Data and Signal

by

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Outline of The Lecture

The Topics will be covered in this lecture:

- What is data?
- Distinguish between data and signal.
- Distinguish between Analog and digital signal.
- Explanation the difference between time and Frequency domain representation of signal.
- Specify the bandwidth of the signal.
- Explain the bit interval and bit rate of the Digital signal.

Data and Data Type

- ***What is Data?***

  Data is an entity that conveys some meaning based on some mutually agreed upon rule/convention between a sender and a receiver.

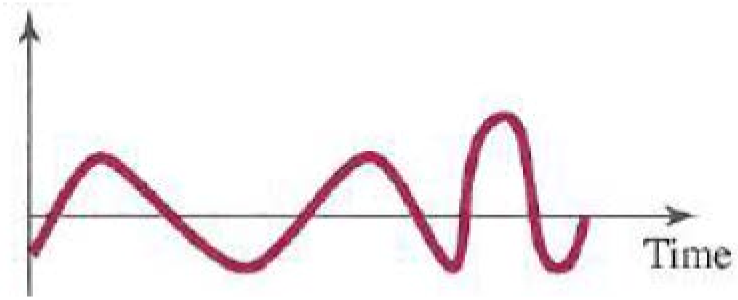
  Data Types

  Data can be analog and digital

Analog Data

- Analog data have continuous values over time.

- **Example:-** Voice and video.

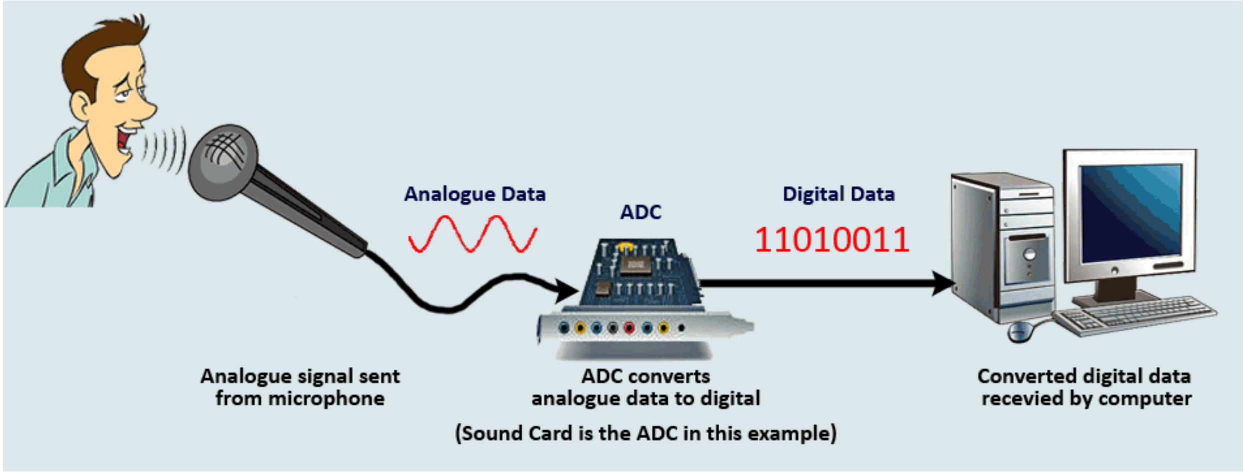


  - Sounds made by a human voice, take on continuous values. When someone speaks, an analog wave is created in the air.

- Physical Parameters: Data collected from all the real world with the help of transducer are continuous in nature.
  - Temperature, Pressure, Light Intensity

Digital Data

- Digital data can take on discrete values.



- **Example of Digital Data:-**
  - Text or character string.
  - Data stored in memory, say CD, have two discrete values, which can be represented by 0 and 1.
  - a digital clock that reports the hours and the minutes will change suddenly from 8:05 to 8:06.

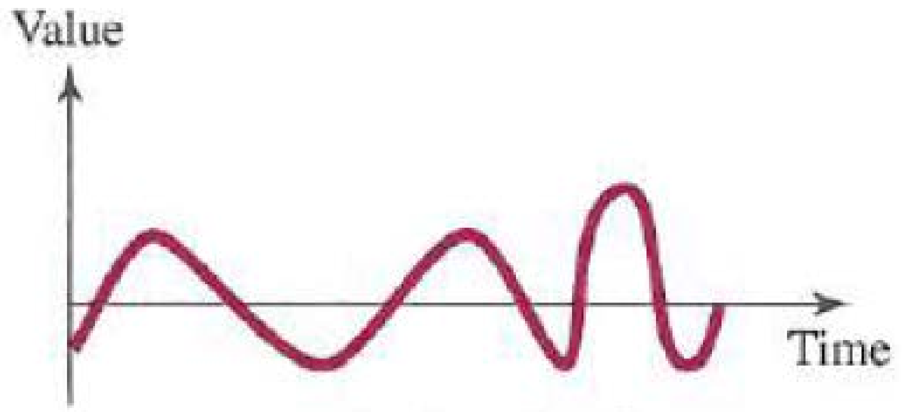
Signal and Signal Type

- **What is signal?**
  - It is electric, electronic or optical representation of data, which can be sent over communication media.

- **Signal Type:** Analog and Digital
  - An analog signal has infinitely many levels of intensity over a period of time.
  - A digital signal can have only a limited number of defined values.

Example of Analog Signal

- A microphone converts voice data into voice signal, which can be sent over a pair of wire.

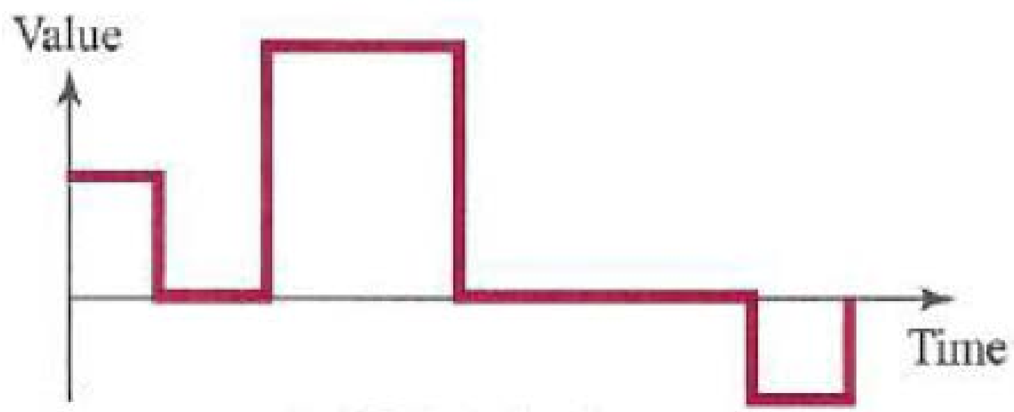


a. Analog signal

- The curve representing the analog signal passes through an infinite number of points.

