

Module Introduction

Purpose:

- This training module provides an introduction to the basic concepts behind RF and wireless technologies.

Objectives:

- Understand the benefits of using RF technology as a communications medium.
- Understand the basic facts about electromagnetic waves and the spectrum.
- Explain the purpose of an antenna and how one works.
- Identify the components of a signal.
- Explain the role of modulation of RF signals in wireless communication.

Content:

- 22 pages
- 4 questions

Learning Time:

- 45 minutes

This training module will give you a good introduction to wireless communications.

In this module, we briefly discuss the benefits of using electromagnetic radiation to transmit information, as opposed to using wires. You will learn some basic theory about waveforms and how antennas are used to propagate electromagnetic waves through space. You will see how radio waves can be modified and become carriers of information signals so that the maximum amount of data is transmitted in each bandwidth. You will also learn the differences between analog and digital transmissions and how mathematics has allowed us to overcome many difficulties throughout the development of wireless communications.

RF as a Communications Medium

- The wireless transmission of information
- One drawback: interference
- Frequency multiplexing
- Electromagnetic radiation
- Wavelength (λ)

Wireless, as the name implies, involves the transmission of information without the use of wires. Information is radiated using radio waves -- a type of electromagnetic radiation -- like light and heat. Radio waves are a convenient way to transmit information to a large number of receivers at once, as with television or radio. They can also be reflected or directed.

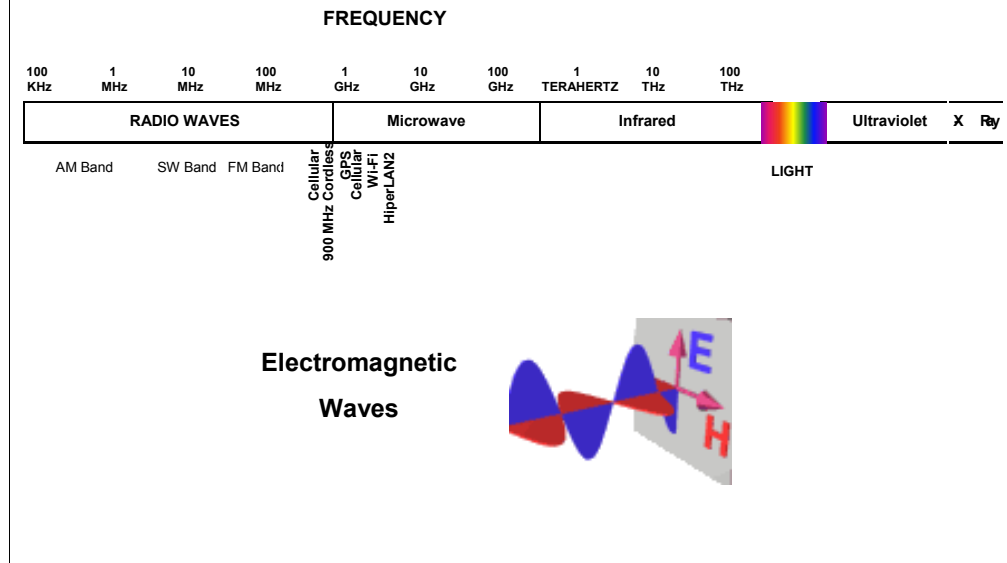
Wires have one advantage over RF: you are able to achieve excellent isolation of each signal. When RF replaces wire transmission, much of the engineering effort is spent in reducing interference. The history of radio is all about the steady improvement in the way we use the available spectrum.

The fact that radio waves can be received by multiple users presents a challenge when different information is to be transmitted to different users. For this reason, a scheme called frequency multiplexing is employed. Simple put, different users establish information channels on different radio frequencies.

Electromagnetic radiation (that is, radio waves) is produced when a time-varying electric current passes through a conductor. The frequency of the signal that is produced corresponds to the frequency of the radiation.

The distance between the peaks or the nulls in a sinusoidal radio wave is know as its wavelength and is denoted by the Greek letter "lambda". Another way to describe wavelength is to say that it is the physical distance between two maximums or minimums of an RF signal. Wavelength is proportional to the speed of light in the medium in which the signal is propagated. The formula would read " $\lambda = f/c$ ", where f equals frequency, and c equals the speed of light in the medium.

