# Modulation and Multiplexing

# The Need for Modulation

Information signals like voice, video, and digital data cannot be transmitted directly by radio. For example, you can not apply voice signals directly to an antenna. The antennas would have to be miles long. Since all of the signals occupy the same frequency range, they would all interfere with one another. Furthermore, the signals would not travel very far.

To transmit an information signal from one place to another by radio, the signal is used to modulate a radio frequency (RF) carrier. The carrier is a sine wave that is set to some radio frequency as assigned by the FCC or other regulatory body. The RF signal with its short wavelength has an antenna of practical size so the signal can be propagated over long distances.

The process of modulation is inherent in any wireless application.

# Modulation

Modulation is the process of having the information signal modify the sine wave carrier in some way.

Looking at the mathematical expression of a sine wave, you can see that there are three ways to vary a sine wave:

$$v = V_p \sin(2\pi ft + \varphi)$$

where v is the instantaneous voltage value of the sine wave, Vp is the peak amplitude, f is the frequency, t is time, and $\varphi$ is the phase angle. You can change the sine wave by varying its amplitude, frequency, or phase shift.

# Types of Modulation

Amplitude modulation (AM) causes the instantaneous amplitude of the carrier wave to vary in proportion to the information signal amplitude.

Frequency modulation (FM) causes the frequency of the carrier to vary in proportion to the amplitude of the information signal while the carrier amplitude remains constant.

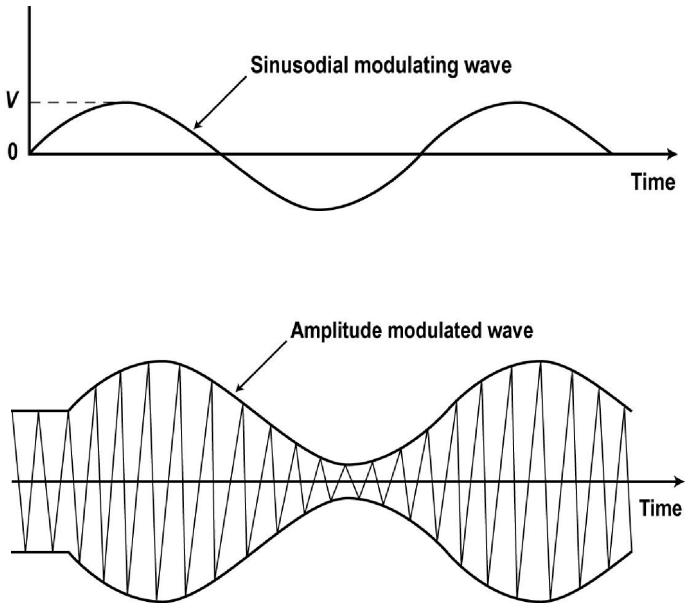
Phase modulation (PM) causes the instantaneous phase shift of the carrier to vary in proportion to the amplitude of the information signal while the amplitude remains constant.

# Visualizing Modulation (AM)

The two figures here show amplitude modulation (AM) of a sine wave carrier by an analog signal such as an audio tone which is also a sine wave.

The top view is the sine wave information signal. The bottom shows the complete AM signal.

The outline of the peaks of the carrier is called the envelope.



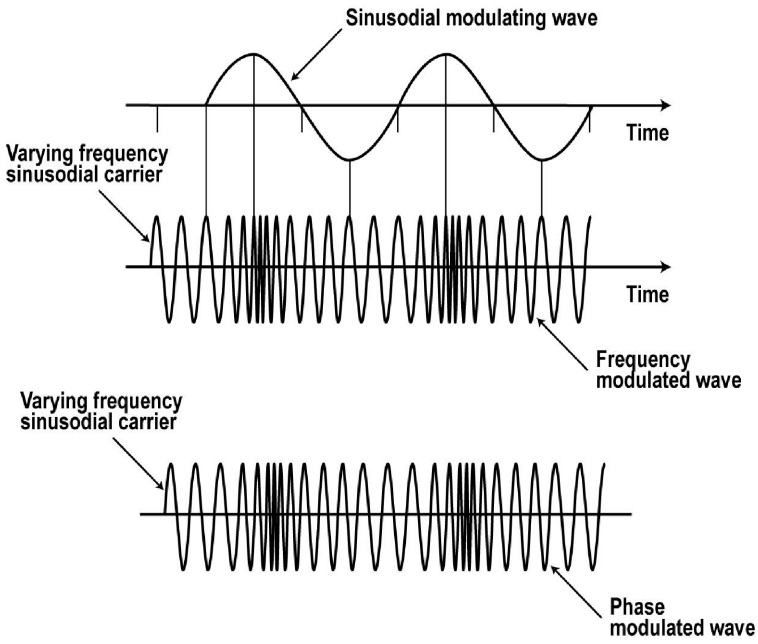
# Visualizing Modulation (FM and PM)

