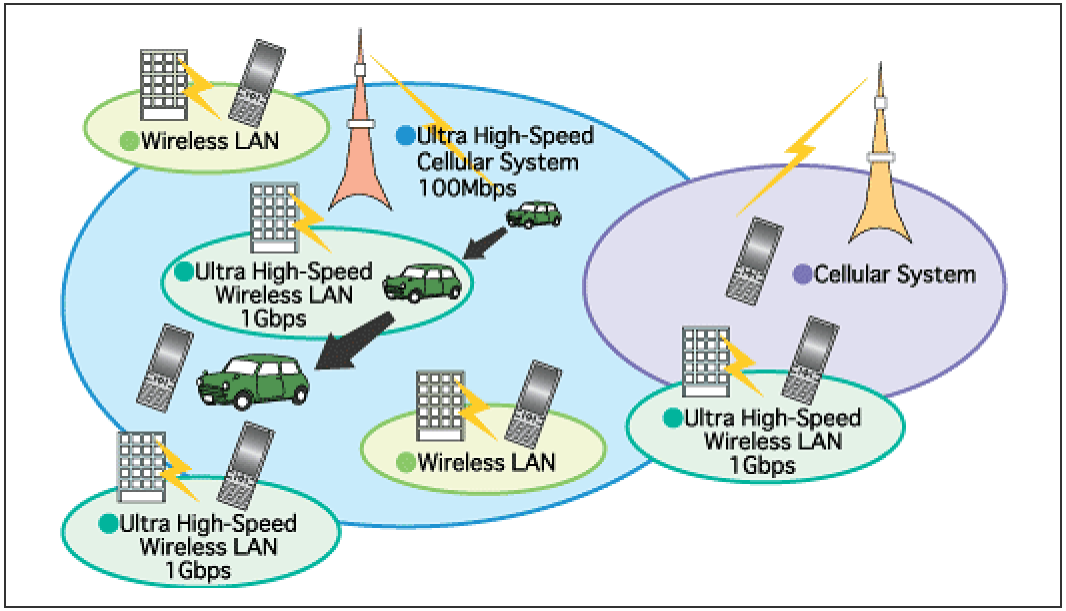
Communications Systems



Modulation, coding, compression and encryption techniques

1 ***Analogue modulation***: time domain (waveforms), frequency domain (spectra), amplitude modulation (am), frequency modulation (fm), phase modulation (pm)

2 ***Digital modulation***: waveforms and spectra, Frequency Shift Keying (FSK), Binary Phase Shift Keying (BPSK) [including Gaussian Minimum Shift Keying (GMSK)], Quadrature Phase Shift Keying (QPSK) [including π/4QPSK]

3 ***Error coding*****:** General principles of block, convolutional, parity, interleaving

4 ***Compression*****:** Regular Pulse Excitation – Linear Predictive Coding – Long Term Prediction (RPE-LPC-LTP)

Overview

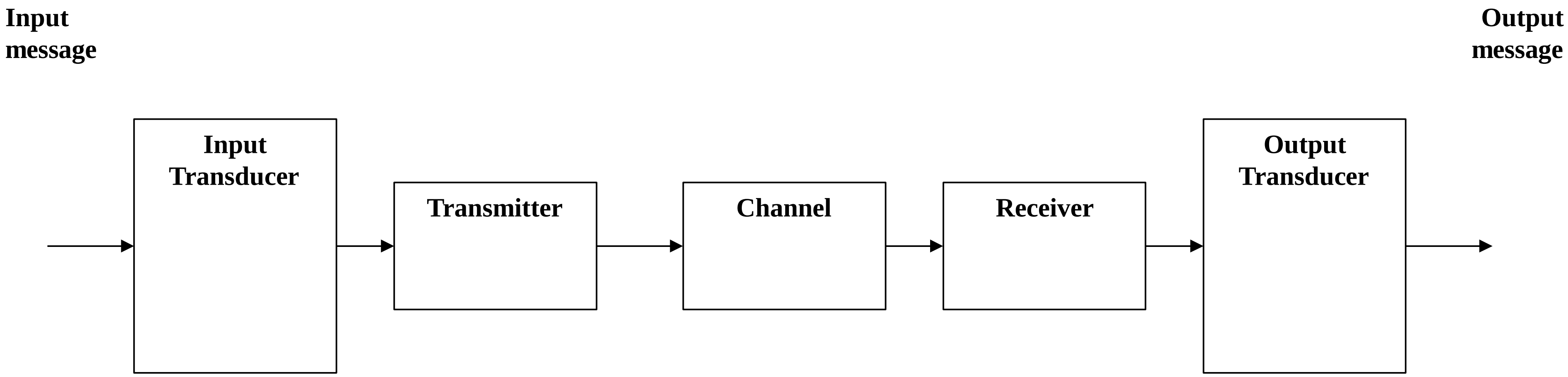
Communication is the transfer of information from one place to another.

This should be done

- *as* ***efficiently*** *as possible*
- *with as much* ***fidelity/reliability*** *as possible*
- *as* ***securely*** *as possible*

Communication System: Components/subsystems act together to accomplish information transfer/exchange.

Elements of a Communication System



Input Transducer: The message produced by a source must be converted by a transducer to a form suitable for the particular type of communication system.

Example: In electrical communications, speech waves are ***converted*** *by a microphone to voltage variation.*

Transmitter: The transmitter processes the input signal to produce a signal suits to the characteristics of the transmission channel.

Signal ***processing*** *for transmission almost always involves* ***modulation*** *and may also include* ***coding****. In addition to modulation, other functions performed by the transmitter are* ***amplification****,* ***filtering*** *and coupling the modulated signal to the channel.*

Channel: The channel can have different forms: The atmosphere (or free space), coaxial cable, fiber optic, waveguide, etc.

The signal undergoes some amount of degradation from noise, interference and distortion

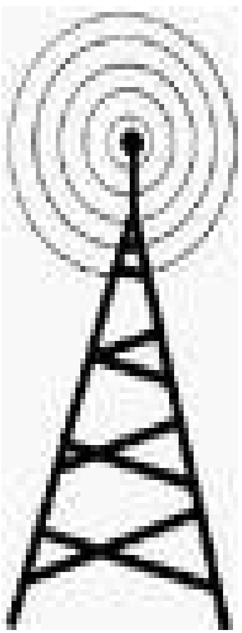
Receiver: The receiver's function is to extract the desired signal from the received signal at the channel output and to convert it to a form suitable for the output transducer.

Other functions performed by the receiver: amplification (the received signal may be extremely weak), demodulation and filtering.

Output Transducer: Converts the electric signal at its input into the form desired by the system user.

Example: Loudspeaker, personal computer (PC), tape recorders.

To be transmitted, Information (Data) must be transformed to electromagnetic signals.



Electromagnetic Waves

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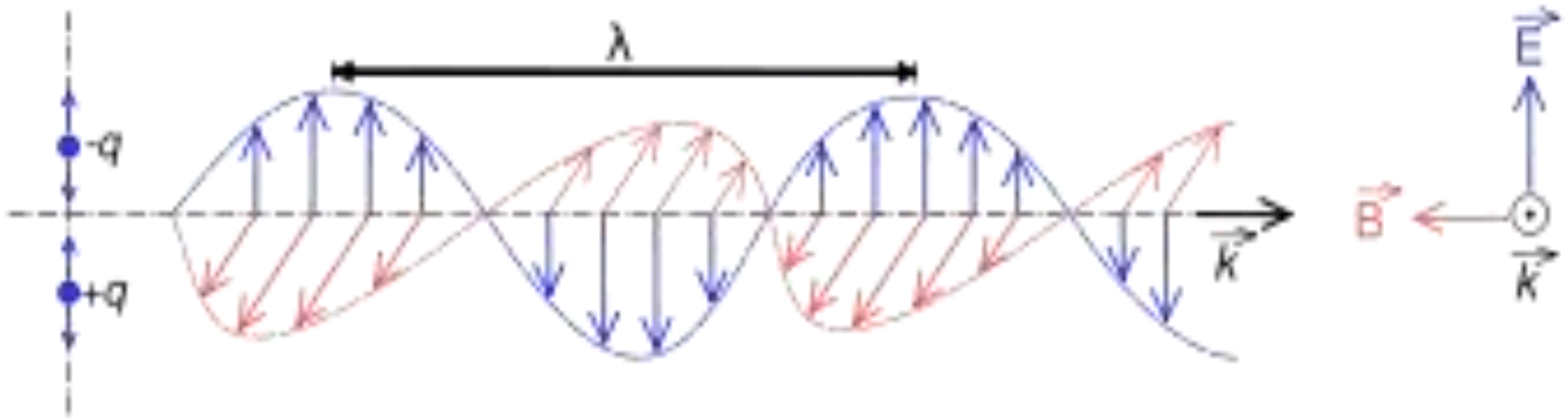
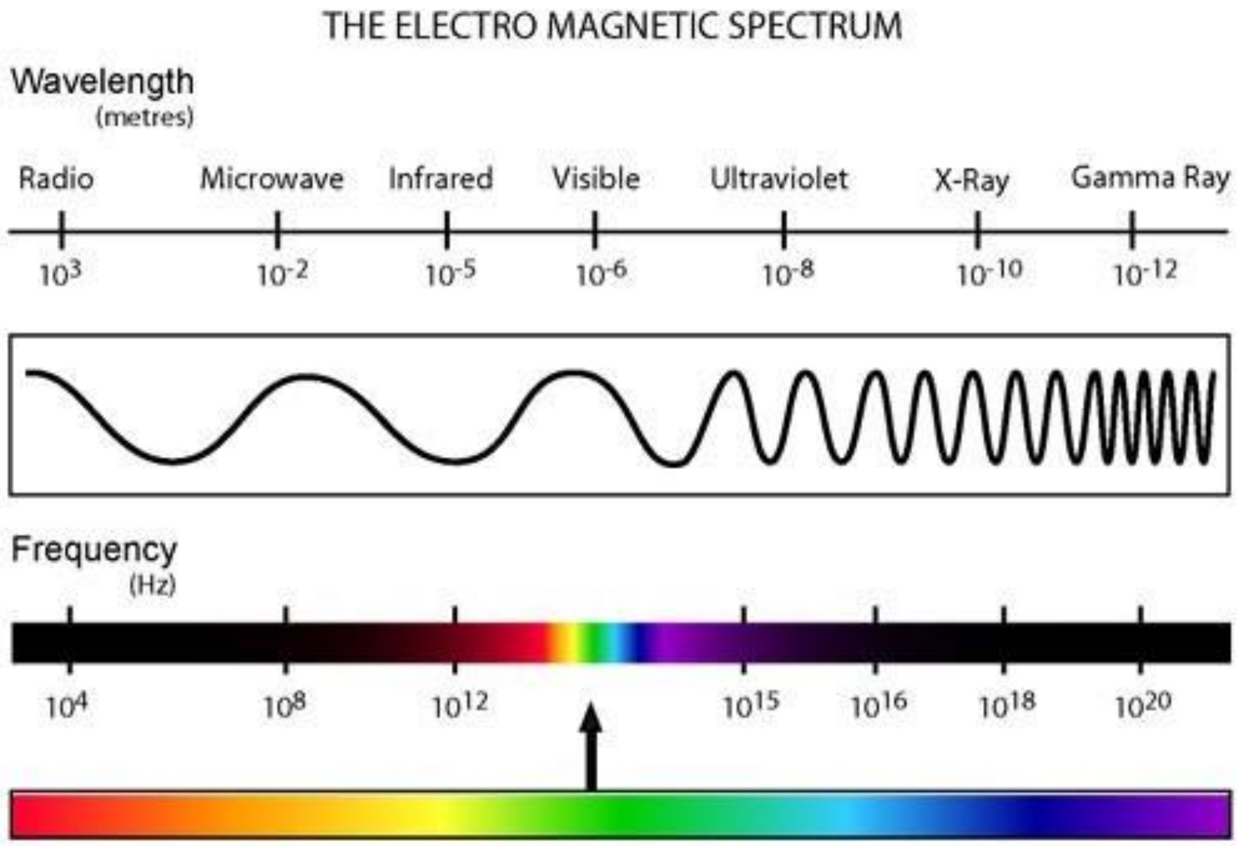
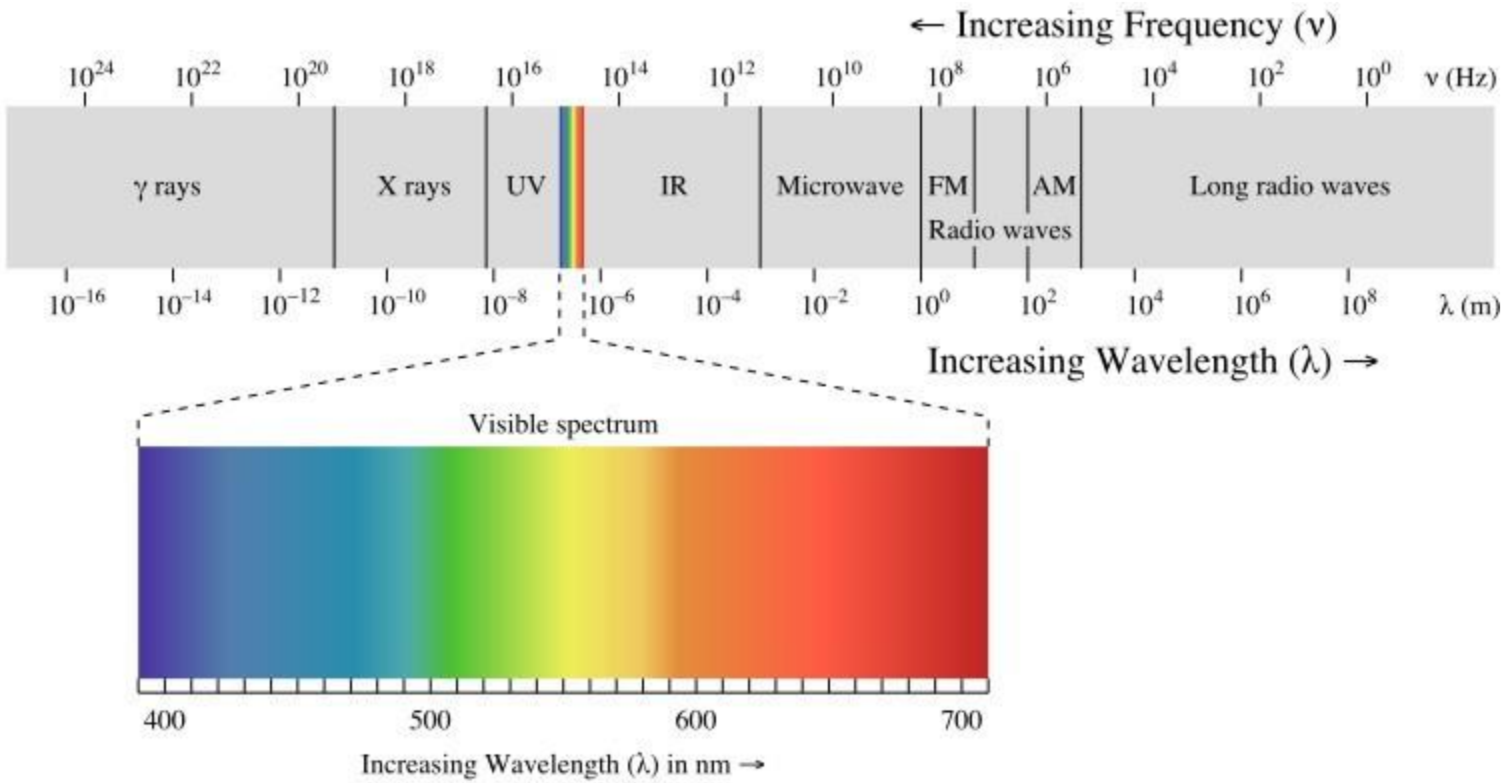


