CSx25: Digital Signal Processing
NCS224: Signals and Systems

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Outline

- ~~Digital Signal Processing Introduction~~
  - ~~Mathematical modeling~~
  - ~~Continuous Time Signals~~
  - ~~Discrete Time Signals~~
- ~~Analyzing Continuous-Time Systems in the Time Domain~~
- ~~Analyzing Discrete Systems in the Time Domain~~
- ~~Fourier Analysis for Continuous-Time Signals and Systems~~
- ~~Sampling and Reconstruction~~
- ~~Analysis and Design of Filters~~
- **Modulation**

Modulation

- The main purpose of any communication system is to facilitate the *transfer of an information-bearing signal* from one point in space to another, with an acceptable level of quality.
- Consider, for example, two people communicating through their cell phones. The *sound* of the person who acts as the information source is detected by the *microphone* on his or her phone, converted to an *electrical signal* for processing within the phone, and eventually converted to an *electromagnetic signal* which is transmitted from the *antenna* of the phone.
- This electromagnetic signal is received by the antennas within the cell phone network, transmitted from cell to cell as needed, possibly travels through various types of connections such as *fiber optics* and *satellite links*, and finally reaches the antenna of the phone that is designated as its destination. Within the receiving phone, the electromagnetic signal is converted back to an electrical signal and is eventually converted to sound.
- Thus, any communication system has a transmitter and a receiver. *The collection of all systems between the transmitter and the receiver is referred to as the* **communication channel**.

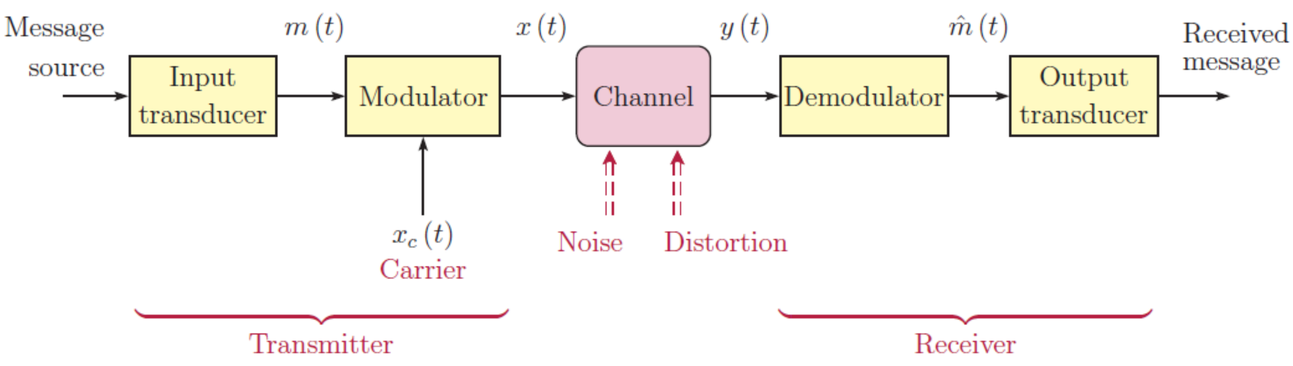
Modulation

- Modulation is the process of *embedding* an information-bearing signal, referred to as the message signal, in another signal known as the ***carrier***.
- The carrier by itself does not contain any information, yet it may have other features that make it desirable. Some examples of these desirable features are:

  1) suitability for transmission through a particular medium

  2) better performance in the presence of noise and interference

  3) suitability to more efficient utilization of resources



Modulation

1. Compatibility of the signal with the channel:
   Modulation gives us the ability to produce a signal that is compatible with the characteristics of the channel that will transmit it.
   Most message signals we encounter in our daily lives involve relatively low frequencies, referred to as the *baseband* frequencies. For example, voice signals used in telephone communications occupy the frequency range from about 300 Hz to about 3600 Hz. High fidelity music signals are typically in the frequency range from about 20 Hz to about 20 kHz. Similarly, baseband video signals such as those encountered on a TV monitor occupy roughly the frequency range from 0 to about 4.2 MHz. Signals such as these can be transmitted using wire links or optical fiber connections, but they are not suitable for over-the-air transmission due to their large wavelengths. The antennas required for over-the-air transmission of these signals in their original form would have to be unreasonably long. Modulating a high frequency carrier with these message signals makes over-the-air broadcast possible while keeping required antenna lengths at practical levels.

Modulation

2. **Reduced susceptibility to noise and interference:**
   Modulation of a carrier with the message signal results in a shift of the range of signal frequencies. This frequency shift can be used in a way that allows us to position the frequency spectrum of the signal where noise and interference conditions are more favorable compared to the conditions at baseband frequencies.
   Additionally, some modulation techniques allow performance improvements in terms of noise susceptibility provided that increased bandwidth is available.
3. **Multiplexing:**
   Modulation allows for more efficient use of available resources by multiplexing different signals in the same medium.
   In sinusoidal modulation, the frequency shift that results from modulation can also be used for mixing multiple messages in one medium, with each message signal modulating a carrier at a different frequency. These modulated carrier signals can be combined and transmitted together. They can later be separated from each other provided that the frequency ranges occupied by different carriers do not overlap with each other. This effect is known as *frequency division multiplexing (FDM)*. On radio and television, FDM forms the basis of simultaneous broadcast of multiple stations in the same air space.
   In digital pulse modulation, the gaps between the successive pulses of a carrier can be used for accommodating messages from multiple sources, a concept known as *time division multiplexing (TDM)*. Multiple digital information sources can utilize the same channel simultaneously, by taking turns in sending data.

Modulation

The overall operation of the communication system can be summarized as follows:

1. The role of the input transducer is to convert the source message from its native format to the form of an electrical signal $m(t)$, referred to as the *message signal*. Some examples of input transducers are microphone, video camera, pressure gauge, temperature sensor, etc.

2. The modulator embeds the message signal $m(t)$ into the carrier signal $x_c(t)$ to create the modulated carrier $x(t)$ which is then transmitted through the channel.

3. The output signal of the channel is a distorted version of $x(t)$ which is also contaminated with noise. In simple terms we have

$$y(t) = \mathrm{Sys}\{x(t)\} + w(t)$$

where $\mathrm{Sys}\{\ldots\}$ represents the effect of the channel on the modulated signal, and $w(t)$ represents the additive channel noise.[1]

4. At the receiver side of the system the demodulator reverses the action of the modulator, and extracts an approximate version $\hat{m}(t)$ of the original message signal $m(t)$ from the received modulated signal $y(t)$. The demodulator may or may not need a local copy of the carrier signal $x_c(t)$.

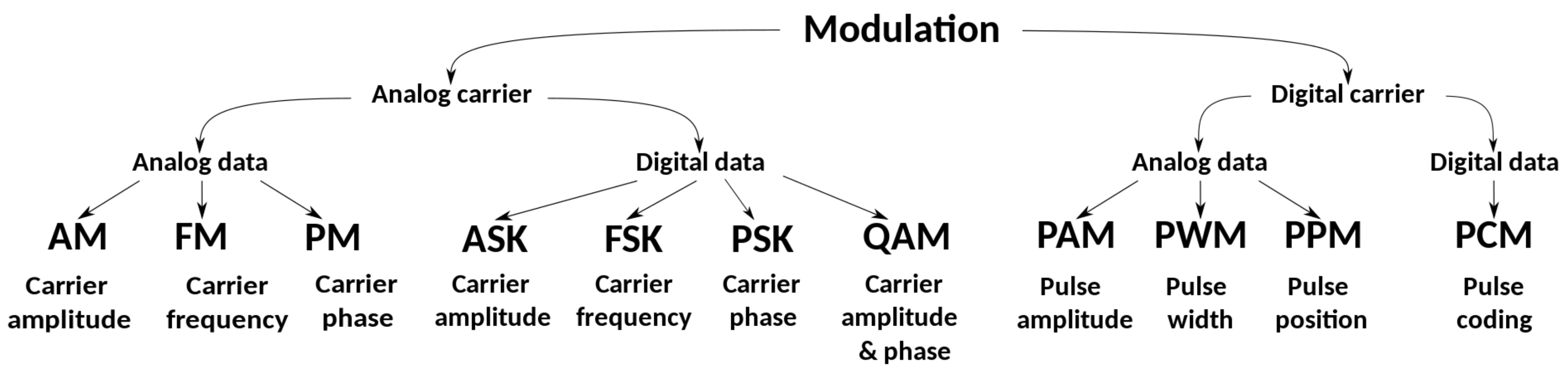
5. Finally, the output transducer converts the electrical signal $\hat{m}(t)$ to its native format. Examples of output transducers are speaker, video display, etc.

