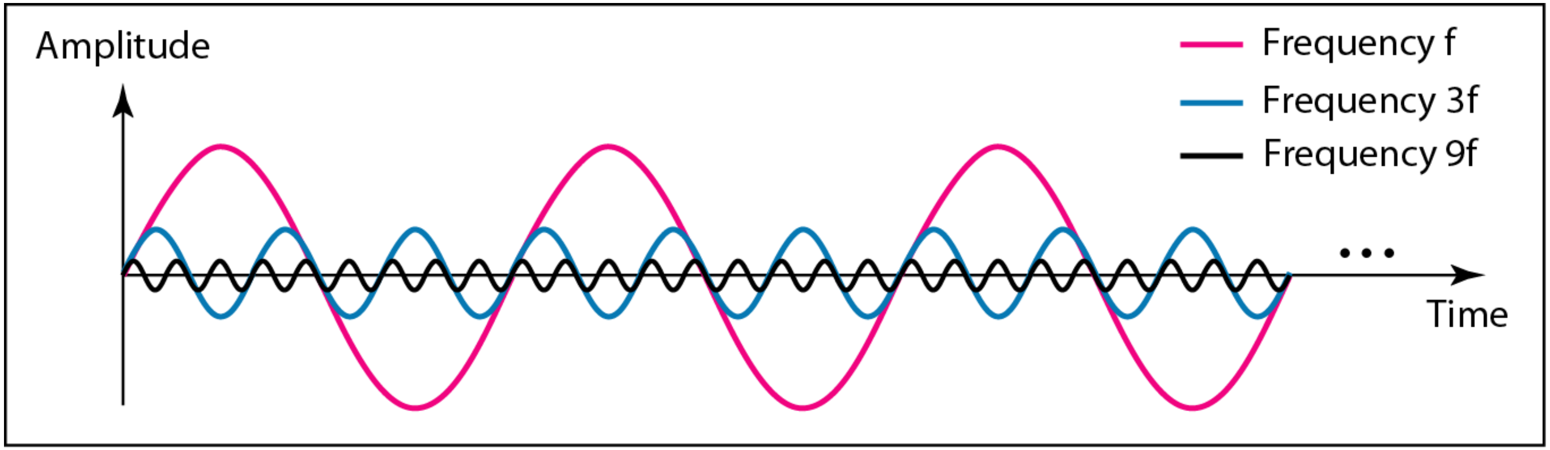
Composite Signal

A single-frequency sine wave is not useful in data communications; we need to send a composite signal, a signal made of many simple sine waves.

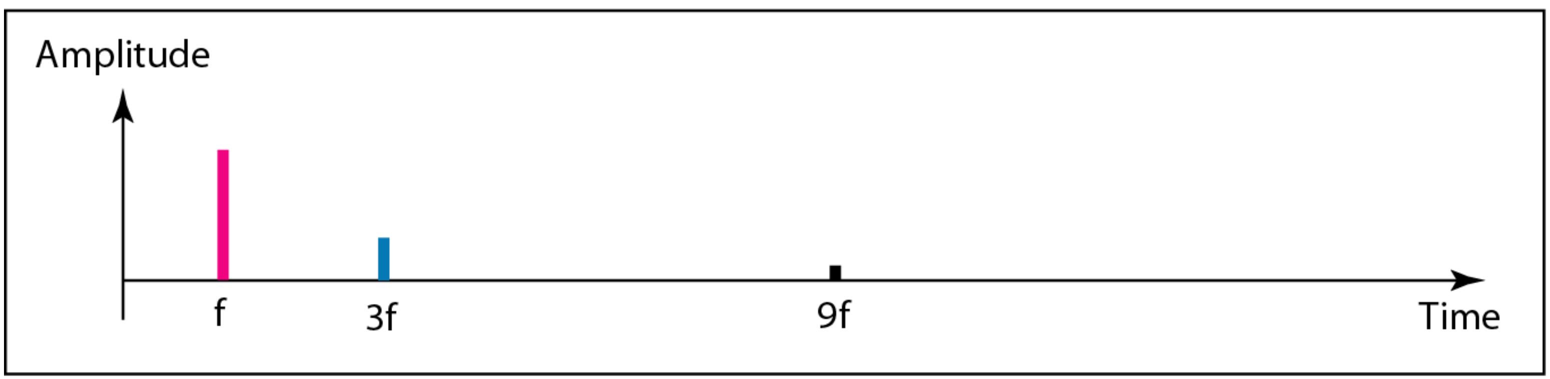
The figure shows a periodic composite signal with frequency ***f***. This type of signal is not typical of those found in data communications. We can consider it to be three alarm systems, each with a different frequency. The analysis of this signal can give us a good understanding of how to decompose signals.