Example of Digital Signal

- Digital signal can have only a limited no of defined values, usually two values 0 and 1.



b. Digital signal

- The vertical lines of the digital signal, however, demonstrate the sudden jump that the signal makes from value to value.

Types of Analog Signal

- Analog signal can be classified as:
  - simple
  - Composite

- Examples
  - simple analog signal: sine wave
  - composite analog signal: consists of a combination of multiple simple signals

Periodic Signal

- A signal is periodic if $s(t+T) = s(t)$, for $-\infty<t<\infty$, where T is the time period.

- A periodic signal can be characterized by the following three parameters- Amplitude, Frequency and Phase

$$s(t) = A \sin(2\Pi ft + \phi)$$

  - Amplitude (A): Value of signal at different instant of time, measured in volts.
  - Frequency (f): Frequency is the rate of change with respect to time. It is measured in Hertz.
  - Phase (ϕ): It gives a measure of relative position of two signals in time, expressed in degree or radian.

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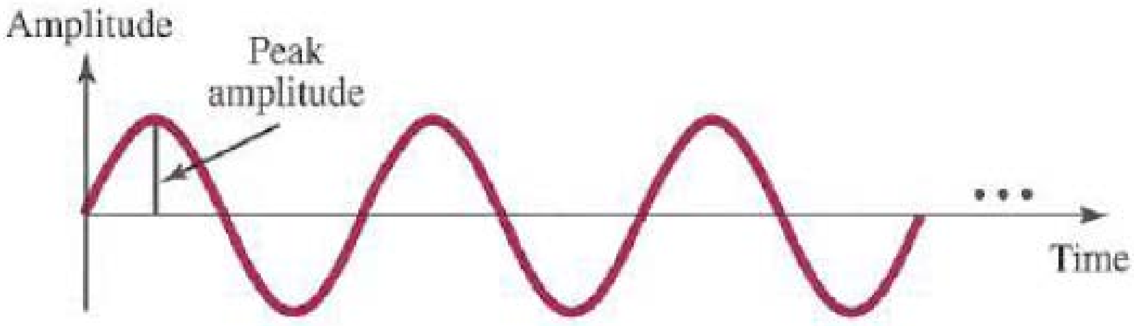
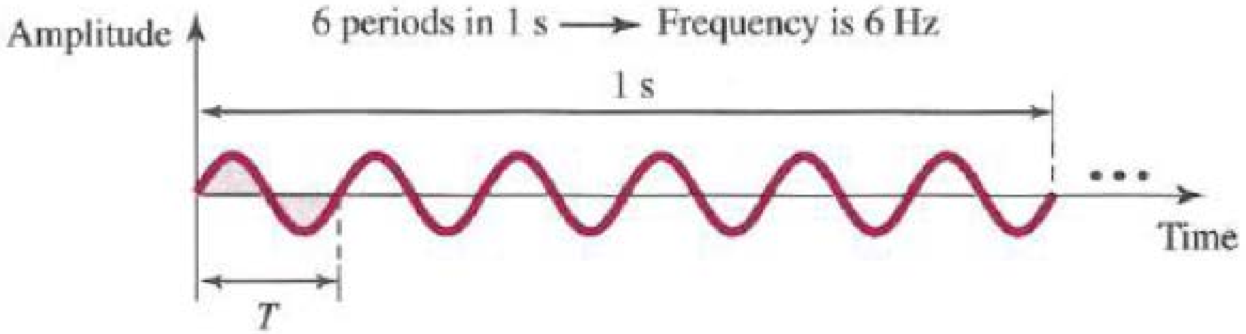
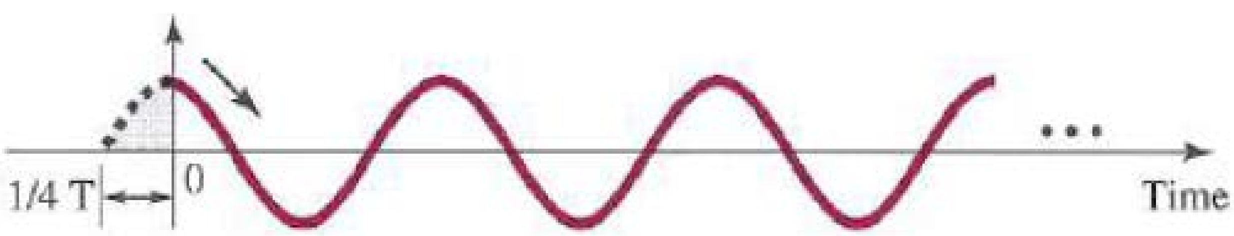