Modulation

Types of Modulation

The type of modulation used in a communication system depends on

1. The type of carrier used (sinusoidal, pulse train, etc…)
2. The particular parameter of the carrier that is utilized for embedding the message signal into it (Amplitude, frequency, phase, etc…)

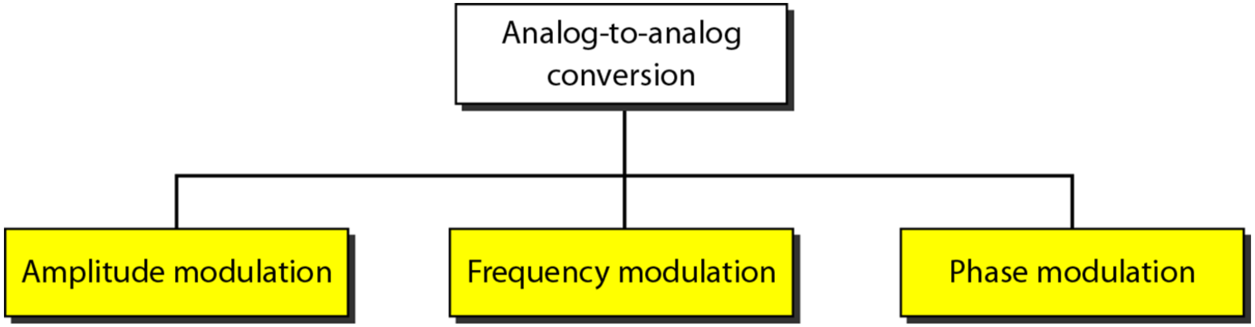


Forouzan, Behrouz A. Data communications and networking. Huga Media, 2007.

Modulation

Analog Modulation

The particular parameter of the carrier that is utilized for embedding the analog signal into it (Amplitude, frequency, phase)



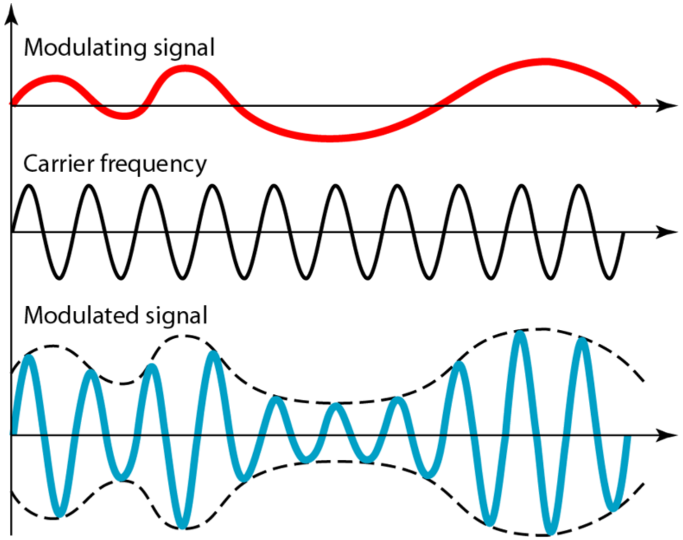
Modulation

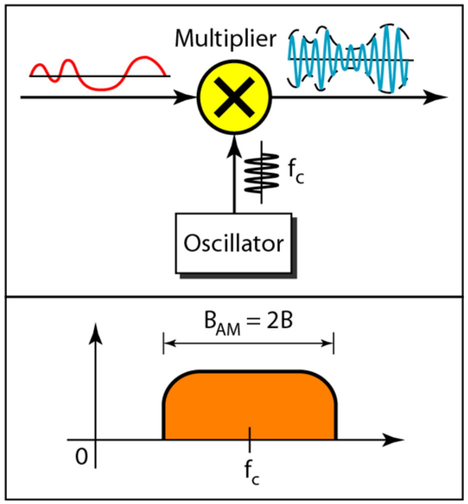
Amplitude Modulation

The type of modulation used in a communication system depends on

- A carrier signal is modulated only in *amplitude value*
- The modulating signal is the *envelope of the carrier*
- The required bandwidth is ***2B***, where B is the bandwidth of the modulating signal
- Since on both sides of the carrier freq f_c, the spectrum is identical,

we can discard one-half, thus requiring a smaller bandwidth for transmission.



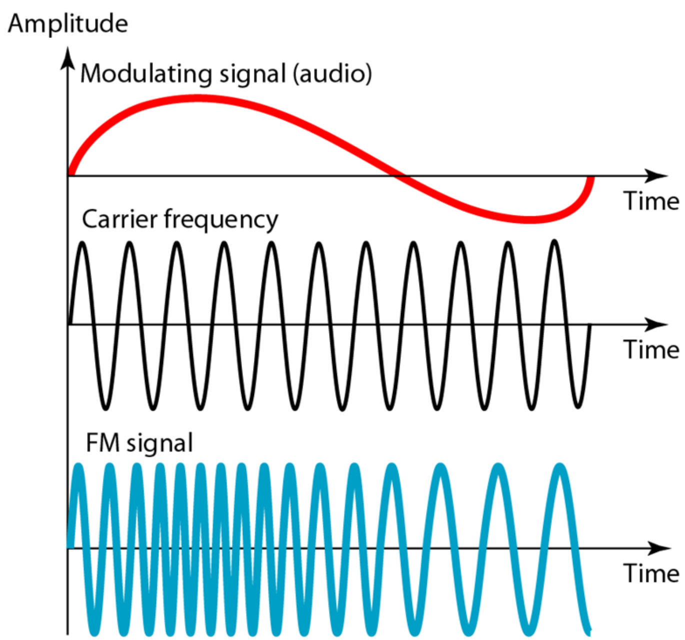


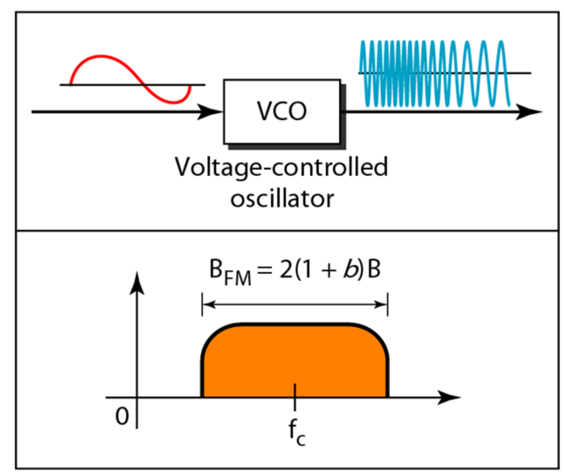
Modulation

Frequency Modulation

- The modulating signal changes the *frequency* f_c of the carrier signal
- The bandwidth $BFM = 2(1 + \beta)B$. Where β is usually 4.