Decomposition of a composite periodic signal in the time and frequency domains



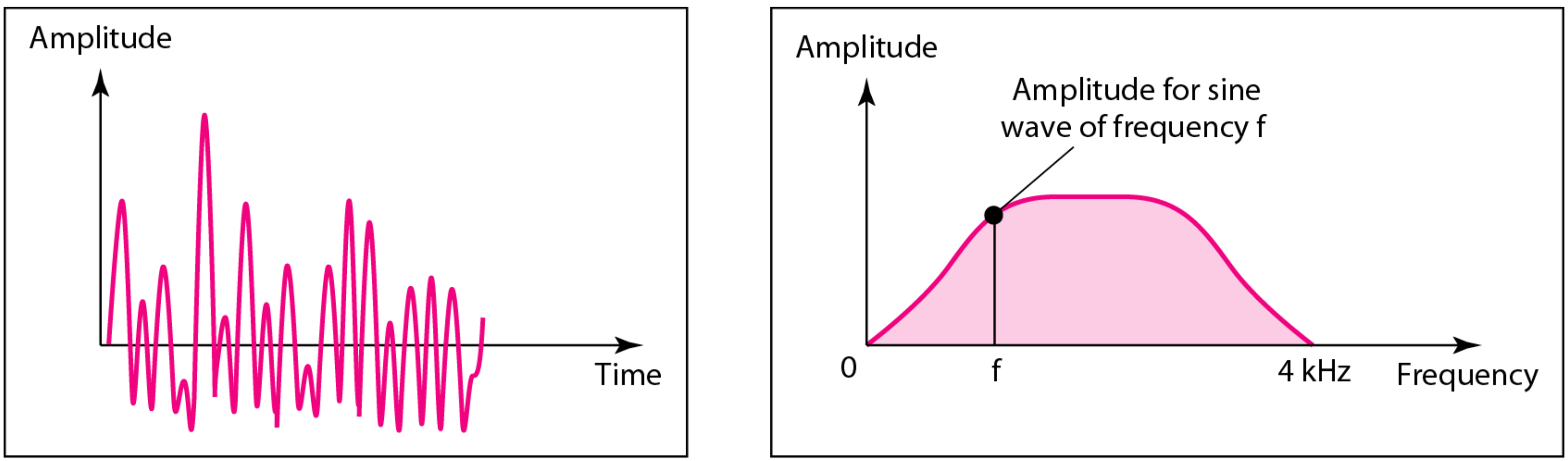
a. Time-domain decomposition of a composite signal



b. Frequency-domain decomposition of the composite signal

Example

Following figure shows a nonperiodic composite signal. It can be the signal created by a microphone or a telephone set when a word or two is pronounced. In this case, the composite signal cannot be periodic, because that implies that we are repeating the same word or words with exactly the same tone.