The figures show frequency modulation (FM) and pulse modulation (PM) of a sine wave carrier by an analog signal such as an audio tone which is also a sine wave.

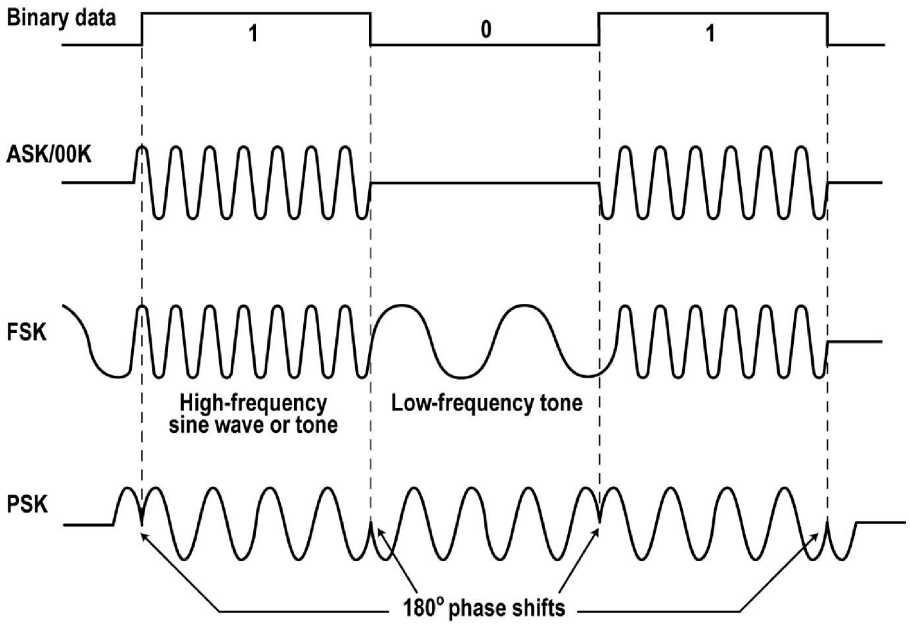
The top one is the sine wave information signal.

The center one shows the FM signal. Note that the amplitude does not change.

The bottom one shows the PM signal. It is similar to the FM signal but shifted in time as shown. PM produces FM.



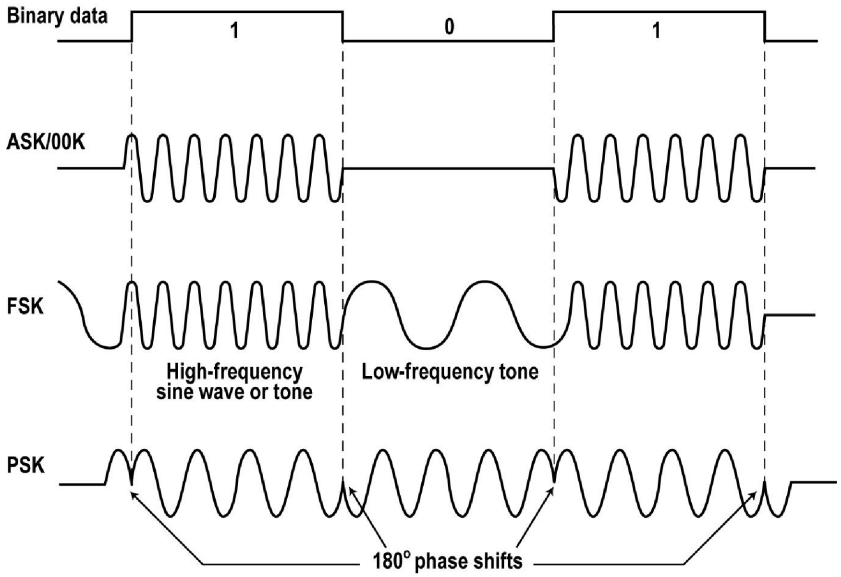
# Digital Data




When the information is digital data, the format is usually binary pulses that modulate the carrier.