The bandwidth for FM is high. It is approx. *10x* the signal frequency



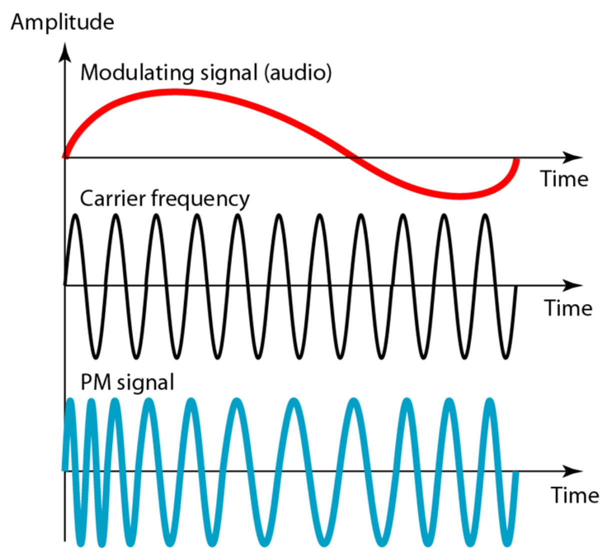


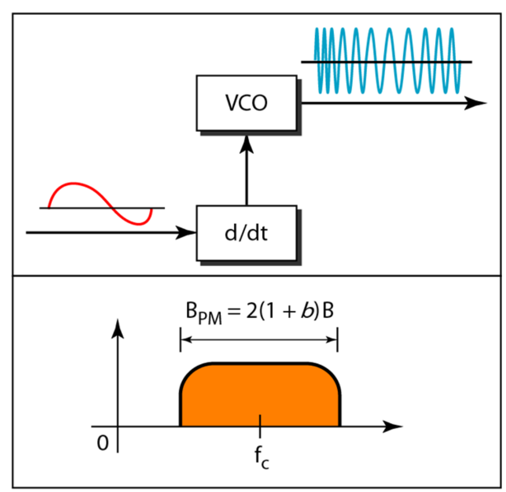
Modulation

Phase Modulation

- The modulating signal only changes the *phase of the carrier signal*.
- The phase change manifests itself as a frequency change, but the instantaneous *frequency change is proportional to the derivative of the amplitude*.
- The bandwidth is *higher than for AM*.

The total bandwidth required for PM can be determined from the bandwidth and maximum amplitude of the modulating signal: BPM = 2(1 + β)B.
Where β = 2 most often.

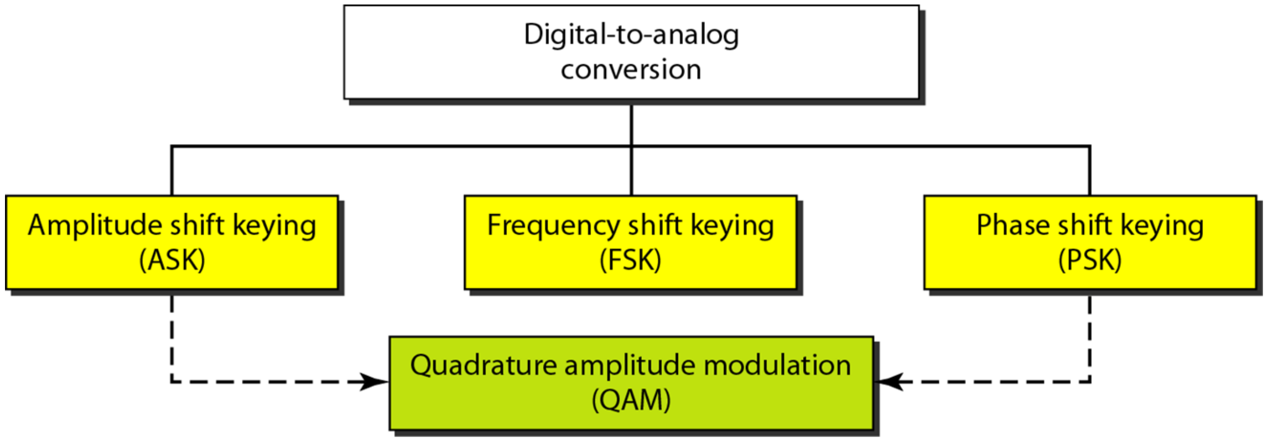




Modulation

Digital to Analog Conversion

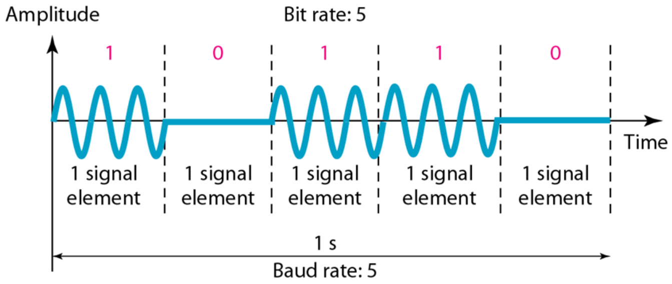
- Digital data needs to be carried on *an analog signal*.
- A *carrier signal* (frequency fc) performs the function of transporting the digital data in an *analog waveform*.
- The analog carrier signal *is manipulated to uniquely* identify the digital data being carried.
- Bit rate, N, is the number of bits per second (bps).
- Baud rate is the number of signal elements per second (bauds).
- In the analog transmission of digital data, the *signal or baud rate is less than or equal to the bit rate*. S=Nx1/r bauds Where r is the number of data bits per signal element.

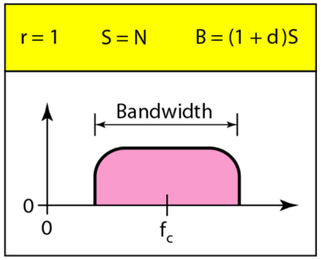


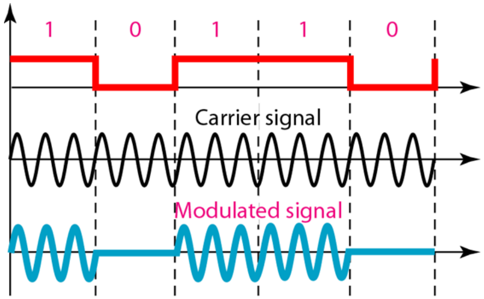
Modulation

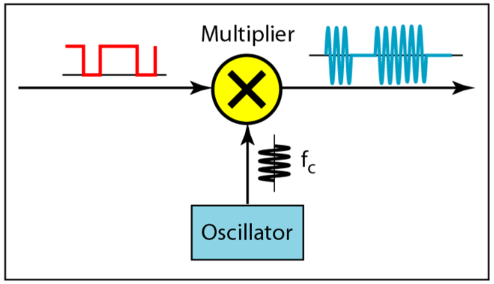
Amplitude Shift Keying (ASK)

- ASK is implemented by changing the *amplitude of a carrier* signal to reflect amplitude levels in the digital signal.
- For example: a digital "1" could not affect the signal, whereas a digital "0" would, by making it zero.
- The line encoding will determine the values of the analog waveform to reflect the digital data being carried.
- The bandwidth B of ASK is proportional to the signal rate S. B = (1+d)S "d" is due to modulation and filtering, which lies between 0 and 1.





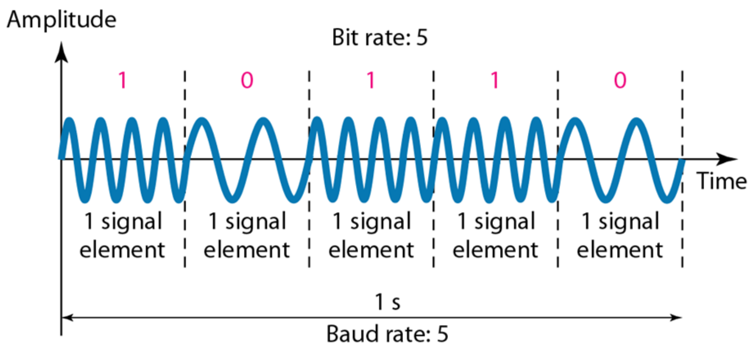


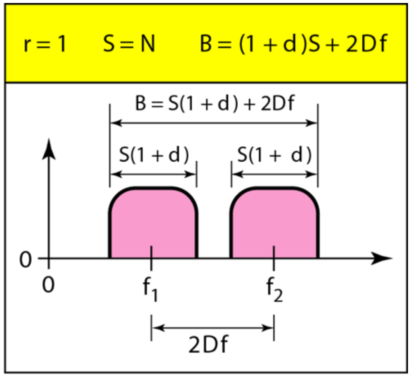


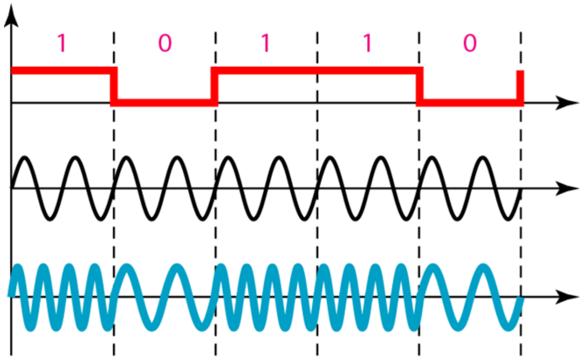
Modulation

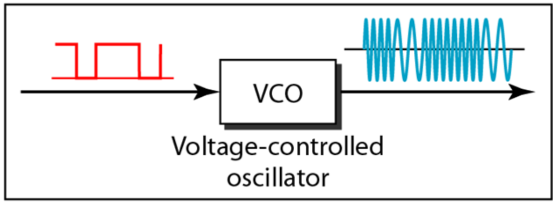
Frequency Shift Keying

- The digital data stream changes the *frequency of the carrier* signal, fc.
- For example, a "1" could be represented by f1=fc +Δf, and a "0" could be represented by f2=fc-Δf.







