Unit-1

RF Signals and Modulation

This chapter covers the following topics

- ✓ **Introduction to Mobile Computing**— Terminology, Definitions, Components, Attribute of Mobility and Limitations
- ✓ **Introduction of Wireless Communication** — Data Transmission Signals – Basics Channel Capacity, Analog and Digital, Five Basic Propagation Mechanisms Transmission Media.
- ✓ **Understanding Frequency** — Continuous frequency spectrum, Understanding RF Power and dB, Effective isotropic radiated power (EIRP), Understanding Power Levels at the Receiver and Carrying Data Over an RF Signal

1. Introduction

Mobile computer with wireless network is current trend in human-computer interaction technology as well as the social lifestyle. The smart-phone is the first mobile computer and smart pad comes next replacing the notebook which is replacing the desk top computer. Mobile computing is composed of mobile communication, mobile hardware, and mobile software. Communication issues include ad hoc and infrastructure networks as well as communication properties, protocols, data formats and concrete technologies.

Hardware includes mobile devices or device components. Mobile software deals with the characteristics and requirements of mobile applications.

2. Mobile computing

2.1 Terminology

Mobile

Mobile simply describes a computing device that is not restricted to a desktop. A **mobile device** may be a PDA, a “smart” cell phone or Web phone, a laptop computer, a tablet PC or any one of numerous other devices that allow the user to complete computing tasks without being physically connected to a network. Mobile computing does not necessarily require wireless communication. In fact, it may not require communication between devices at all.

Wireless

Wireless refers to the method of transferring information between a computing device, such as a personal data assistant (PDA), and a data source, such as an agency database server, without a physical connection. Not all wireless communications technologies are mobile. For example, lasers are used in wireless data transfer between buildings, but cannot be used in mobile communications at this time.

Mobility

Mobility originated from the desire to move either toward resources or away from scarcity. The need for information anywhere-anytime has been a driving force (i.e., reasons) for the increasing growth in Web and Internet technology, wireless communication, and portable computing devices.

2.2 Mobile Computing alternative definitions:

1) Mobile computing is about both physical and logical computing entities that move. Physical entities are computers that change locations while logical entities are instances of a running user application or a mobile agent.
2) Mobile Computing is a technology that allows transmission of data, voice, and video via a computer or any other wireless-enabled device.
3) Mobile Computing is using a computer (of one kind or another) while on the move
4) Mobile Computing is when a work process is moved from a normal fixed position to a more dynamic position.
5) Mobile Computing is when a work process is carried out somewhere where it was not previously possible
6) Mobile Computing is an umbrella term used to describe technologies that enable people to access services anytime and anywhere
7) It can be defined as a computing environment of physical mobility.

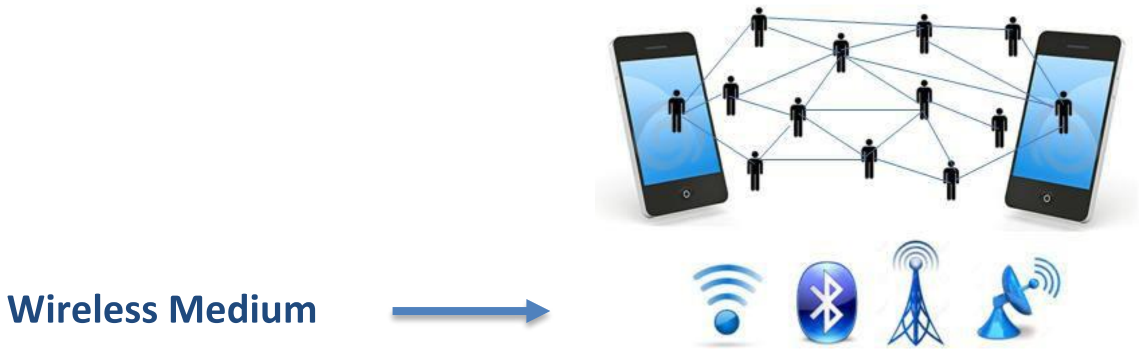


Figure 1: Mobile Computing

2.3 Mobile Computing involves the following:

- **Mobile communication**
  - Mobile communication refers to the infrastructure put in place to ensure that seamless and reliable communication.
  - These would include devices such as protocols, services, bandwidth, and portals necessary to facilitate and support the stated services.
  - Media is unguided/wireless; the infrastructure is basically radio wave-oriented.
- **Mobile Hardware**
  - Mobile hardware includes mobile devices or device components that receive or access the service of mobility.
  - Devices are laptops, smartphones, tablet Pc's, Personal Digital Assistants.
  - These devices have capable of sending and receiving signals.
  - These devices are configured to operate in full- duplex means sending and receiving signals at the same time in wireless network.
- **Mobile Software**
  - Mobile software is the actual program that runs on the mobile hardware.

- In other terms, it is the operating system of the appliance.
- It's the essential component that operates the mobile device.
- It deals with the characteristics and requirements of mobile applications.

For example, the manufacturers of Apple's iPhone OS, Google's Android' Microsoft Windows Mobile, Research In Motion's Blackberry OS.

2.4 Attribute of Mobility

- **User Mobility**
  - User should be able to move from one physical location to another location and use the same service.
  - **Example**: User moves from London to New York and uses the Internet in either place to access the corporate application.
- **Network Mobility**
  - User should be able to move from one network to another network and use the same service.
  - **Example**: User moves from Hong Kong to Singapore and uses the same GSM phone to access the corporate application.
- **Bearer Mobility**
  - User should be able to move from one bearer to another while using the same service.
  - **Example**: User is unable to access the WAP bearer due to some problem in the GSM network then he should be able to use voice or SMS bearer to access that same corporate application.
  - Like Hike Messenger
- **Device Mobility**
  - User should be able to move from one device to another and use the same service.
  - **Example**: User is using a PC to do his work. During the day, while he is on the street he would like to use his mobile to access the corporate application.
- **Session Mobility**
  - A user session should be able to move from one user - agent environment to another.
  - **Example**: An unfinished session moving from a mobile device to a desktop computer is a good example.
- **Service Mobility**
  - User should be able to move from one service to another.
  - **Example**: User is writing a mail. Suddenly, he needs to refer to something else. In a PC, user simply opens another service and moves between them. User should be able to do the same in small wireless devices.
- **Host Mobility**
  - User should be able to move while the device is a host computer.
  - **Example**: The laptop computer of a user is a host for grid computing network. It is connected to a LAN port. Suddenly, the user realizes that he needs to leave for an offsite meeting. He disconnects from the LAN and should get connected to wireless LAN while his laptop being the host for grid computing network.

2.5 Limitation of Mobile Computing

- **Limitations of the wireless network**
  - Heterogeneity of fragmented networks
  - Frequent disconnections
  - Limited communication bandwidth

- **Limitations imposed by mobility**
  - Lack of mobility awareness by system / applications
  - Route breakages

- **Limitations of the mobile computer**
  - Short battery lifetime
  - Limited capacities (memory, processing speed, etc.)

3. Introduction of Wireless Communication

- **Wireless Communication** involves the transmission of information over a distance without the help of wires, cables or any other forms of electrical conductors.
- It is a term that connecting and communicating between two or more devices using a wireless signal through wireless communication technologies and devices.

Figure 2: Wireless Communication

- The transmitted distance can be anywhere between a few meters (**for example:** a television's remote control) and thousands of kilometers (**for example:** radio communication).
- Wireless communication can be used for cellular telephony, wireless access to the internet, wireless home networking, and so on.

3.1 Applications of Wireless Communication

1. GPS Units
2. Wireless keyboard-mouse.
3. Headsets
4. Radio Receivers
5. Satellite Television
6. Broadcast Television
7. Cordless Telephones etc…

3.2 Signals - Basics

- **Wave** can be described as a disturbance that travels and transfers energy through a matter or space from one location to another.

  Example 1:

  A group of people at a football stadium jumps up and sits back down as in Figure (a). They seem like a wave travelling around the stadium. However, all individual people remain at their seats.

  Example 2:

  Sound wave pulse passes through, the particles in the air oscillate back and forth about their equilibrium positions but it is the disturbance which travels, not the individual particles in the medium as in Figure (b).

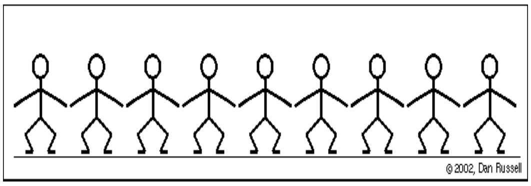


Figure (a)

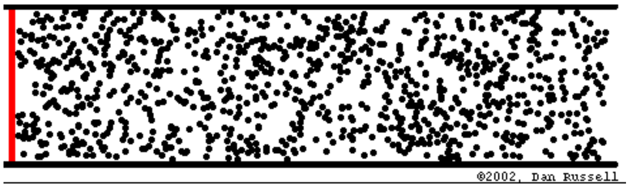
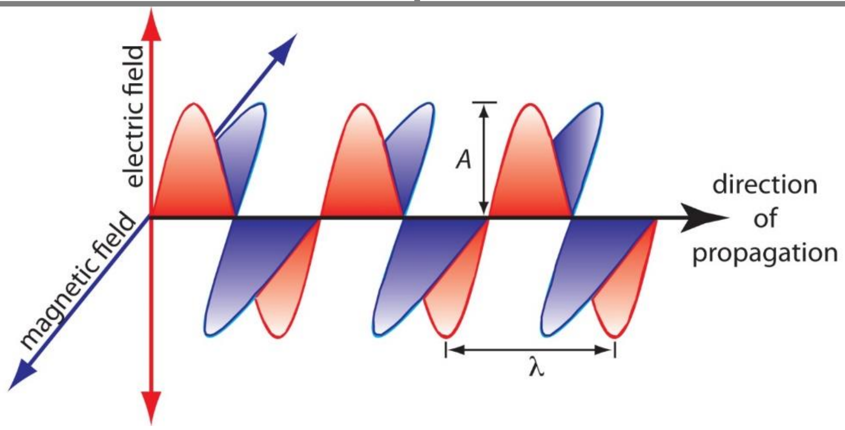


Figure (b)

- **Electromagnetic wave**

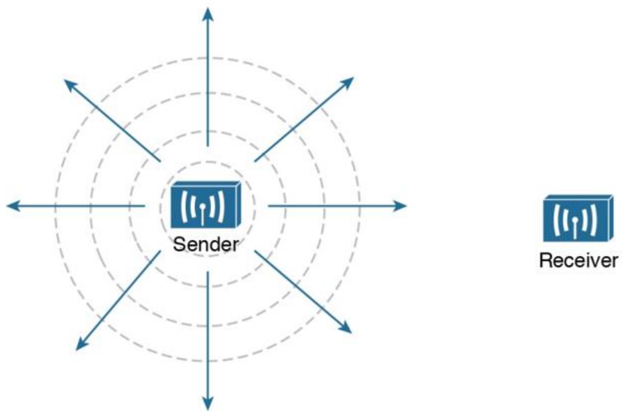
  Electromagnetic waves or EM waves are waves that are created as a result of vibrations between an electric field and a magnetic field. In other words, EM waves are composed of oscillating magnetic.

