Communication Circuits Design

Academic year 2018/2019 – Semester 2 – Week 2

Lecture 1.2: Communication Systems

Francesco Fioranelli, Wasim Ahmad, Faisal Tariq

Objectives

- After completing this lecture, you will be able to:
  - Describe the system used to classify different types of electronic communication and list examples of each type.
  - Discuss the role of modulation and multiplexing in facilitating signal transmission.
  - Define the electromagnetic spectrum and explain why the nature of electronic communication makes it necessary to regulate the electromagnetic spectrum.
  - Explain the frequency, wavelength, and bandwidth.

Types of Electronic Communication

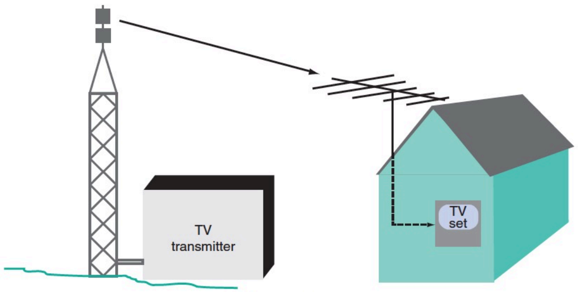
- Electronic communications are classified according to whether they are
  - one-way (simplex)
  - two-way (full duplex or half duplex) transmissions
  - analog signals
  - digital signals.

Simplex

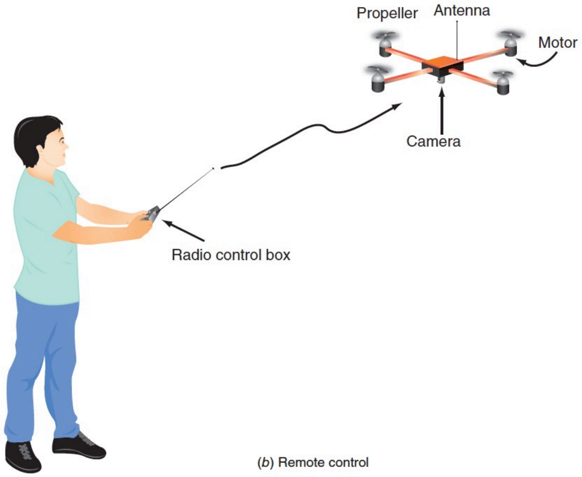
- The simplest way in which electronic communication is conducted is one-way communications, normally referred to as simplex communication.

- The most common forms of simplex communication are radio and TV broadcasting.

- Another example of one-way communication is transmission to a remotely controlled vehicle like a toy car or an unmanned aerial vehicle (UAV or drone).