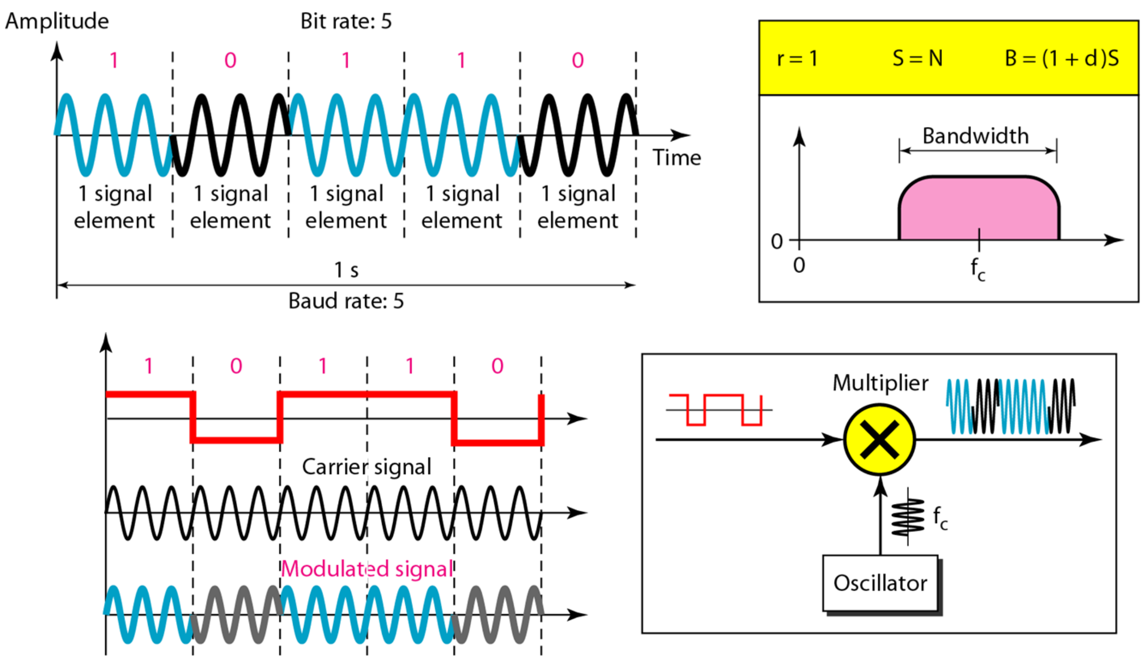


Modulation

Phase Shift Keying

- The digital data stream changes the *[phase shift](#)* of the carrier signal to represent digital data.
- The bandwidth requirement, B is: B = (1+d)xS
- PSK is much more robust than ASK as it is not that vulnerable to noise, which changes the amplitude of the signal.

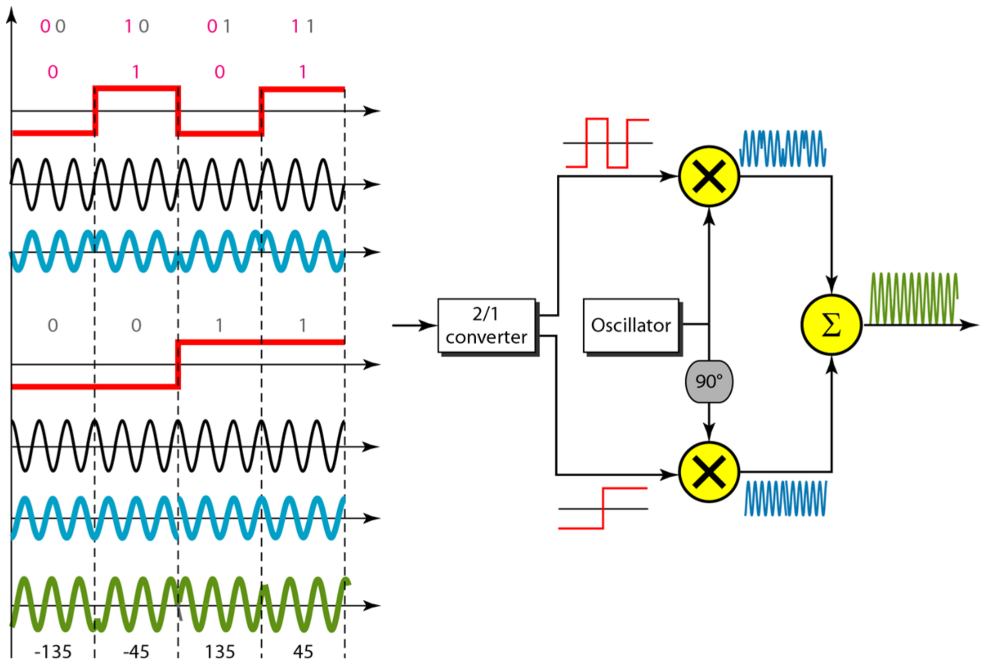
Binary phase shift keying



Modulation

Quadrature Phase Shift Keying

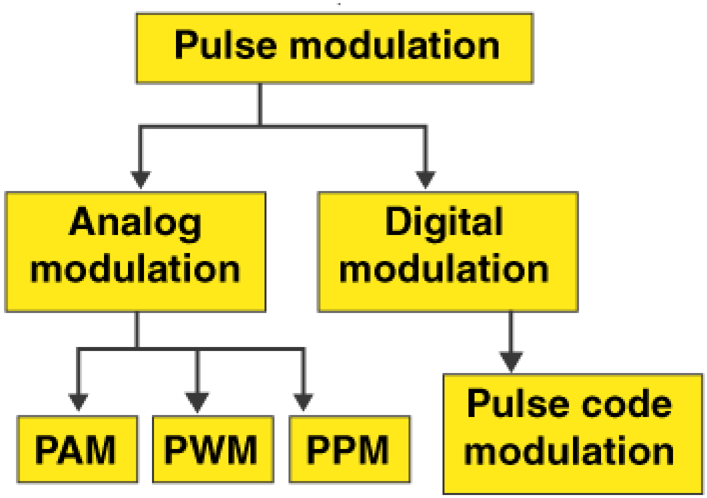
- To *increase the bit rate*, we can code 2 or more bits onto one signal element.
- In QPSK, we parallelize the bit stream so *that every two incoming bits are split up and PSK a carrier frequency*. One carrier frequency is phase shifted 90o from the other - in quadrature.
- The two PSKed signals are then added to produce one of 4 signal elements. L = 4 here.