Electromagnetic Spectrum



Radio waves, including the lower frequencies of microwaves, make up a small segment of the electromagnetic spectrum. They are convenient in that they are non-ionizing like the higher frequency X-rays and gamma rays but possess convenient propagation characteristics. Their wavelengths are also easy to manage from an engineering standpoint.

Electromagnetic waves are related patterns of electric and magnetic force. They are generated by the oscillation of electric charges.

Antennas

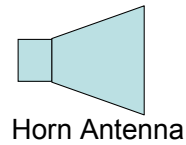
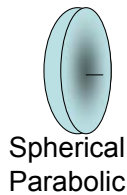
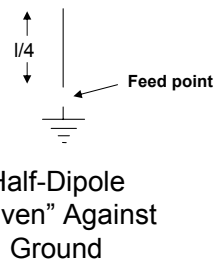
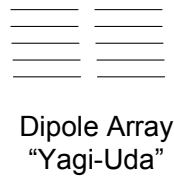
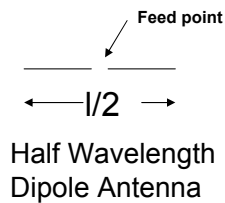
- What is an antenna?
- Reducing interference
- Antenna “gain”

An antenna is any structure that acts as a conductor of time-varying electric current. If the structure is the right shape and size, it will form an interface between electric circuits and “free space,” allowing for the efficient radiation of electromagnetic (EM) waves.

Any conductor passing time-varying electric current acts as an antenna. This is a problem since such things as electric motors and power lines fit this definition and can become sources of interference. We can make an antenna more efficient by ensuring the conductor’s physical dimensions fit the signal’s wavelength.

Antenna gain is achieved by propagating signals in a certain direction. It is often related in decibels to an “ideal” or isotropic antenna. An isotropic antenna is one that radiates equally in all directions.

Examples of Antennas



There are many varieties of antennas. One of the most common designs is the half wavelength dipole. The dipole is the basis for many other designs. The common vertical or whip antenna is a variation on the same design. Dipole elements can be shortened by electrically "loading" them with inductors or capacitors.

Parabolic antennas are often used at microwave frequencies and actually reflect or beam the EM energy much as a parabolic mirror focuses light. The actual radiating element is often a dipole that, because of the short wavelength, is rather small.

Horn antennas are also used at microwave frequencies. With these structures, the EM radiation is coupled directly into free space from a structure called a "waveguide." Again, somewhere within the horn antenna is a structure that resembles a dipole.

Question

What is the name of the design that is found in almost every type of antenna? Select the correct answer and then click Done.

- a. Wavelength horn
- b. Spherical parabolic
- c. Half wavelength dipole
- d. Time-varying conductor

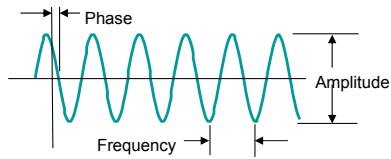
Let's take a moment to review some of what you learned about antennas.

Correct! The most common antenna design is the half wavelength dipole. The dipole is the basis for many other designs.

Signals and Waves

Wave characteristics:

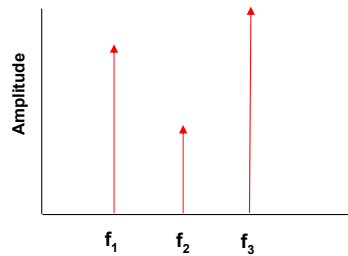
- Frequency (f_c)
- Amplitude (A)
- Phase (φ)



Electric or electromagnetic signals can look quite complex but in fact are simply made up of a variety of sinusoidal signals. A sine wave (or sinusoid) is a pure signal or wave. All other waveforms are combinations of sine waves. Sinusoids can be described by their amplitude, their phase, and their frequency (noted in Hertz or “cycles per second”). Phase and frequency are related.

Fourier Series

Mathematically separated signals plotted in the frequency (f) domain



Fourier analysis is a convenient way to analyze signals. When separated mathematically, signals can be displayed as spectral lines at discrete frequencies. Plotting signals according to their frequencies shows how they have different amplitudes. Separating signals into their frequency components is the basis of Digital Signal Processing, DSP.

A pure sinusoid has only one spectral component. The other extreme is an impulse response square wave which, in theory, has an infinite number of components.