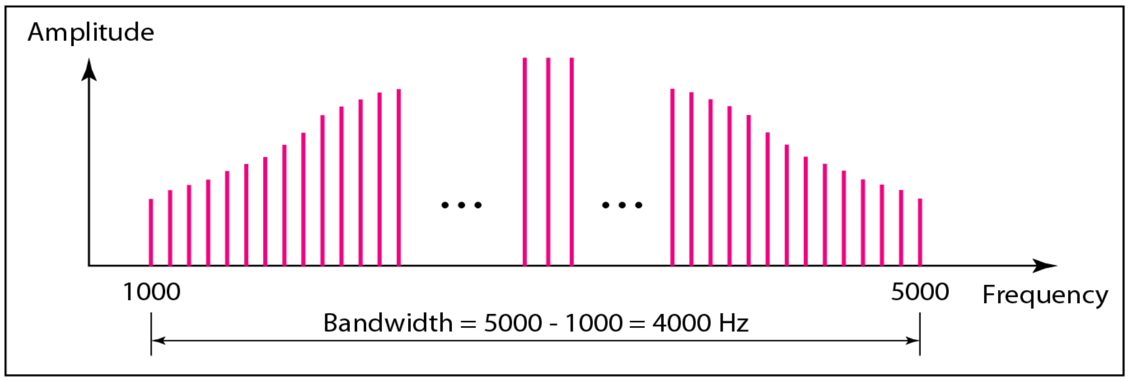


a. Time domain

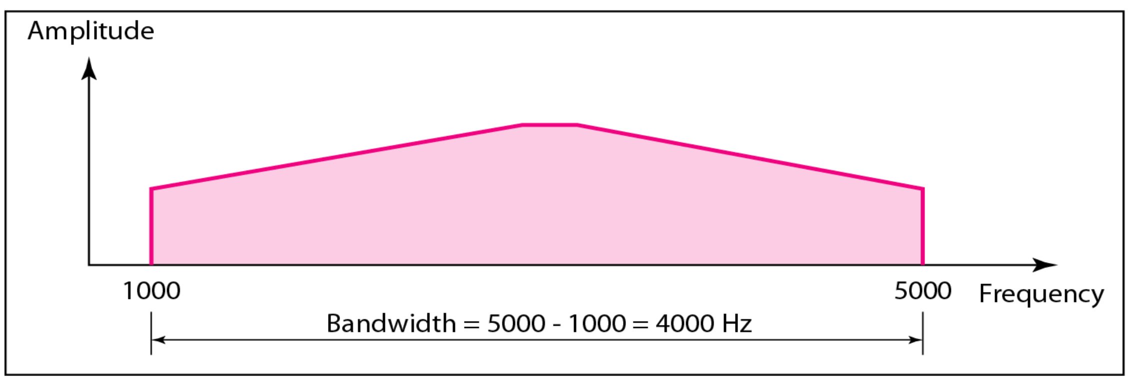
b. Frequency domain

Bandwidth

The bandwidth of a composite signal is the difference between the highest and the lowest frequencies contained in that signal.



a. Bandwidth of a periodic signal



b. Bandwidth of a nonperiodic signal

Example (1)

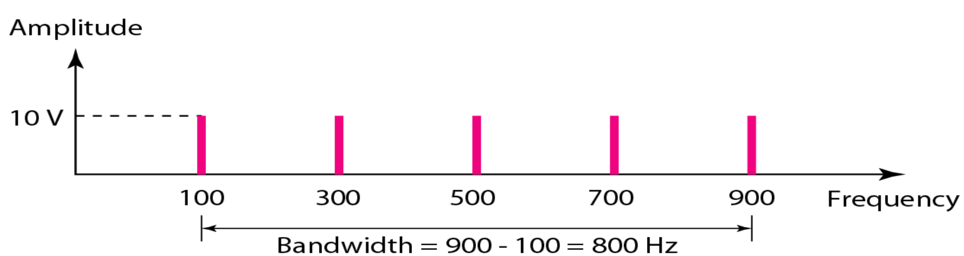
If a periodic signal is decomposed into five sine waves with frequencies of 100, 300, 500, 700, and 900 Hz, what is its bandwidth? Draw the spectrum, assuming all components have a maximum amplitude of 10 V.

Solution

Let f_h be the highest frequency, f_l the lowest frequency, and **B** the bandwidth. Then

$$B = f_h - f_l = 900 - 100 = 800 \text{ Hz}$$

The spectrum has only five spikes, at 100, 300, 500, 700, and 900 Hz



Example (2)

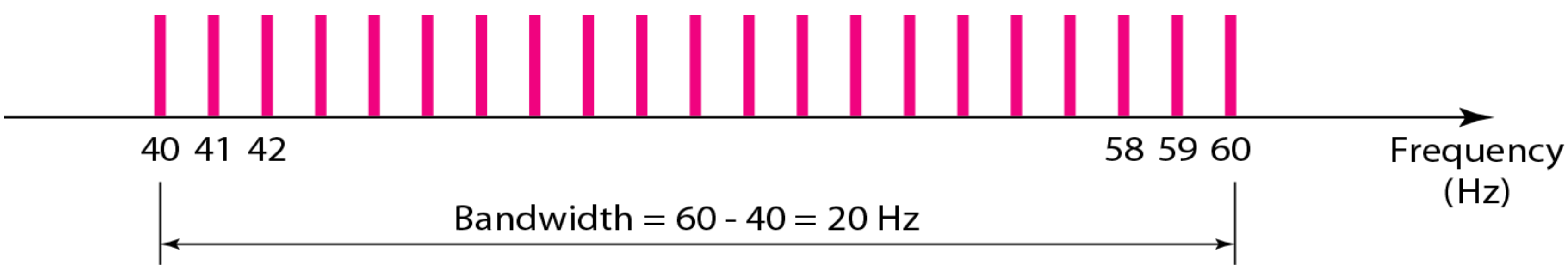
A periodic signal has a bandwidth of 20 Hz. The highest frequency is 60 Hz. What is the lowest frequency? Draw the spectrum if the signal contains all frequencies of the same amplitude.