Amplitude



Frequency



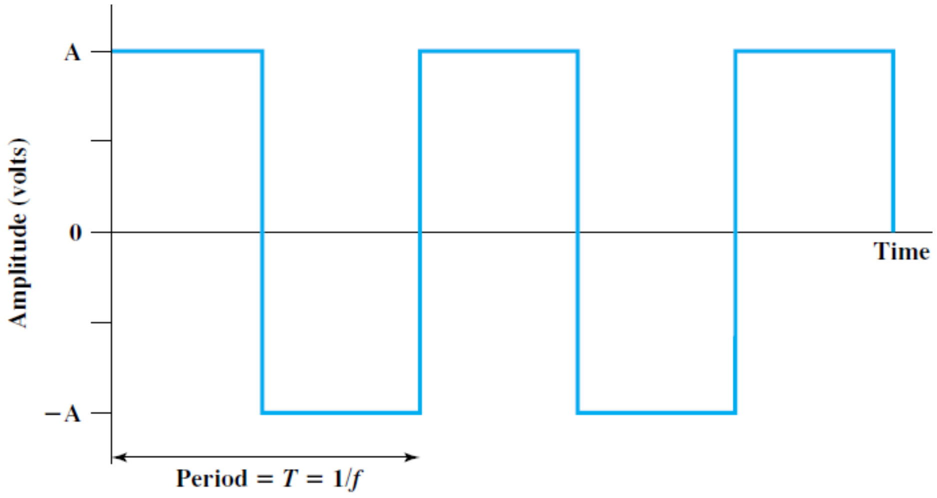
b. 90 degrees

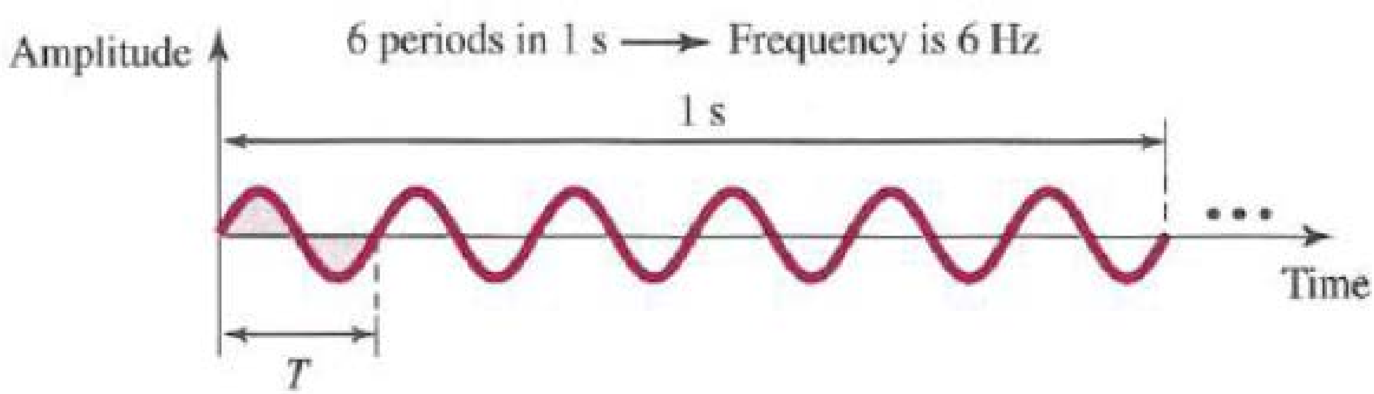
Phase

Cont…

- Period (T) refers to the amount of time, in seconds, a signal needs to complete 1 cycle.
- Frequency (f) refers to the number of periods in 1 sec.

f = 1/T





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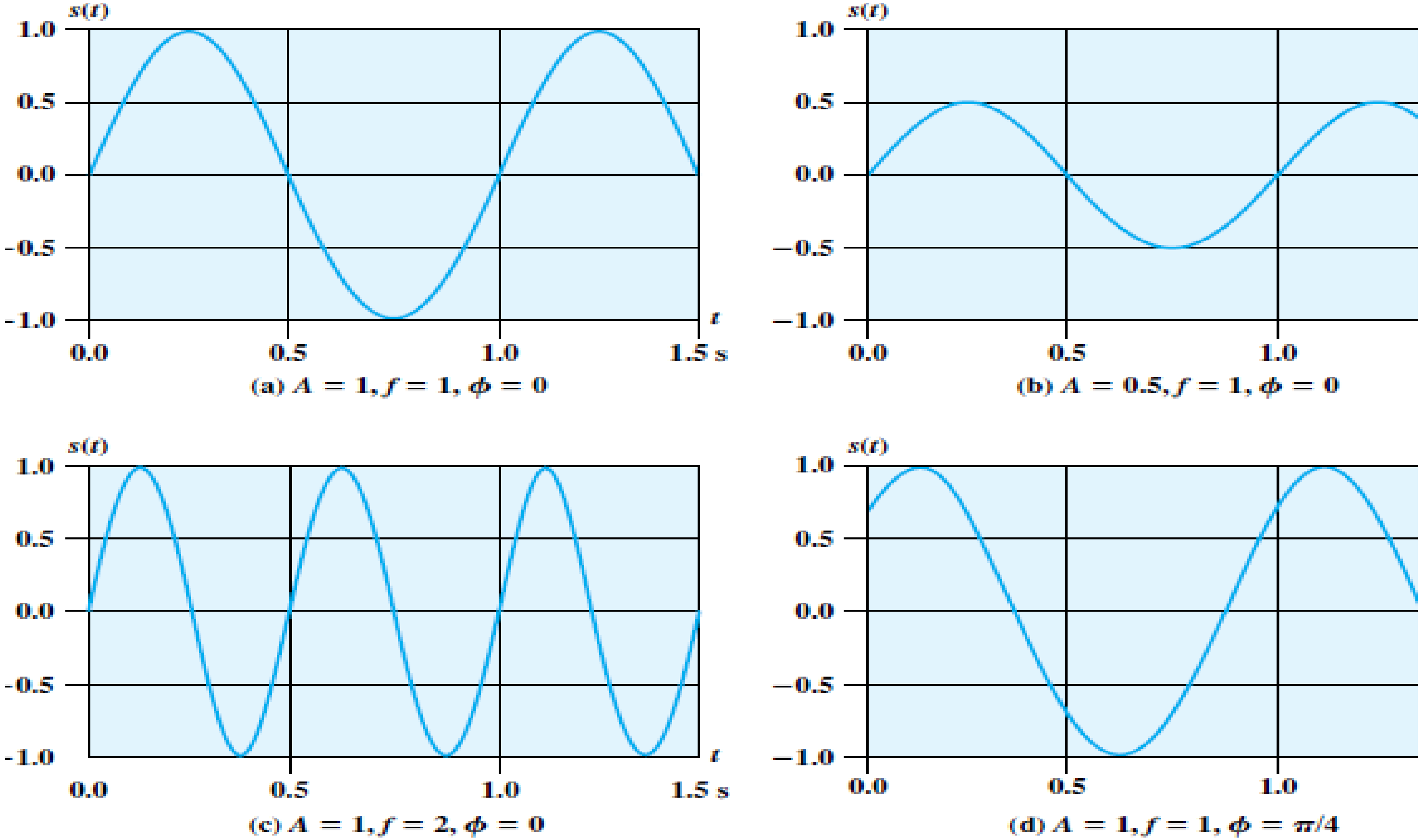
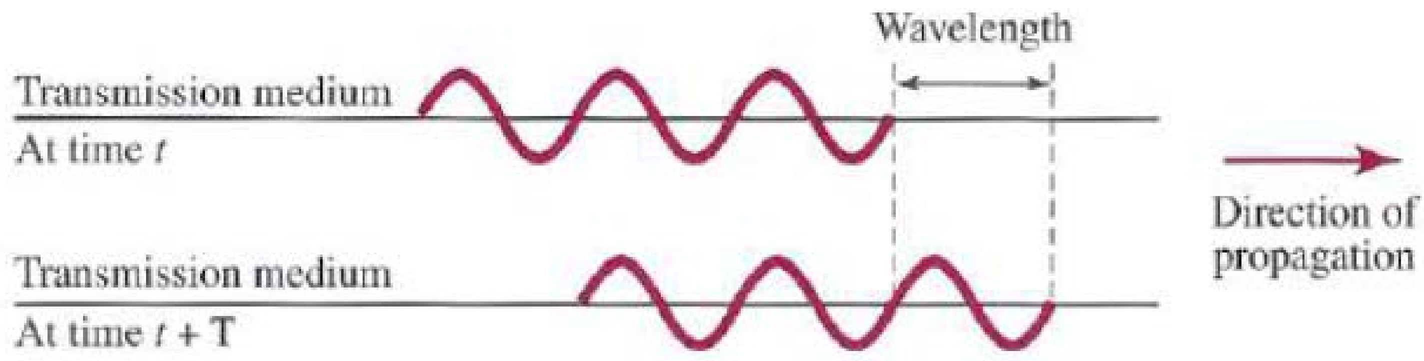


'igure 3.3 $s(t) = A\sin(2\pi ft + \phi)$

Cont…

- The wavelength (λ) of a signal is the distance occupied by a single cycle, or,
- the distance between two points of corresponding phase of two consecutive cycles.