Modulation

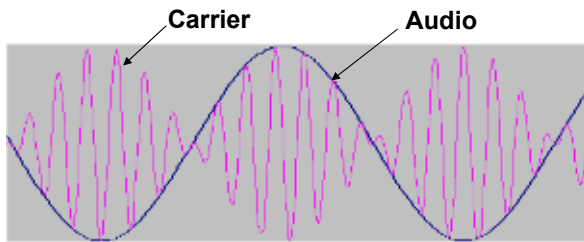
- The RF signal as a carrier
- What is “modulation”?
- 3 types of modulation:
 - Amplitude Modulation (AM)
 - Frequency Modulation (FM)
 - Phase Modulation (PM)

The concept of adding signals together is one of the underlying principals of wireless communications: a signal representing information can be added to an RF signal, radiated via an antenna, received by another antenna, and then separated to allow for recovery of the information. The RF signal becomes the carrier. The propagation characteristics of the carrier are preserved, allowing relatively low frequency information to be propagated at RF frequencies.

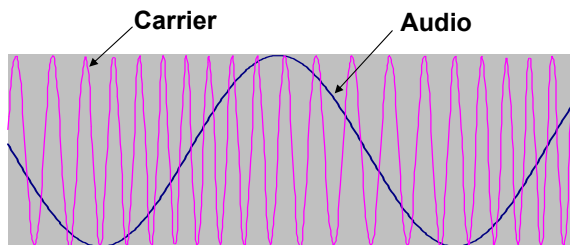
In order to make an RF signal carry another signal, you must change the RF signal’s amplitude, frequency, or phase. This change is called “modulation.” You could think of modulation as a type of coding in that the receiving equipment must know what scheme was used to modulate the RF signal in order to recover or decode the information.

Again, modulation is achieved by varying a signal’s amplitude, frequency, or phase. When the amplitude has been changed, the result is called Amplitude Modulation, or AM. Changing the frequency results in Frequency Modulation, or FM. Phase Modulation, or PM, results when phase is changed. FM and PM are related: if the frequency is modulated less than 1 Hz, the result is a PM signal.

Analog Modulation



AM

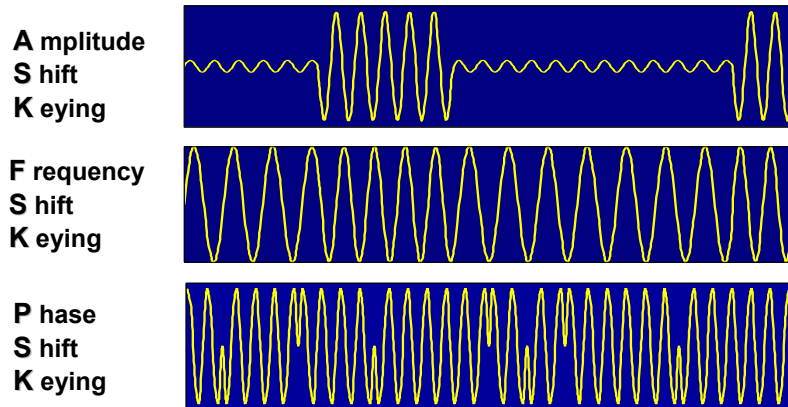


FM

These diagrams show how an audio sinusoid modulates a higher frequency carrier when the two are added. In amplitude modulation (AM), the audio changes the amplitude of the carrier. In frequency modulation (FM), the carrier frequency is changed consistent with the rate of change of the audio. When an applied analog signal modulates a carrier, the result is called Analog Modulation. This techniques is what is commonly used for radio and television transmissions.

Digital Modulation

Digital Information can be transmitted as AM, FM or PM.



Modulation can be discrete intervals representing 1's and 0's. This allows the transmission of information in digital form.

Digital AM shifts between two distinct amplitude levels.

Digital FM shifts between two discrete frequencies.

Digital PM shifts between two discrete phases.

The first digital communication schemes that were developed employed ASK or FSK.

Question

What do we do to an RF signal that allows it to carry Digital information? Select the correct answer and then click Done.

- a. Modulate the signal's amplitude, frequency, or phase.
- b. Modulate the signal at discrete intervals representing 1's and 0's.
- c. Digitize the signal through the use of DSP.
- d. Use a digital decoder that demodulates the signal in digital form.

Here's a chance to show that you understand the difference between analog and digital signals.