There are three similar modulation methods for binary data: amplitude shift keying (ASK), frequency shift keying (FSK), and phase shift keying (PSK).

# Visualizing Digital Data




In ASK, the binary data pulses change the amplitude of the carrier. In some cases they just turn the carrier off and on producing on-off keying (OOK).

In FSK, the pulses change the frequency of the carrier. The carrier shifts between two different frequencies.

In PSK, the phase of the carrier changes as the binary signals change.

# Modulation Types

The circuit used to produce modulation at the transmitter is called a modulator while a demodulator is a circuit used to recover the original information signal from the received carrier.

There are many different versions of the basic modulation types. One of the most common is quadrature amplitude modulation (QAM) which is a combination of ASK and PSF. It is used in dial-up and cable TV modems and some types of wireless applications such as broadband wireless.

# Multiplexing

Multiplexing is the process of allowing two or more information signals to be transmitted concurrently on the same channel or communications medium.

Multiplexing aids in efficient spectrum use and reduces equipment costs in the transmission and reception of multiple signals.

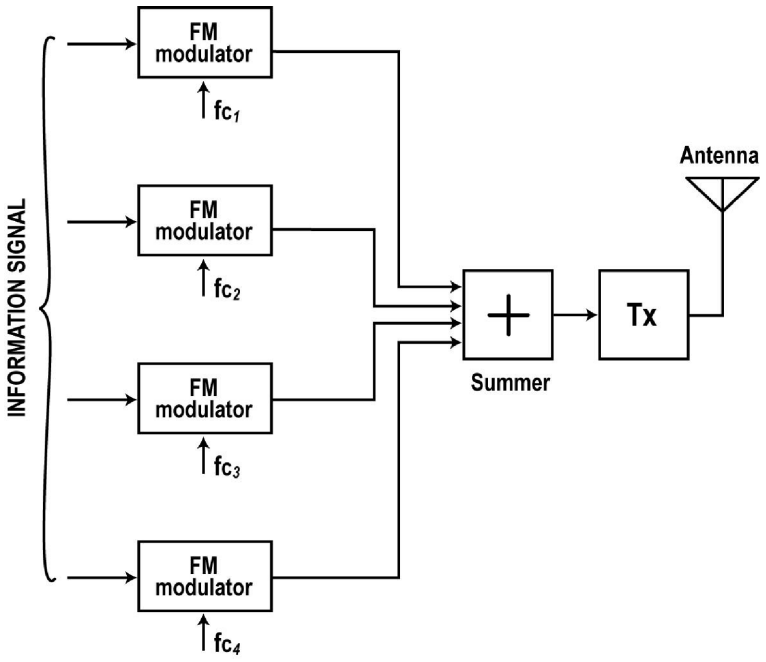
There are two types of multiplexing: frequency division multiplexing (FDM) and time division multiplexing (TDM).

In FDM, the information signals are used to modulate carriers on different but closely spaced carriers. All of these signals are simply added together and the resulting complex signal transmitted over a cable or a single wireless channel.