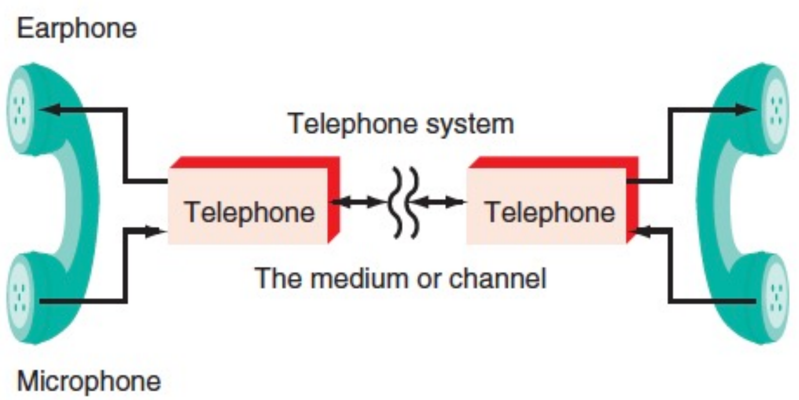
(*a*) TV broadcasting



(*b*) Remote control

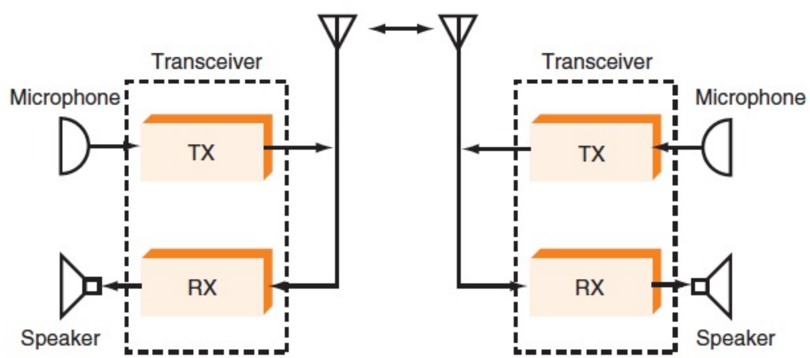
Full Duplex

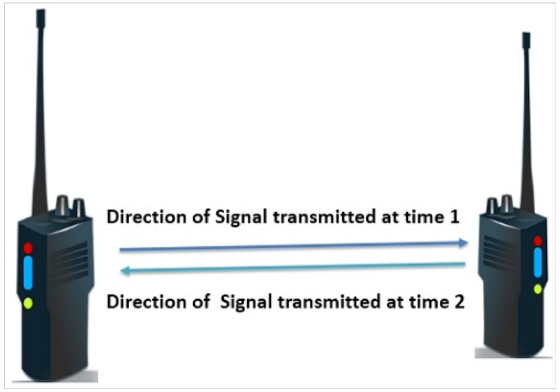
- The bulk of electronic communication is two-way, or duplex communication.
- Typical duplex applications are shown in Figure below. For example, people communicating with one another over the telephone can talk and listen simultaneously.
- This is called full duplex communication.



Half Duplex

- The form of two-way communication in which only one party transmits at a time is known as half duplex communication.
- The communication is two-way, but the direction alternates: the communicating parties take turns transmitting and receiving.
- Most radio transmissions, such as those used in the military, fire, police, aircraft, marine, and other services, are half duplex communication.
- Citizens band (CB), Family Radio, and amateur radio communication are also half duplex.

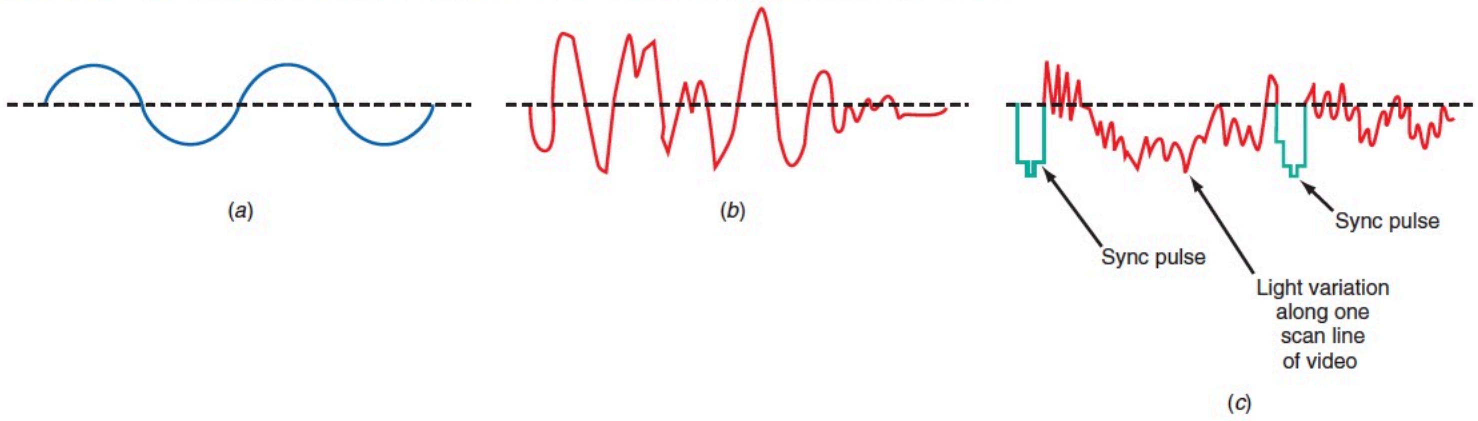




Analog Signal

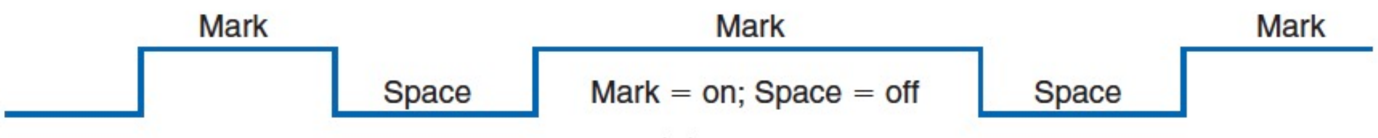
- An analog signal is a smoothly and continuously varying voltage or current.
- Some typical analog signals are shown in Figure below.
- A sine wave is a single-frequency analog signal. Voice and video voltages are analog signals that vary in accordance with the sound or light variations that are analogous to the information being transmitted.