Correct! Digital information must always be received as 1's and 0's. To propagate digital information, we modulate the RF carrier with shifts between either two distinct amplitude levels (for AM signals), frequencies (for FM signals), or phases (for PM signals).

Information Bandwidth

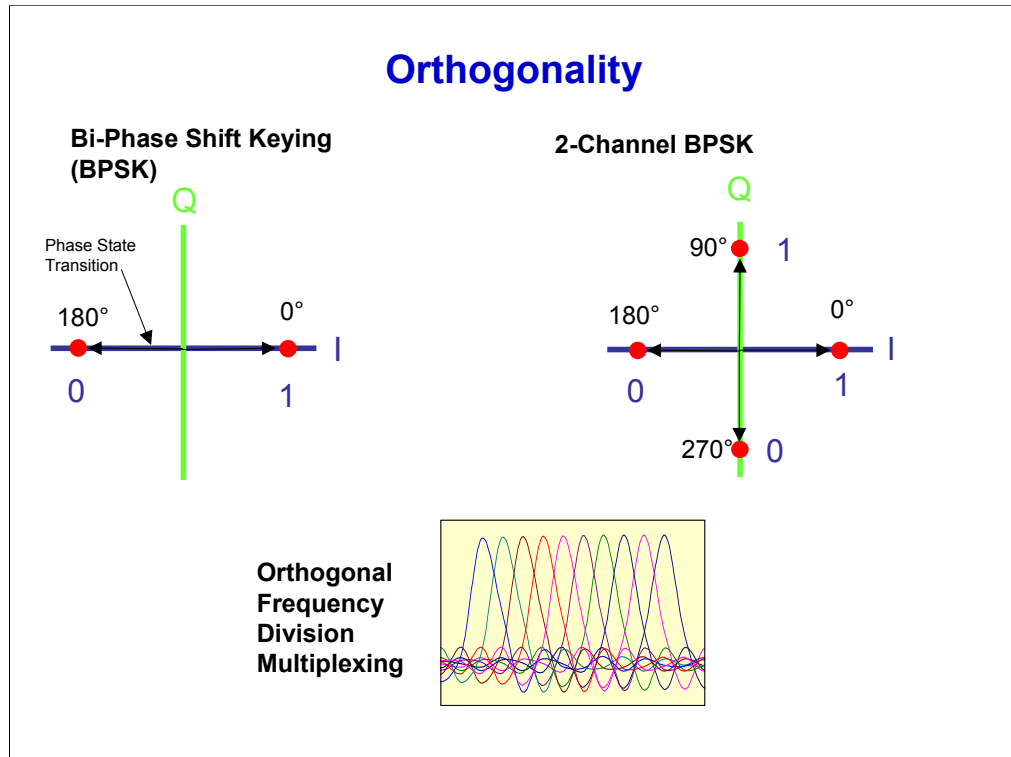
- Increasing information bandwidth
- Multiple-level AM and multi-frequency FM
- The catch: signals are harder to demodulate

Information bandwidth is a measure of how well the electromagnetic spectrum is being utilized. Since the beginning of wireless communications, the quest has been to fit more information in the same bandwidth.

Information bandwidth is a measure of the amount of data that can be transmitted in a fixed amount of frequency spectrum. It is often quantified in “bits per Hertz.” Multiple-level AM and multi-frequency FM can be used to transmit higher data rates in a given RF bandwidth.

As more communications move to the digital realm, applying more information to AM and FM signals has been difficult. Signals are harder to demodulate and distinguish from one another.

Orthogonality



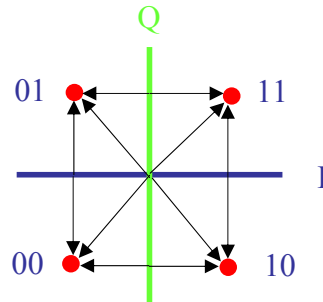
As with other aspects of information theory, mathematics plays an important role in advanced modulations schemes. One principal currently being exploited in the phase and frequency domain is the concept of “orthogonality.” Signals which are orthogonal are mathematically unrelated and, therefore, easy to distinguish from each other. Sine and cosine signals are orthogonal because they are separated by 90° . When a sine wave’s amplitude is maximum, a cosine’s amplitude is minimum. This concept gives phase and frequency modulation an advantage over amplitude modulation.

Using the same principal, two bi-phase shift keying (BPSK) signals can be transmitted together on the same frequency with a minimum of interference if they are separated by 90° .