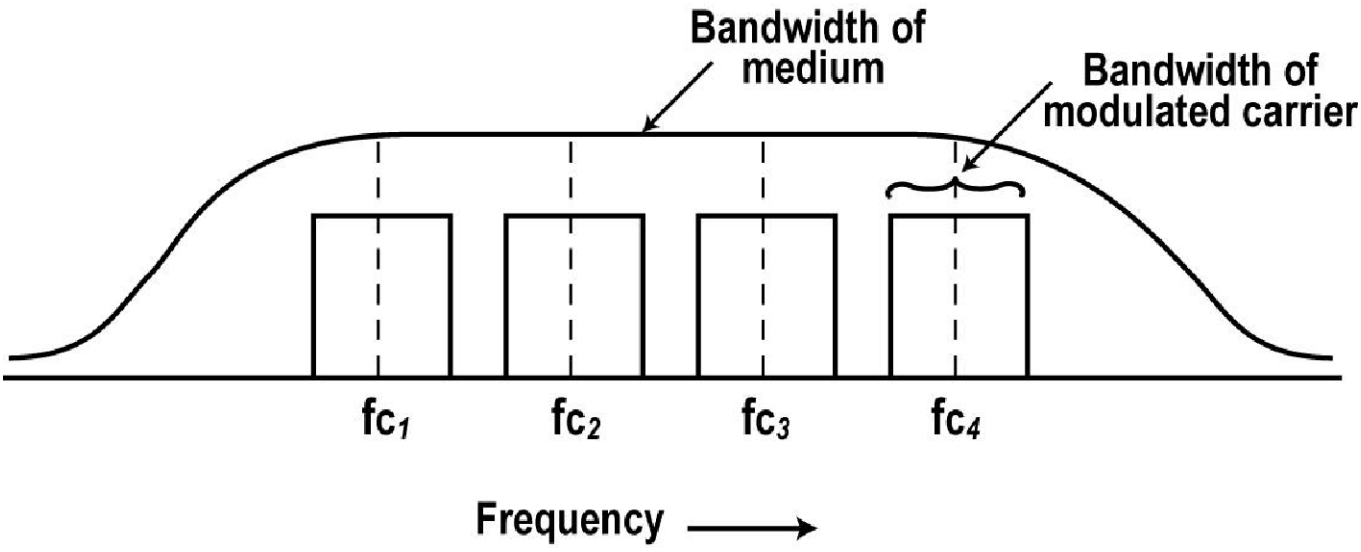
In TDM, the information signals are first digitized by an analog-to-digital converter (ADC). The binary data from each ADC is then transmitted one word at a time with the words interleaved.

# Frequency Division Multiplexing

In a FDM system, the individual information signals are used to frequency modulate carriers on different frequencies ($f_{c1}$, $f_{c2}$, $f_{c3}$, $f_{c4}$). All of the signals are then added together and the result is used to modulate a carrier in the transmitter (TX) for transmission.