Figure 1-5 Analog signals. (*a*) Sine wave "tone." (*b*) Voice. (*c*) Video (TV) signal.



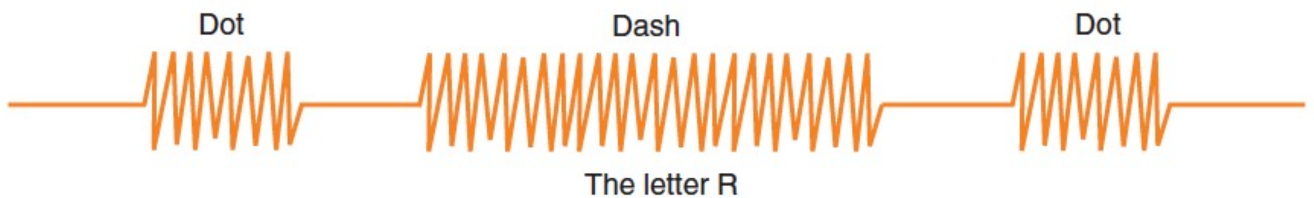
Digital Signal (1)

- Digital signals do not vary continuously, but change in steps or in discrete increments.
- Most digital signals use binary or two-state codes. Some examples are shown in Figure below.
- The earliest forms of both wire and radio communication used a type of on/off digital code.
- The telegraph used Morse code, with its system of short and long signals (dots and dashes) to designate letters and numbers.



Digital Signal (2)

- In radio telegraphy, also known as continuous-wave (CW) transmission, a sine wave signal is turned off and on for short or long durations to represent the dots and dashes.



- Data used in computers is also digital. Binary codes representing numbers, letters, and special symbols are transmitted serially by wire, radio, or optical medium.
- The most commonly used digital code in communications is the American Standard Code for Information Interchange (ASCII , pronounced “ask key”).

Digital Signal (3)

- Many transmissions are of signals that originate in digital form, e.g., telegraphy messages or computer data, but that must be converted to analog form to match the transmission medium.
- An example is the transmission of digital data over the telephone network, which was designed to handle analog voice signals only.
- If the digital data is converted to analog signals, such as tones in the audio frequency range, it can be transmitted over the telephone network.
- Analog signals can also be transmitted digitally. It is very common today to take voice or video analog signals and digitize them with an analog-to-digital (A /D) converter.
- The data can then be transmitted efficiently in digital form and processed by computers and other digital circuits.

Advantages of Digital over Analogue

- Advantages
  - Flexibility (simply changing program)
  - Accuracy
  - Storage
  - Ability to apply highly sophisticated algorithms.

- Disadvantages
  - It has certain limitations (very fast sample rate is needed when
  - the bandwidth of signal is very large)
  - It has a larger time delay compared to the analogue.

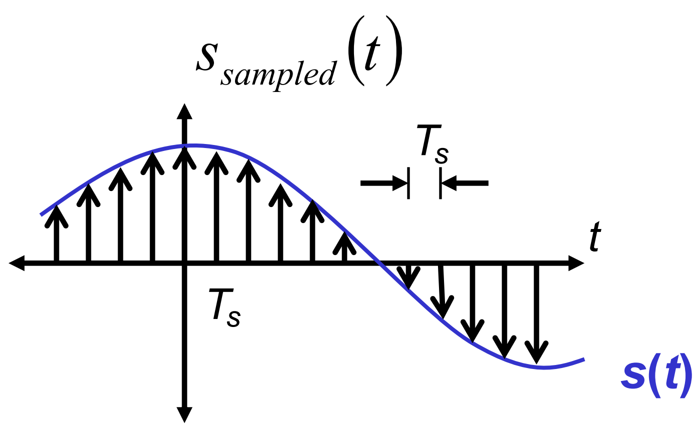
Sampling Theorem

- Many signals originate as continuous-time signals, e.g. conventional music or voice
- By sampling a continuous-time signal at isolated, equally-spaced points in time, we obtain a sequence of numbers
- $s[n] = s(nT_s)$

  $n \in \{\ldots, -2, -1, 0, 1, 2, \ldots\}$

  T_s is the sampling period.

$$s_{sampled}(t) = s(t) \underbrace{\sum_{n=-\infty}^{\infty} \delta(t - n\,T_s)}_{\textit{impulse train}}$$



Sampled analog waveform

Shannon Sampling Theorem

- A continuous-time signal $s(t)$ with frequencies no higher than f_{max} can be reconstructed from its samples $s[n] = s(nT_s)$ if the samples are taken at a rate f_s which is greater than $2\ f_{max}$.