  Electromagnetic waves are formed when an electric field comes in contact with a magnetic field. They are hence known as ‘electromagnetic’ waves. The electric field and magnetic field of an electromagnetic wave are perpendicular (at right angles) to each other. They are also perpendicular to the direction of the EM wave.



An electromagnetic wave can travel through anything - be it air, a solid material or vacuum. It does not need a medium to propagate or travel from one place to another. Mechanical waves (like sound waves or water waves), on the other hand, need a medium to travel. EM waves are 'transverse' waves. This means that they are measured by their amplitude (height) and wavelength (distance between the highest/lowest points of two consecutive waves).

The waves produced expand outward in a spherical shape. They will eventually reach the receiver, in addition to many other locations in other directions.



At the receiving end of a wireless link, the process is reversed. As the electromagnetic waves reach the receiver's antenna, they induce an electrical signal. If everything works right, the received signal will be a reasonable copy of the original transmitted signal.

- **Signals**

  A signal is an electrical or electromagnetic current that is used for carrying data from one device or network to another. It is the key component behind virtually all:

  - Communication and Computing
  - Networking and Electronic devices

A signal can be either analog or digital. Here, we are concerned with electromagnetic signals used as a means to transmit information. An electromagnetic signal is a function of time, but it can also be expressed as a function of frequency; that is, the signal consists of components of different frequencies.

- Time Domain
- Frequency Domain

The frequency domain view of a signal is far more important to an understanding of data transmission than a time domain view. As a function of time, an electromagnetic signal can be either analog or digital.

1) **An analog signal** is one in which the signal intensity varies in a smooth fashion over time. In other words, there are no breaks or discontinuities in the signal.
2) **A digital signal** is one in which the signal intensity maintains a constant level for some period of time and then changes to another constant level.

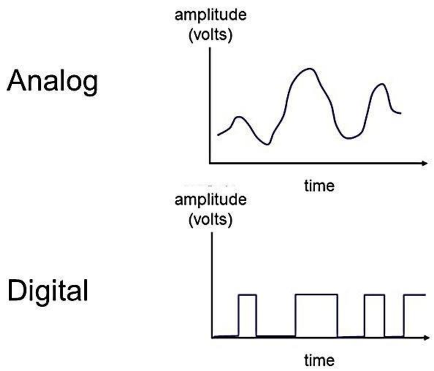


Figure 3: Analog and Digital Waveforms

Figure 3 shows examples of both kinds of signals. The analog signal might represent speech, and the digital signal might represent binary 1s and 0s.

1) **Periodic signal**: An analog or digital signal pattern that repeats over time.
2) **Aperiodic signal**: An analog or digital signal pattern that doesn't repeat over time.

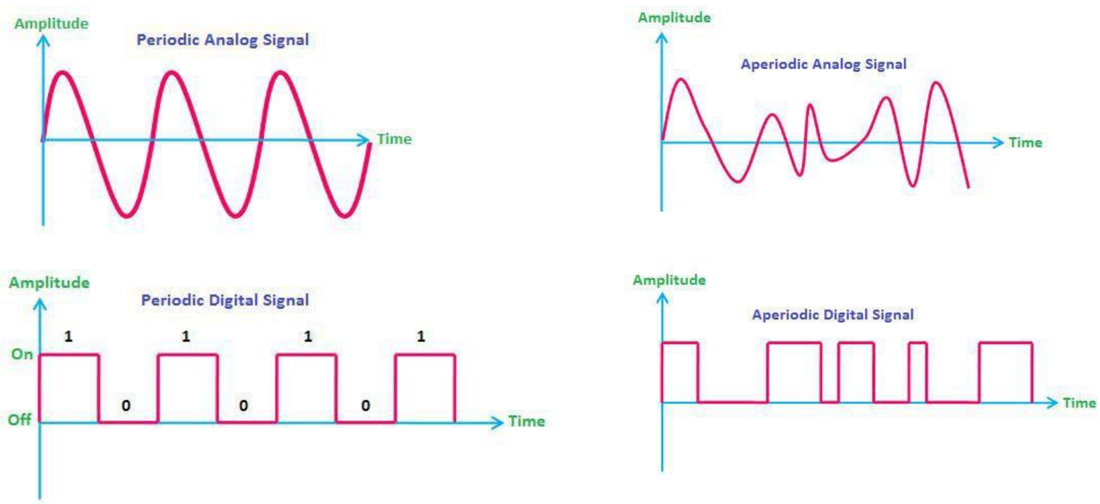
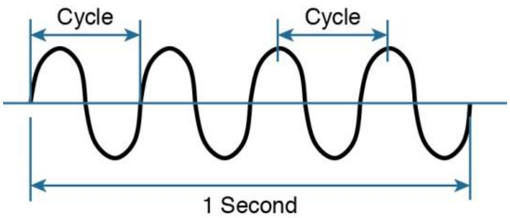


Figure 4: Periodic and Aperiodic Signal

- **Properties of Waves**

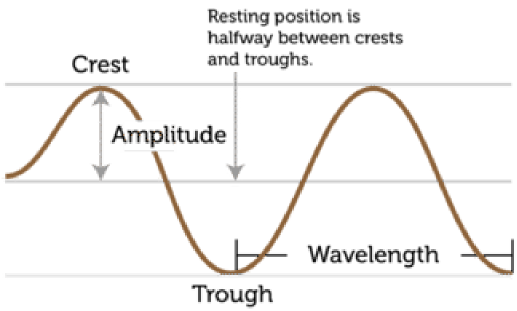
A cycle : is measured from the center of one peak to the center of the next peak.



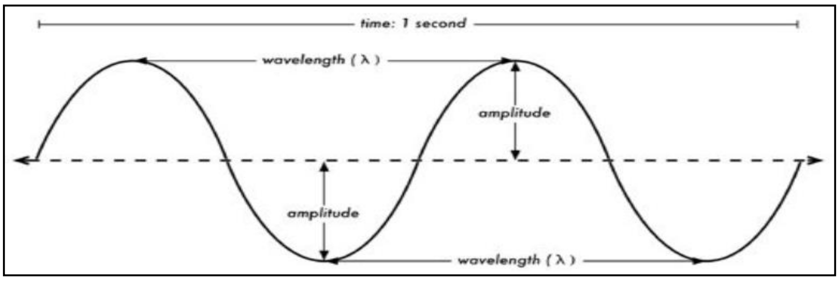
A hertz (Hz) : is the frequency unit and is nothing other than one cycle per second.

Unit	Abbreviation	Meaning
Hertz	Hz	Cycles per second
Kilohertz	kHz	1000 Hz
Megahertz	MHz	1,000,000 Hz
Gigahertz	GHz	1,000,000,000 Hz

Peak amplitude (*A*): Maximum value or strength of the signal over time. Typically measured in volts.



Frequency (*f*): Rate, in cycles per second, or Hertz (Hz), at which the signal repeats.



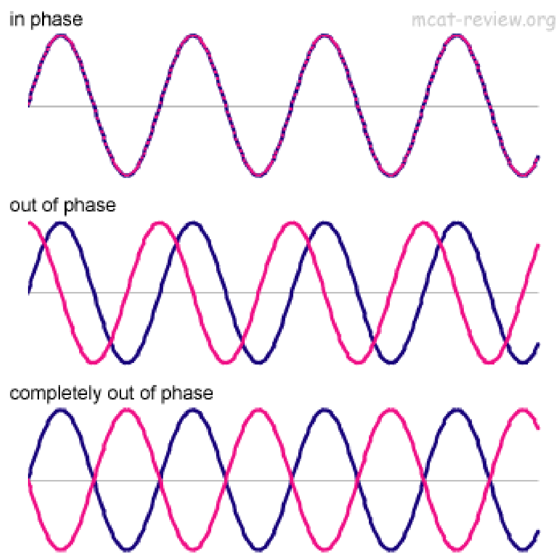
The frequency is 2 cycles per second, or 2 Hz, while the speed is 1 m/s.

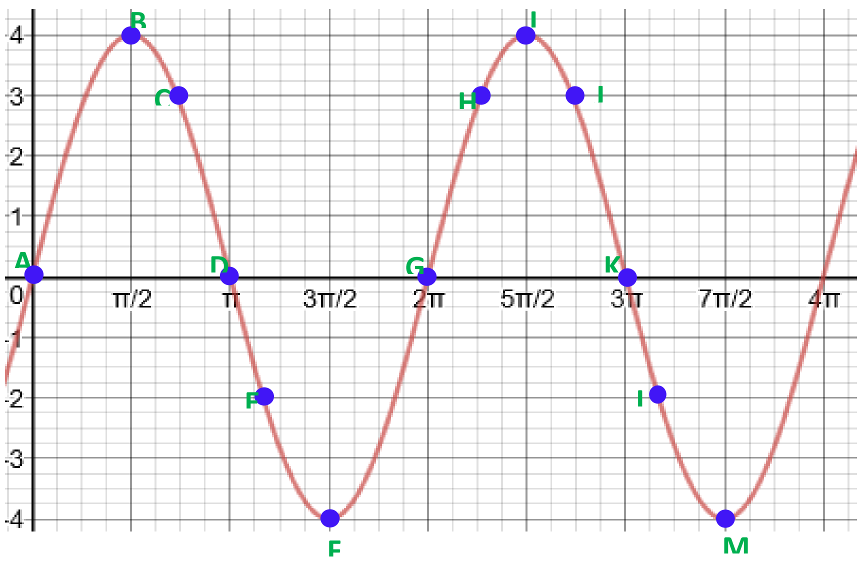
Phase (ϕ): A measurement of the relative position in time within a single period of a signal. In other word, it used to describe a location of a point on a single periodic waveform cycle

1. Two points are said to be in-phase if they are in the same place and do the same thing, i.e.

the direction of the wave are the same.

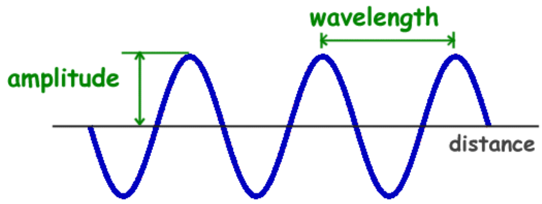
2. Two points are said to be out-phase if even they are in the same place, they not doing the same thing, i.e. the direction of the wave are not the same.