- the frequency of a signal is independent of the medium, the wavelength depends on both the frequency and the medium.

- Assume that the signal is traveling with a velocity *v*. Then the wavelength is related to the period as follows:

  Wavelength = (propagation speed) x period

  => $\lambda = v.T = v/f$

Time and Frequency Domain

- According to Fourier analysis, any composite signal can be expressed as a combination of simple sine wave with different amplitudes, frequencies and phase.
- An electromagnetic signal is commonly a composite signal made up of many frequencies.

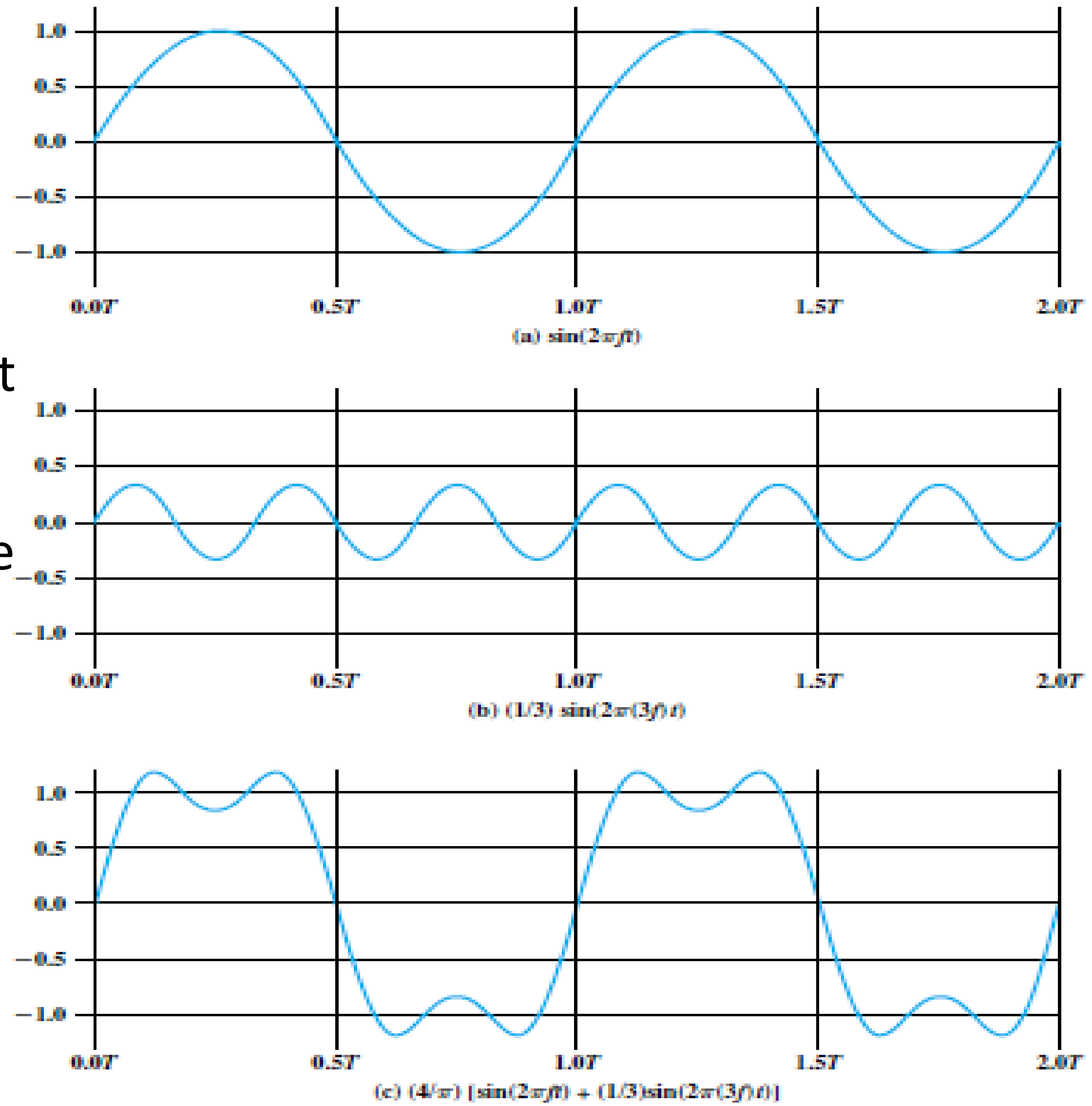
$$s(t) = A_1\sin(2\Pi f_1+\phi_1) + A_2\sin(2\Pi f_2+\phi_2) + \ldots\ldots$$

Time Domain

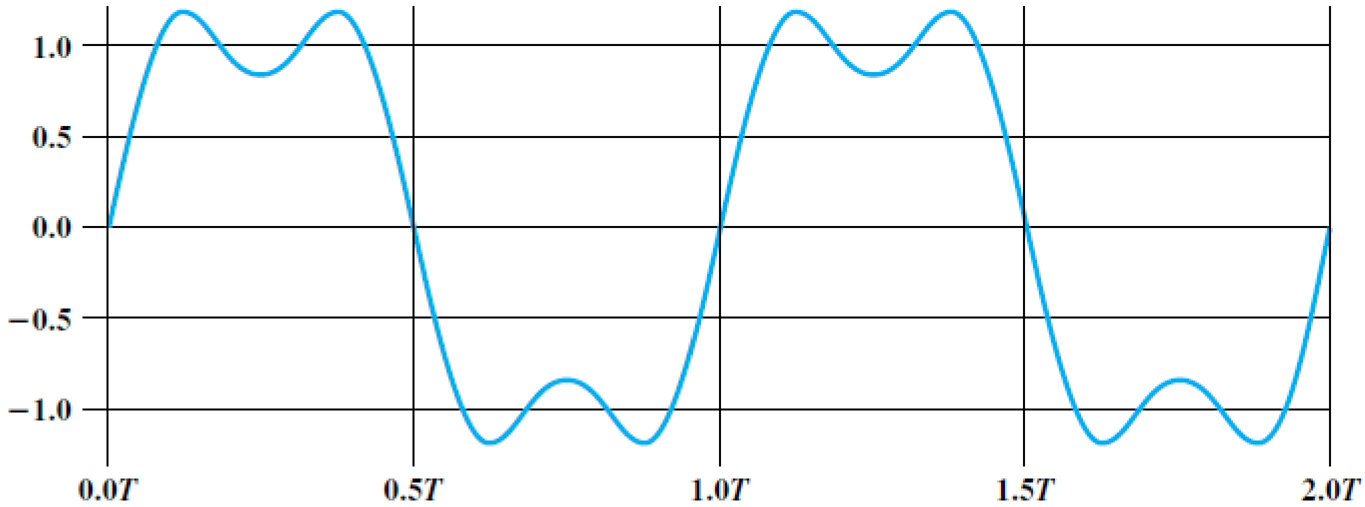
Example:

s(t)= sin(2Πft) +
(1/3) sin(2Π(3f)t)

- The second frequency is an integer multiple of the first frequency.
- When all of the frequency components of a signal are integer multiples of one frequency, the latter frequency is referred to as the fundamental frequency.
- The period of the total signal is equal to the period of the fundamental frequency.



Frequency Spectrum

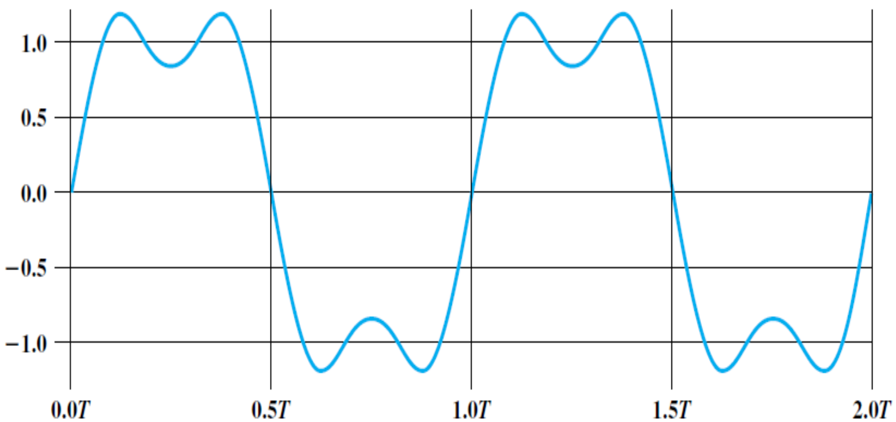


(c) $(4/\pi)\ [\sin(2\pi ft) + (1/3)\sin(2\pi(3f)t)]$

- Frequency spectrum of a signal is the range of frequencies a signal contains.
  - e.g., f to 3f in the above figure
- The absolute bandwidth of a signal is the width of the spectrum.
  - e.g., bandwidth is 2f in the above figure

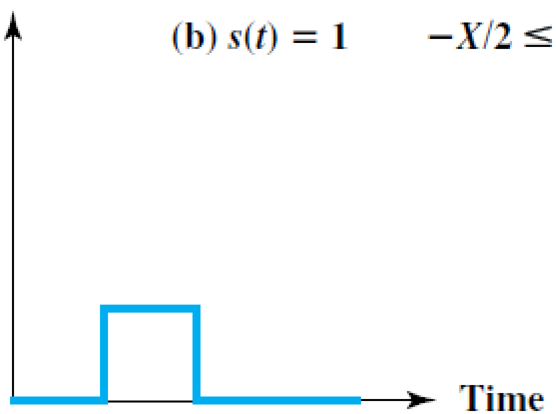
Time to Frequency Conversion

Time Domain

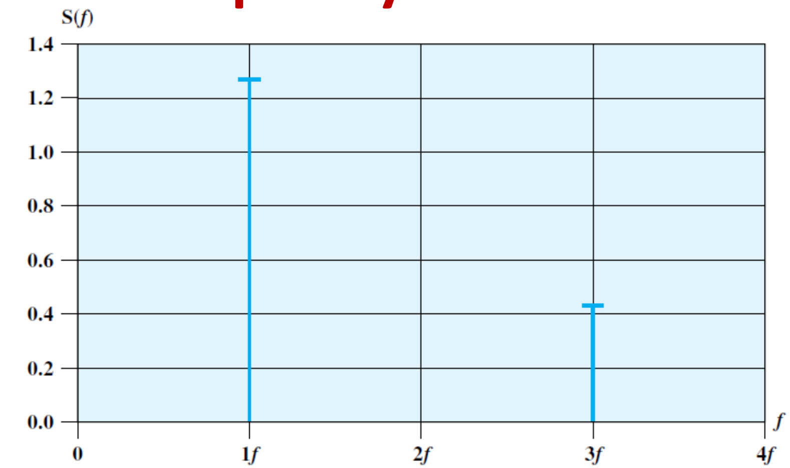


(a) $s(t) = (4/\pi)[\sin(2\pi ft) + (1/3)\sin(2\pi(3f)t)]$

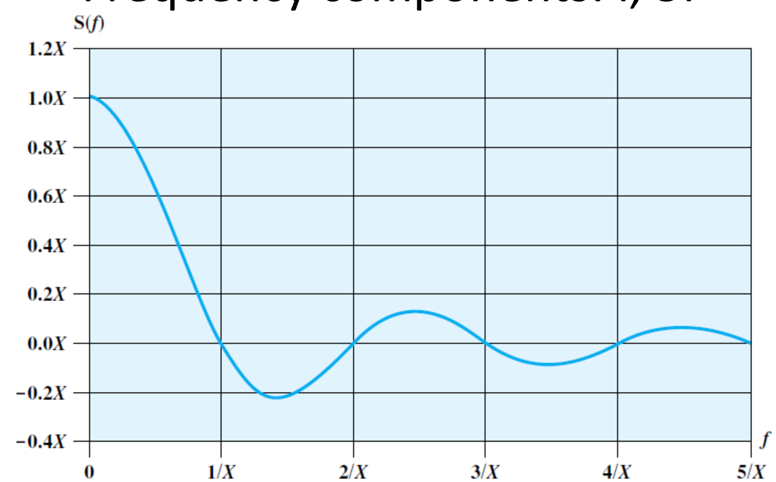
(b) $s(t) = 1 \quad -X/2 \leq t \leq X/2$



Frequency Domain



Frequency components: f, 3f



Frequency components: many !