  Nyquist rate = $2\ f_{max}$

  Nyquist frequency = $f_s/2$.

- What happens if $f_s = 2f_{max}$?

Modulation and Multiplexing

- Modulation and multiplexing are electronic techniques for transmitting information efficiently from one place to another.
- Modulation makes the information signal more compatible with the medium.
- Multiplexing allows more than one signal to be transmitted concurrently over a single medium.
- Multiplexing has been used in the music industry to create stereo sound. In stereo radio, two signals are transmitted and received - one for the right and one for the left channel of sound.
- Modulation and multiplexing techniques are basic to electronic communication.
- Once you have mastered the fundamentals of these techniques, you will easily understand how most modern communication systems work.

Baseband Signal

- The information or intelligence must be converted to an electronic signal compatible with the medium before its transmission.
- A microphone changes voice signals (sound waves) into an analog voltage of varying frequency and amplitude, which is then passed over wires to a speaker or headphones.
- A video camera generates an analog signal , which is then transmitted over a coaxial cable.
- Binary data is generated by a keyboard attached to a computer, which is then transmitted on cables to peripherals such as a printer or to other computers over a LAN.
- Regardless of whether the original information or intelligence signals are analog or digital, they are all referred to as baseband signals.

Baseband Transmission

- In a communication system, baseband information signals can be sent directly and unmodified over the medium or can be used to modulate a carrier for transmission over the medium.
- Putting the original voice, video, or digital signals directly into the medium is referred to as baseband transmission.
- For example, in many telephone and intercom systems, it is the voice itself that is placed on the wires and transmitted over some distance to the receiver.
- In most computer networks, the digital signals are applied directly to coaxial or twisted-pair cables for transmission to another computer.

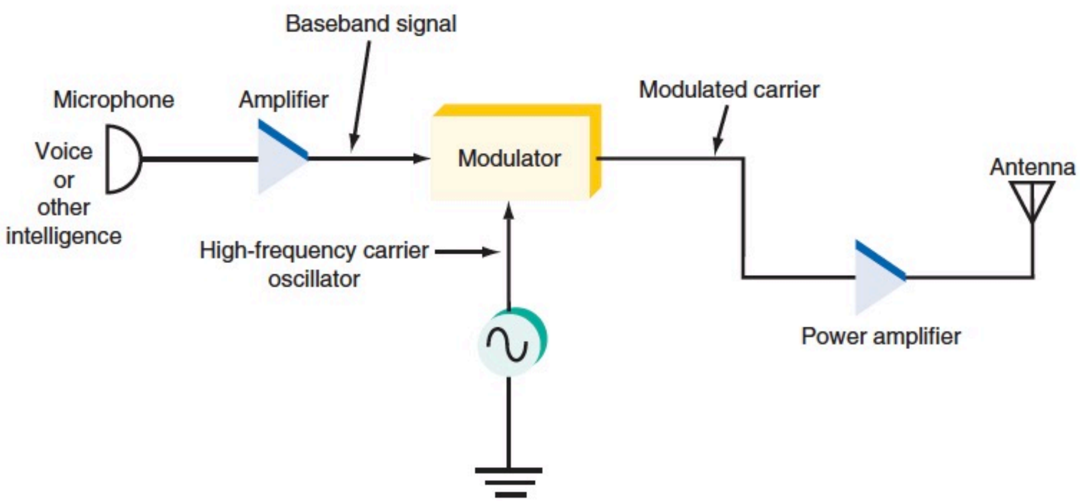
Carrier

- In many instances, baseband signals are incompatible with the medium.
- Although it is theoretically possible to transmit voice signals directly by radio, realistically it is impractical.
- Therefore, the baseband information signal is normally used to modulate a high-frequency signal called a carrier.
- The higher-frequency carriers radiate into space more efficiently than the baseband signals themselves.
- Such wireless signals consist of both electric and magnetic fields.
- These electromagnetic signals, which are able to travel through space for long distances, are also referred to as radio-frequency (RF) waves, or just radio waves.

Broadband Transmission (1)

- Modulation is the process of having a baseband voice, video, or digital signal modify another, higher-frequency signal, the carrier. The process is illustrated in Figure below.
- The information or intelligence to be sent is said to be impressed upon the carrier.
- The carrier is usually a sine wave generated by an oscillator.