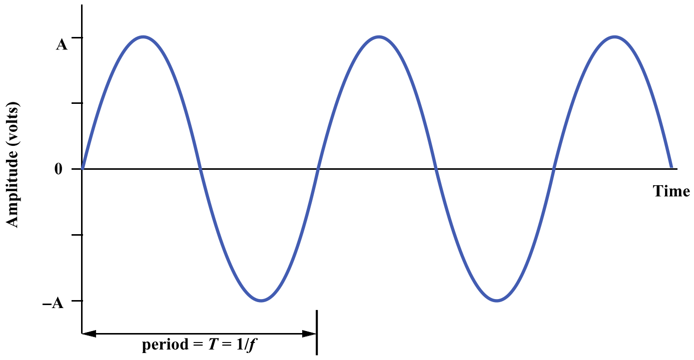


- A and G are in-phase
- B and I are in-phase
- C and J are in-phase
- D and K are in-phase
- E and L are in-phase
- F and M are in-phase
- A and D are out-phase
- C and H are out-phase
- G and K are out-phase

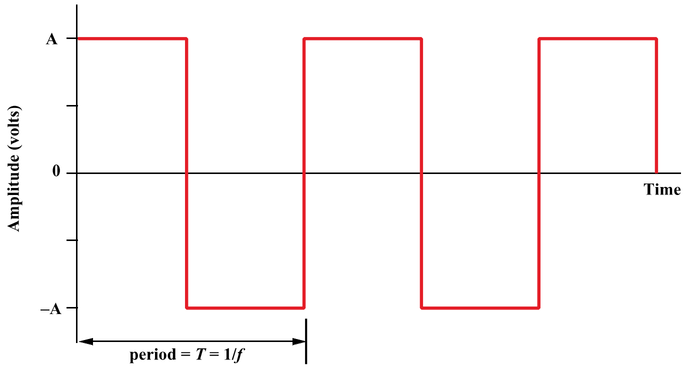
Wavelength (λ) is the distance between identical points in adjacent cycles of a waveform signal propagated in space or along a wire, usually peak-to-peak or trough-to-trough.



Wave period (*T*) is just how much time wave takes for one cycle to pass and the units are always in terms of time. The faster a wave moves, its wave period becomes smaller. *T = 1/f*



(a) Sine wave



(b) Square wave

Wave Speed: speed = Frequency * Wavelength**.**

Example 1:

If a wave on water travels at one metre per second, and it oscillates five times per second, then each wave will be twenty centimetres long:

*1 metre/second = 5 cycles/second * λ*

λ = 1 / 5 metres

λ = 0.2 metres = 20 cm

Example 2:

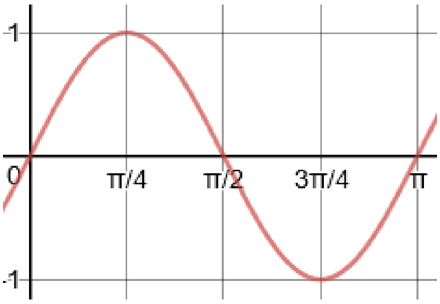
Knowing the speed of light, we can calculate the wavelength for a given frequency. Let us take the example of the frequency of 802.11b wireless networking, which is *f = 2.4 GHz = 2,400,000,000* cycles / second*.* Then the wavelength is given as

wavelength (λ) = c / f = $3*10^8$ / $2.4*10^9$ = $1.25*10^{-1}$ m = 12.5 cm

The fundamental equation of a sine wave

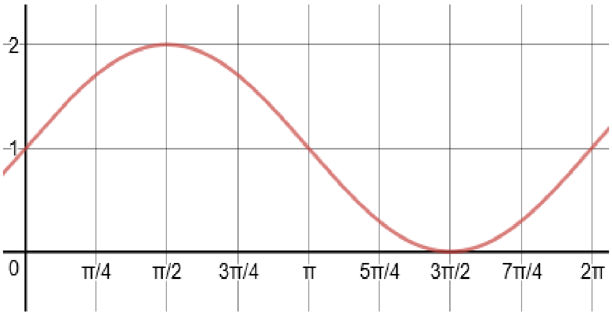
y = A sin(Bx + C) + D

- amplitude is **A**
- period **P** is **2π/B**
- phase shift is Bx +C=0. That is x= **−C/B**
- vertical shift is **D**



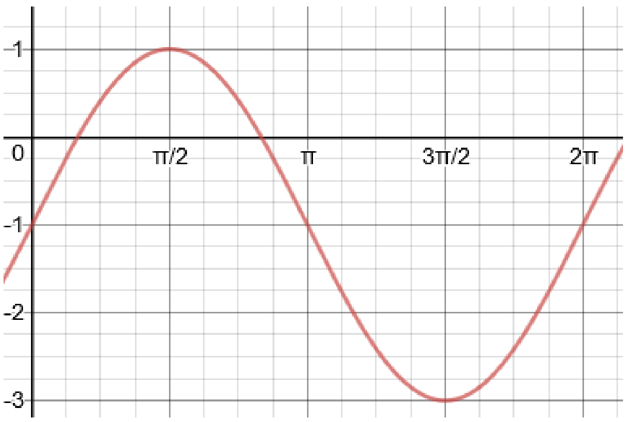
Y=+sin(2x

- amplitude is **A=1**
- period **P=2π/2=π**
- phase shift is Bx+C=0 → 2x+0=0 →x=0
- vertical shift is **D =0**
- Range [D+A, D-A]=[0+1,0-1]=[1,-1]



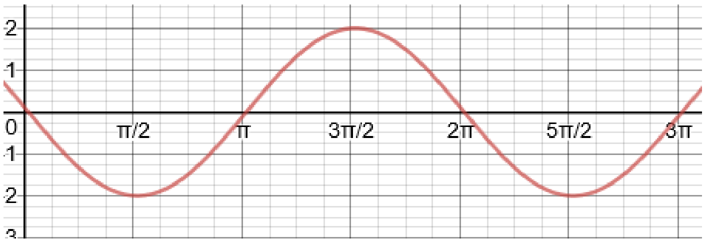
Y=+sin(x)+1

- amplitude is **A=1**
- period **P=2π/1=2π**
- phase shift is Bx+C=0 → x+0=0 →x=0
- vertical shift is **D =1**.
- Range [D+A, D-A]=[1+1,1-1]=[2,0]



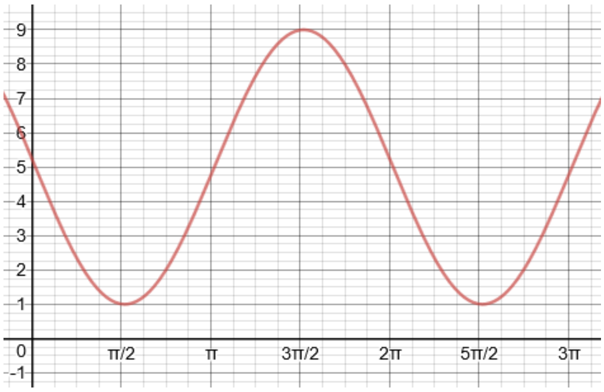
Y=2sin(x)-1

- amplitude is **A=2**
- period **P=2π/1=2π**
- phase shift is Bx+C=0 → x+0=0 →x=0
- vertical shift is **D = -1**.
- Range [D+A, D-A]=[-1+2,-1-2]=[1,-3]



$Y=2\sin(x-\pi)$

- amplitude is **A=2**
- period **$P=2\pi/1=2\pi$**
- Horizontal shift is Bx+C=0 → x-**π=0** → **x=π**
- vertical shift is **D =0**.
- Range [D+A, D-A]=[0+2,0-2]=[2,-2]



$Y=-4\sin(1/2x-1/2\pi)+5$

- amplitude is **A=4**
- period **$P=2\pi/1/2=4\pi$**
- Horizontal shift is Bx+C=0 → 1/2x-1/2**π**=0 →x=**π**
- vertical shift is **D = 5**.
- Range [D+A, D-A]=[5+4,5-4]=[9,1]

3.3 Analog and Digital Data Transmission

- The terms analog and digital correspond, roughly, to continuous and discrete, respectively.
- These two terms are used frequently in data communications in at least three contexts:
  - Data
  - Signals
  - Transmission
- **Data**: data as entities that convey meaning, or information.
- **Signals** are electric or electromagnetic representations of data.
- **Transmission** is the communication of data by the propagation and processing of signals.
- **Analog data** take on continuous values in some interval.
  - **For example**, voice and video are continuously varying patterns of intensity.
  - Most data collected by sensors, such as temperature and pressure, are continuous valued.
- **Digital data** take on discrete values.
  - **Examples** are text and integers.

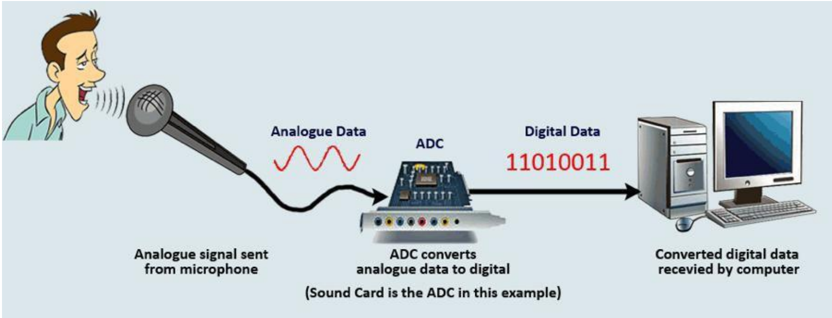
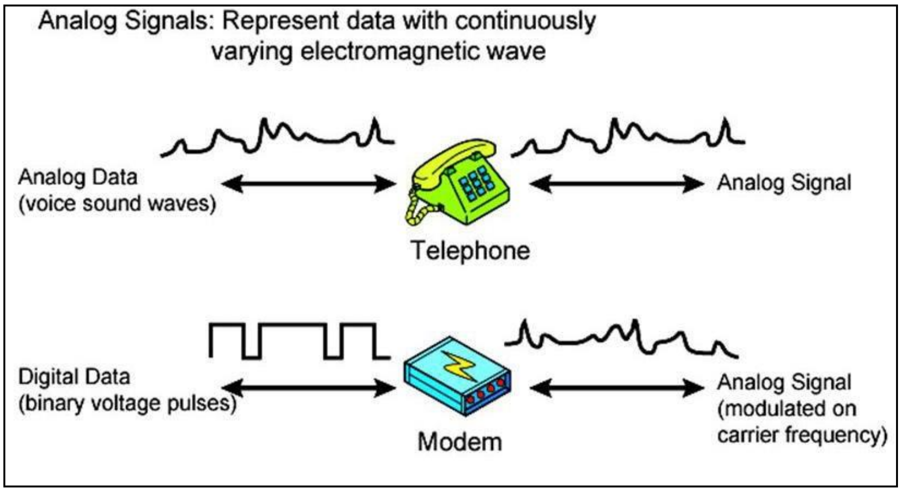
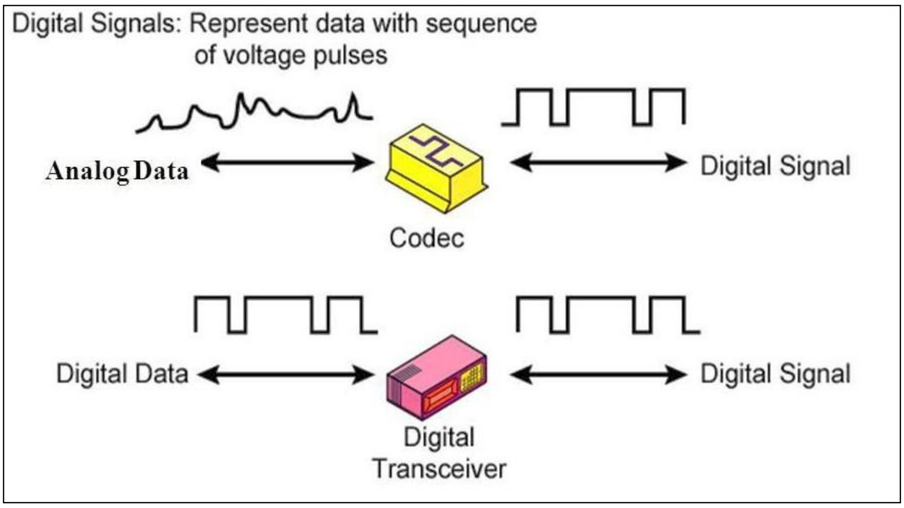


Figure 6: Analog and Digital Data

- **An analog signal** is a continuously varying electromagnetic wave that may be propagated over a variety of media, depending on frequency.
    - **Examples** are copper wire media, such as twisted pair and coaxial cable; fiber optic cable; and atmosphere or space propagation (wireless).