Solution

Let f_h be the highest frequency, f_l the lowest frequency, and **B** the bandwidth. Then

$$B = f_h - f_l \quad \Rightarrow \quad 20 = 60 - f_l \quad \Rightarrow \quad f_l = 60 - 20 = 40 \text{ Hz}$$

The spectrum contains all integer frequencies. We show this by a series of spikes

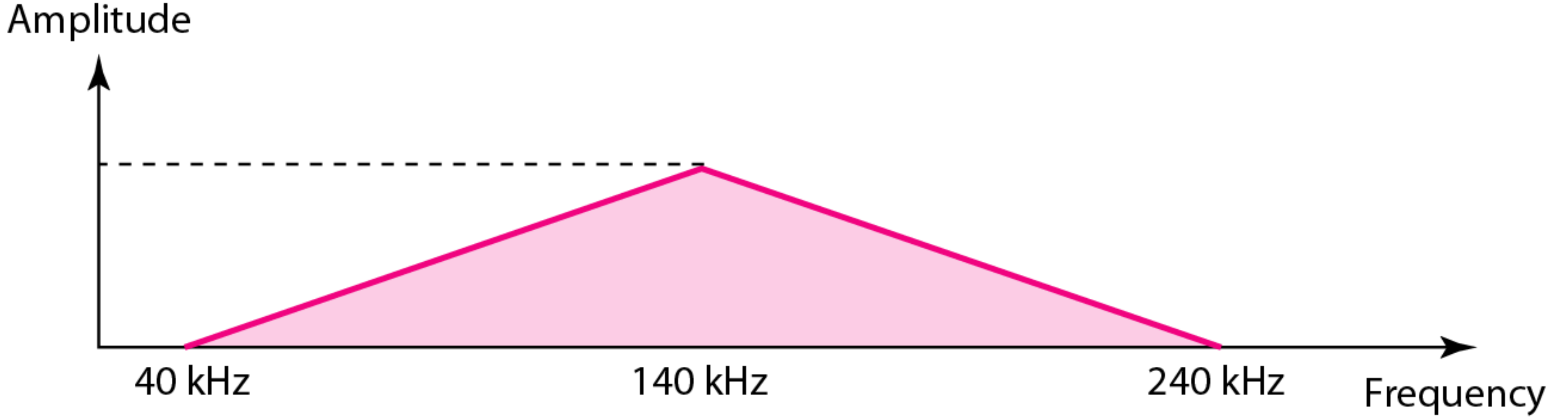


Example (3)

A nonperiodic composite signal has a bandwidth of 200 kHz, with a middle frequency of 140 kHz and peak amplitude of 20 V. The two extreme frequencies have an amplitude of 0. Draw the frequency domain of the signal.

Solution

The lowest frequency must be at 40 kHz and the highest at 240 kHz. Figure 3.15 shows the frequency domain and the bandwidth.



Digital Signal

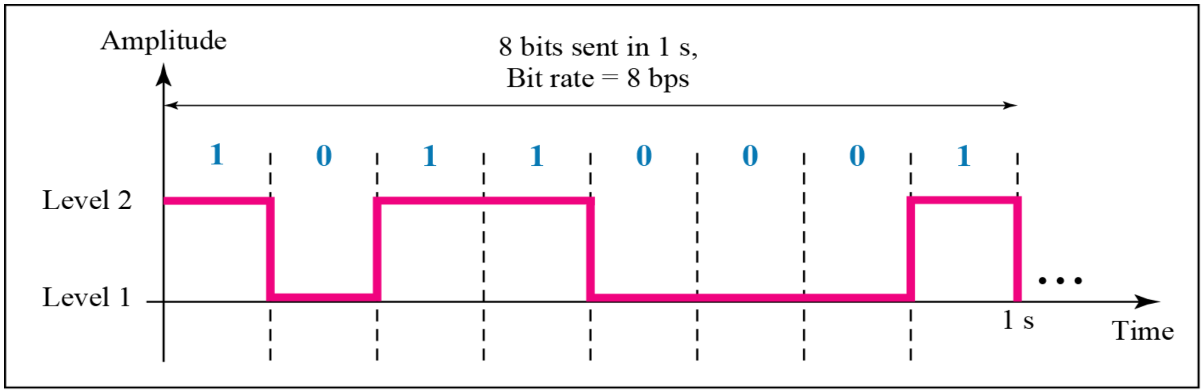
In addition to being represented by an analog signal, information can also be represented by a digital signal. For example, a 1 can be encoded as a positive voltage and a 0 as zero voltage. A digital signal can have more than two levels. In this case, we can send more than 1 bit for each level.