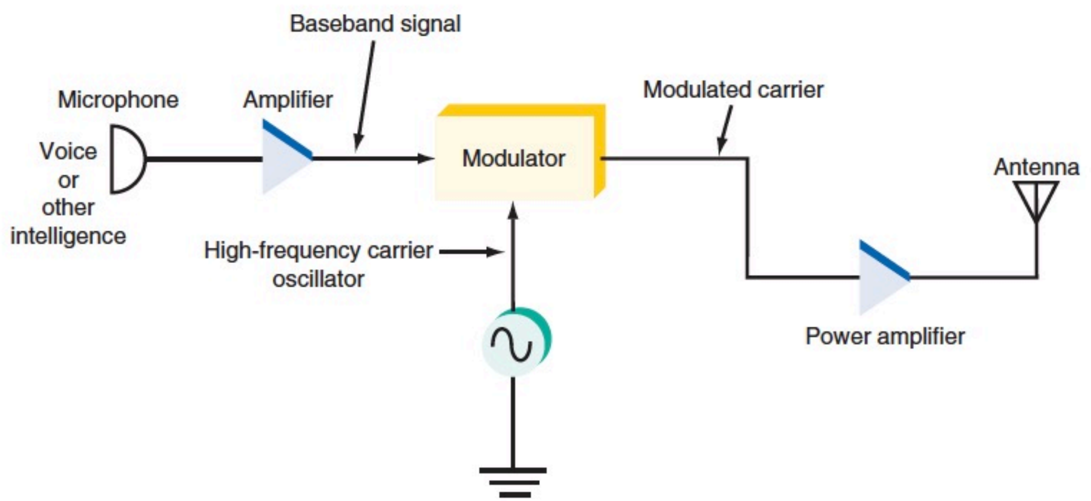
Figure 1-7 Modulation at the transmitter.



Broadband Transmission (2)

- The carrier is fed to a circuit called a modulator along with the baseband intelligence signal.
- The intelligence signal changes the carrier in a unique way. The modulated carrier is amplified and sent to the antenna for transmission.
- This process is called broadband transmission.

Figure 1-7 Modulation at the transmitter.



Broadband Transmission (3)

- Consider the common mathematical expression for a sine wave:

$$v = V_p \sin(2\pi f t + \theta) \quad \text{or} \quad v = V_p \sin(\omega t + \theta)$$

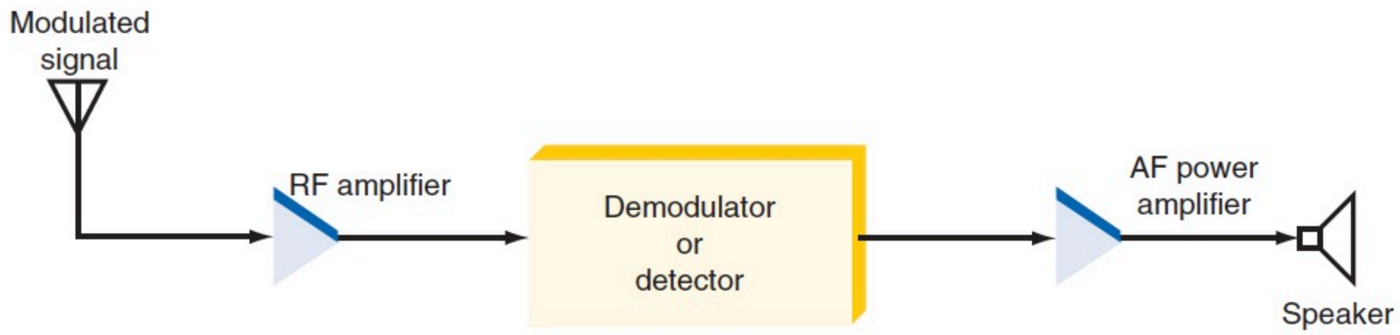
where v = instantaneous value of sine wave voltage
V_p = peak value of sine wave
f = frequency, Hz
ω = angular velocity = $2\pi f$
t = time, s
$\omega t = 2\pi f t$ = angle, rad ($360° = 2\pi$ rad)
θ = phase angle

- The three ways to make the baseband signal change the carrier sine wave are to vary its amplitude, vary its frequency, or vary its phase angle.
- The most common methods of modulation are:
    - Amplitude Modulation (AM)
    - Frequency Modulation (FM)
    - Phase Modulation (PM).