Modulation

Pulse Modulation

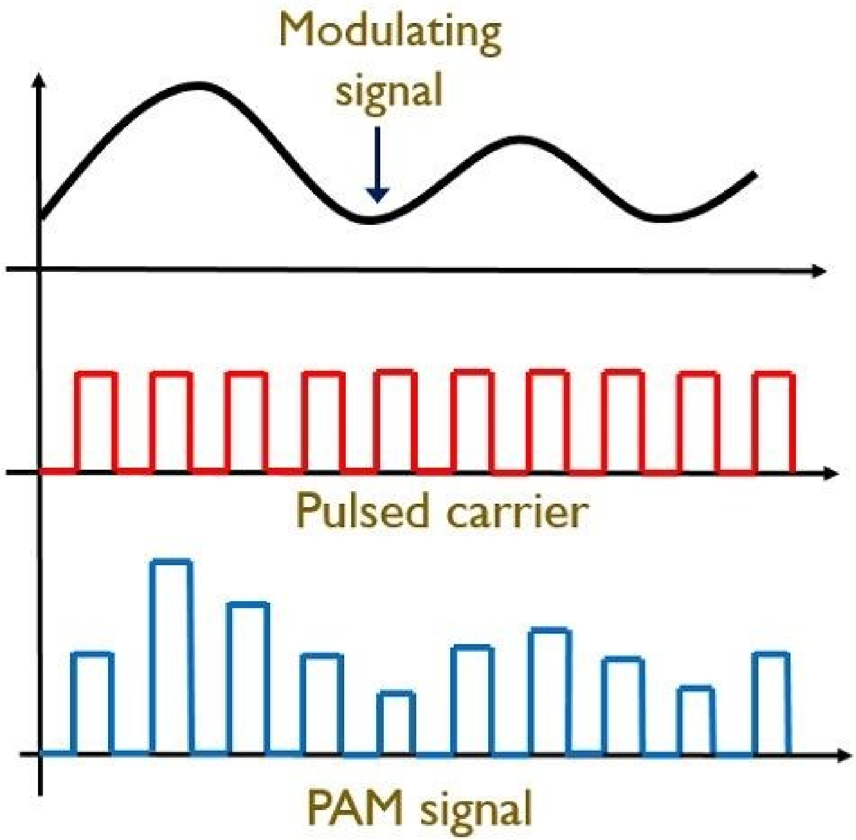
- Digital Carrier – Analog Data
- Pulse modulation is further divided into analog and digital modulation. The analog modulation techniques are mainly classified into Pulse Amplitude Modulation, Pulse Duration Modulation/Pulse Width Modulation, and Pulse Position Modulation.



Modulation

Pulse Amplitude Modulation (PAM)

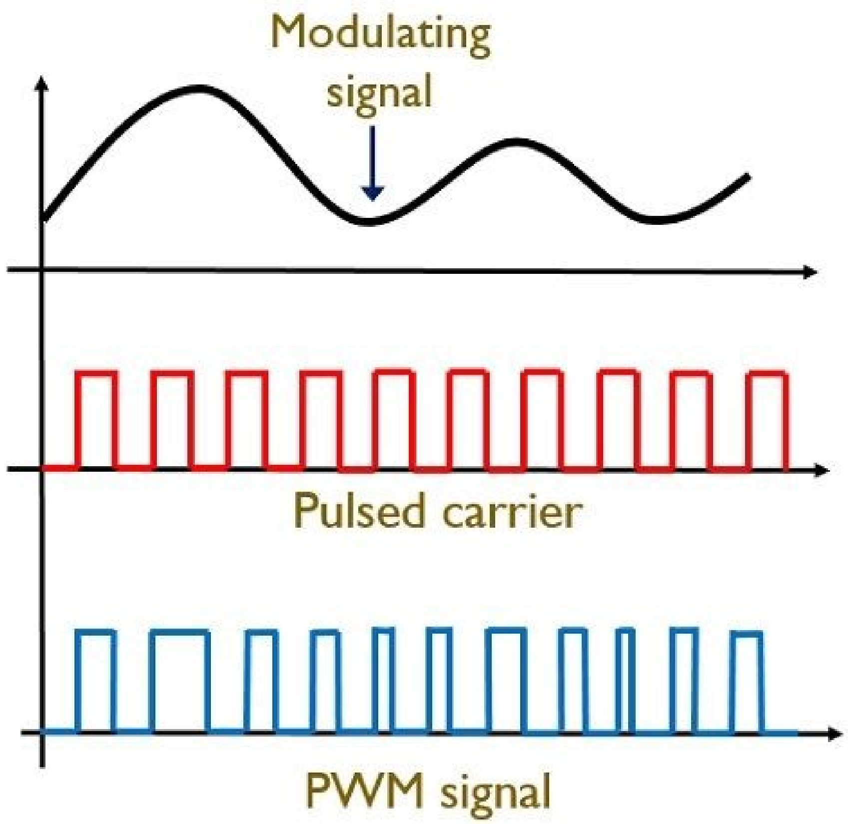
- The amplitude of the pulsed carrier signal is changed according to the amplitude of the message signal.



Modulation

Pulse Width Modulation (PWM)

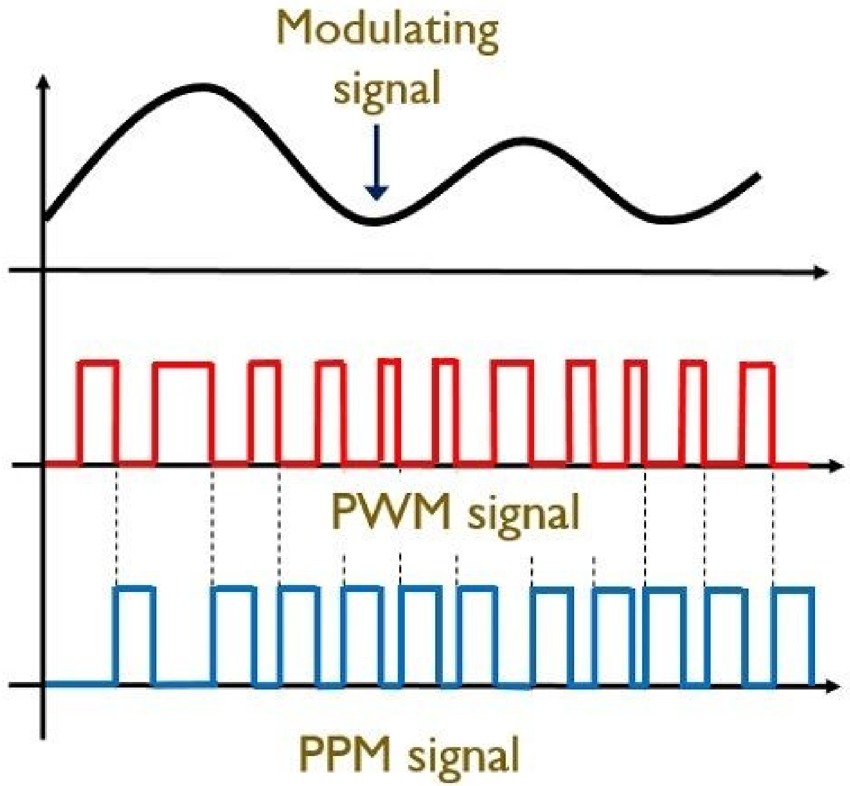
- The width of the pulses is varied according to the amplitude of the message signal. The figure below shows the pulse width modulated signal.



Modulation

Pulse Position Modulation (PPM)

- The position of the pulses is changed in accordance with the amplitude of the modulating signal.