Electromagnetic Waves

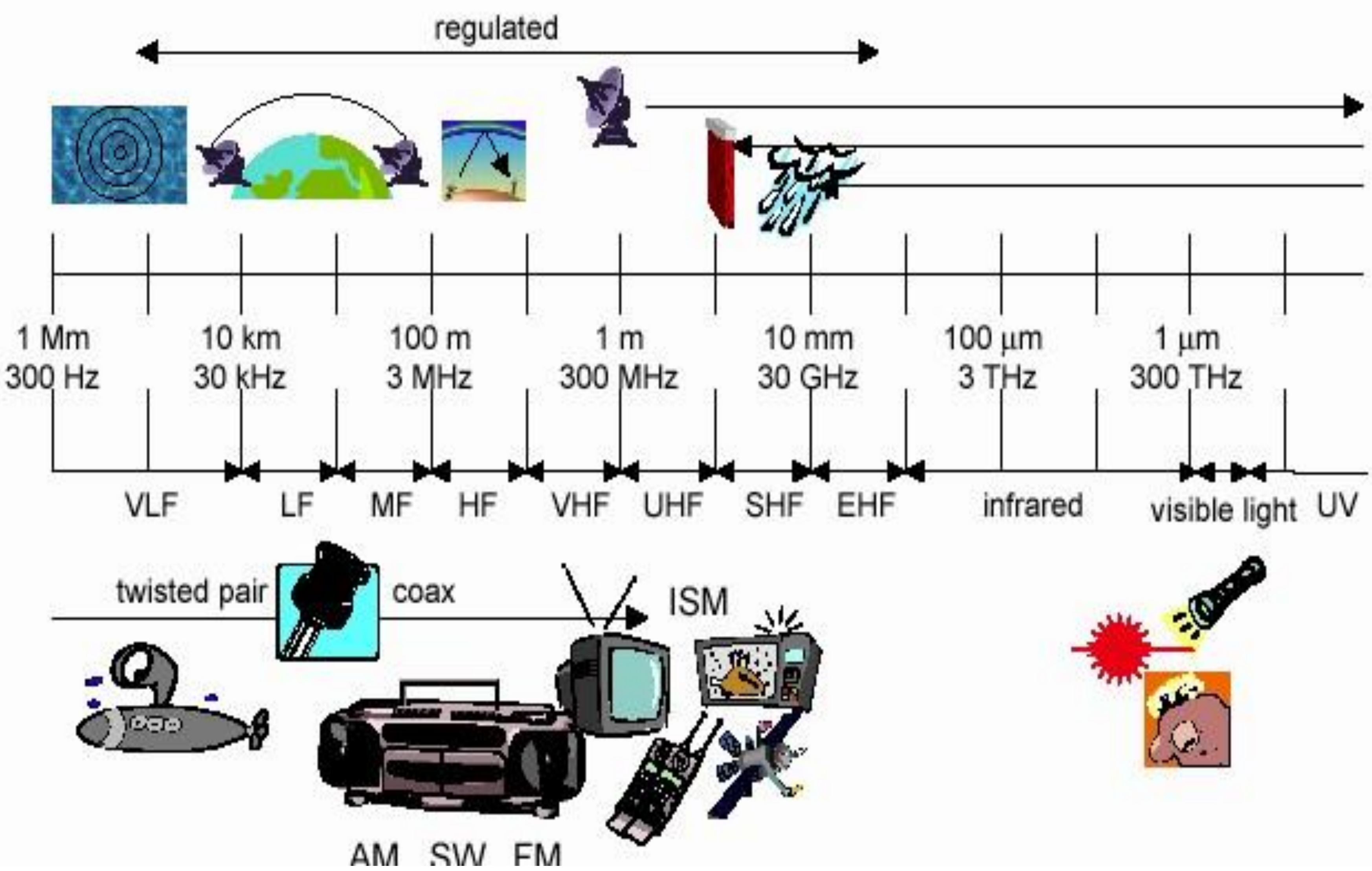
- 

Electromagnetic Spectrum



http://www.edumedia-sciences.com/a185_l2-transverse-electromagnetic-wave.html

Electromagnetic Spectrum



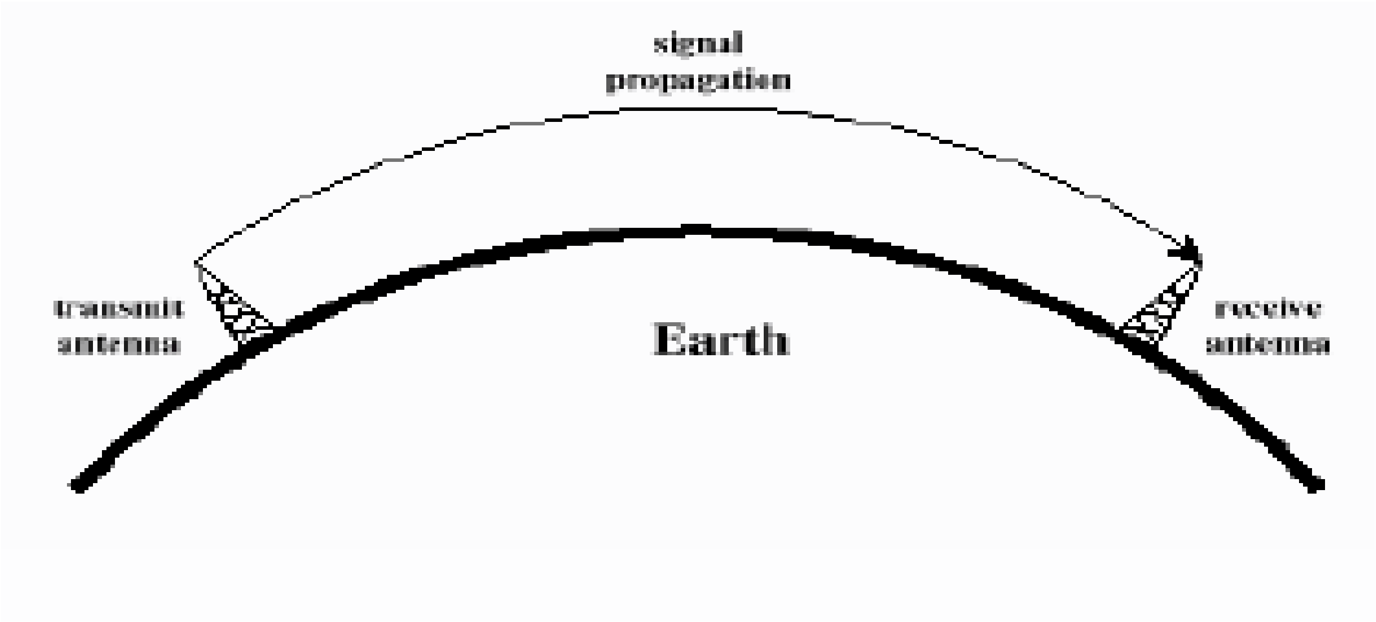
Wave length	**Frequency Designations**	**Transmission Media**	**Propagation Modes**	**Representative Applications**	**Frequency**
1 cm	Extra High Frequency (EHF)	Wave guide		Satellite, Microwave relay, Earth-satellite radar.	100 GHz
10 cm	Super High Frequency (SHF)		Line-of-sight radio		10 GHz
1 m	Ultra High Frequency (UHF)			Wireless comm. service, Cellular, pagers, UHF TV	1 GHz
10m	Very High Frequency (VHF)	Coaxial Cable	Sky wave radio	Mobile, Aeronautical, VHF TV and FM, mobile radio	100 MHz
100m	High Frequency (HF)			Amateur radio, Civil Defense	10 MHz
1 km	Medium High Frequency (MF)		Ground wave radio	AM broadcasting	1 MHz
10 km	Low Frequency (LF)	Wire pairs		Aeronautical, Submarine cable, Navigation, Transoceanic radio	100 kHz
100km	Very Low Frequency (VLF)				10 kHz

1.6 Radio Wave Propagation Modes

1 Ground Wave Propagation

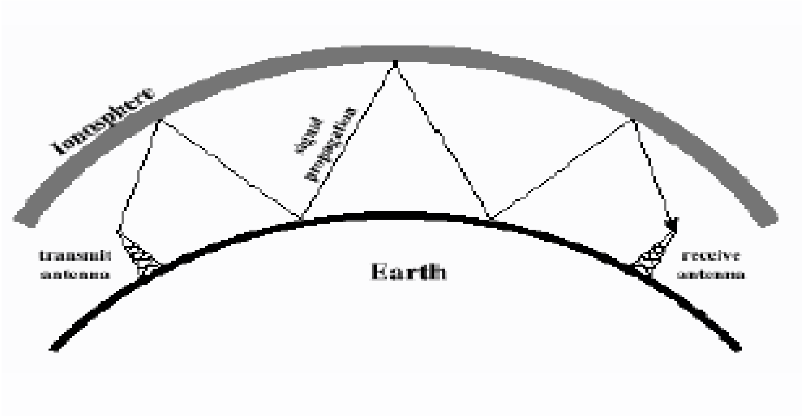
Follows contour of the earth Can Propagate considerable distances

Frequencies up to 2 MHz Example : AM radio



2Sky Wave Propagation Signal reflected from ionized layer of atmosphere. Signal can travel a number of hops, back and forth

Examples SW radio



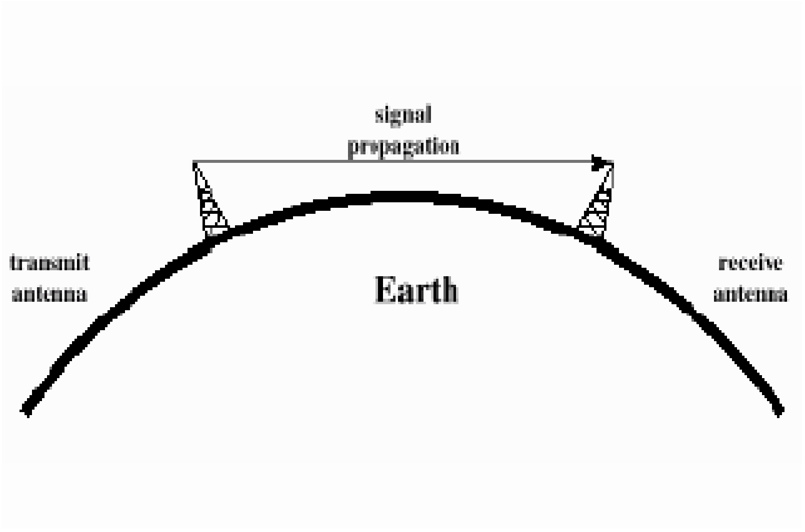
3Line-of-Sight Propagation

Transmitting and receiving antennas must be within line of sight

example

Satellite communication

Ground communication



ANALOG AND DIGITAL

Data (Information) 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.