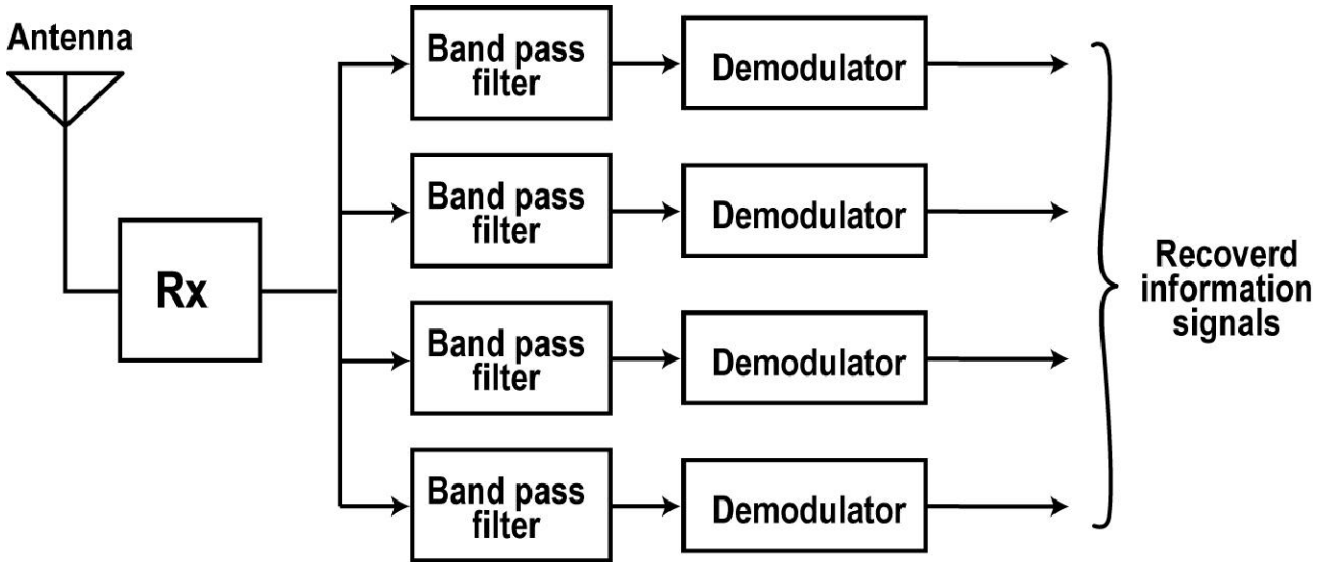


# Frequency Division Multiplexing



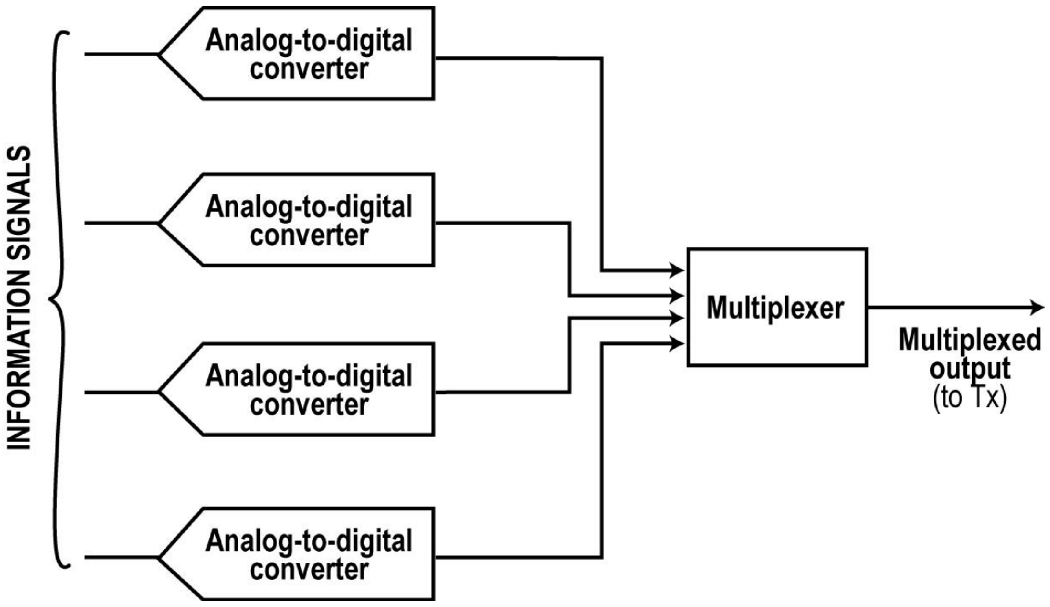

This figure shows the resulting mulitplexed signal where each information signal occupies a narrow range of spectrum (called bandwidth) in the total bandwidth of the medium.