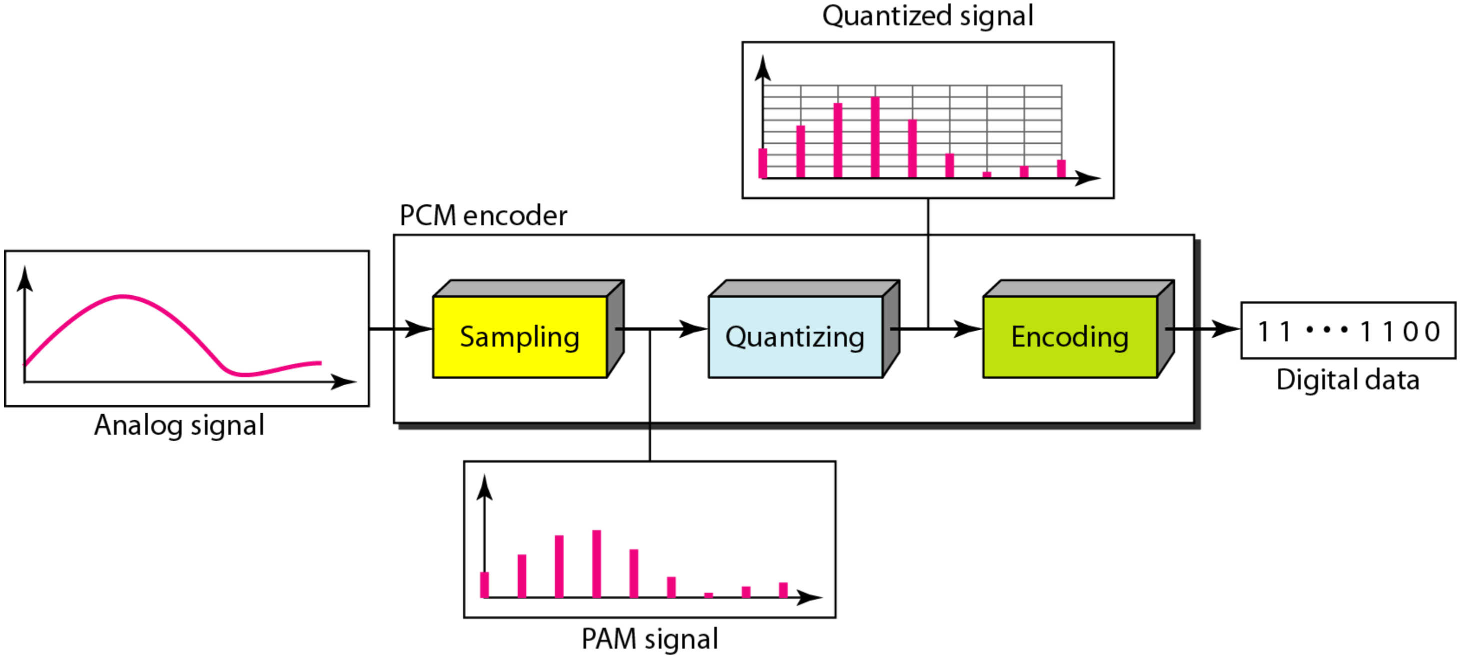


Modulation

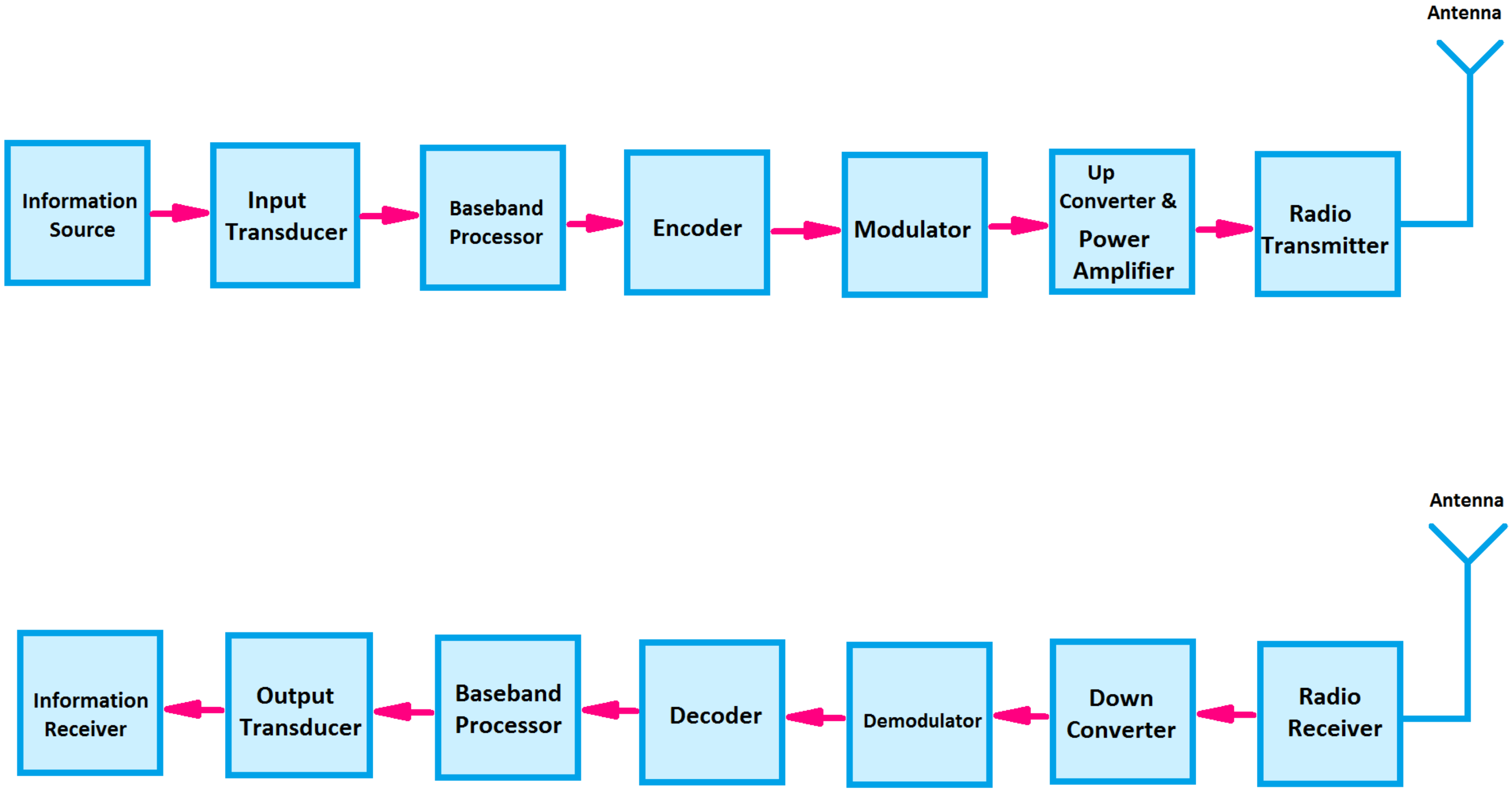
Pulse Code Modulation

PCM consists of three steps to digitize an analog signal:

- Sampling
- Quantization
- Binary encoding



Modulation

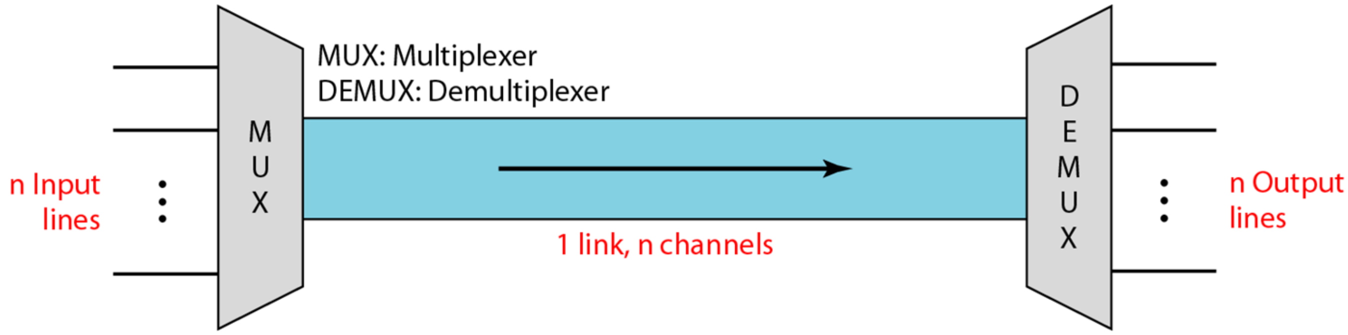


Wireless Radio Communication Block Diagram

Bandwidth Utilization

Multiplexing

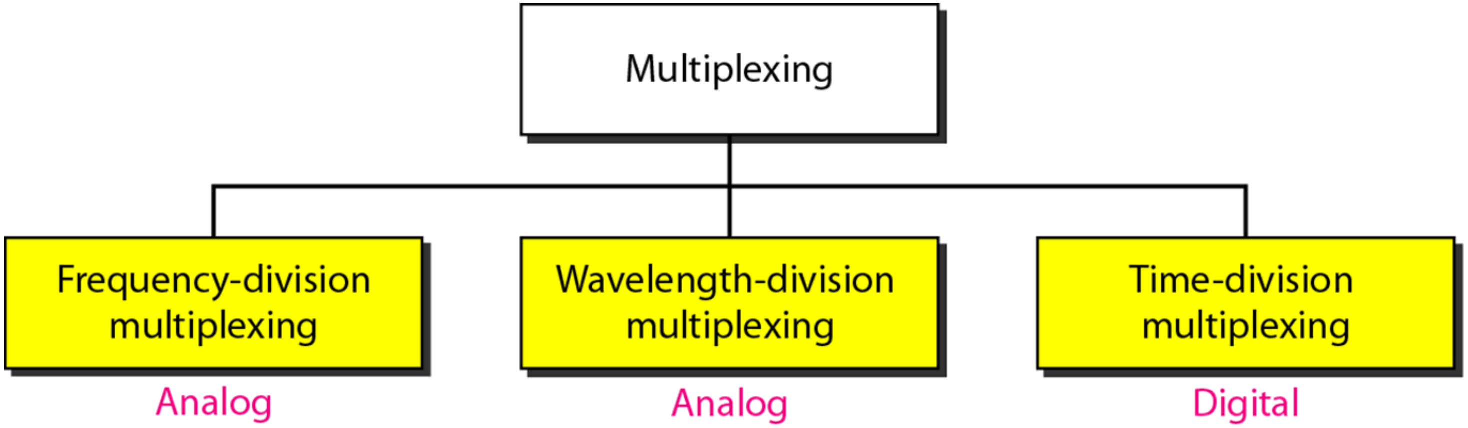
Multiplexing is the set of techniques that allows the (simultaneous) transmission of multiple signals across a single data link to achieve efficiency.