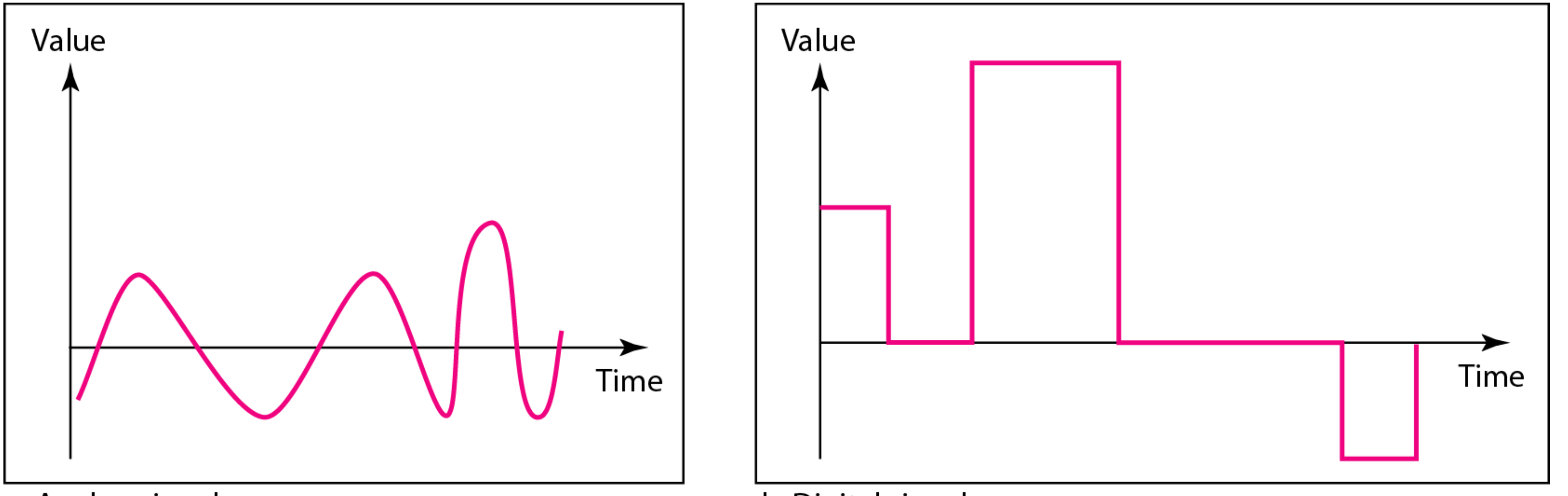
Topics discussed in this section:

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

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.

Figure ***Comparison of analog and digital signals***



a. Analog signal

b. Digital signal

In communication systems, 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

Figure *A sine wave*

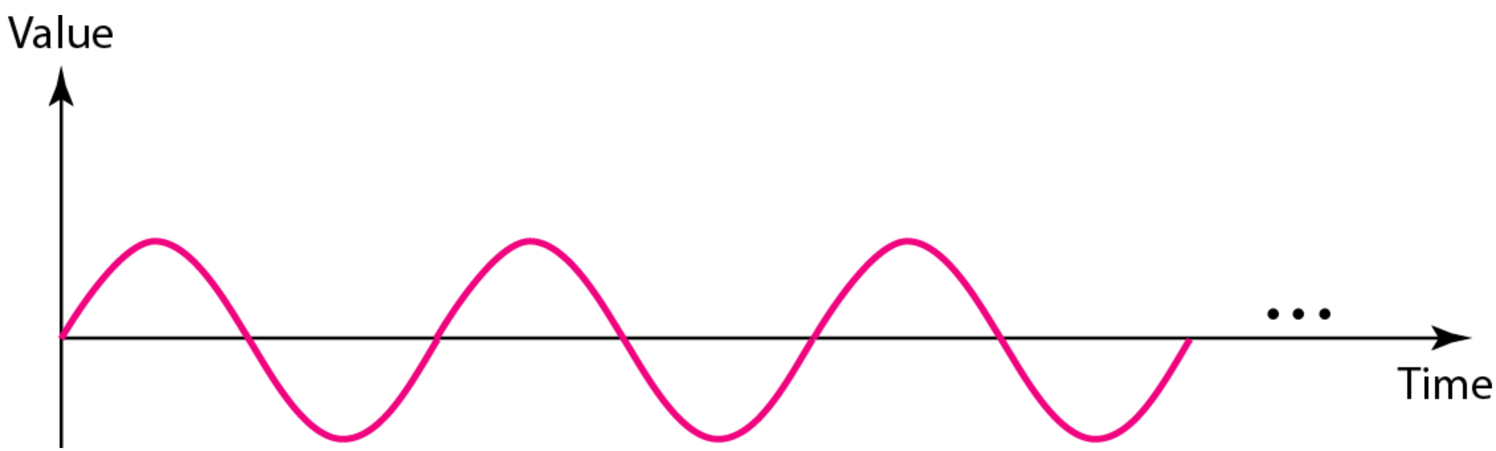
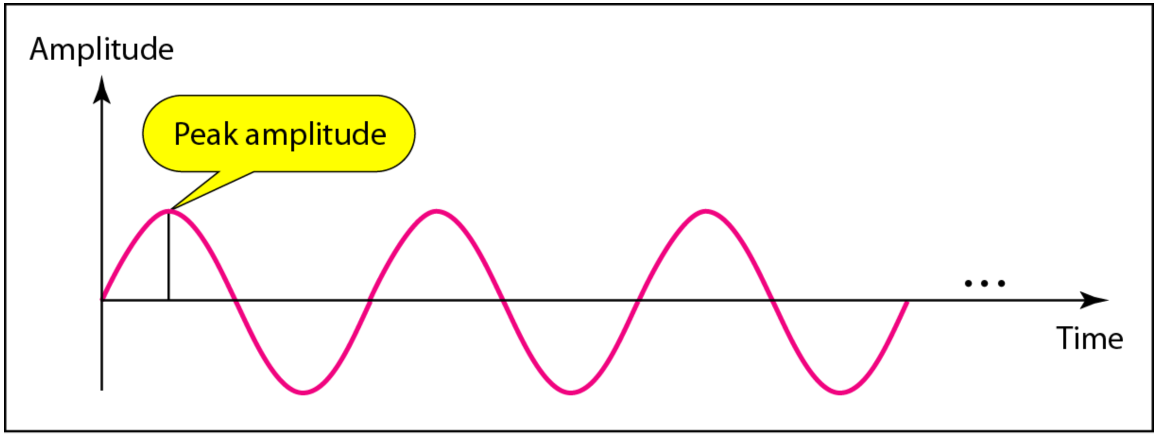
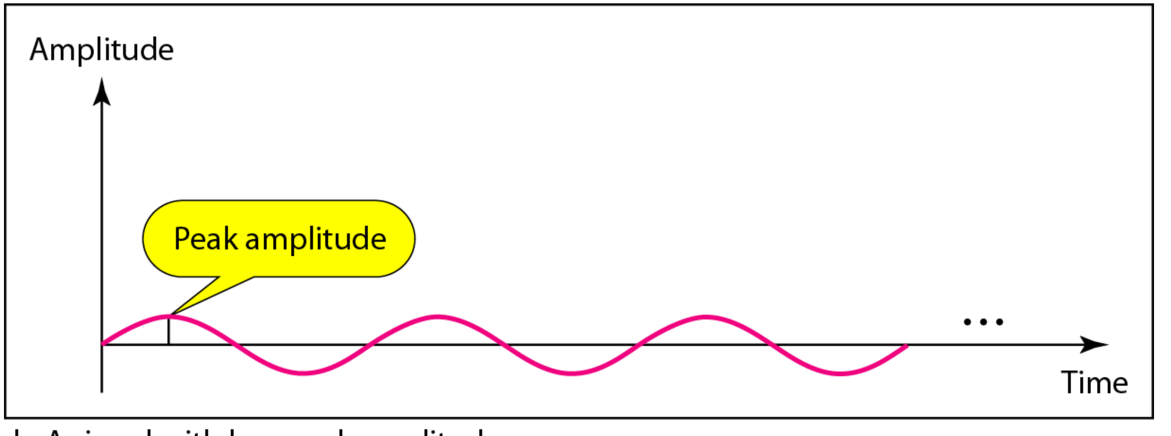


Figure Two signals with the same phase and frequency, but different amplitudes



a. A signal with high peak amplitude

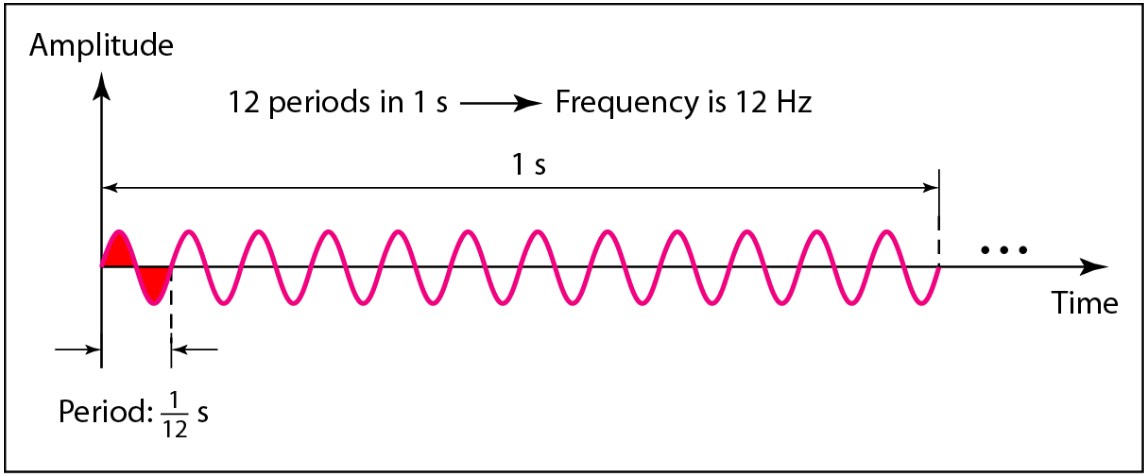


b. A signal with low peak amplitude

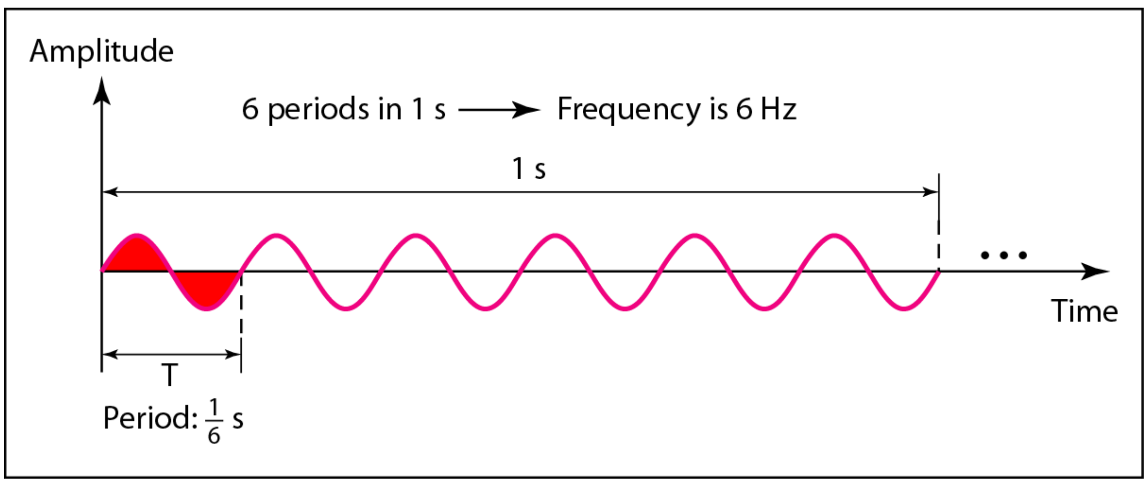
Frequency and period are the inverse of each other.

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

Figure ***Two signals with the 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

Table ***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

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).

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

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

Frequency is the rate of change with respect to time.

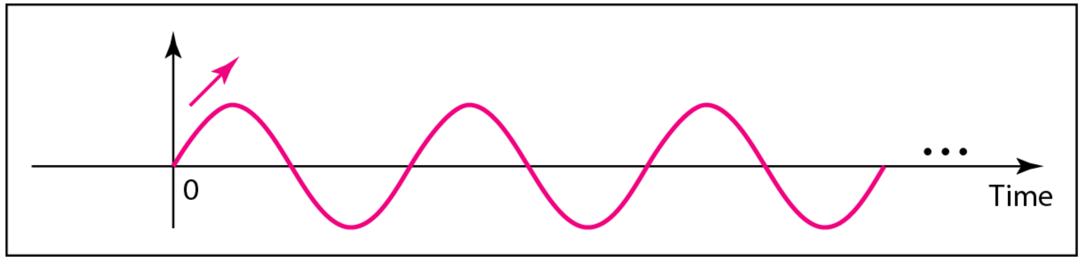
Change in a short span of time means high frequency.

Change over a long span of time means low frequency.

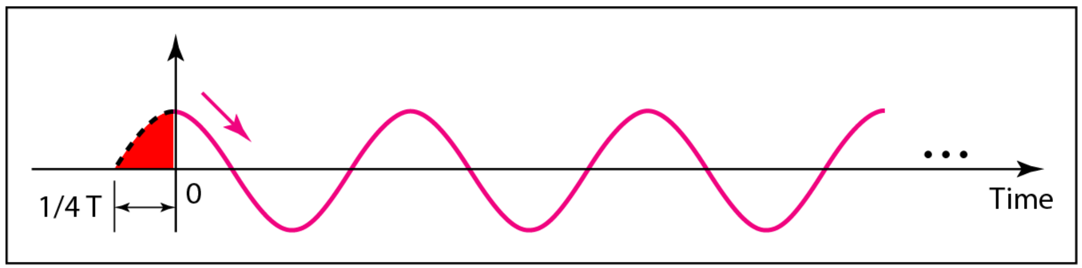
If a signal does not change at all, its frequency is zero.
If a signal changes instantaneously, its frequency is infinite.