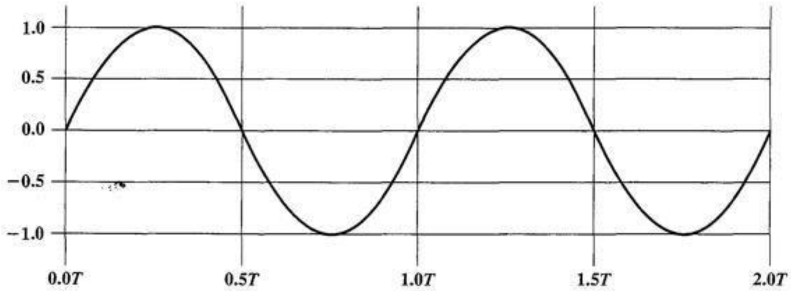
- **A digital signal** is a sequence of voltage pulses that may be transmitted over a copper wire medium.
    - **Example**, a constant positive voltage level may represent binary 0 and a constant

negative voltage level may represent binary 1.

- The principal advantages of digital signaling are that it is generally cheaper than analog signaling and is less susceptible to noise interference.
- The principal disadvantage is that digital signals suffer more from attenuation than do analog signals.

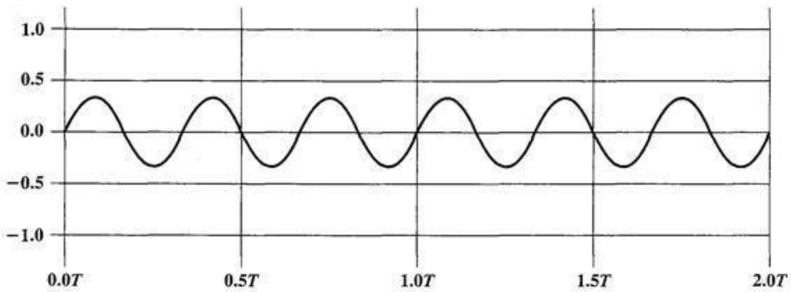
- **In frequency domain view**, A signals lie in the frequency range, theoretically signals are composed of many sinusoidal signals with different frequencies (like Fourier Series).
- It is actually composed of infinite sinusoidal signal at different amplitudes, frequencies, and phases. An electromagnetic signal can be made up of **many frequencies**.

$\sin(2\pi f t)$

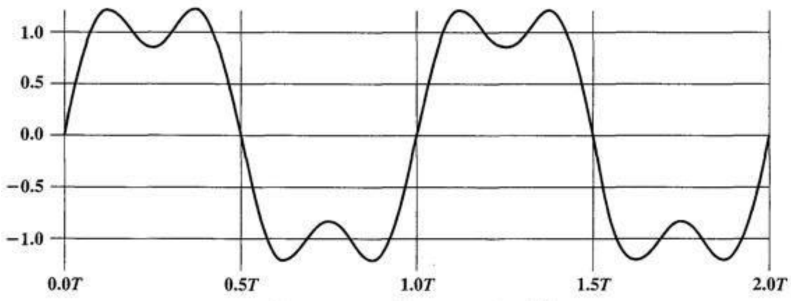


(a) $\sin(2\pi ft)$

$(\frac{1}{3})\sin(2\pi(3f)t)$

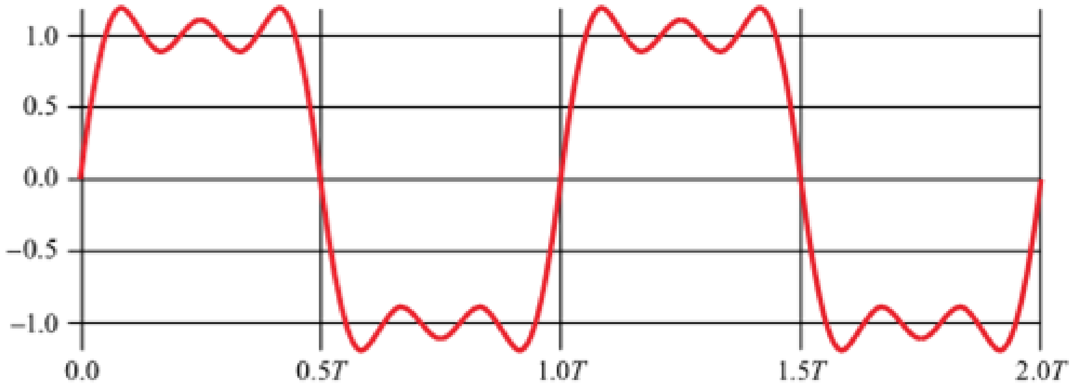


(b) $(1/3)\sin(2\pi(3f)t)$

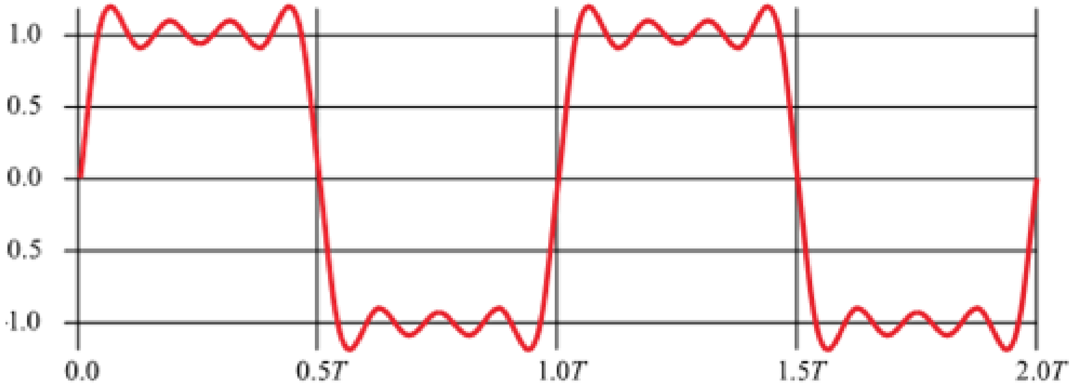


$$s(t) = (\frac{4}{\pi})(\sin(2\pi f t) + (\frac{1}{3})\sin(2\pi(3f)t))$$

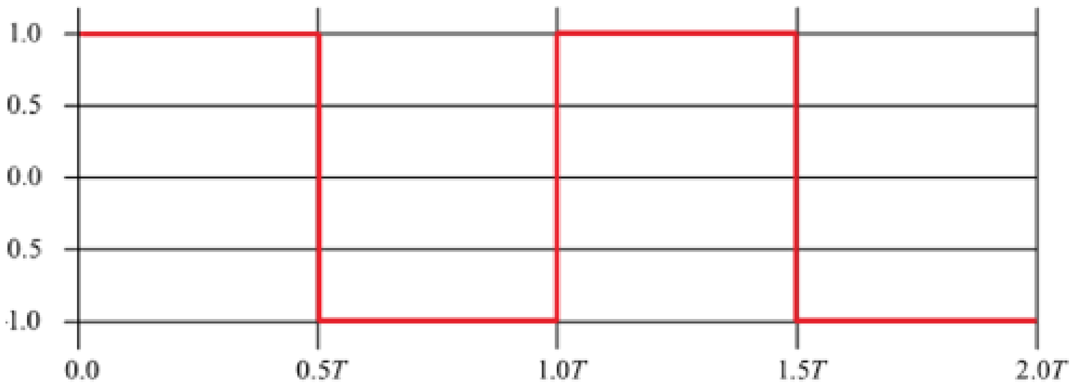
Frequency Domain View



(a) $(4/\phi)\ [\sin(2\phi ft) + (1/3)\sin(2\phi(3f)t) + (1/5)\sin(2\phi(5f)t)]$



(b) $(4/\phi)\ [\sin(2\phi ft) + (1/3)\sin(2\phi(3f)t) + (1/5)\sin(2\phi(5f)t) + (1/7)\sin(2\phi(7f)t)]$



(c) $(4/\phi)\ \Sigma(1/k)\sin(2\phi(kf)t)$, for k odd

3.4 Channel Capacity

- The maximum rate at which data can be transmitted over a given communication path, or channel, under given conditions is referred to as the channel capacity.
- There are four concepts here that we are trying to relate to one another:
- **Data rate**: This is the rate, in bits per second (bps), at which data can be communicated.
    - Data rate depends upon 3 factors:
        1. The bandwidth available
        2. Number of levels in digital signal
        3. The quality of the channel – level of noise
- **Bandwidth**: a measure of the width of a range of frequencies, measured in Hertz.
- **Noise**: We are concerned with the average level of noise over the communications path.
- **Error rate**: This is the rate at which errors occur, where an error is the reception of a 1 when a 0 was transmitted or the reception of a 0 when a 1 was transmitted.

Shannon and Nyquist Capacity Formula

- Two theoretical formulas were developed to calculate the data rate:
    1. **Nyquist** for a noiseless channel
    2. **Shannon** for a noisy channel
- Data rate governs the speed of data transmission.
- A very important consideration in data communication is how fast we can send data, in bits per second, over a channel.