Broadband Transmission (4)

- At the receiver, the carrier with the intelligence signal is amplified and then demodulated to extract the original baseband signal.
- Another name for the demodulation process is detection.

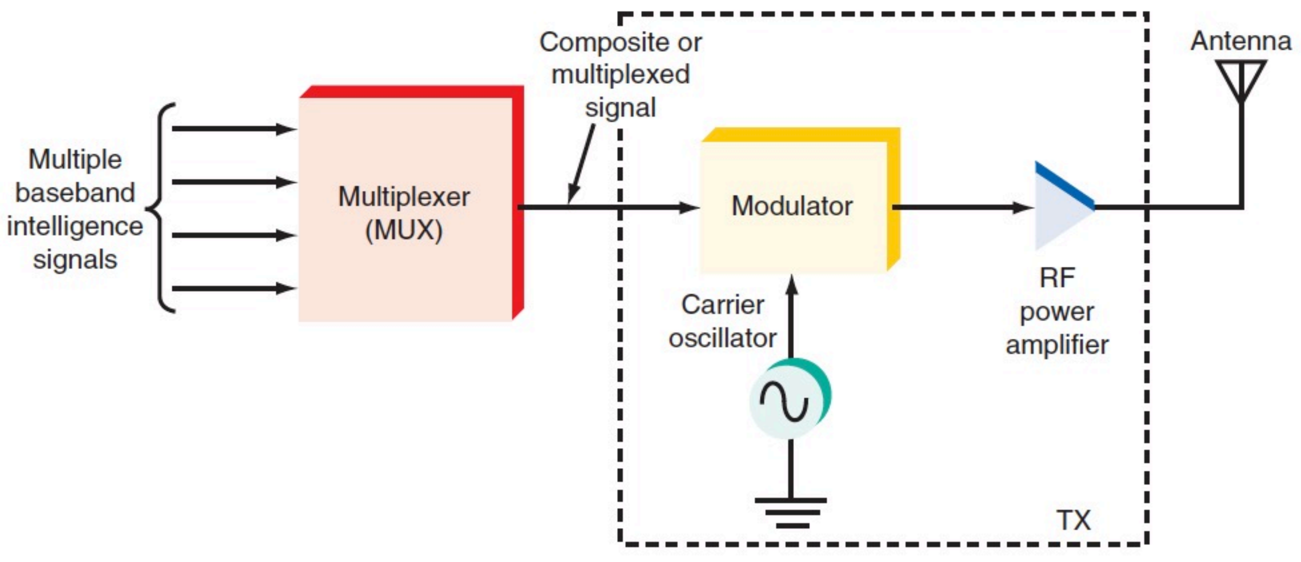
Figure 1-10 Recovering the intelligence signal at the receiver.



Multiplexing - Transmitter

- Multiplexing is the process of allowing two or more signals to share the same medium or channel.
- A multiplexer converts the individual baseband signals to a composite signal that is used to modulate a carrier in the transmitter.

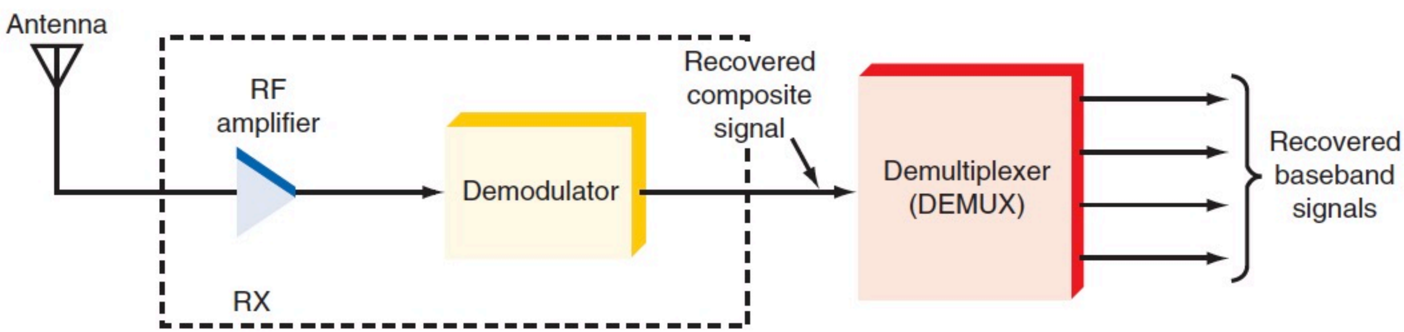
Figure 1-11 Multiplexing at the transmitter.