Cont…

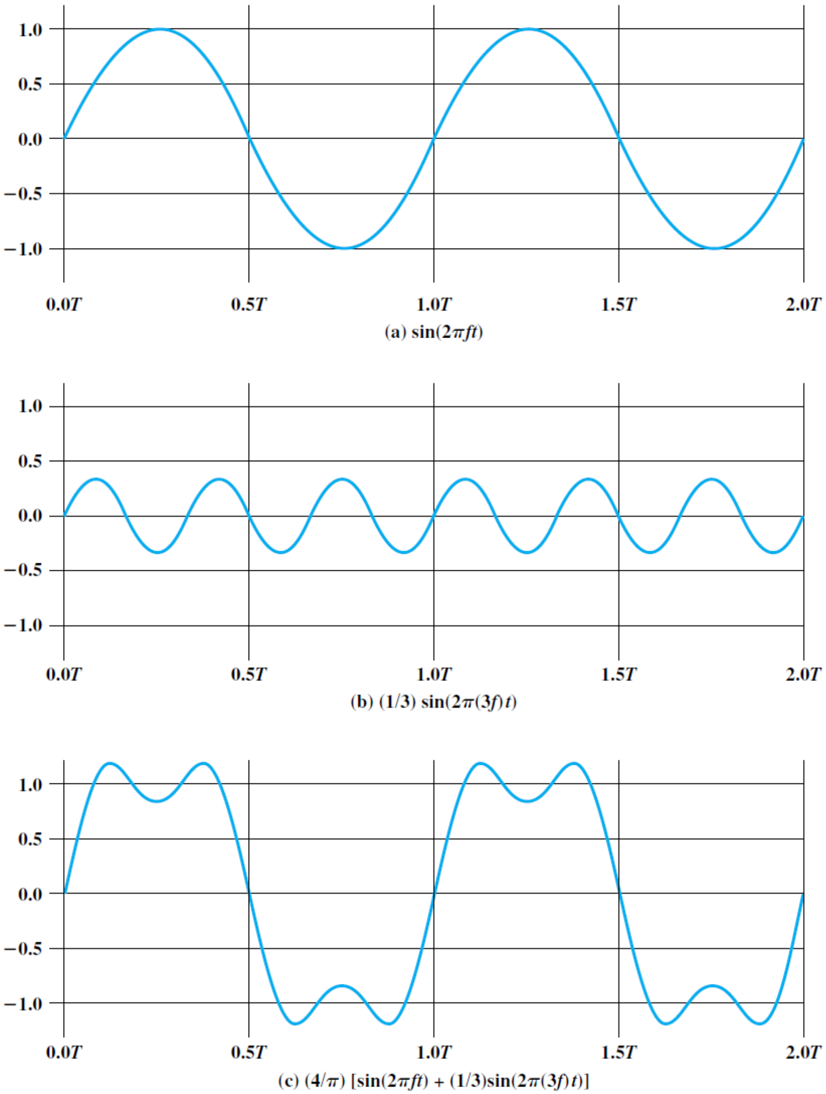


Figure 3.4 Addition of Frequency Components ($T = 1/f$)

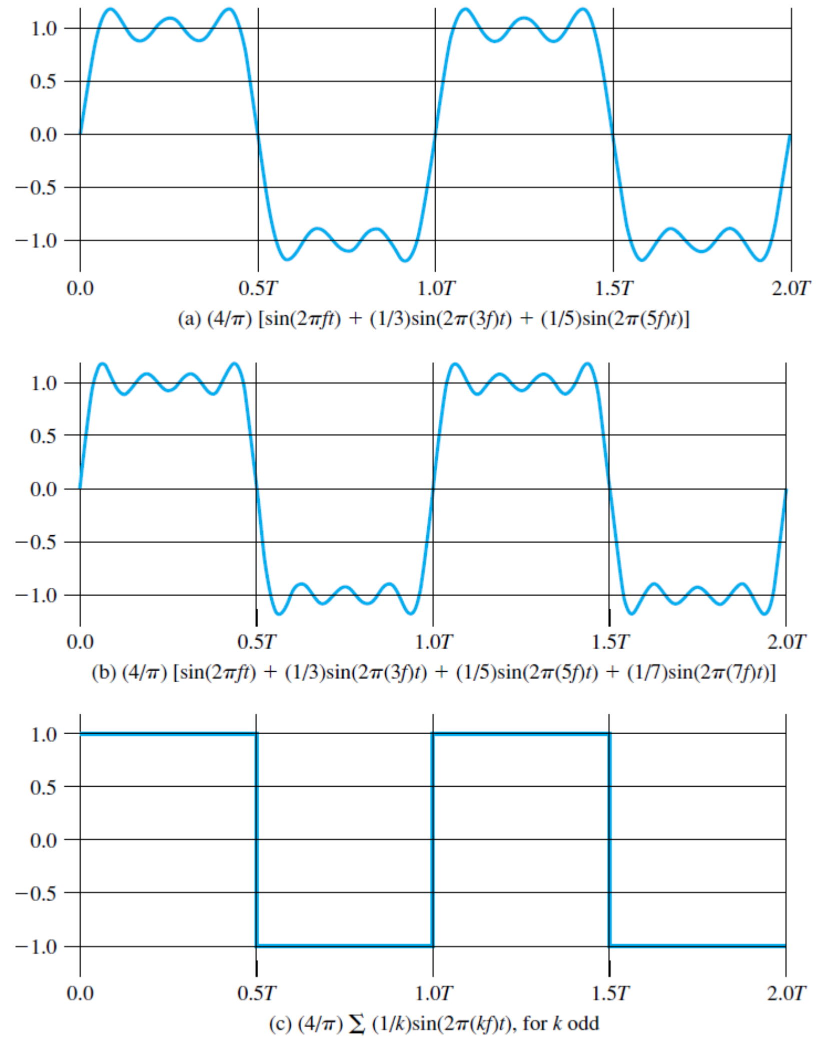
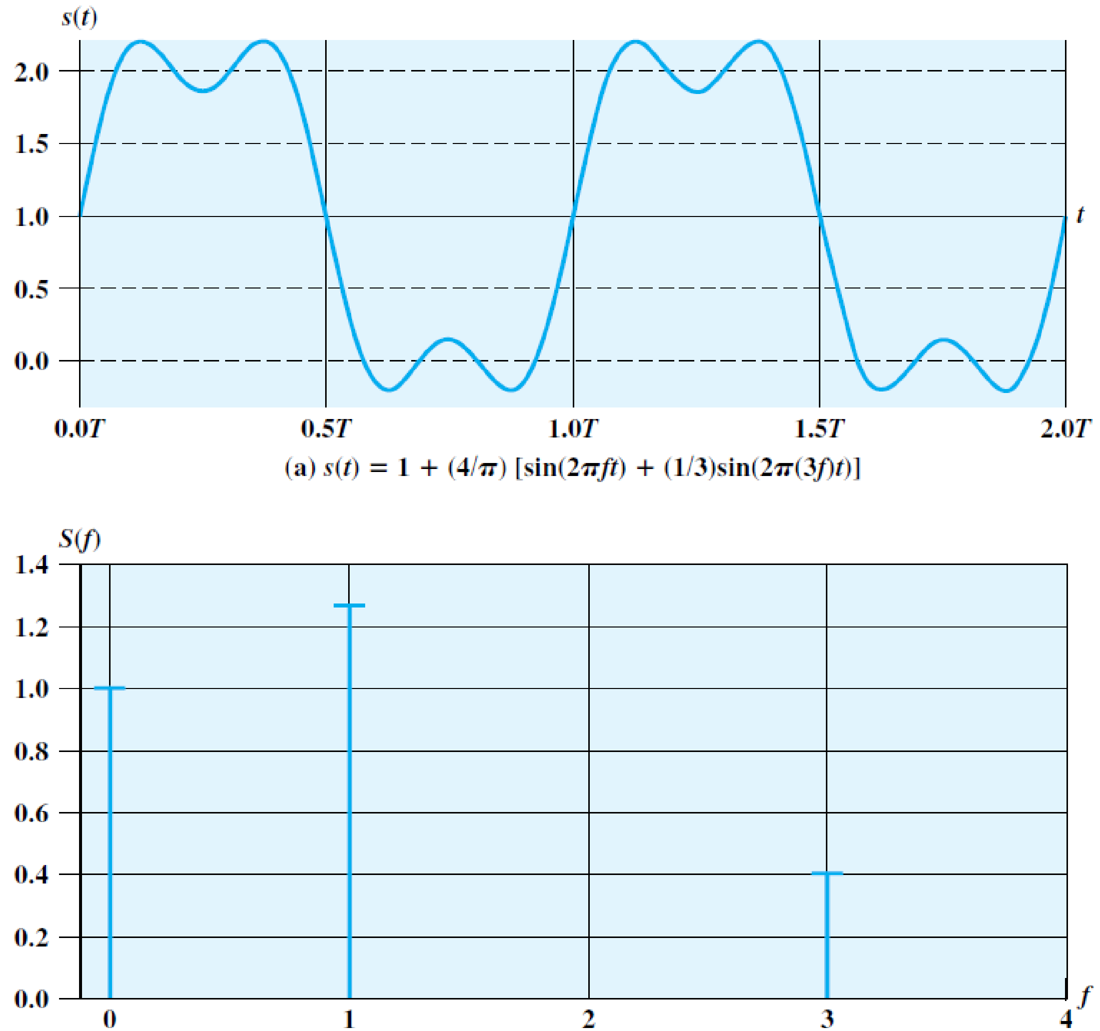