Noiseless Channel : Nyquist Bit Rate

- For a noiseless channel, the Nyquist bit rate formula defines the theoretical maximum bit rate.

$$\boxed{C = 2\,B \log_2 M}$$

- Where:
    - B is the bandwidth of the channel
    - M is the number of signal levels used to represent data
    - C is the bit rate in bits per second.
- Bandwidth is a fixed quantity, so it cannot be changed. Hence, the data rate is directly proportional to the number of signal levels.
- Note that, Increasing the levels of a signal may reduce the reliability of the system.
- **Example-1**: Consider a noiseless channel with a bandwidth of 4000 Hz transmitting a signal with two signal levels. What can be the maximum bit rate?
- **Answer**: Bit-Rate = 2 * 4000 * log2(2) = 8000bps
- **Example**-2: We need to send 250 kbps over a noiseless channel with a bandwidth of 30 kHz. How many signal levels do we need?
- **Answer**: 250000 = 2 * 30000 * log2(L)
- log2(L) = 4.17

- L = 2^4.17 = 18 levels

Noisy Channel : Shannon Capacity

- In reality, we cannot have a noiseless channel; the channel is always noisy.
- Shannon capacity is used to determine the theoretical highest data rate for a noisy channel.

$$C = B \log_2(1 + SNR)$$

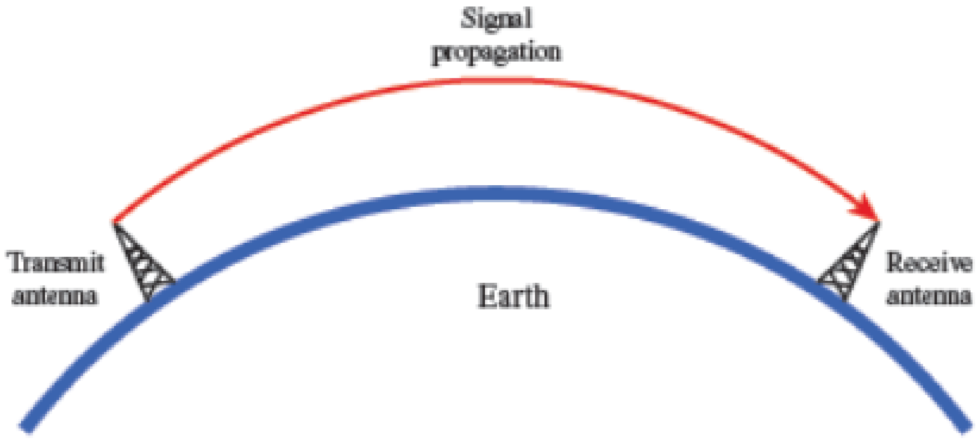
- Where:
    - B is the bandwidth of the channel
    - SNR is the signal-to-noise ratio
    - C is the capacity of the channel in bits per second
- Bandwidth is a fixed quantity, so it cannot be changed.
- So, the channel capacity is directly proportional to the power of the signal, as SNR = Power of signal / power of noise.
- The signal-to-noise ratio (S/N) is usually expressed in decibels (dB).
- **Example**: A telephone line normally has a bandwidth of 3000 Hz (300 to 3300 Hz) assigned for data communication. The SNR is usually 3162. What will be the capacity for this channel?
- **Answer**: C = 3000 * log2(1 + SNR) = 3000 * 11.62 = 34860 bps

3.5 Unguided (Wireless) transmission media

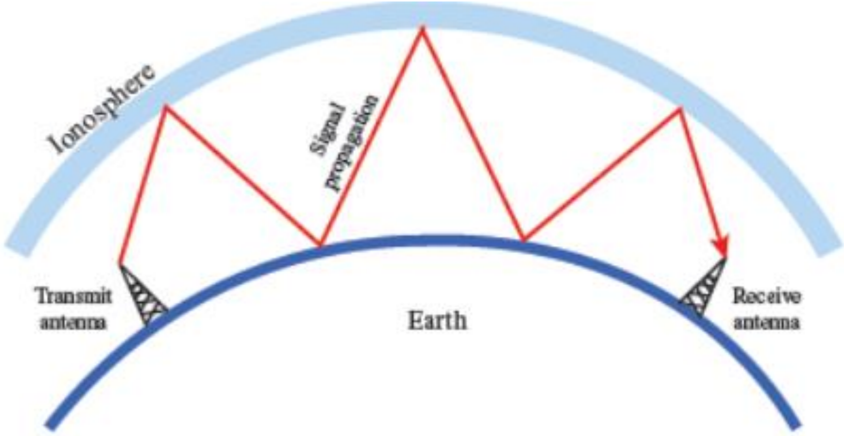
Unguided media transport electromagnetic waves without using a physical conductor. This type of communication is often referred to as wireless communication.

A. Radio Transmission

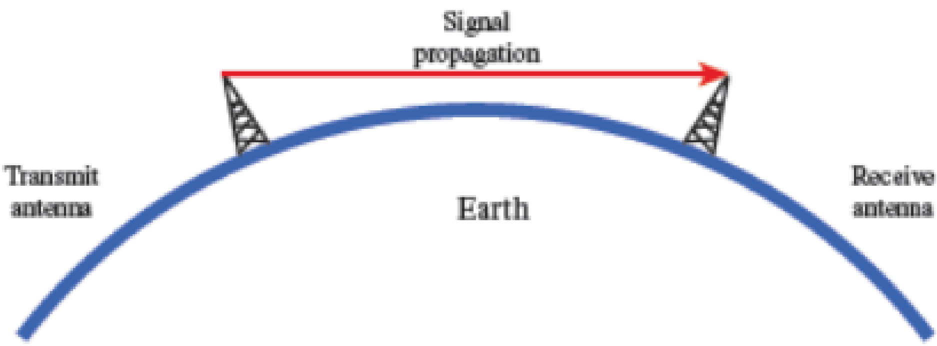
- Radio waves are easy to generate, can travel long distances, and can penetrate buildings easily, so they are widely used for communication, both indoors and outdoors.
- Radio waves also are omnidirectional, meaning that they travel in all directions from the source, so the transmitter and receiver do not have to be carefully aligned physically.
- The properties of radio waves are frequency dependent.
- At low frequencies, radio waves pass through obstacles well, but the power falls off sharply with distance from the source, roughly as $1/r^2$ in air.
- At high frequencies, radio waves tend to travel in straight lines and bounce off obstacles. They are also absorbed by rain.
- At all frequencies, radio waves are subject to interference from motors and other electrical equipment.
- In the VLF, LF, and MF bands, radio waves follow the curvature of the earth.
- In the HF they bounce off the ionosphere



(a) Ground wave propagation (below 2 MHz)



(b) Sky wave propagation (2 to 30 MHz)



(c) Line-of-sight (LOS) propagation (above 30 MHz)

B. Microwave Transmission

- Since the microwaves travel in a straight line, if the towers are too far apart, the earth will get in the way. Consequently, repeaters are needed periodically.
- Unlike radio waves at lower frequencies, microwaves do not pass through buildings well. In addition, even though the beam may be well focused at the transmitter, there is still some divergence in space.
- Above 100 MHz, the waves **travel in straight lines** and can therefore be narrowly focused. Concentrating all the energy into a small beam using a **parabolic antenna** gives a much higher signal to noise ratio.

- **Advantages:**
  - No right way is needed (compared to wired media).
  - Relatively inexpensive.
  - Simple to install.
- **Disadvantages:**
  - Do not pass through buildings well.
  - Multipath fading problem (the delayed waves cancel the signal).
  - Absorption by rain above 8 GHz.
  - Severe shortage of spectrum.

C. Infrared

- Unguided infrared and millimeter waves are widely used for short-range communication.
- The remote controls used on televisions, VCRs, and stereos all use infrared communication.
- They are relatively directional, cheap, and easy to build but have a major drawback: they do not pass through solid objects (try standing between your remote control and your television and see if it still works).
- In general, as we go from long-wave radio toward visible light, the waves behave more and more like light and less and less like radio.
- On the other hand, the fact that infrared waves do not pass through solid walls well is also a plus.
- It means that an infrared system in one room of a building will not interfere with a similar system in adjacent rooms or buildings.
- Furthermore, security of infrared systems against eavesdropping is better than that of radio systems precisely for this reason.
- Therefore, no government license is needed to operate an infrared system, in contrast to radio systems, which must be licensed outside the ISM bands.

3.6 Five Basic Propagation Mechanisms

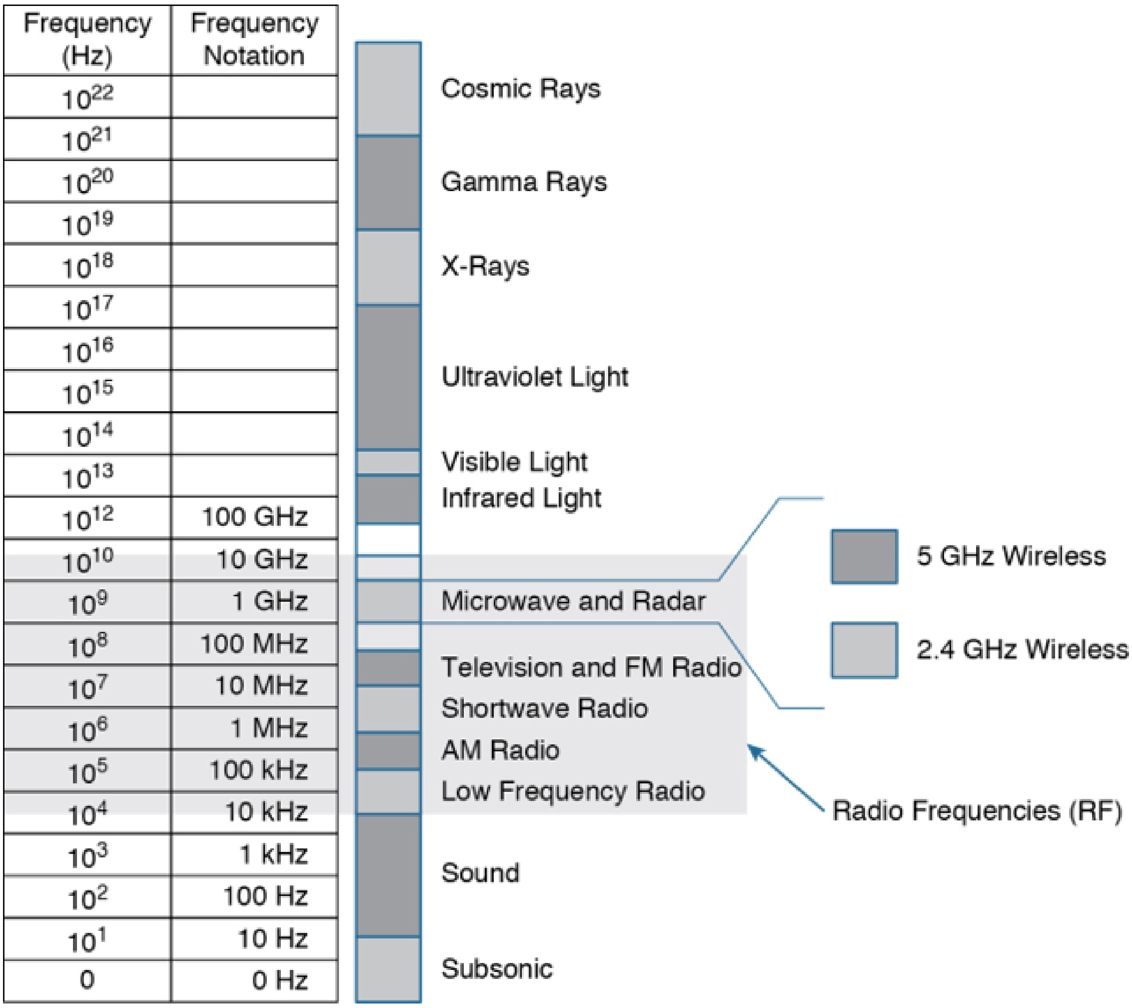
There are five different mechanisms by which electromagnetic signals can transfer information from a transmitter to a receiver:

1. **Free- space propagation** transmits a wave when there are no obstructions. The signal strength decays as a function of distance.
2. **Transmission propagates** a signal as it penetrates in and through a medium. The signal is refracted at the surface of the medium to a different angle of transmission.
3. **Reflections** occur when electromagnetic waves impinge upon surfaces that are large relative to the wavelength of a signal.
4. **Diffraction** occurs when a signal is obstructed by an object with sharp edges. Secondary waves are then present behind the sharp edges to deliver the signal to a possibly shadowed receiver.
5. **Scattering** is involved when a signal interacts with large numbers of objects that are small relative to its wavelength. This can involve rough surfaces, foliage, street signs, etc. in a typical communication system.