Bandwidth Utilization

Multiplexing

- Frequency-Division Multiplexing
- Wavelength-Division Multiplexing
- Time-Division Multiplexing



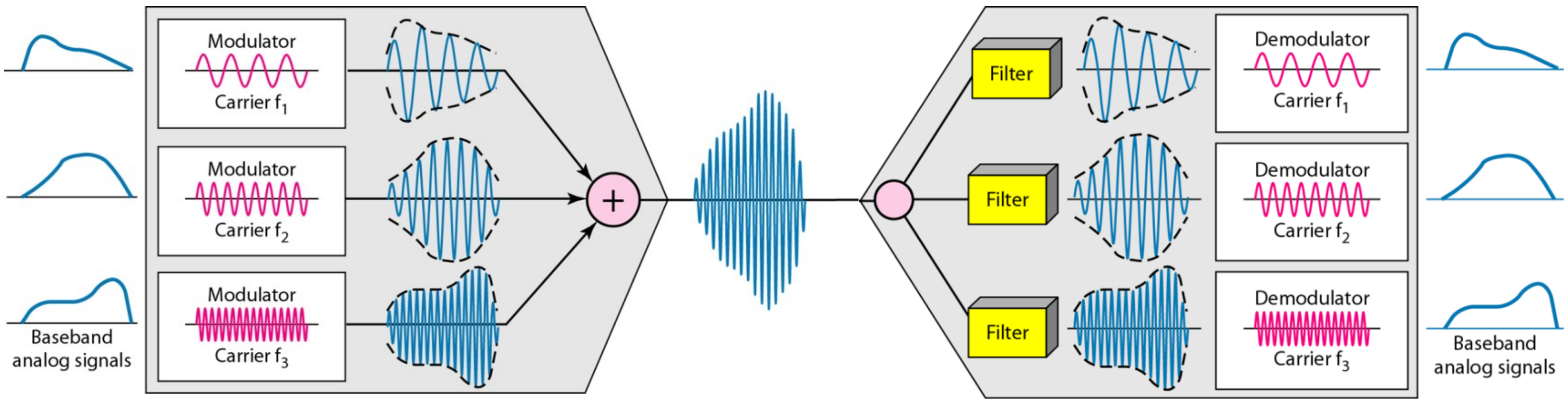
Bandwidth Utilization

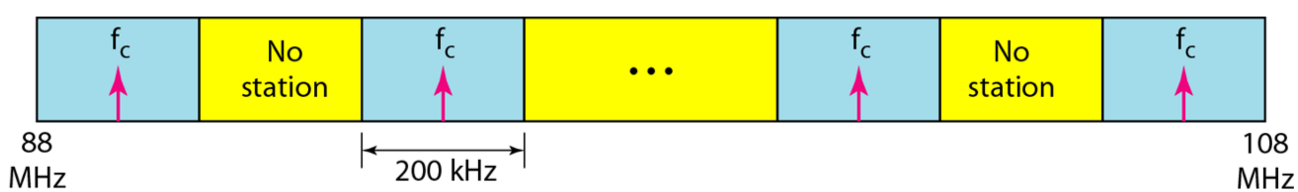
Frequency-Division Multiplexing

- FDM is an analog multiplexing technique that combines analog signals.
- It uses the concept of modulation

Bandwidth Utilization

Frequency-Division Multiplexing

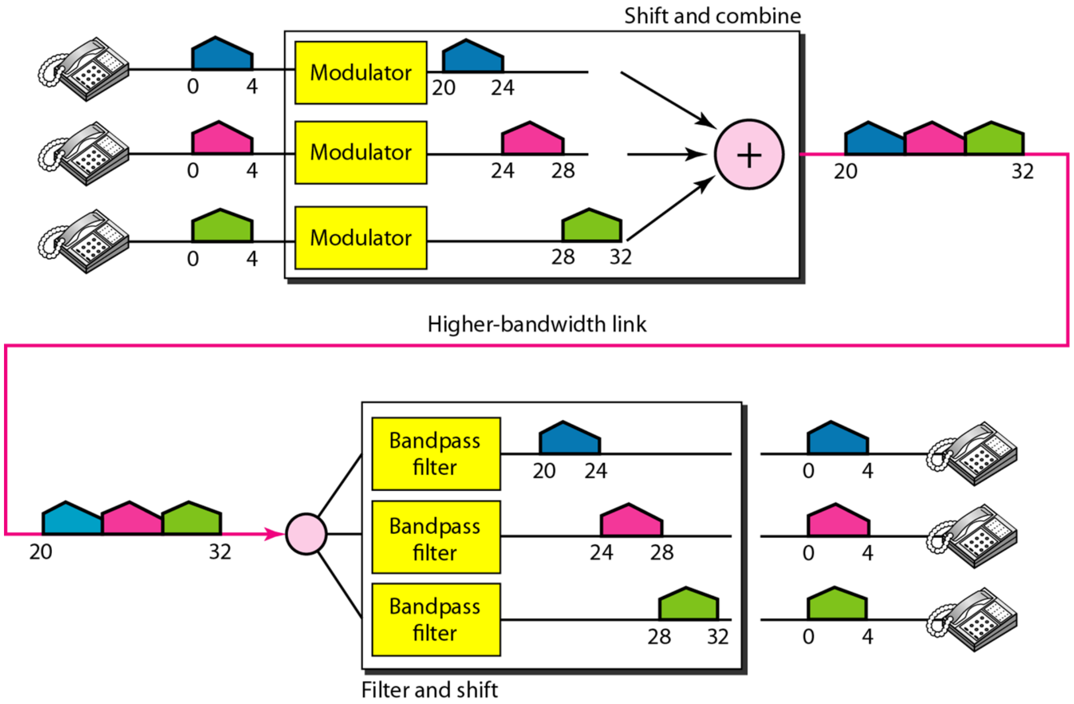




Bandwidth Utilization

Example: Frequency-Division Multiplexing

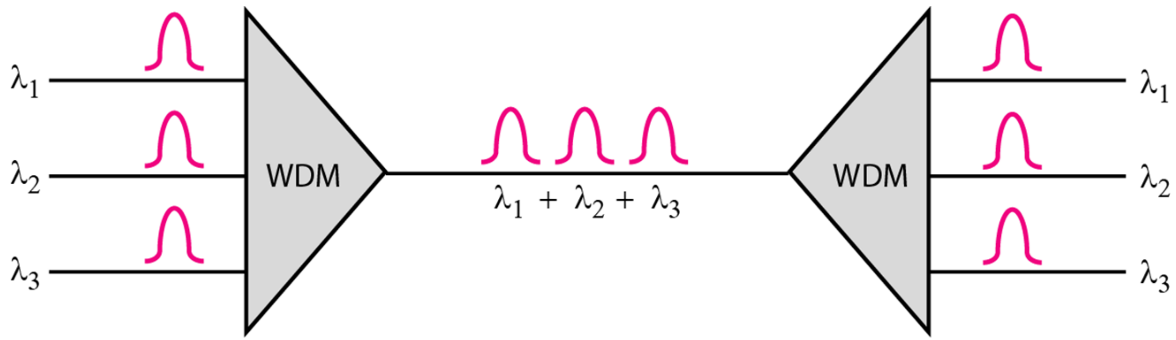
Assume that a voice channel occupies a bandwidth of 4 kHz. We need to combine three voice channels into a link with a bandwidth of 12 kHz, from 20 to 32 kHz. Show the configuration, using the frequency domain. Assume there are no guard bands.