They use multiple orthogonal carriers, each having complex amplitude and phase modulation in what is called Orthogonal Frequency Division Multiplexing, or OFDM. The newest wireless local area network schemes apply this principal.

QPSK

- When channels I and Q are mapped as “di-bits,” the result is QPSK.
- Various forms are widely used and are the result of different bitmap schemes:
 - OQPSK
 - DQPSK
 - $\pi/4$ DQPSK



If the information is mapped as “di-bits”, that is, two bits at a time, a pattern or constellation is mapped with two BPSK signals. Even though the data are related, the carriers are still orthogonal. This scheme is called QPSK and is the basis for many popular modulation techniques used in cellular and terrestrial telephony. The result is the same: in theory, two bits of information are transmitted simultaneously. In practice, impairment of the signals and imperfect hardware force some bit errors and a more realistic number is 1.6 bits.

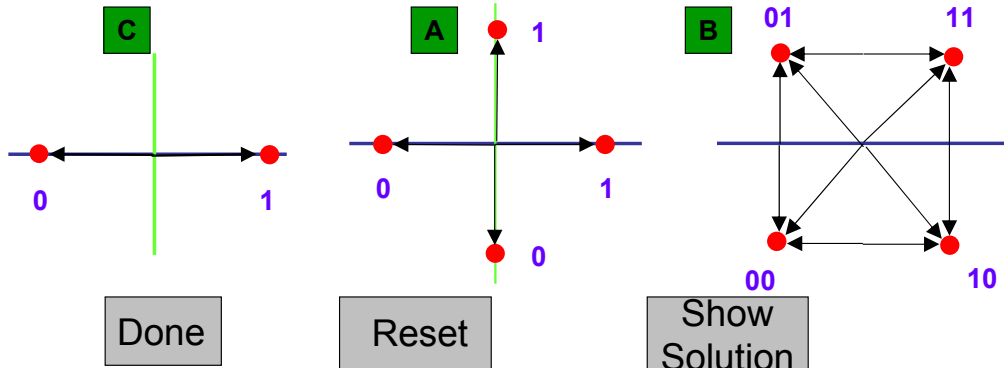
Question

Label the three digital phase modulation schemes by dragging the letters at the top to their corresponding diagrams below. Click "Done" when you are finished.

A 2-Channel BPSK

B QPSK

C BPSK

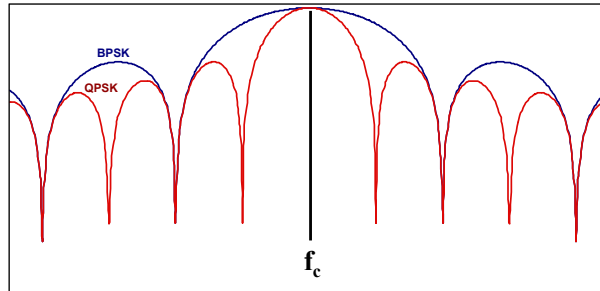


Let's take a moment to review the three types of phase modulated signals that were just covered.

Correct. In simple bi-phase shift keying (BPSK), digital information is coded as 0° or 180° phase states as in the diagram on the left. The middle diagram illustrates how two bi-phase shift keying (BPSK) signals can be transmitted together on the same frequency, forming a 2-channel BPSK. Finally, in the QPSK scheme, information is mapped two bits at a time. Each point in the "constellation," as it is called, represents two data bits.

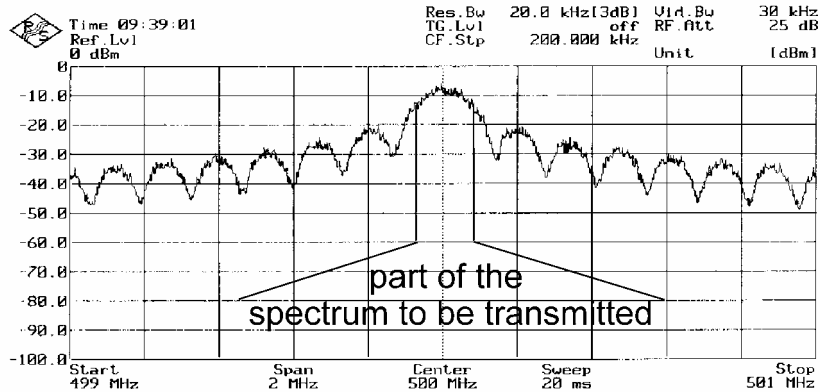
Spectral Limiting

- Because of the instantaneous transitions from one state to another, PSK schemes occupy wide frequency spectrum.
- This is not efficient for “channelized” communications systems.