Figure 3.7 Frequency Components of Square Wave ($T = 1/f$)

DC Component

- If a signal includes a component of zero frequency, that component is a direct current (dc) or constant component.
- With no dc component, a signal has an average amplitude of zero, as seen in the time domain.
- With a dc component, it has a frequency term at f=0 and a nonzero average amplitude.

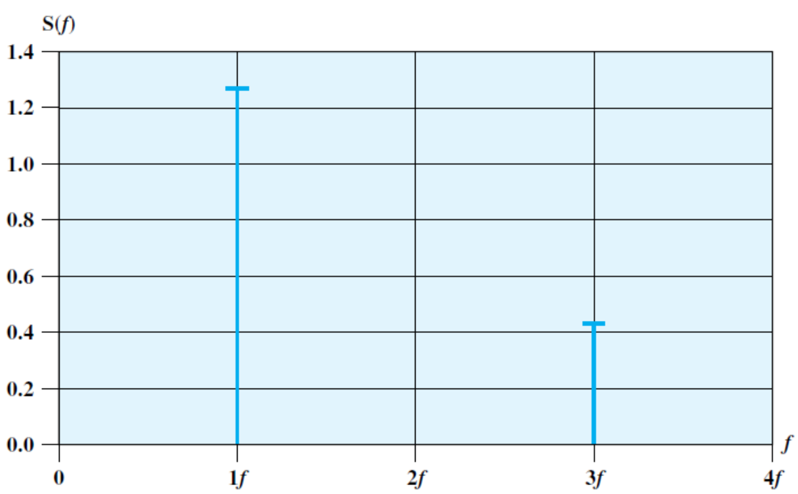


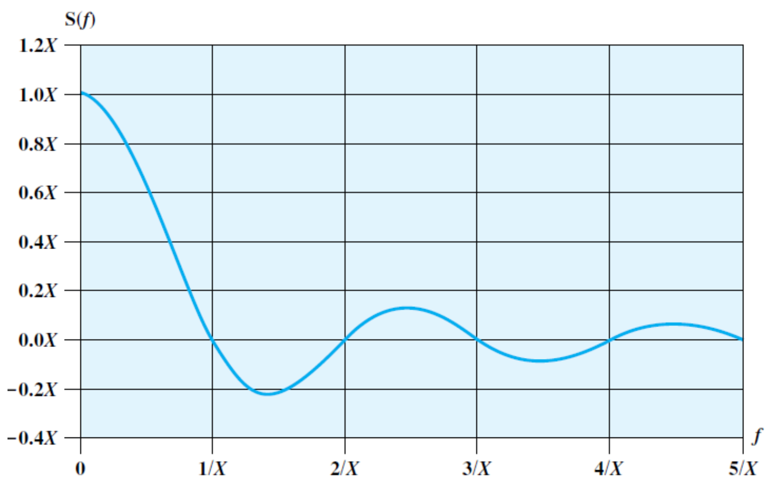
(a) $s(t) = 1 + (4/\pi)\,[\sin(2\pi ft) + (1/3)\sin(2\pi(3f)t)]$

(b) $S(f)$

Bandwidth

- Range of frequencies over which most of the signal energy of signal is contained is known as bandwidth or effective bandwidth of the signal.