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

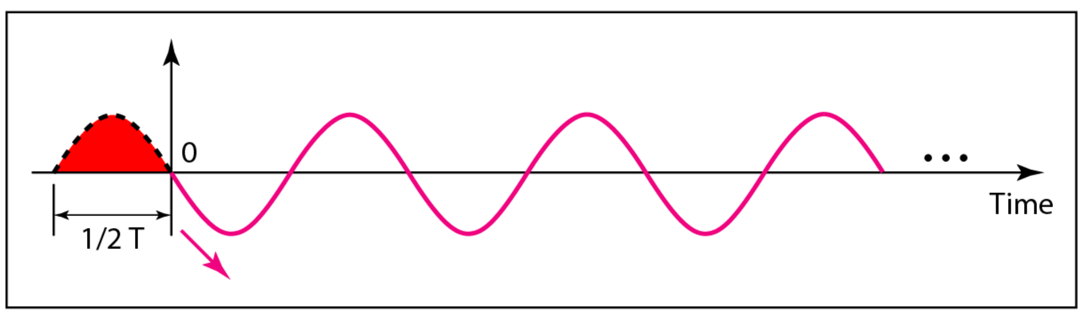
Figure *Three sine waves with the same amplitude and frequency, but different phases*



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

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

Figure *Wavelength and period*

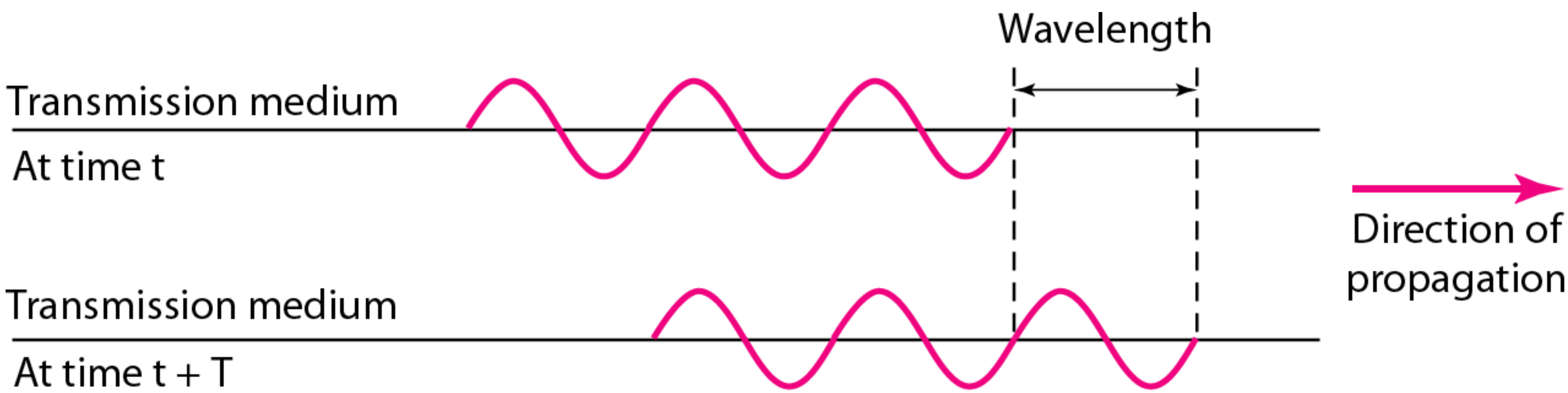
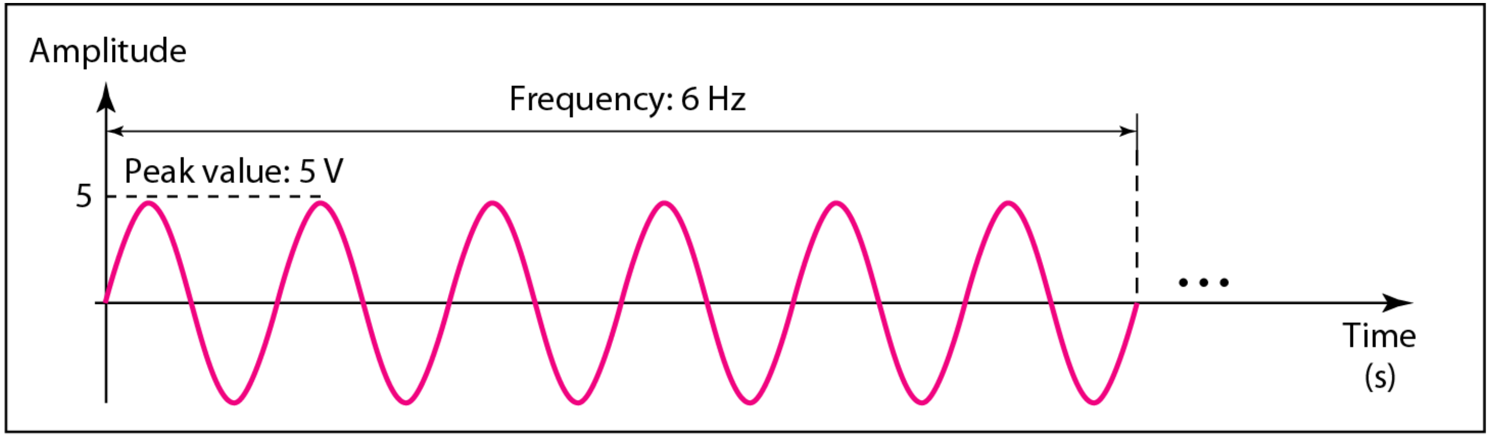
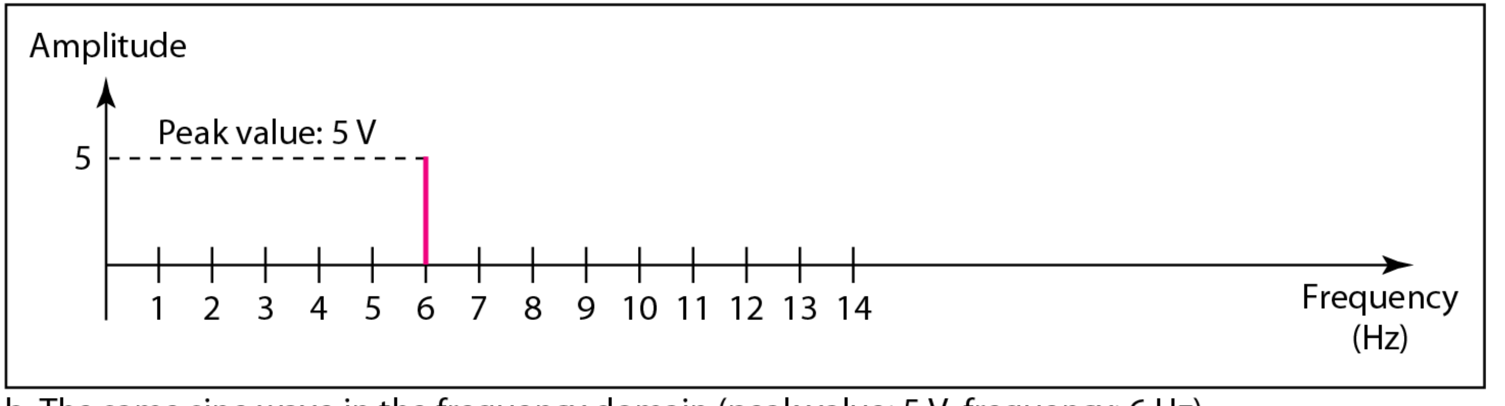


Figure *The time-domain and frequency-domain plots of a sine wave*



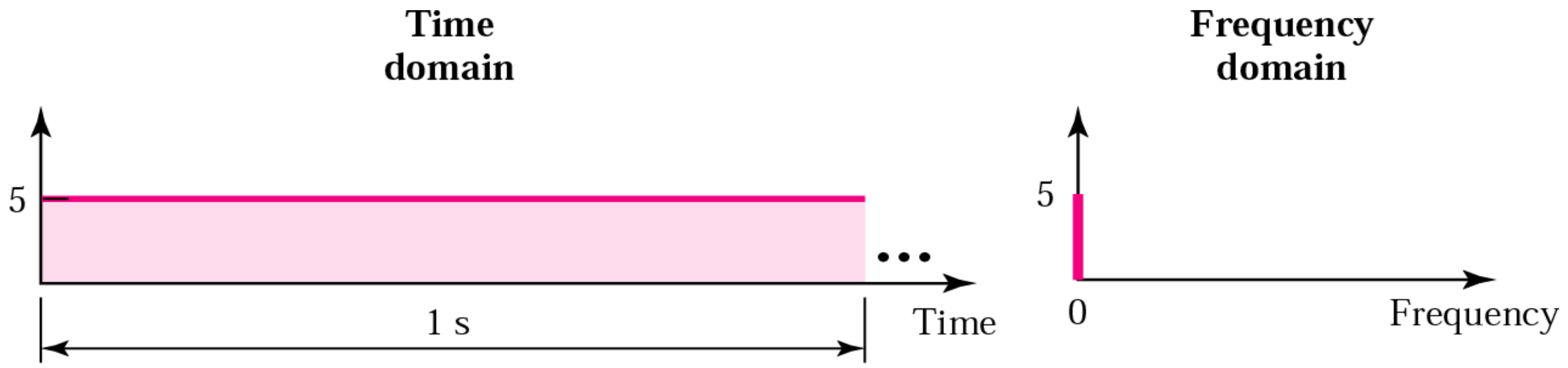
a. A sine wave in the time domain (peak value: 5 V, frequency: 6 Hz)



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

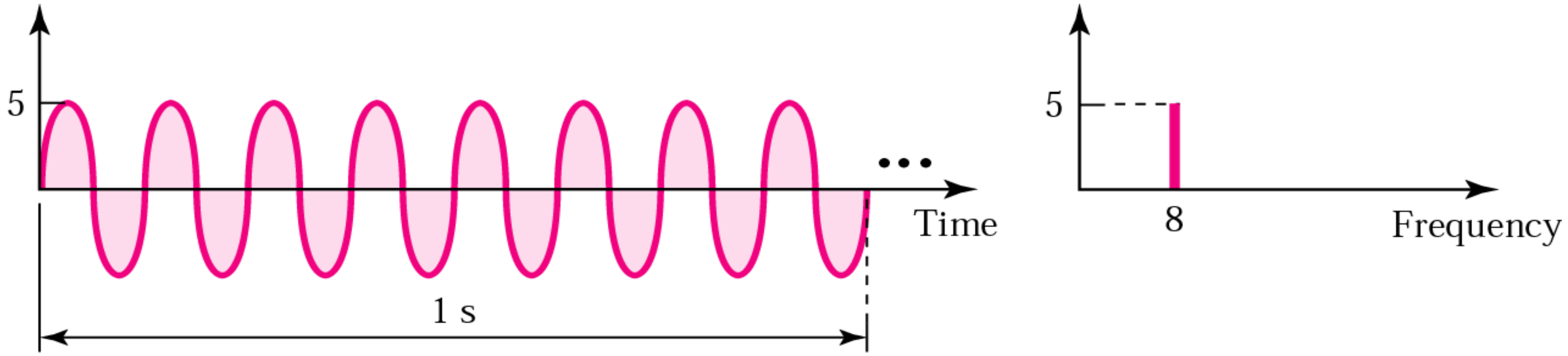
A complete sine wave in the time domain can be represented by one single spike in the frequency domain.

Time and frequency domains



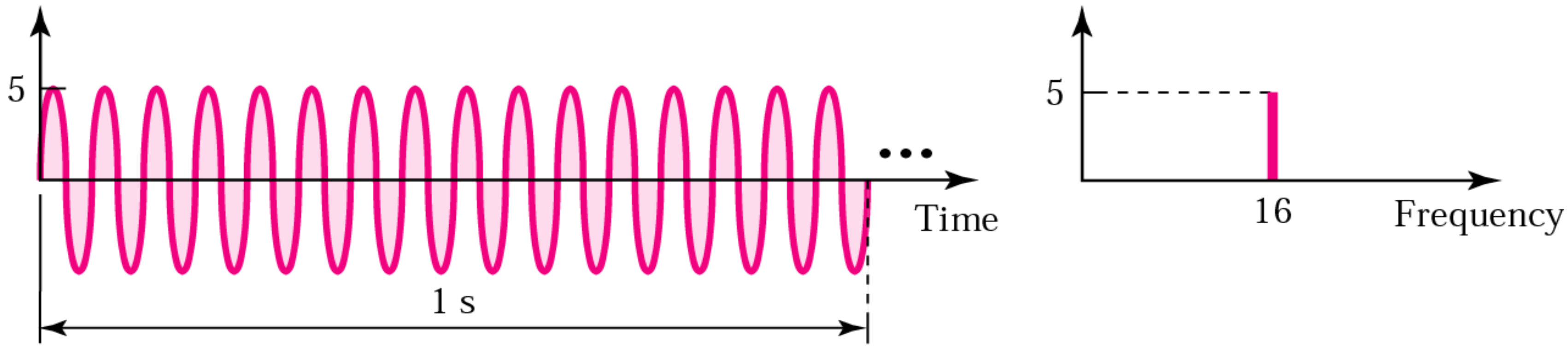
a. A signal with frequency 0

Time and frequency domains (continued)



b. A signal with frequency 8

Time and frequency domains (continued)