Multiplexing - Receiver

- At the receiver, the composite signal is recovered at the demodulator, then sent to a demultiplexer where the individual baseband signals are regenerated.

Figure 1-12 Demultiplexing at the receiver.



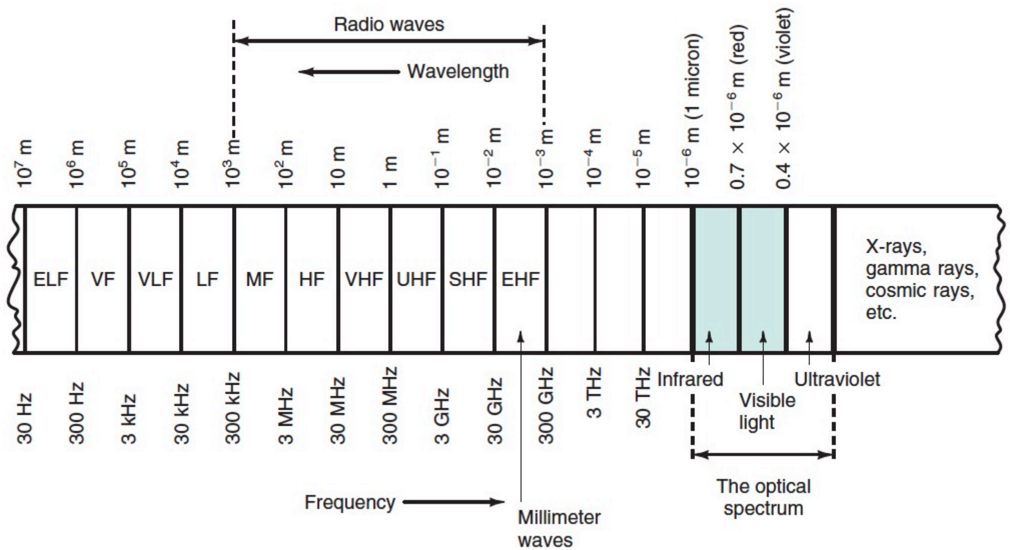
- There are three basic types of multiplexing:
  - Frequency division
  - Time division
  - Code division

Electromagnetic Spectrum

- Electromagnetic waves are signals that oscillate; i.e., the amplitudes of the electric and magnetic fields vary at a specific rate.
- The field intensities fluctuate up and down, and the polarity reverses a given number of times per second.
- The electromagnetic waves vary sinusoidally. Their frequency is measured in cycles per second (cps) or hertz (Hz).
- These oscillations may occur at a very low frequency or at an extremely high frequency.
- The range of electromagnetic signals encompassing all frequencies is referred to as the electromagnetic spectrum.

Radio Frequencies

- All electrical and electronic signals that radiate into free space fall into the electromagnetic spectrum.
- Figure below shows the entire electromagnetic spectrum, giving both frequency and wavelength.
- Within the middle ranges are located the most commonly used **radio frequencies** for two-way communication, TV, cell phones, wireless LANs, radar, and other applications.



Electronic Communication

- Figure below is a listing of the generally recognized segments in the spectrum used for electronic communication.

Name	Frequency	Wavelength
Extremely low frequencies (ELFs)	30–300 Hz	10^7–10^6 m
Voice frequencies (VFs)	300–3000 Hz	10^6–10^5 m
Very low frequencies (VLFs)	3–30 kHz	10^5–10^4 m
Low frequencies (LFs)	30–300 kHz	10^4–10^3 m
Medium frequencies (MFs)	300 kHz–3 MHz	10^3–10^2 m
High frequencies (HFs)	3–30 MHz	10^2–10^1 m
Very high frequencies (VHFs)	30–300 MHz	10^1–1 m
Ultra high frequencies (UHFs)	300 MHz–3 GHz	1–10^{-1} m
Super high frequencies (SHFs)	3–30 GHz	10^{-1}–10^{-2} m
Extremely high frequencies (EHFs)	30–300 GHz	10^{-2}–10^{-3} m
Infrared	—	0.7–10 μm
The visible spectrum (light)	—	0.4–0.8 μm