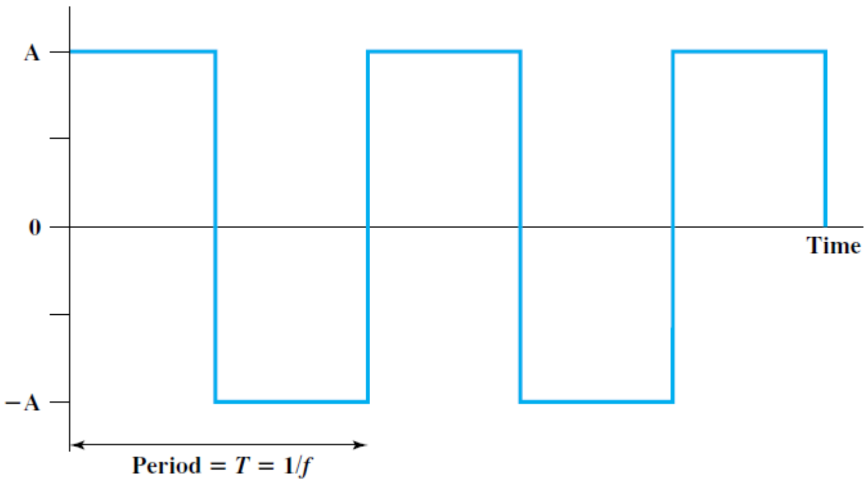




Absolute Bandwidth: 2f
Effective Bandwidth: ≤ 2f

Absolute Bandwidth: ∞
Effective Bandwidth: << ∞

Data Rate



- let a positive pulse represent binary 0 and a negative pulse represent binary 1.
- Then, the waveform represents the binary stream 01010 . . .
- The duration of each pulse is $1/(2f)$; thus the data rate is $2f$ bits per second (bps).

- In general, any digital waveform will have infinite bandwidth.

- If we attempt to transmit this waveform as a signal over any medium, the transmission system will limit the bandwidth that can be transmitted.

Example

- Let us attempt to transmit a sequence of alternating 1s and 0s as the square wave.

  What data rate can be achieved?

- Case 1: Let our square wave with the waveform of Figure 3.7a (Slide no. 19).

Let $f = 10^6$ cycles/sec = 1 MHz,
So, bandwidth of the signal = (5-1)x f = 4 MHz, and
period of the fundamental frequency is $T = 1/f = 1$ µs.

If we treat this waveform as a bit string of 1s and 0s, one bit occurs every 0.5 µs, for a data rate of 2 bits/ µs = 2 Mbps.

Thus, for a bandwidth of 4 MHz, a data rate of 2 Mbps is achieved.

Cont…

- Case 2:

Let us look again at Figure 3.7a, but now with f = 2 MHz.

So, bandwidth of the signal = $(5 - 1) \times 2 \times 10^6$ = 8 MHz,
period of the fundamental frequency is $T = 1/f$ = 0.5 μs.

So, one bit occurs every 0.25 μs, for a data rate of 4 bits/μs = 4 Mbps

Thus, other things being equal, by doubling the bandwidth, we double the potential data rate.

Cont…

- **Case 3**:

Now suppose that the waveform of Figure 3.4c (slide no. 19) is considered adequate for approximating a square wave.

Now suppose f = 2 MHz and so, $T = 1/f$ = 0.5 μs.
One bit occurs every 0.25 μs, for a data rate of 4 Mbps.

So, the bandwidth of the signal is $(3 - 1) \times 2 \times 10^6$ = 4 MHz

Conclusion:

- A given bandwidth can support various data rates depending on the ability of the receiver to discern the difference between 0 and 1 in the presence of noise and other impairments.
- In general, any digital waveform will have infinite bandwidth. If we attempt to transmit this waveform as a signal over any medium, the transmission system will limit the bandwidth that can be transmitted.
- The more limited the bandwidth, the greater the distortion, and the greater the potential for error by the receiver.

Effect of Bandwidth on Digital Signal

- Thus, there is a direct relationship between data rate and bandwidth.
- The higher the data rate of a signal, the greater is its required effective bandwidth.
- Looked at the other way, the greater the bandwidth of a transmission system, the higher is the data rate that can be transmitted over that system.
- The higher the center frequency, the higher the potential bandwidth and therefore the higher the potential data rate.

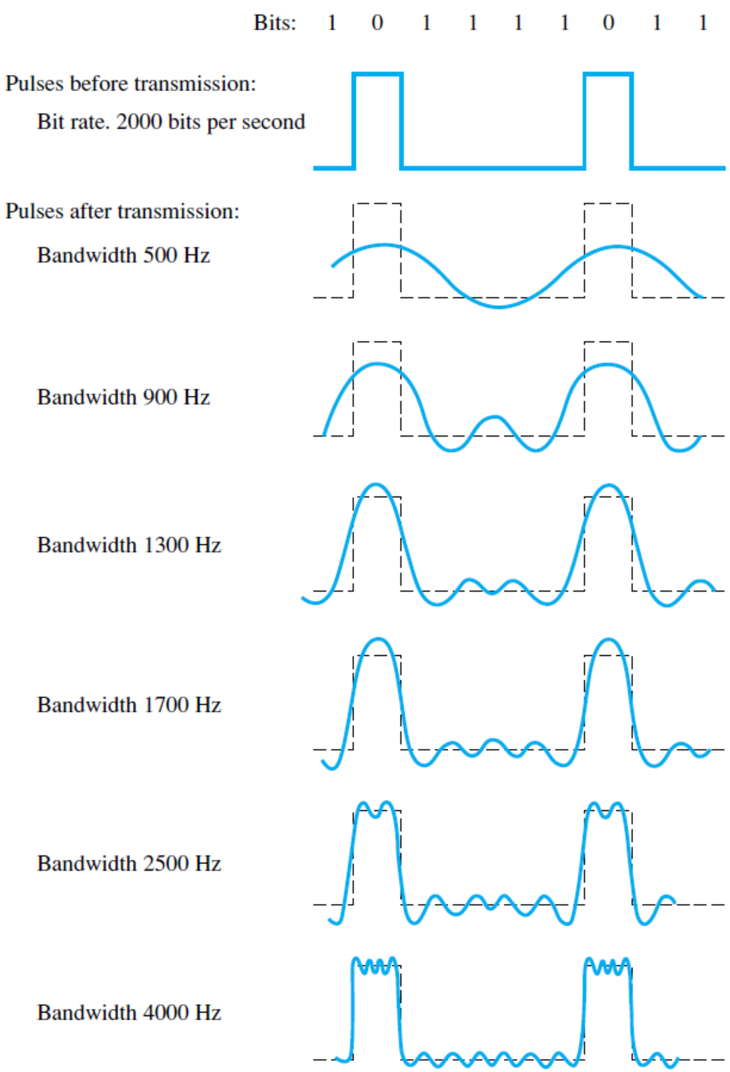


Figure 3.8 Effect of Bandwidth on a Digital Signal

Thanks!

Figure and slide materials are taken from the following sources:

1. W. Stallings, (2010), Data and Computer Communications
2. NPTL lecture on Data Communication, by Prof. A. K. Pal, IIT Kharagpur
3. B. A. Forouzan, (2013), Data Communication and Networking