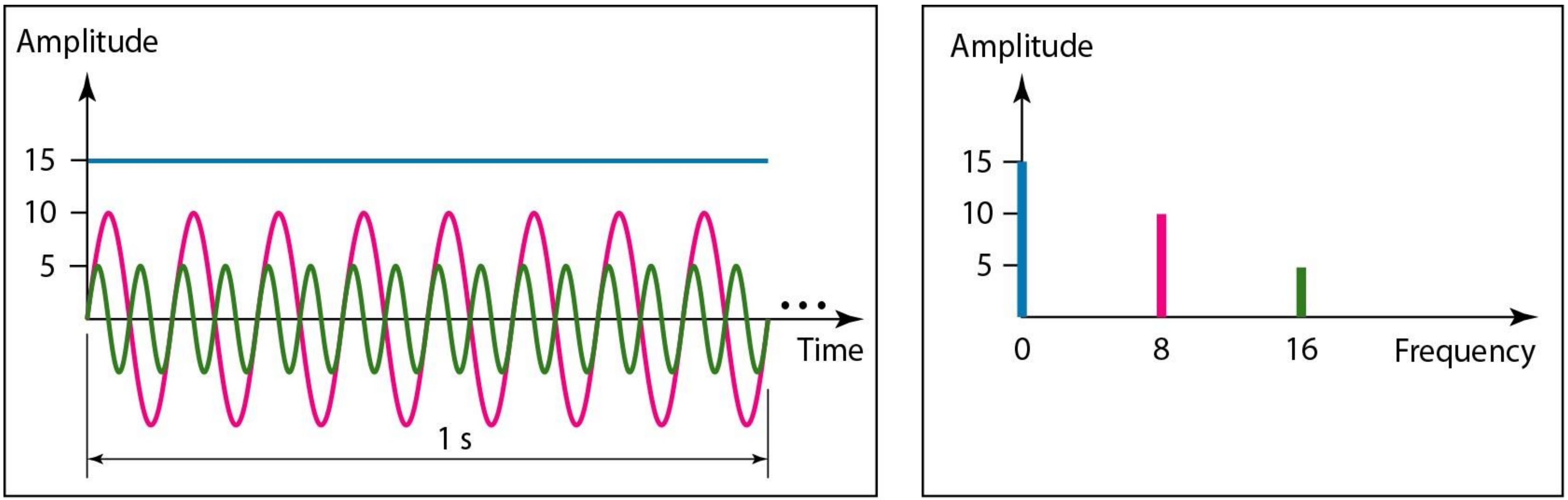


c. A signal with frequency 16

Example

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

Figure *The time domain and frequency domain of three sine waves*

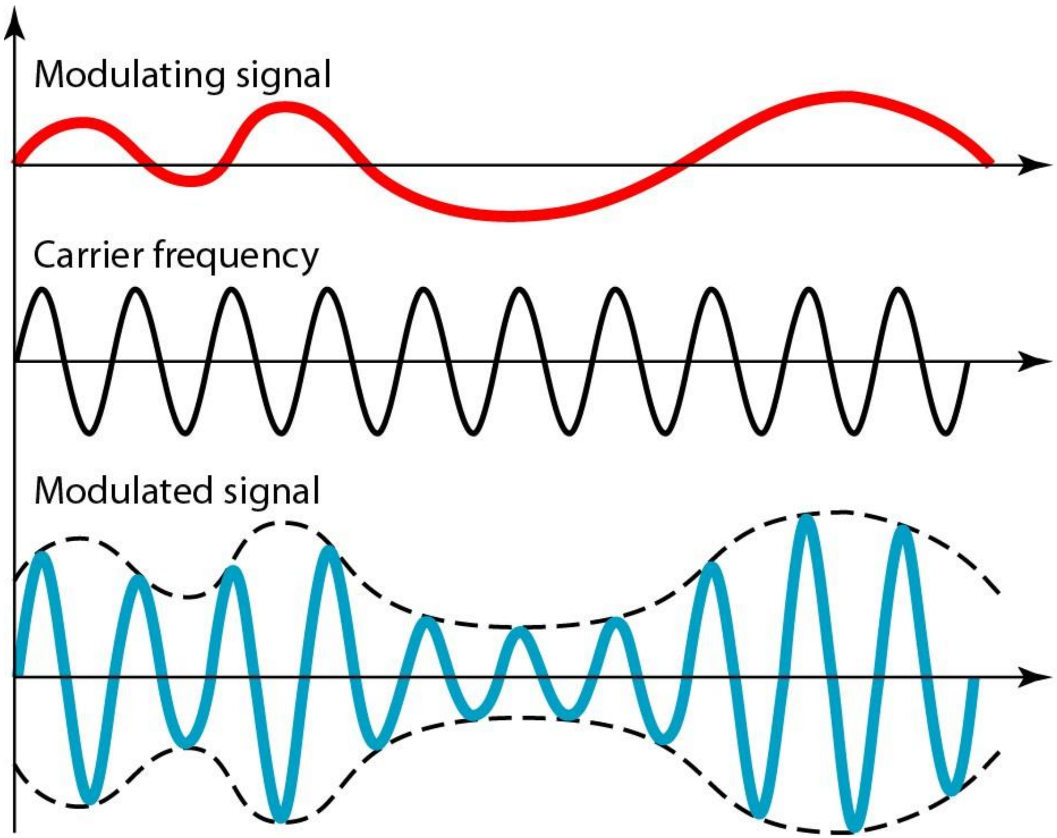


a. Time-domain representation of three sine waves with frequencies 0, 8, and 16

b. Frequency-domain representation of the same three signals

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

Example *Amplitude modulation*



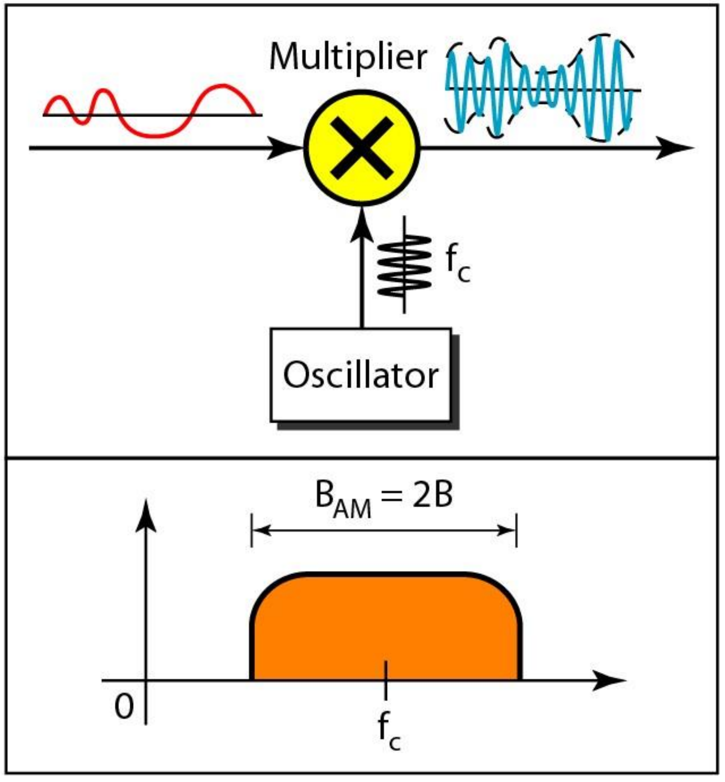


Figure ***AM band allocation***

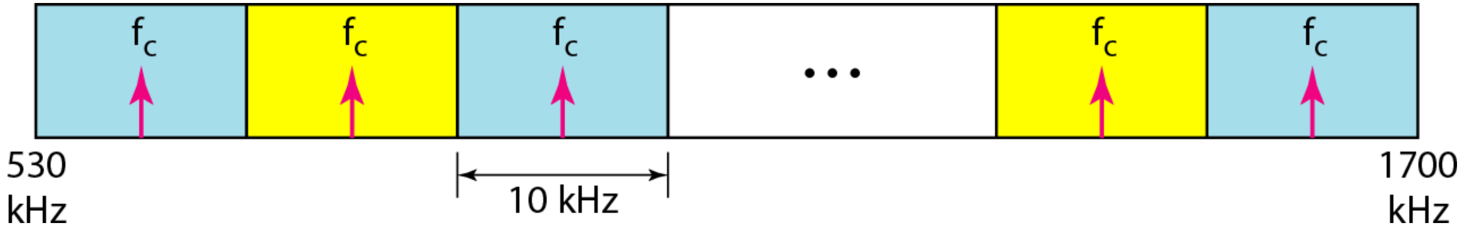


Figure *Frequency modulation*

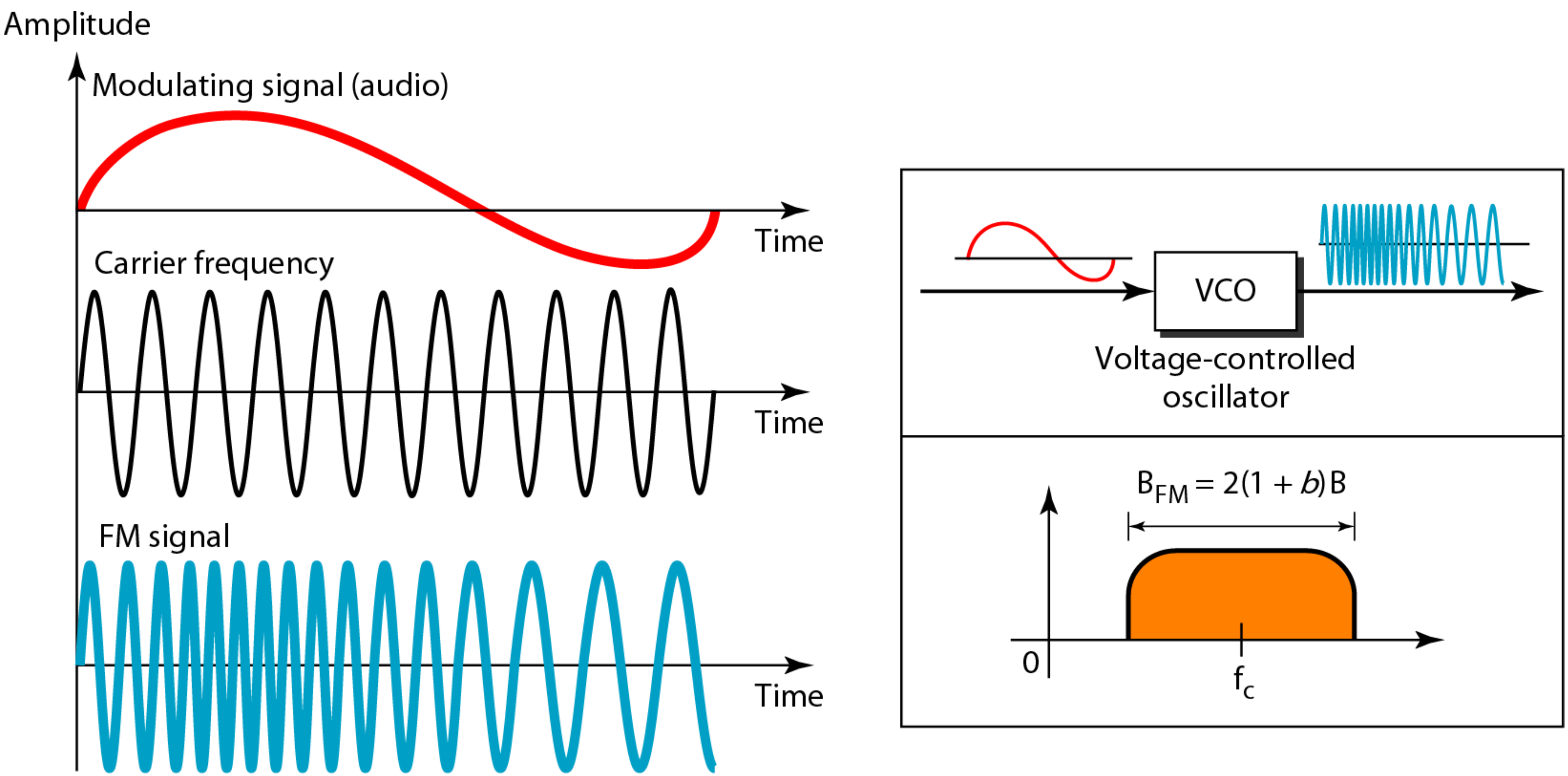


Figure *FM band allocation*

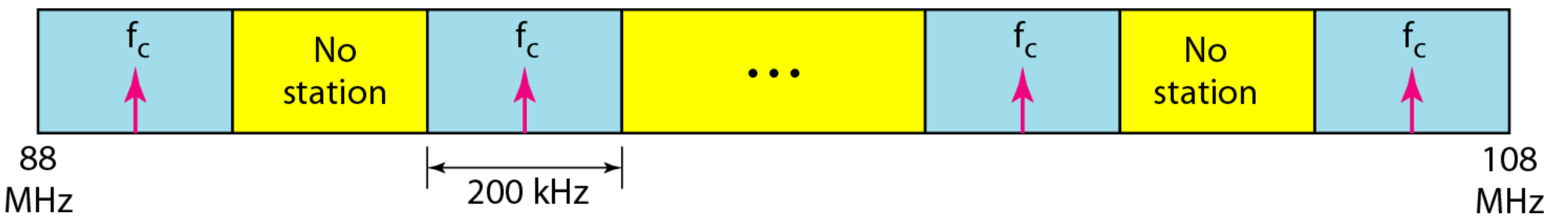
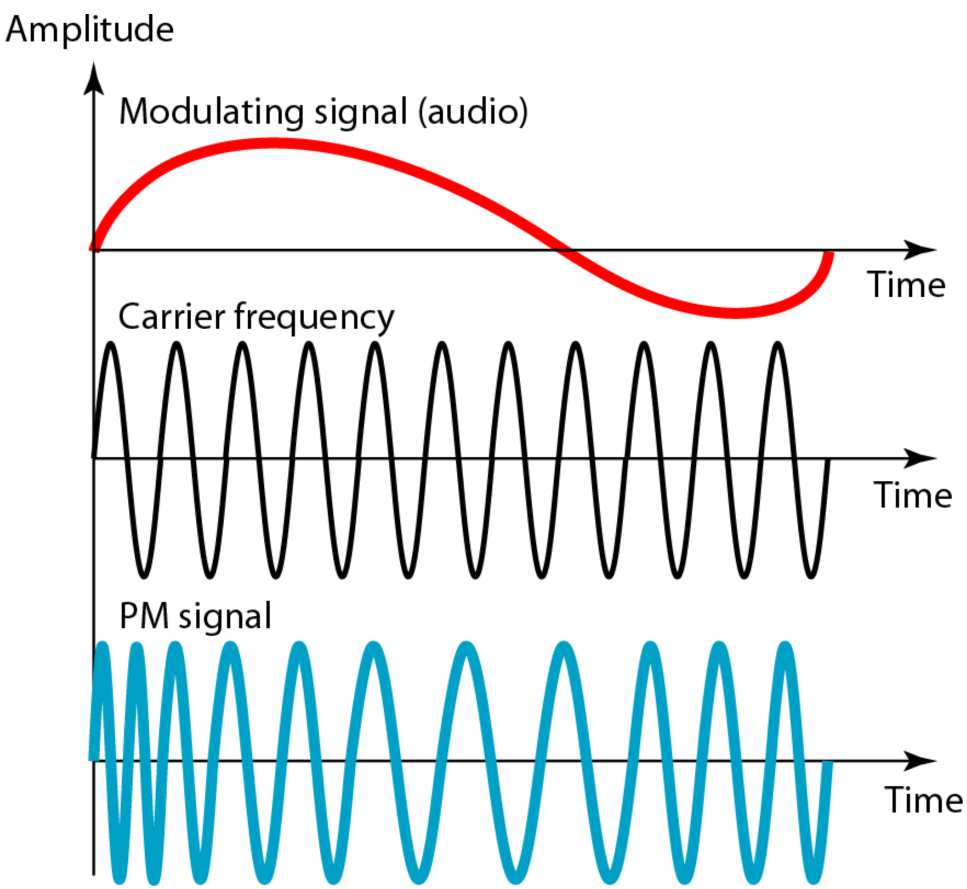
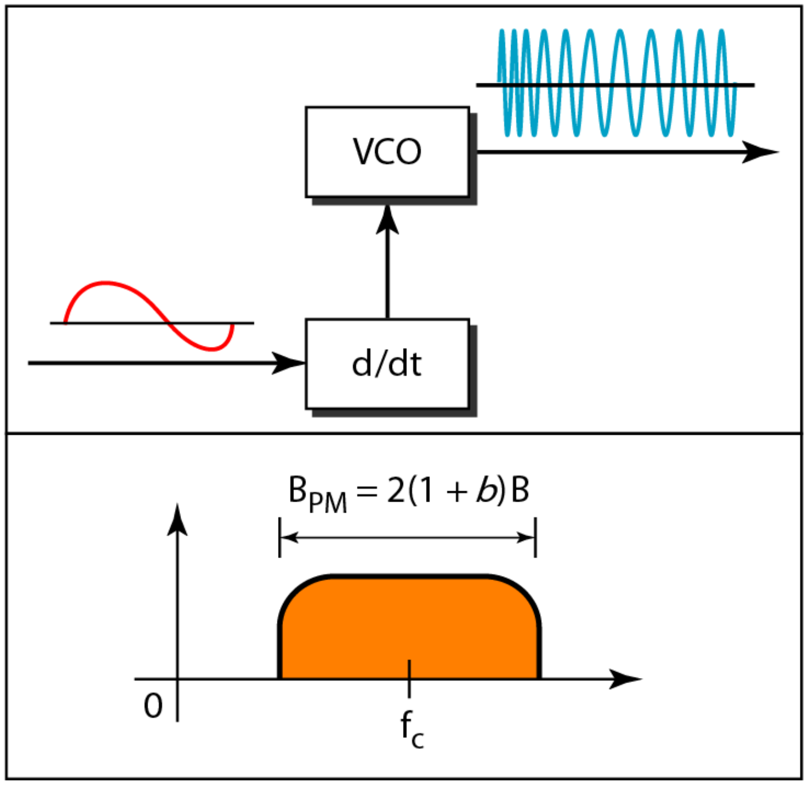


Figure *Phase modulation*