# Frequency Division Multiplexing



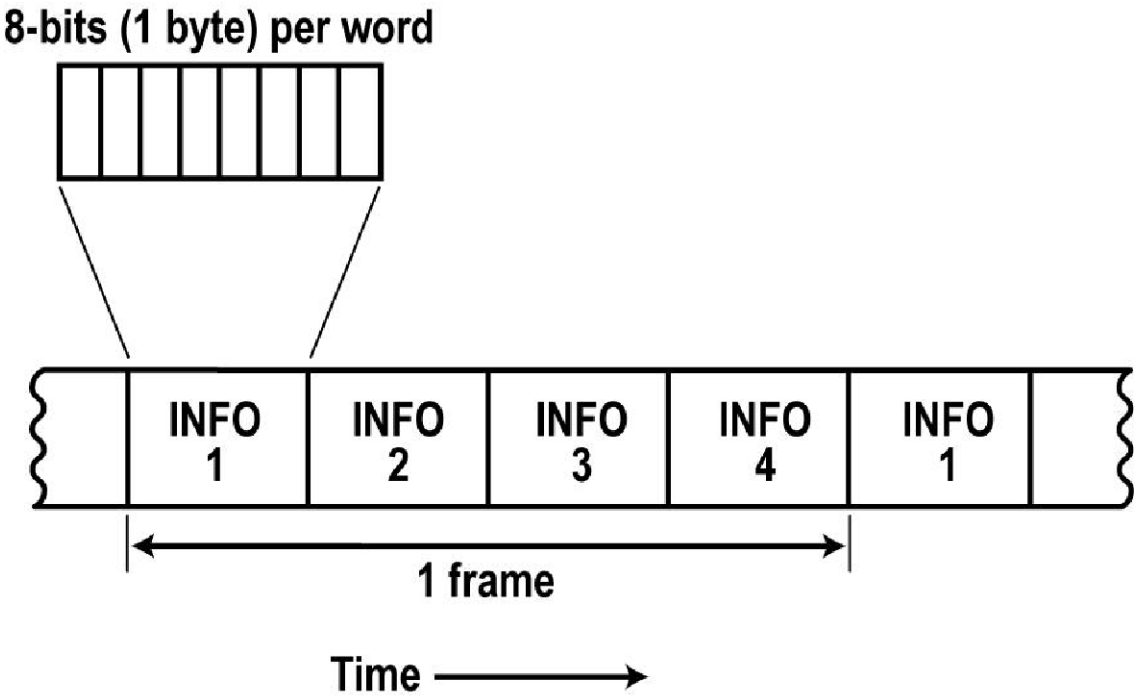

At the receiver (RX), the complete multiplexed signal is then recovered and band pass filters (BPF) are used to separate the modulated carriers. The filter outputs are then demodulated to recover the original information signals.

# Time Division Multiplexing



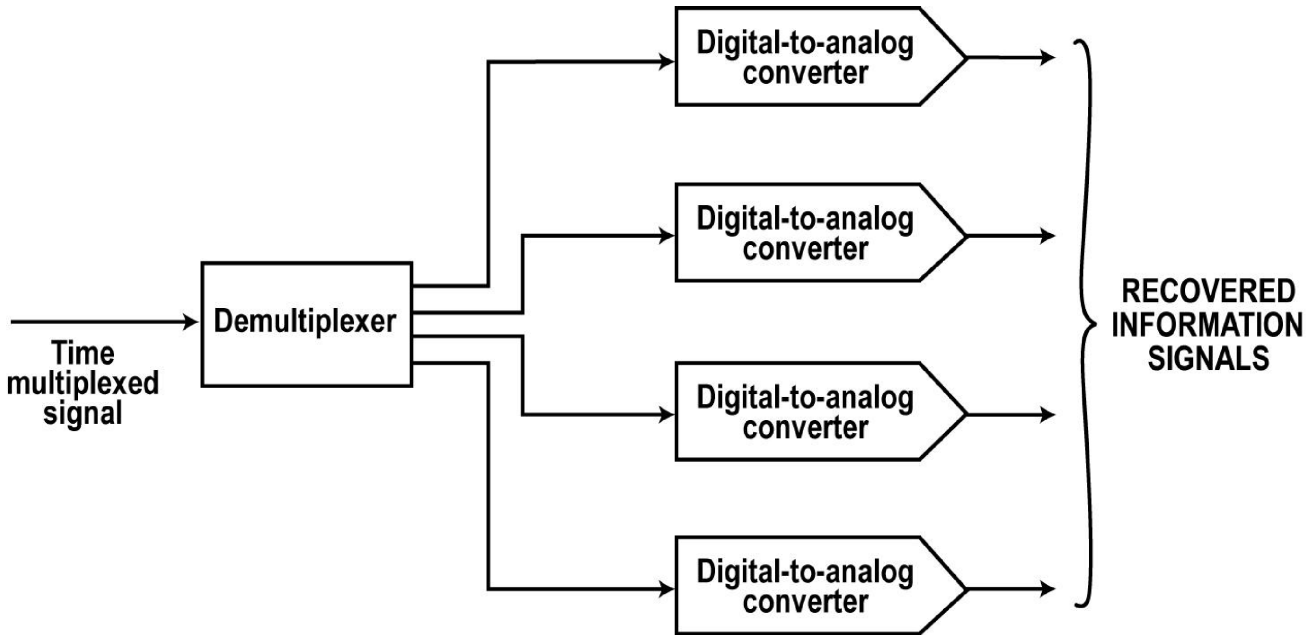

In the TDM system shown here, four information signals are digitized with ADCs. The multiplexer (MPX) then transmits one word of each signal alternately one after another. Once one word of each signal has been transmitted, each succeeding word is then transmitted one after the other.

# Serial Bit Stream




This figure shows the binary signal out of the multiplexer. This is a serial bit stream with alternating words from each information source.

# Demultiplexer




At the receiver, a demultiplexer, sorts out the individual digital words and sends them to digital-to-analog converters (DACs) to recover the original signals.

# Test your knowledge

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## Modulation and Multiplexing

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