Topics discussed in this section:

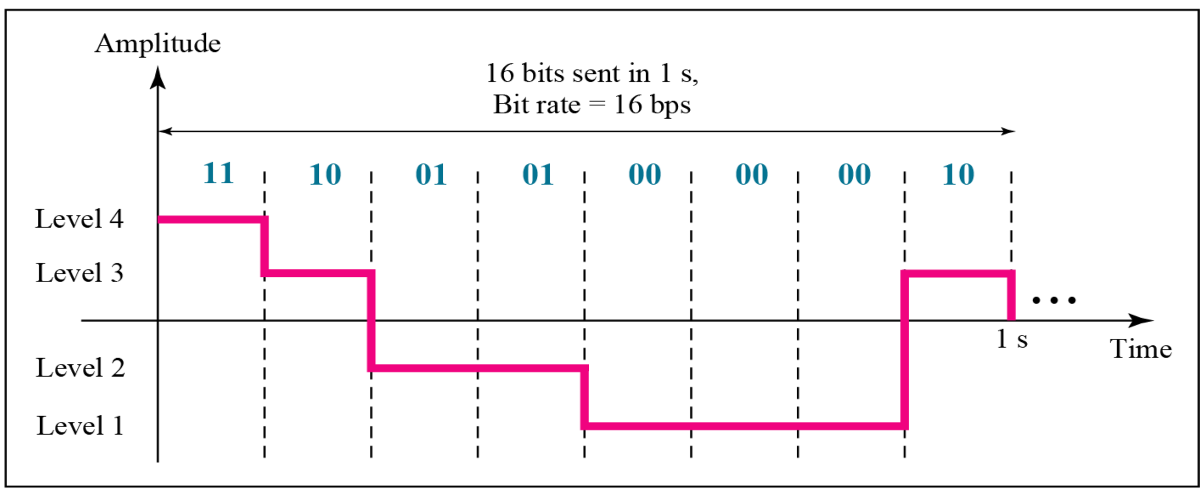
Bit Rate
Bit Length
Digital Signal as a Composite Analog Signal
Application Layer

Two Digital Signals

one with two signal levels and the other with four signal levels



a. A digital signal with two levels



b. A digital signal with four levels

Example (1)

A digital signal has eight levels. How many bits are needed per level?

Solution

We calculate the number of bits from the formula $\mathbf{log_2 n}$

$$\text{Number of bits per level} = \log_2 8 = 3$$

Each signal level is represented by 3 bits.

Example (2) Signal Level Vs Bits

A digital signal has nine levels. How many bits are needed per level?

Solution

We calculate the number of bits by using the formula $\log_2 n$, i.e. $\log_2 9=3.17$

So each signal level is represented by 3.17 bits. However, this answer is not realistic. The number of bits sent per level needs to be an integer as well as a power of 2. For this example, 4 bits can represent one level.

Bit rate and bit interval

- Most digital signals are aperiodic, so the period or frequency are not appropriate.
- Bit interval (instead of period) and bit rate (instead of frequency) are used to describe digital signals.
- **Bit interval** is the time required to send one single bit
- **Bit rate** is the number of bit intervals per second
  —Usually expressed as bits per second (bps)

Example (3) bit rate for text

Assume we need to download text documents at the rate of 100 pages per minute. What is the required bit rate of the channel?

Solution

A page is an average of 24 lines with 80 characters in each line. If we assume that one character requires 8 bits, the bit rate is

$$100 \times 24 \times 80 \times 8 = 1{,}636{,}000 \text{ bps} = 1.636 \text{ Mbps}$$

Example (4) bit rate for audio

A digitized voice channel, is made by digitizing a 4-kHz bandwidth analog voice signal. We need to sample the signal at twice the highest frequency (two samples per hertz). We assume that each sample requires 8 bits. What is the required bit rate?

Solution

The bit rate can be calculated as

$$2 \times 4000 \times 8 = 64,000 \text{ bps} = 64 \text{ kbps}$$

Example (4) bit rate for video

What is the bit rate for high-definition TV (HDTV)?

Solution

HDTV uses digital signals to broadcast high quality video signals. The HDTV screen is normally a ratio of 16 : 9. There are 1920 by 1080 pixels per screen, and the screen is renewed 30 times per second. Twenty-four bits represents one color pixel.

$$1920 \times 1080 \times 30 \times 24 = 1,492,992,000 \text{ or } 1.5 \text{ Gbps}$$

The TV stations reduce this rate to 20 to 40 Mbps through compression.


THANK
YOU