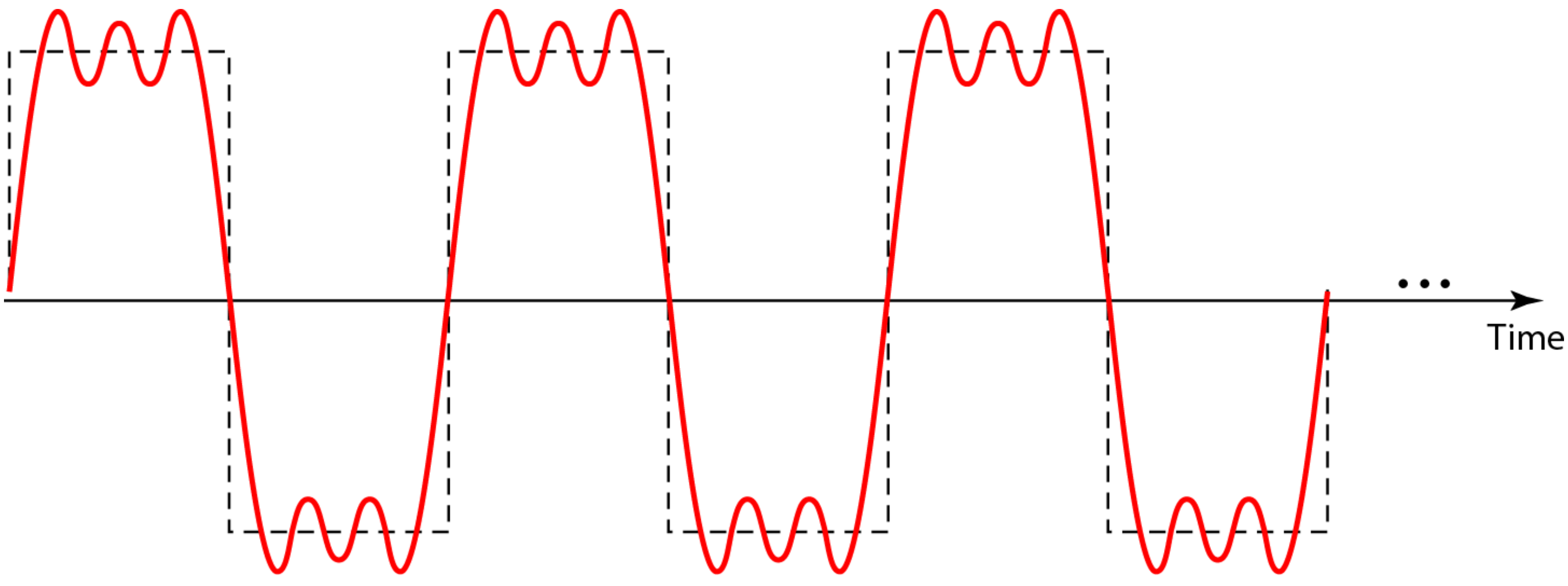




According to Fourier analysis, any composite signal is a combination of simple sine waves with different frequencies, amplitudes, and phases.

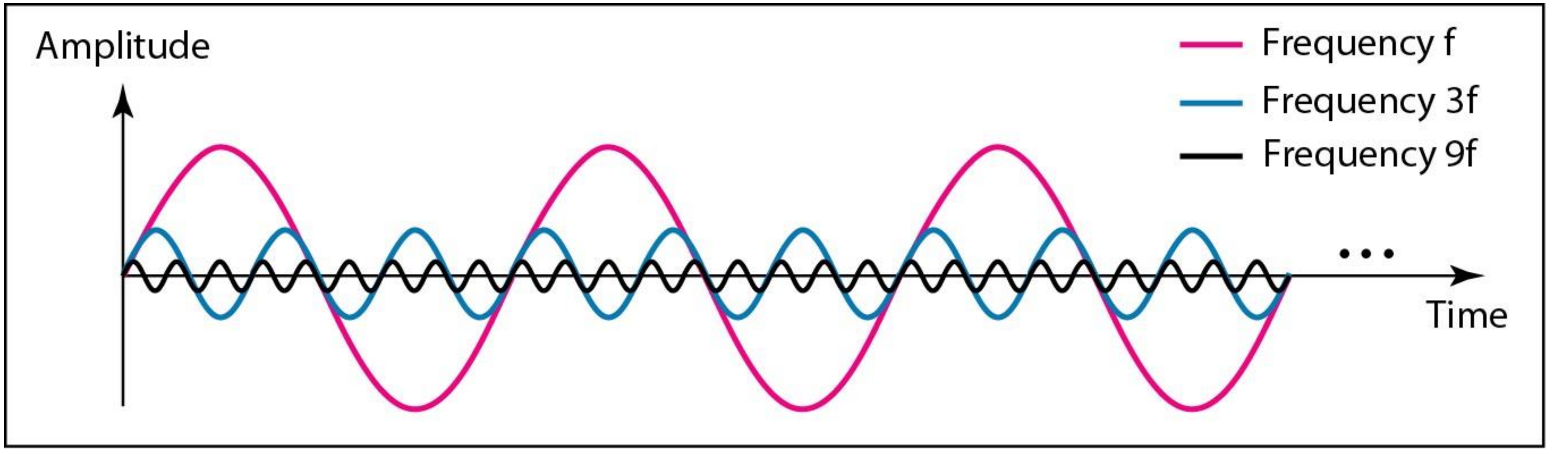
If the composite signal is periodic, the decomposition gives a series of signals with discrete frequencies; if the composite signal is nonperiodic, the decomposition gives a combination of sine waves with continuous frequencies.

Figure *A composite periodic signal*

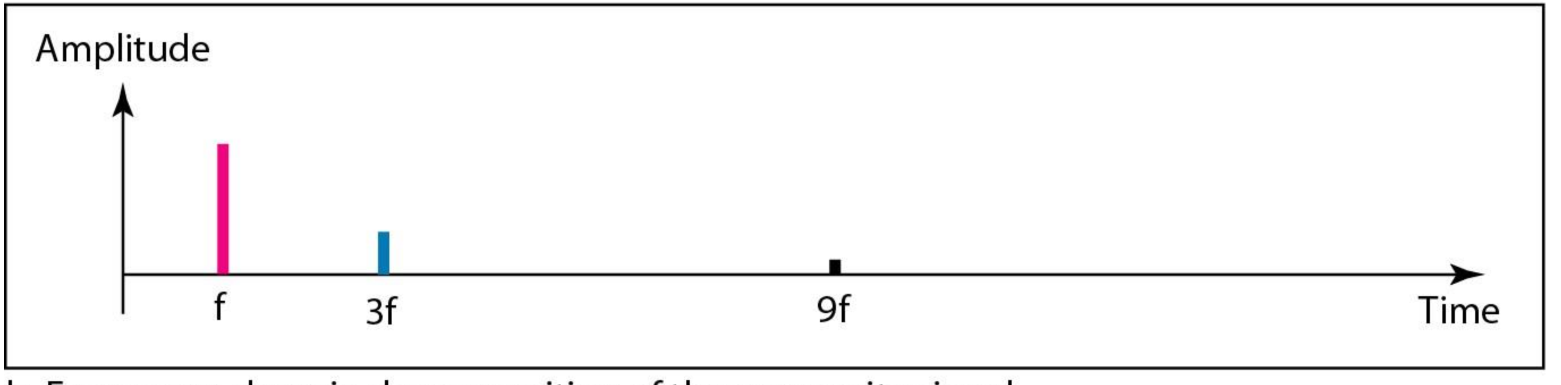


Above Figure shows a periodic composite signal with frequency f. This type of signal is not typical of those found in data communications. We can consider it to be three alarm systems, each with a different frequency. The analysis of this signal can give us a good understanding of how to decompose signals.