4. Understanding Frequency

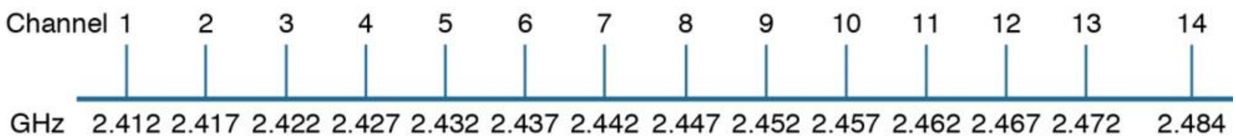
- The below Figure shows a simple representation of the continuous frequency spectrum ranging from 0 Hz to 1022 (or 1 followed by 22 zeros) Hz.
- At the low end of the spectrum are frequencies that are too low to be heard by the human ear, followed by audible sounds.
- The highest range of frequencies contains light, followed by X, gamma, and cosmic rays.
- The frequency ranges from around 3 kHz to 300 GHz is commonly called radio frequency (RF). It includes many different types of radio communication, including:
    1. low-frequency radio,
    2. AM radio,
    3. shortwave radio,
    4. television, FM radio and
    5. microwave, and radar.
- The microwave category also contains the two main frequency ranges that are used for wireless LAN communication: **2.4** and **5** GHz. Because a range of frequencies might be used for the same purpose, it is customary to refer to the range as a **band** of frequencies. For example, the range from 530 kHz to around 1710 kHz is used by AM radio stations; therefore, it is commonly called the **AM band** or the **AM broadcast band**.
- One of the two main frequency ranges used for wireless LAN communication lies between 2.400 and 2.4835 GHz. This is usually called the **2.4-GHz band**.
- The other wireless LAN range is usually called the **5-GHz** band because it lies between **5.150 and 5.825 GHz**. The 5-GHz band actually contains the following four separate and distinct bands:
    1. 5.150 to 5.250 GHz
    2. 5.250 to 5.350 GHz
    3. 5.470 to 5.725 GHz

4. 5.725 to 5.825 GHz



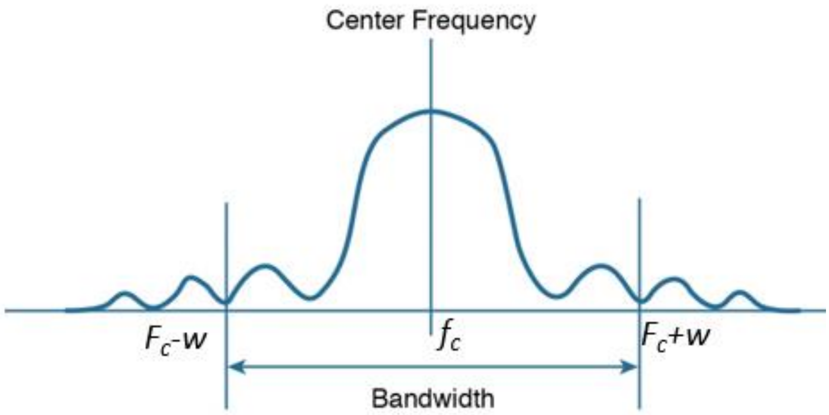
> **Tip** You might have noticed that most of the 5-GHz bands are contiguous except for a gap between 5.350 and 5.470. At the time of this writing, this gap exists and cannot be used for wireless LANs. However, some governmental agencies have moved to reclaim the frequencies and repurpose them for wireless LANs. Efforts are also underway to add 5.825 through 5.925 GHz.

Bands are usually divided up into distinct channels with a specific frequency for each. For example, the WLAN 2.4-GHz band contains 14 channels numbered 1 through 14. The channels are spaced at regular intervals that are 0.005 GHz (or 5 MHz) apart, except for channel 14.

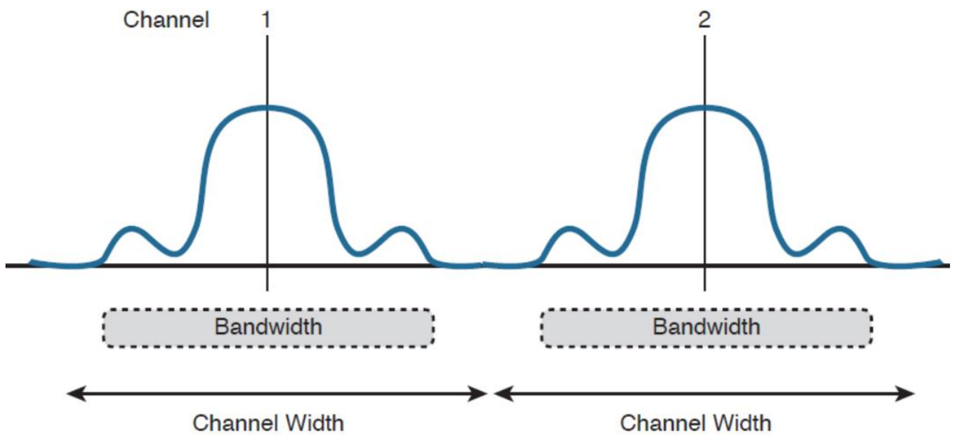


In practice, an RF signal is not infinitely narrow. Instead, it spills above and below a center frequency. It is the center frequency that defines the channel location within the band. The actual frequency range needed for the transmitted signal is known as the signal bandwidth.

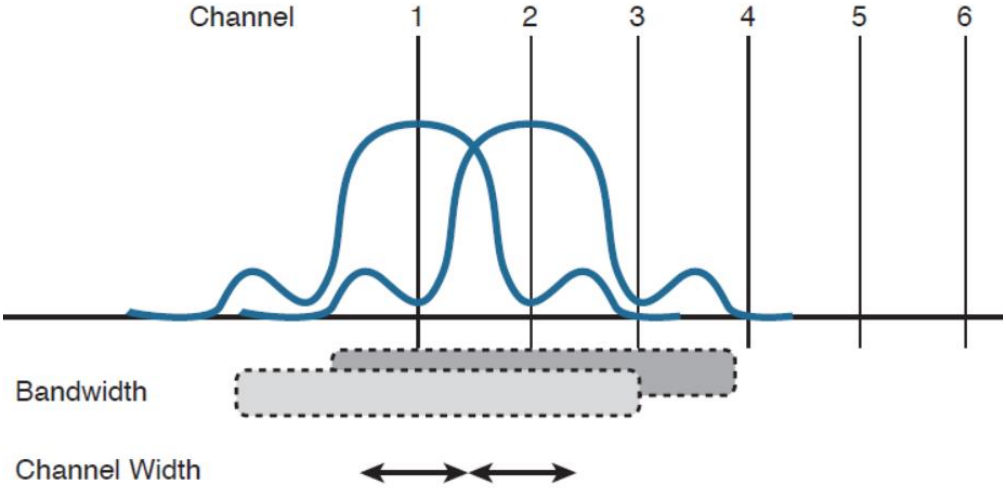
For example, a signal with **a 22-MHz** bandwidth is bounded at 11 MHz above and below the center frequency.



Ideally, the **signal bandwidth** should be **less** than the **channel width** so that a different signal could be transmitted on every possible channel with no chance that two signals could **overlap** and **interfere** with each other.

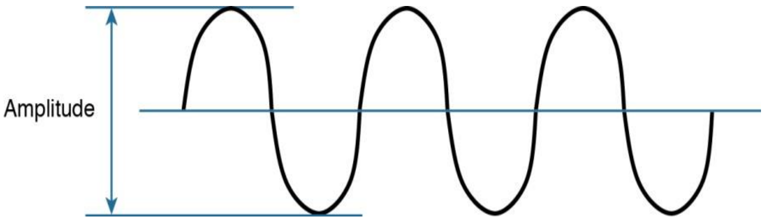


It is entirely possible that the channels in a band are narrower than the signal bandwidth. <u>In this case, signals centered on adjacent channels cannot possibly coexist without overlapping and interfering.</u> Instead, the signals must be placed on more distant channels to prevent overlapping, thus limiting the number of channels that can be used in the band.



4.1 Understanding RF Power and dB

This strength or power of signal can be measured as the amplitude, or the height from the top peak to the bottom peak of the signal's waveform.