Units of Measure and Abbreviations:

kHz = 1000 Hz

MHz = 1000 kHz = 1×10^6 = 1,000,000 Hz

GHz = 1000 MHz = 1×10^6 = 1,000,000 kHz

= 1×10^9 = 1,000,000,000 Hz

m = meter

$\mu m = \text{micrometer} = \frac{1}{1{,}000{,}000} m = 1 \times 10^{-6} m$

Frequency

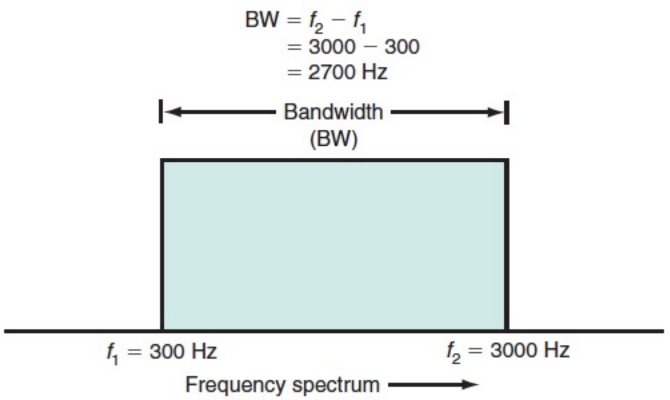
- Frequency is the number of times a particular phenomenon occurs in a given period of time.
- In electronics, frequency is the number of cycles of a repetitive wave that occurs in a given time period.
- A cycle consists of two voltage polarity reversals, current reversals, or electromagnetic field oscillations. The cycles repeat, forming a continuous but repetitive wave.
- Frequency is measured in cycles per second (cps).
- In electronics, the unit of frequency is the hertz, named for the German physicist Heinrich Hertz, who was a pioneer in the field of electromagnetics.

Wavelength

- Wavelength is the distance occupied by one cycle of a wave, and it is usually expressed in meters.
- Wavelength is measured between identical points on succeeding cycles of a wave.
- If the signal is an electromagnetic wave, one wavelength is the distance that one cycle occupies in free space. It is the distance between adjacent peaks or valleys of the electric and magnetic fields making up the wave.
- Wavelength is also the distance traveled by an electromagnetic wave during the time of one cycle.
- Electromagnetic waves travel at the speed of light, or 299,792,800 m/s. The speed of light and radio waves in a vacuum or in air is usually rounded off to 300,000,000 m/s (3 3 $x10^8$ m/s).
- The speed of transmission in media such as a cable is less.

Bandwidth

- Bandwidth (BW) is that portion of the electromagnetic spectrum occupied by a signal.
- It is also the frequency range over which a receiver or other electronic circuit operates.
- More specifically, bandwidth is the difference between the upper and lower frequency limits of the signal or the equipment operation range.
- Figure below shows the bandwidth of the voice frequency range from 300 to 3000 Hz. The upper frequency is f_2 and the lower frequency is f_1. The bandwidth, then, is: $BW = f_2 - f_1$



Channel Bandwidth (1)

- When information is modulated onto a carrier somewhere in the electromagnetic spectrum, the resulting signal occupies a small portion of the spectrum surrounding the carrier frequency.
- The modulation process causes other signals, called sidebands, to be generated at frequencies above and below the carrier frequency by an amount equal to the modulating frequency.
- For example, in AM broadcasting, audio signals up to 5 kHz can be transmitted.
- If the carrier frequency is 1000 kHz, or 1 MHz, and the modulating frequency is 5 kHz, sidebands will be produced at 1000 - 5 = 995 kHz and at 1000 + 5 = 1005 kHz.

Channel Bandwidth (2)

- In other words, the modulation process generates other signals that take up spectrum space.
- It is not just the carrier at 1000 kHz that is transmitted. Thus the term bandwidth refers to the range of frequencies that contain the information.
- The term channel bandwidth refers to the range of frequencies required to transmit the desired information.

Advantage of using the Higher Frequencies

- The benefit of using the higher frequencies for communication carriers is that:

  a signal of a given bandwidth represents a smaller percentage of the spectrum at the higher frequencies than at the lower frequencies.
- For example, at 1000 kHz, the 10-kHz-wide AM signal represents 1 percent (1%) of the spectrum:
- But at 1 GHz, or 1,000,000 kHz, it represents only one-thousandth of 1 percent (0.001%):
- In practice, this means that there are many more 10-kHz channels at the higher frequencies than at the lower frequencies.
- In other words, there is more spectrum space for information signals at the higher frequencies.

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References

- Louis E. Frenzel, *"*Principles of Electronic Communication Systems*"*, McGraw-Hill Education*, 4th ed. – Chapter 1*