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

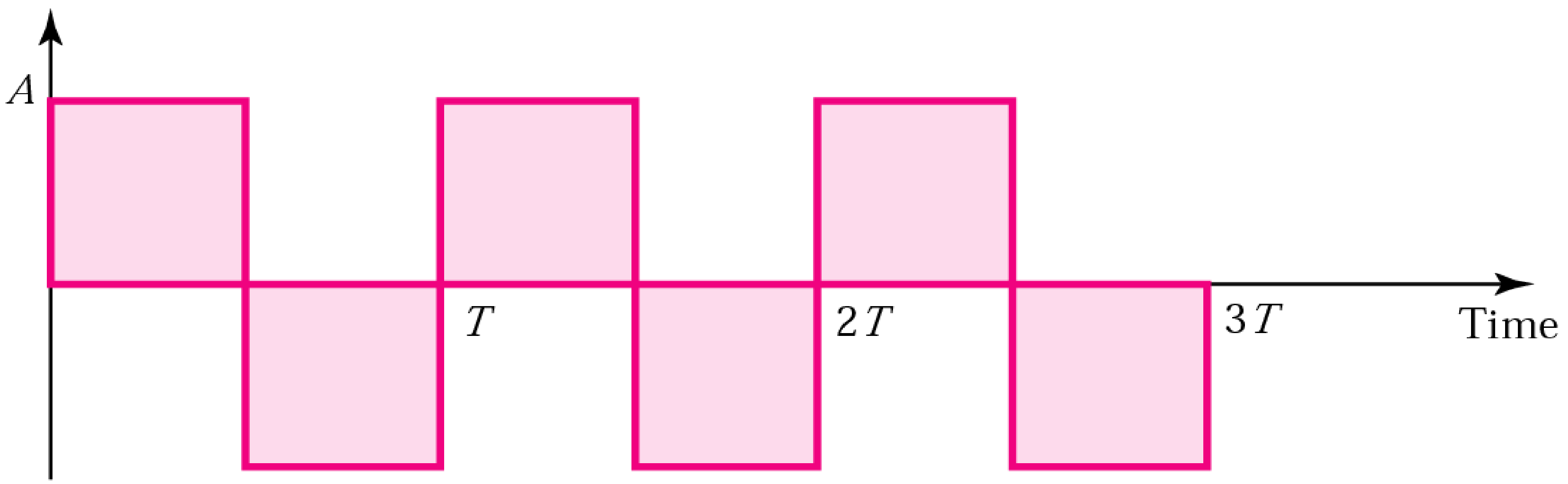


a. Time-domain decomposition of a composite signal

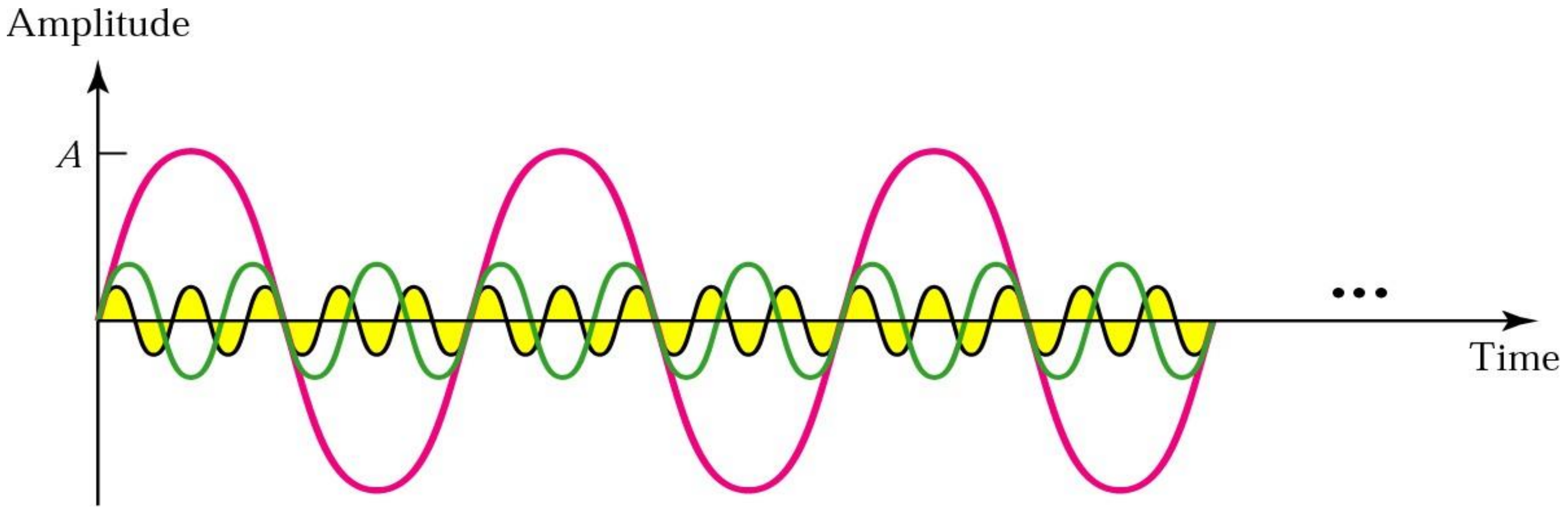


b. Frequency-domain decomposition of the composite signal

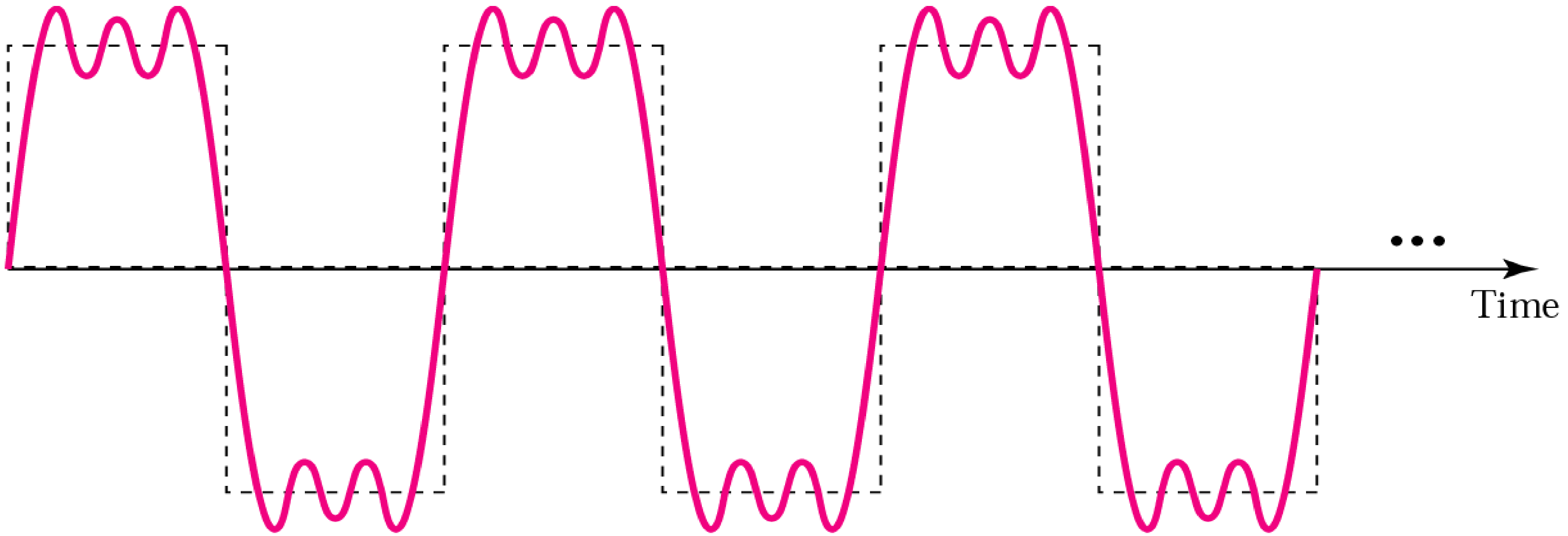
Square wave



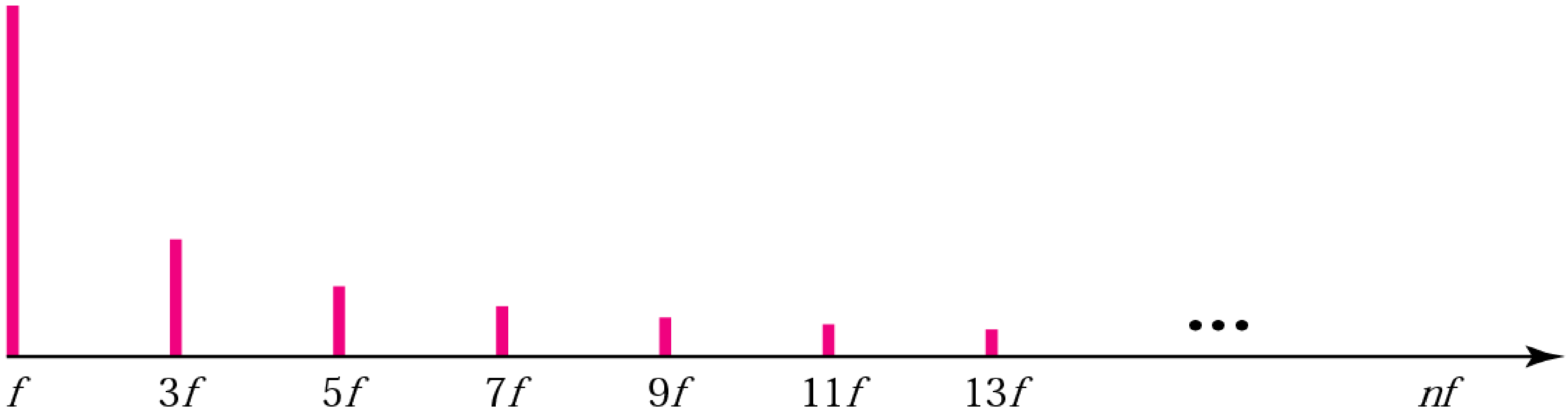
Three harmonics



Adding first three harmonics



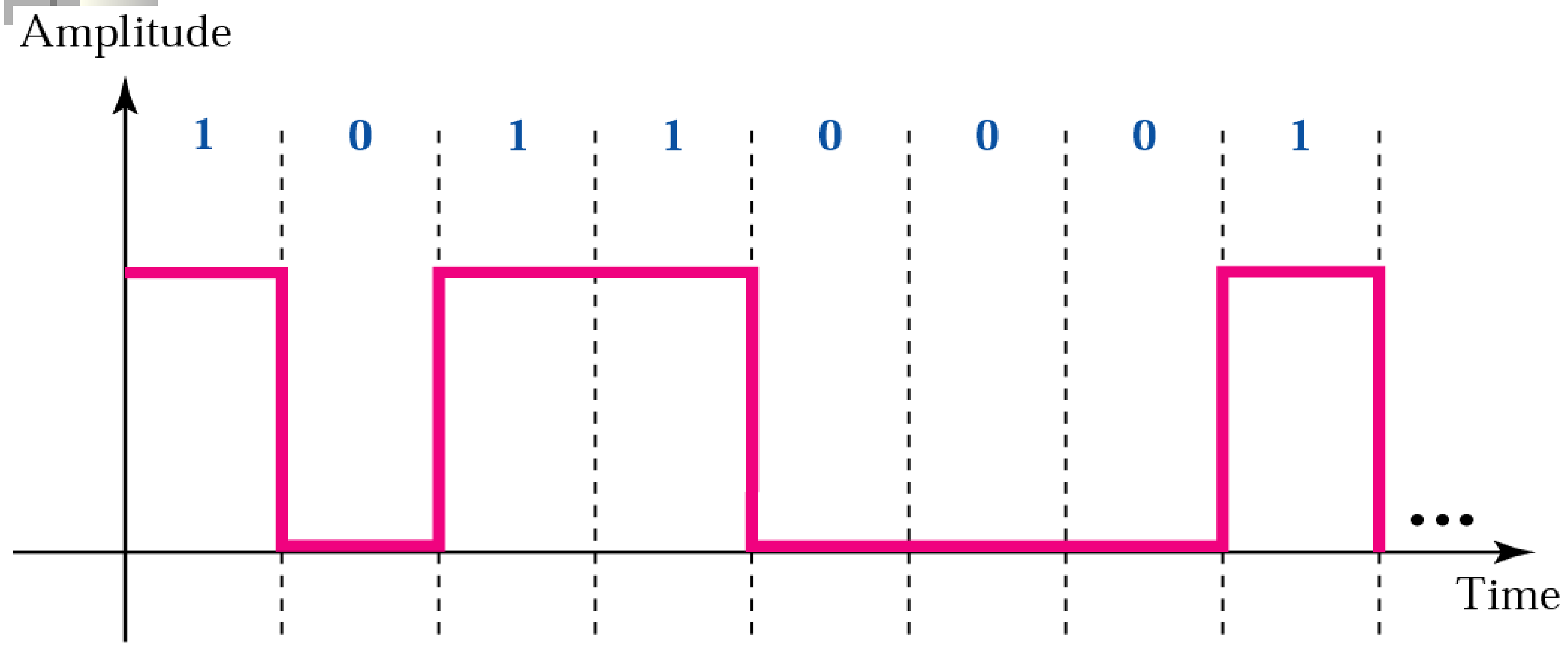
Frequency spectrum comparison



a. Frequency spectrum of a square wave

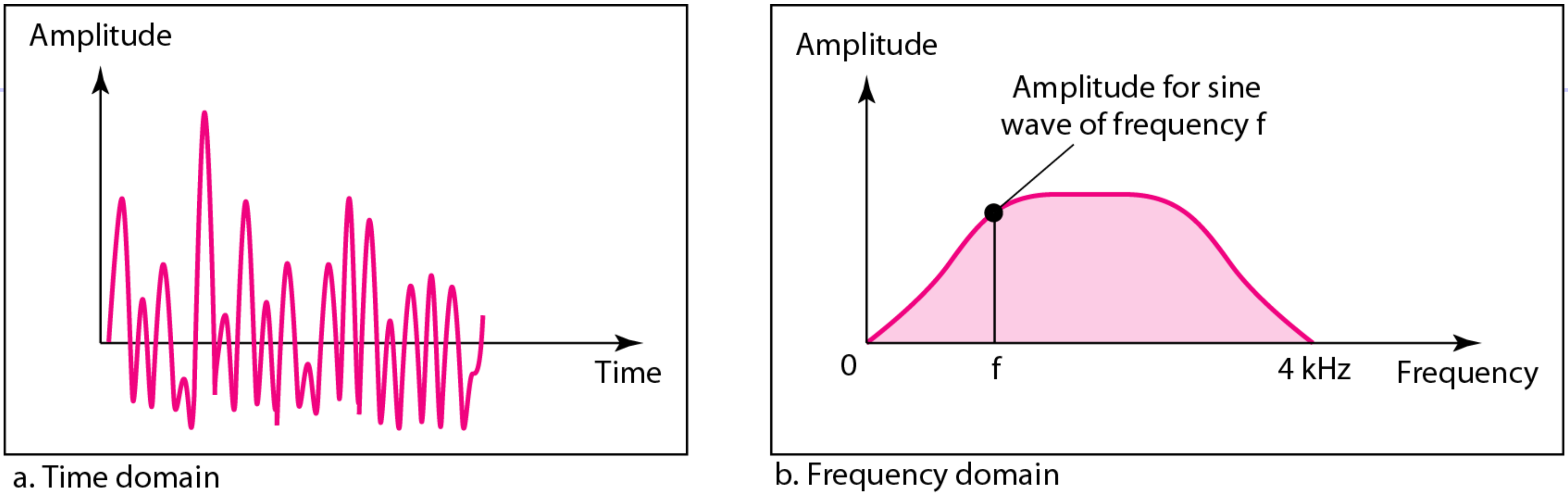
b. Frequency spectrum of an approximation with only three harmonics

A digital signal



A digital signal is a composite signal with an infinite bandwidth.