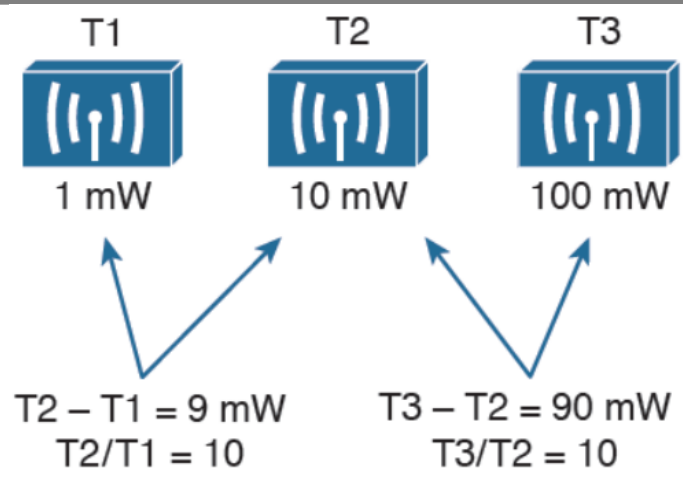


- **Absolute Power Measurement**

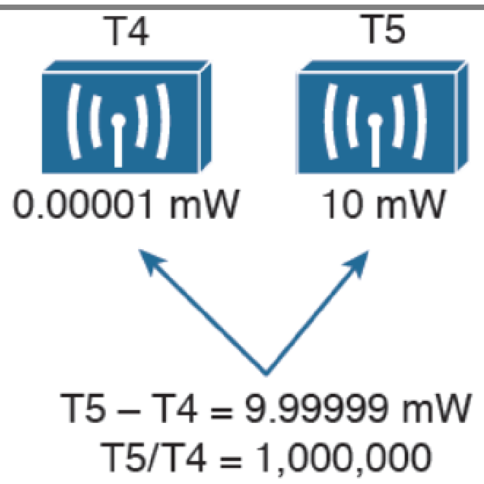
The strength of an RF signal is usually measured by its power, in watts (W). For example:

1. *AM radio station broadcasts at a power of 50,000 W.*
2. *FM radio station might use 16,000 W.*
3. *A wireless LAN transmitter usually has a signal strength between 0.1 W (100 mW) and 0.001 W (1 mW).*

When power is measured in watts or milliwatts, it is considered to be an **absolute power measurement.**



Comparing Power Levels Between Transmitters



Comparing Power Levels That Differ By Orders of Magnitude

Because absolute power values can fall anywhere within a huge range, from a tiny decimal number to hundreds, thousands, or greater values, we need a way to transform the exponential range into a linear one. The logarithm function can be leveraged to do just that. In a nutshell, a logarithm takes values that are orders of magnitude apart (0.001, 0.01, 0.1, 1, 10, 100, and 1000, for example) and spaces them evenly within a reasonable range.

Tip The base-10 logarithm function, denoted by log10, computes how many times 10 can be multiplied by itself to equal a number. For example, log10$^{(10)}$ equals 1 because 10 is used only once to get the result of 10. The log10$^{(100)}$ equals 2 because 10 is multiplied twice (10 × 10), to reach the result of 100.

The ***decibel*** (dB) is a handy function that uses logarithms to compare one absolute measurement to another. The following equation is used to calculate a dB value, where P1 and P2 are the absolute power levels of two sources:

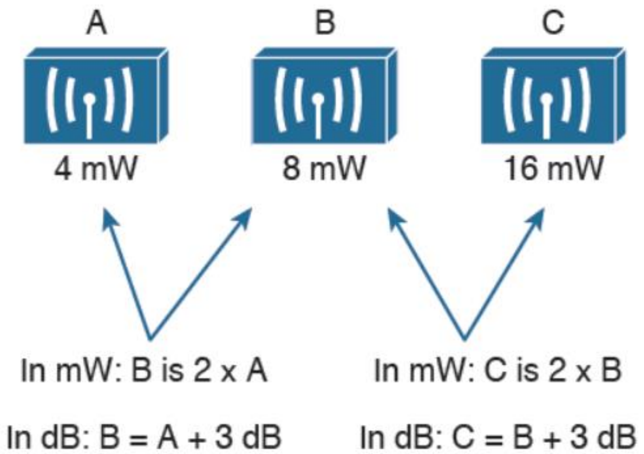
$$dB = 10log_{10}\left(\frac{P2}{P1}\right)$$

- **Law of Zero (0 dB)** —If the two power values are equal, the ratio inside the logarithm is 1, and the log10$^{(1)}$ is 0. This law is intuitive; if two power levels are the same, one is 0 dB more than the other.

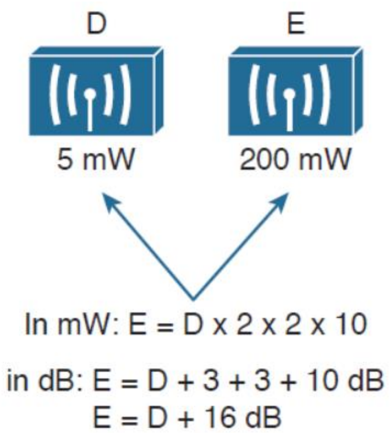
- **Law of 3s**—A value of 3 dB means that the power value of interest is double the reference value; a value of –3 dB means the power value of interest is half the reference. When P2 is twice P1, the ratio is always 2. Therefore, $10\log10^{(2)} = 3$ dB. When the ratio is 1/2, $10\log10^{(1/2)} = -3$ dB.
- **Law of 10s**—A value of 10 dB means that the power value of interest is 10 times the reference value; a value of –10 dB means the power value of interest is 1/10 of the reference. When P2 is 10 times P1, the ratio is always 10. Therefore, $10\log10^{(10)} = 10$ dB. When P2 is one tenth of P1, then the ratio is 1/10 and $10\log10^{(1/10)} = -10$ dB.

Power Change	dB Value
=	0 dB
× 2	+3 dB
/ 2	–3 dB
× 10	+10 dB
/ 10	–10 dB

Power Changes and Their Corresponding dB Values



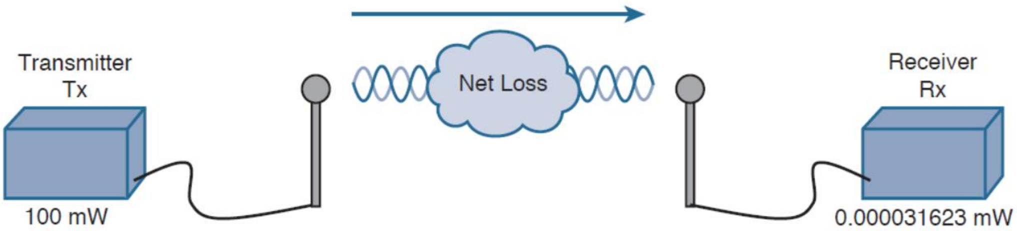
Comparing Power Levels Using dB



Example of Computing dB with Simple Rules

- **Comparing Power Against a Reference: dBm**

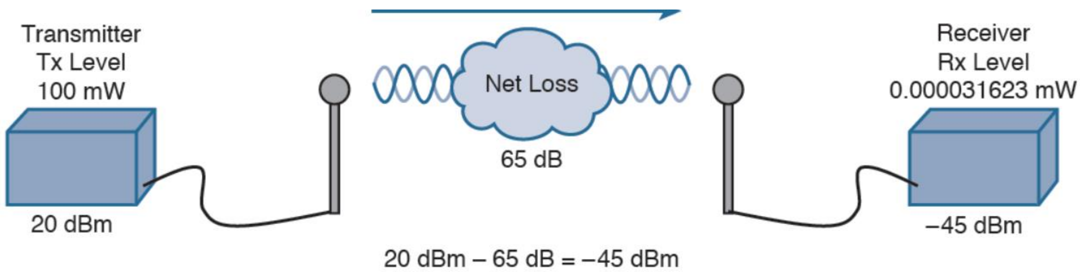
Beyond comparing two transmitting sources, a wireless LAN engineer must be concerned about the RF signal propagating from a transmitter to a receiver. As the following Figure depicts, the power level leaving the transmitter is 100 mW. At the receiver, the power level is measured as 0.000031623 mW.



The net loss over the signal path turns out to be a decrease of 65 dB.

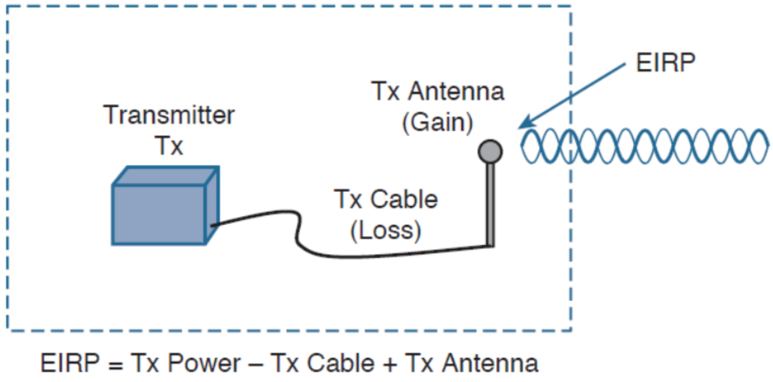
$$dB = 10 log_{10}\left(\frac{0.000031623\,mW}{100\,mW}\right) = -65\,dB$$

In wireless networks, the reference power level is usually **1mW**. Referring to the following Figure, the absolute power values at the transmitter and receiver can be converted to dBm. The transmitter dBm plus the net loss in dB equals the received signal in dBm.

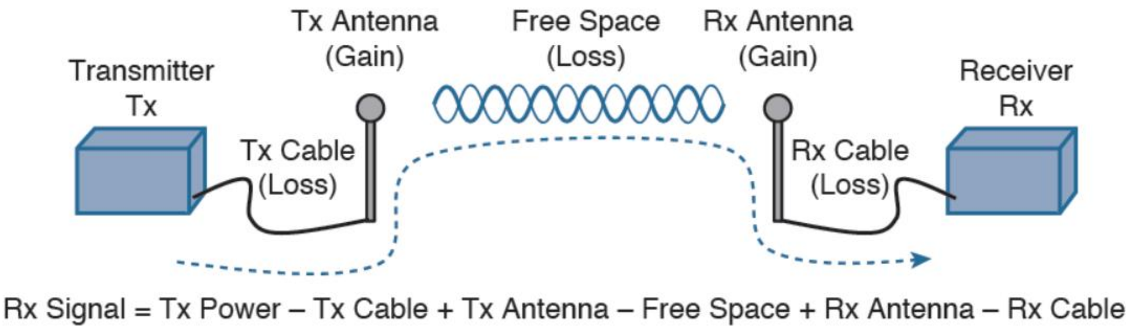


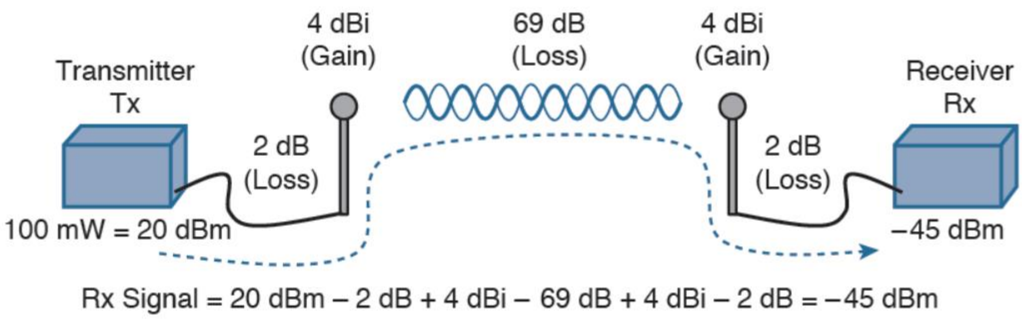
4.2 Effective isotropic radiated power (EIRP),

Once you know the complete combination of transmitter power level, the length of cable, and the antenna gain, you can figure out **the actual power level that will be radiated from the antenna**. This is known as the effective isotropic radiated power (EIRP), measured in dBm.