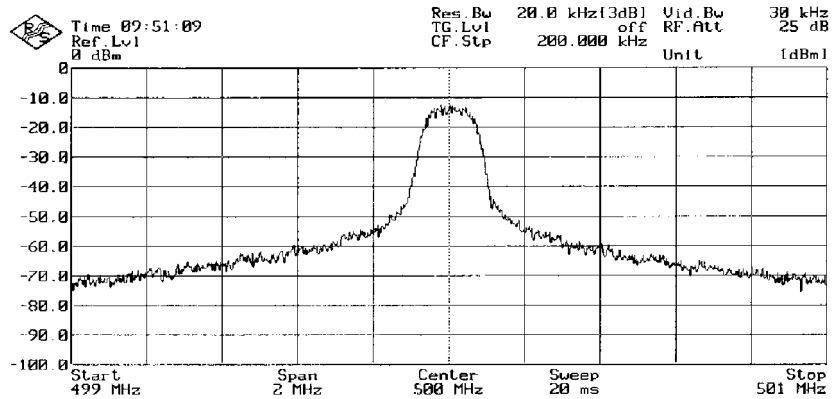
One drawback to digital modulation is that the instantaneous transitions from one state to the other create an infinite series of frequencies. While practical circuitry limits the transitions, the result is still a rather wide spectrum around the carrier. This is unacceptable in systems where adjacent frequencies are occupied by other users.

Filtering the QPSK Spectrum



Fortunately, mathematics comes to the rescue again. Most of the information required to recover the 1's and 0's is contained in the first few lobes of the spectrum. Most of the sidebands are unnecessary for communication and can be removed by filtering. Once they are removed, interference with adjacent channels is greatly reduced.

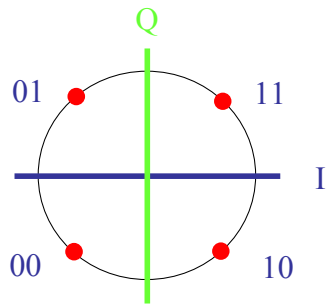
QPSK Spectrum After Filtering



The diagram shows how once the modulation signal has been filtered, the side lobes are reduced but most of the bit energy is still transmitted. Filtered QPSK has a spectrum which looks similar to AM indicating that there is residual AM in the signal. This has consequences in receiver and transmitter linearity.

Minimum Shift Keying

- Phase transitions are carefully limited.
- MSK is not as spectrally efficient as QPSK, but can be non-linearly amplified



Another popular modulation scheme used in GSM-based systems is Minimum Shift Keying (MSK). Here, the di-bits are carefully mapped such that the phase can only shift 90° at a time. When filtered, the constellation is nearly a circle.

While not as efficient as QPSK schemes because of the mapping constraints, MSK is relatively easy to generate. Also, since there is no residual amplitude modulation (AM), MSK can be amplified by amplifiers with reduced linearity (like FM).

Question

Why do we need to filter the baseband signals of QPSK and other digital modulation schemes before RF transmission? Select all answers that apply and then click Done.

Digital modulation creates an infinite series of frequencies, resulting in a rather wide spectrum around the carrier.

An unfiltered spectrum contains digital information evenly across each of the lobes of the spectrum.

Unfiltered QPSK contains residual AM in the signal, which greatly hampers digital FM reception.

Without filtering, signals would interfere with adjacent frequencies that are occupied by other users.

Let's see if you remember why a modulation signal needs to be filtered for digital communications.

Correct! The instantaneous transitions from one state to the other that occurs during digital modulation create an infinite series of frequencies. This is unacceptable in systems where adjacent frequencies are occupied by other users. Filtering the sidebands greatly reduces any interference with adjacent channels.

Module Summary

An introduction to wireless communication:

- The benefits of RF technology
- The electromagnetic spectrum
- Waves and antennas
- Analog and digital signals
- Modulation and various types of shift keying.

In this module, you learned some of the basic concepts of wireless communications, including facts about RF technology, the electromagnetic spectrum, waves, antennas, signals, and modulation.