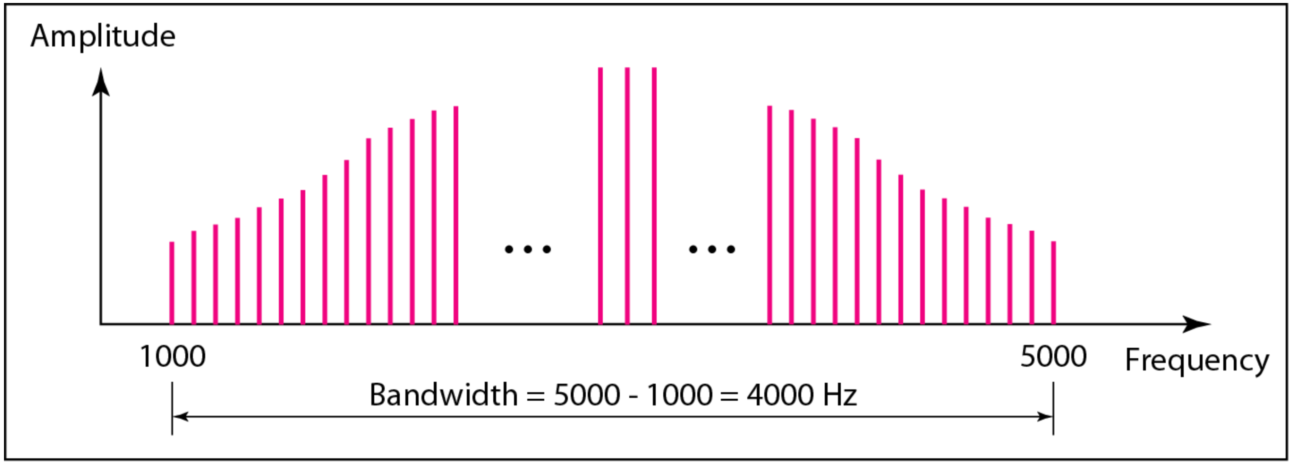
Figure *The time and frequency domains of a nonperiodic signal*



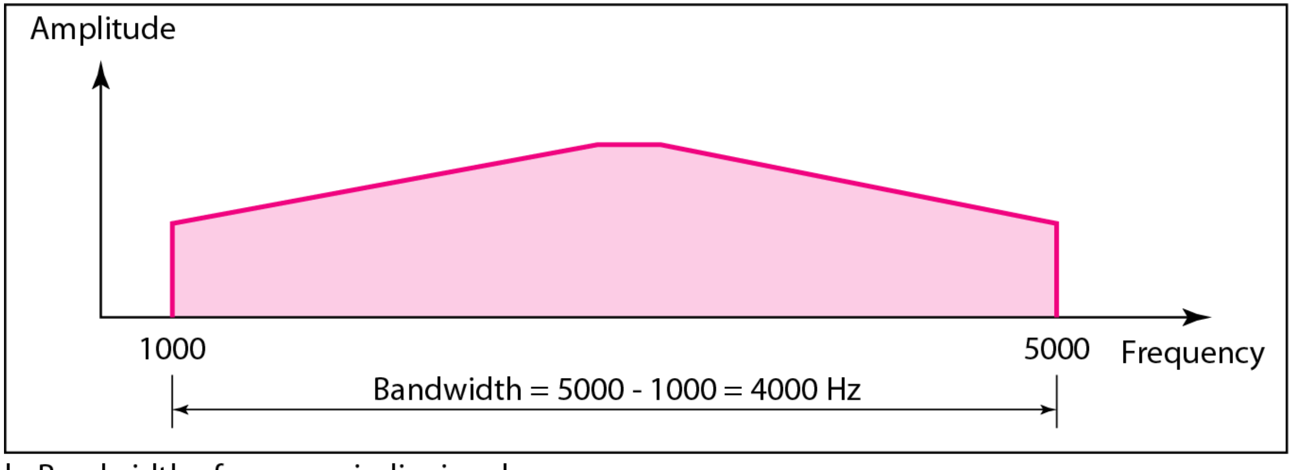
Above Figure shows a nonperiodic composite signal. It can be the signal created by a microphone or a telephone set when a word or two is pronounced. In this case, the composite signal cannot be periodic, because that implies that we are repeating the same word or words with exactly the same tone.

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

Figure *The bandwidth of periodic and nonperiodic composite signals*



a. Bandwidth of a periodic signal



b. Bandwidth of a nonperiodic signal

Example

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.

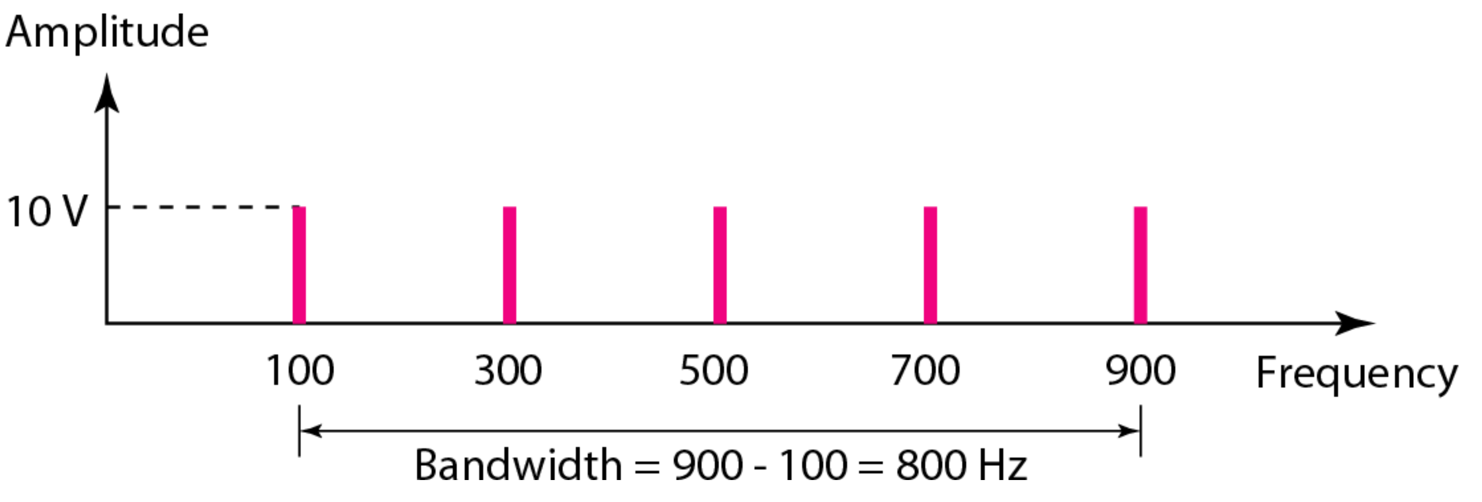
Solution

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 (see next Figure).

Figure ***The bandwidth for Example***



Example

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.

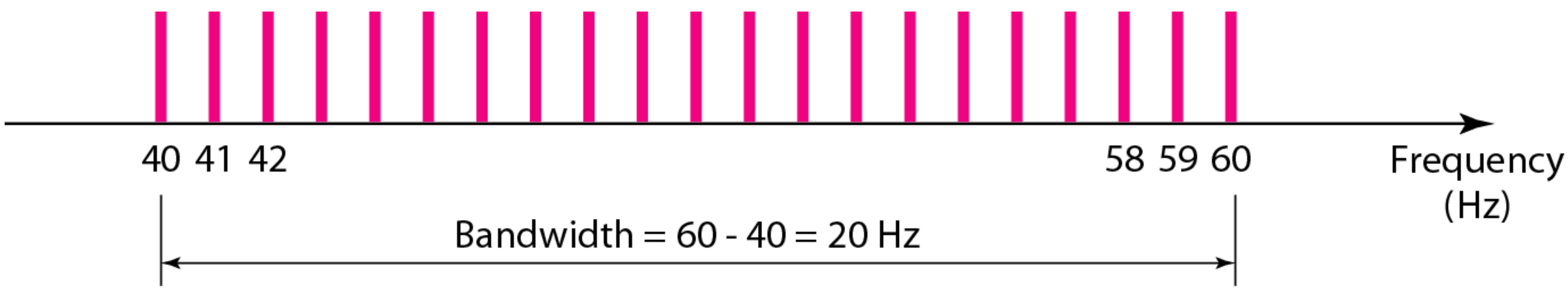
Solution

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 (see next Figure).

Figure ***The bandwidth for Example***



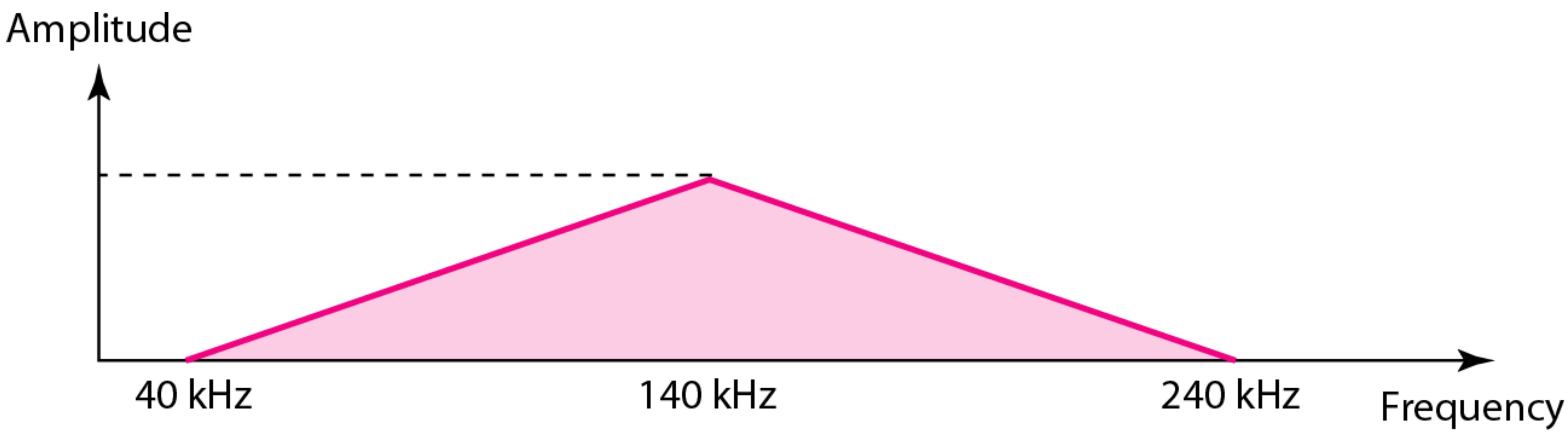
Example

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. Next Figure shows the frequency domain and the bandwidth.

Figure ***The bandwidth for Example***



Example

An example of a nonperiodic composite signal is the signal propagated by an AM radio station. Each AM radio station is assigned a 10-kHz bandwidth. The total bandwidth dedicated to AM radio ranges from 530 to 1700 kHz.

Example

Another example of a nonperiodic composite signal is the signal propagated by an FM radio station. Each FM radio station is assigned a 200-kHz bandwidth. The total bandwidth dedicated to FM radio ranges from 88 to 108 MHz.

Analog and Digital Communication Systems

There are many kinds of information sources, which can be categorized into two distinct message categories, *analog* and *digital.*

an ***analog communication system*** *should deliver this waveform with a specified degree of fidelity.*

a ***digital communication system*** *should deliver data with a specified degree of accuracy in a specified amount of time.*

Comparisons of Digital and Analog Communication Systems

Digital Communication System	Analog Communication System
Advantage : • inexpensive digital circuits • privacy preserved (data encryption) • can merge different data (voice, video and data) and transmit over a common digital transmission system • error correction by coding	**Disadvantages :** • expensive analog components : L&C • no privacy • can not merge data from diff. sources • no error correction capability
Disadvantages : • larger bandwidth • synchronization problem is relatively difficult	**Advantages :** • smaller bandwidth • synchronization problem is relatively easier

Brief Chronology of Communication Systems

- 1844 *Telegraph*:
- 1876 *Telephony*:
- 1904 *Radio:*
- 1923-1938 *Television*:
- 1936 Armstrong's case of FM radio
- 1938-1945 *World War II* Radar and microwave systems
- 1948-1950 *Information Theory and coding*. C. E. Shannon
- 1962 *Satellite* communications begins with Telstar I.
- 1962-1966 *High Speed digital communication*
- 1972 Motorola develops *cellular telephone*.