Usually, the reference antenna is an isotropic antenna, so the gain is measured in dBi (dBisotropic).



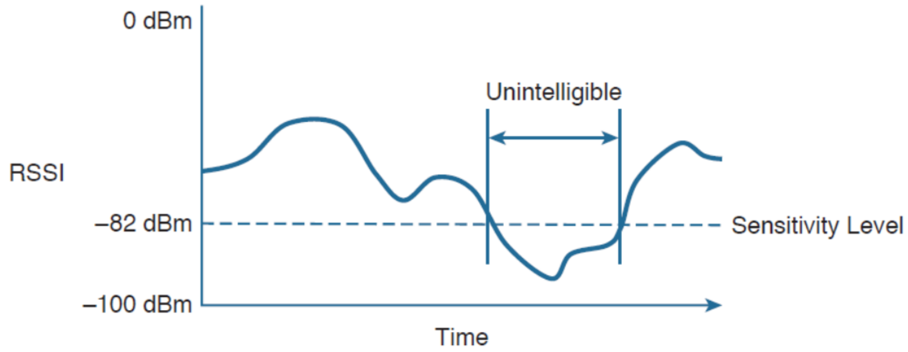


4.3 Understanding Power Levels at the Receiver

Receivers measure a signal's power in dBm according to the received signal strength indicator (**RSSI**) scale. When you work with wireless LAN devices, the EIRP levels leaving the ***transmitter's*** antenna normally range from 100 mW down to 1 mW. This corresponds to the range +20 dBm down to 0 dBm.

At the receiver, the power levels are ranging from 1 mW approaching 0 mW. The corresponding range of received signal levels is from 0 dBm down to about –100 dBm.

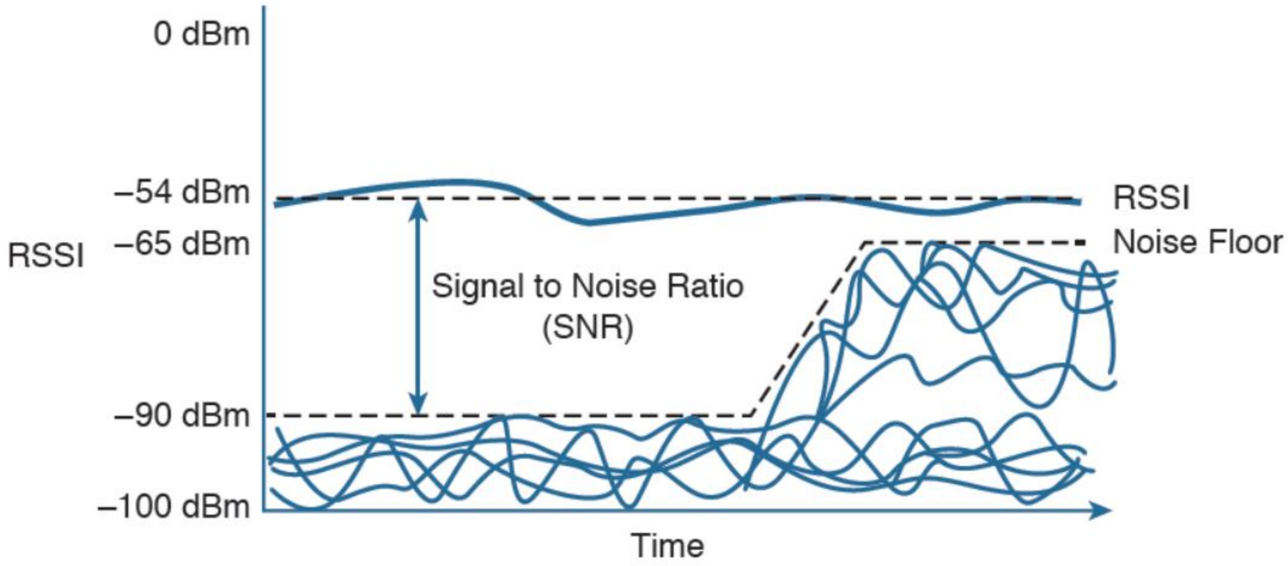
Therefore, the RSSI of a received signal can range from 0 to –100, where 0 is the strongest and –100 is the weakest. Every receiver has a sensitivity level or a threshold that divide **intelligible**, useful signals from **unintelligible** ones.



Example of Receiver Sensitivity Level

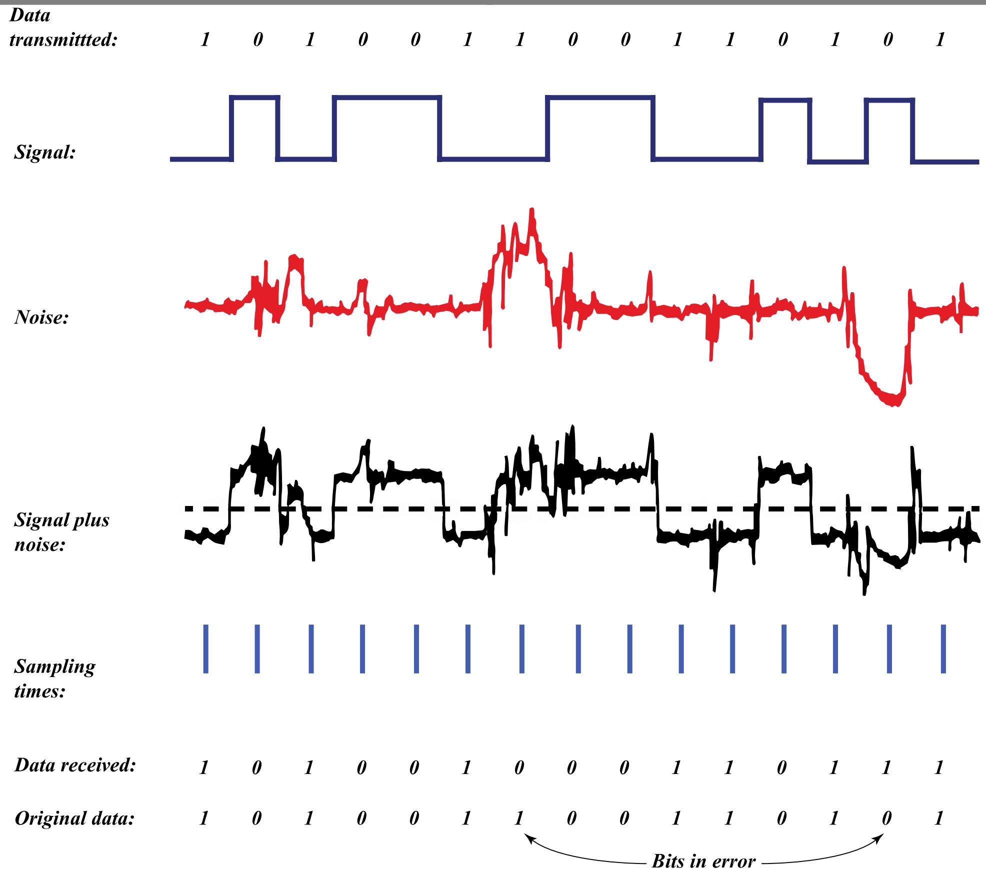
All other signals that are received on the same frequency as the one you are trying to receive are simply viewed as noise. The noise level, or the average signal strength of the noise, is called the ***noise floor***.

The signal strength must be greater than the ***noise floor*** by a decent amount so that it can be received and understood correctly. The difference between the signal and the noise is called the signal-to-noise ratio (SNR), measured in dB. A higher SNR value is preferred.



Example of a Changing Noise Floor and SNR

$$SNR_{dB} = 10 \log_{10} \frac{\text{signal power}}{\text{noise power}}$$



4.4 Data Over an RF Signal

This basic RF signal is called a carrier signal because it is used to carry other useful information.

1. In AM and FM radio signals, the carrier signal also transports audio signals.
2. In TV, the carrier signals have to carry both audio and video.
3. In the case of Wireless LAN, the carrier signals must carry data.

Altering the carrier signal in a way that indicates the information to be carried is known as modulation, where the carrier signal is modulated or changed according to some other source. At the receiver, the process is reversed; demodulation interprets the added information based on changes in the carrier signal.

RF modulation schemes generally have the following goals:

1. Carry data at a predefined rate
2. Be reasonably immune to interference and noise
3. Be practical to transmit and receive

Questions

1. Which one of the following is the common standard that defines wireless LAN operation?

    a. IEEE 802.1

    b. IEEE 802.1x

    c. IEEE 802.11

    d. IEEE 802.3

2. Which of the following represent the frequency bands commonly used for wireless LANs? (Choose two.)

    a. 2.4 MHz

    b. 2.4 GHz

    c. 5.5 MHz

    d. 11 GHz

    e. 5 GHz

3. Two transmitters are each operating with a transmit power level of 100 mW. When you compare the two absolute power levels, what is the difference in dB?

    a. 0 dB

    b. 20 dB

    c. 100 dB

    d. You can’t compare power levels in dB.

4. A transmitter is configured to use a power level of 17 mW. One day it is reconfigured to transmit at a new power level of 34 mW. How much has the power level increased in dB?

    a. 0 dB

    b. 2 dB

    c. 3 dB

    d. 17 dB

    e. None of these answers are correct; you need a calculator to figure this out.

5. Transmitter A has a power level of 1 mW, and transmitter B is 100 mW. Compare transmitter B to A using dB, and then identify the correct answer from the following choices.

a. 0 dB

b. 1 dB

c. 10 dB

d. 20 dB

e. 100 dB

6. A transmitter normally uses an absolute power level of 100 mW. Through the course of needed changes, its power level is reduced to 40 mW. What is the power-level change in dB?

a. 2.5 dB

b. 4 dB

c. –4 dB

d. –40 dB

e. None of these answers are correct; where is that calculator?

7. Consider a scenario with a transmitter and a receiver that are separated by some distance. The transmitter uses an absolute power level of 20 dBm. A cable connects the transmitter to its antenna. The receiver also has a cable connecting it to its antenna. Each cable has a loss of 2 dB. The transmitting and receiving antennas each have a gain of 5 dBi. What is the resulting EIRP?

a. +20 dBm

b. +23 dBm

c. +26 dBm

d. +34 dBm

e. None of these answers are correct.

8. A receiver picks up an RF signal from a distant transmitter. Which one of the following represents the best signal quality received? Example values are given in parentheses.

a. Low SNR (10 dB), Low RSSI (–75)

b. High SNR (30 dB), Low RSSI (–75)

c. Low SNR (10 dB), High RSSI (–30)

d. High SNR (30 dB), High RSSI (–30)

9. The typical data rates of 1, 2, 5.5, and 11 Mbps can be supported by which one of the following modulation types?

a. OFDM

b. FHSS

c. DSSS

d. QAM

10. Put the following modulation schemes in order of the number of possible changes that can be made to the carrier signal, from lowest to highest.

a. 16-QAM

b. DQPSK

c. DBPSK

d. 64-QAM