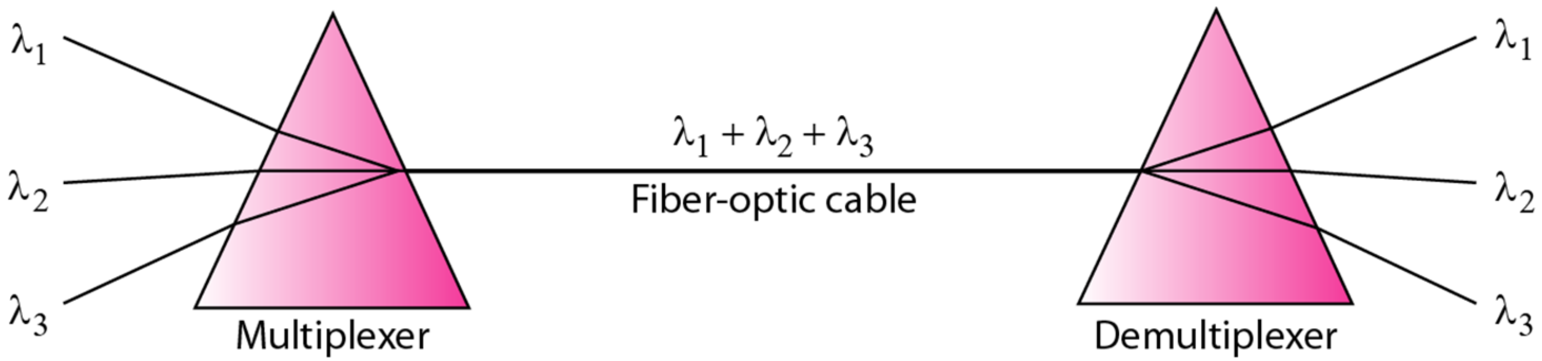


Bandwidth Utilization

Wave-Division Multiplexing

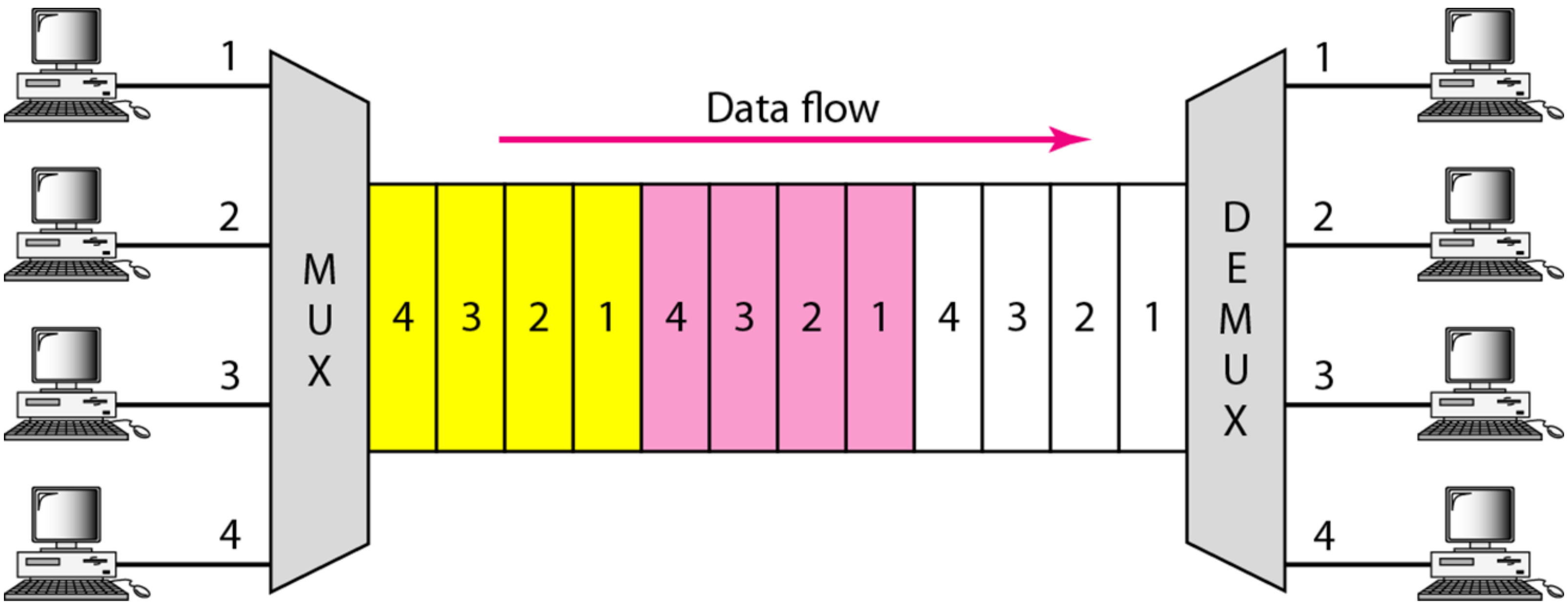
- WDM is an analog multiplexing technique to combine optical signals.





Bandwidth Utilization

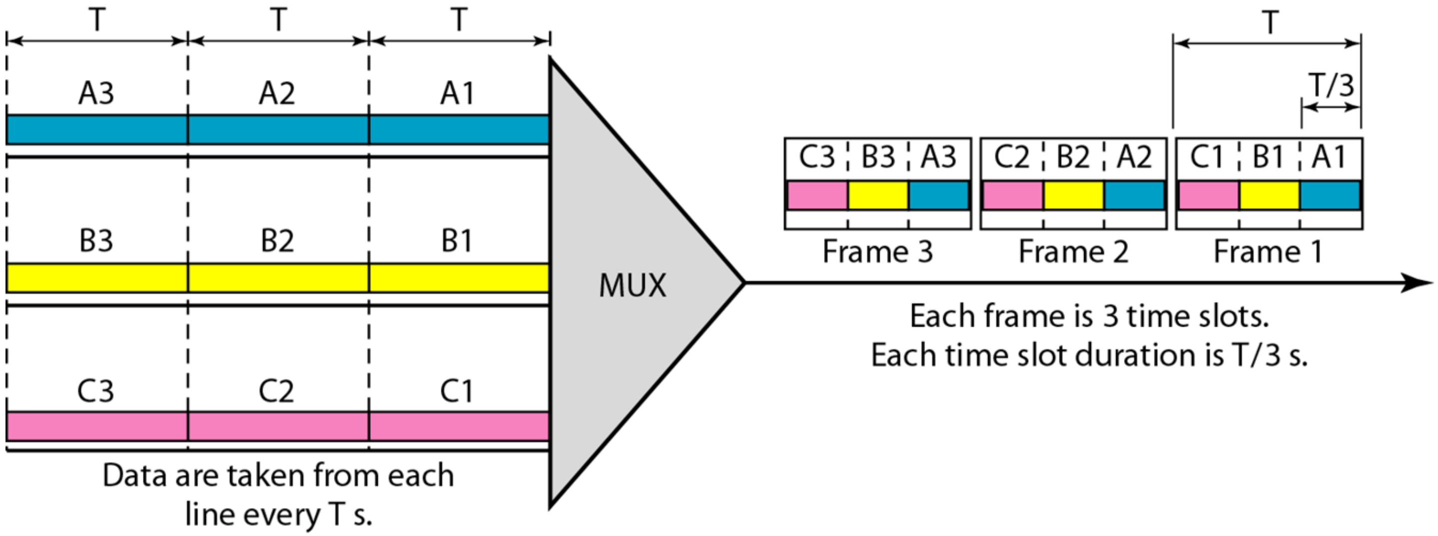
Time-Division Multiplexing



Bandwidth Utilization

Time-Division Multiplexing

- The data rate of the link is n times faster
- The unit duration is n times shorter.

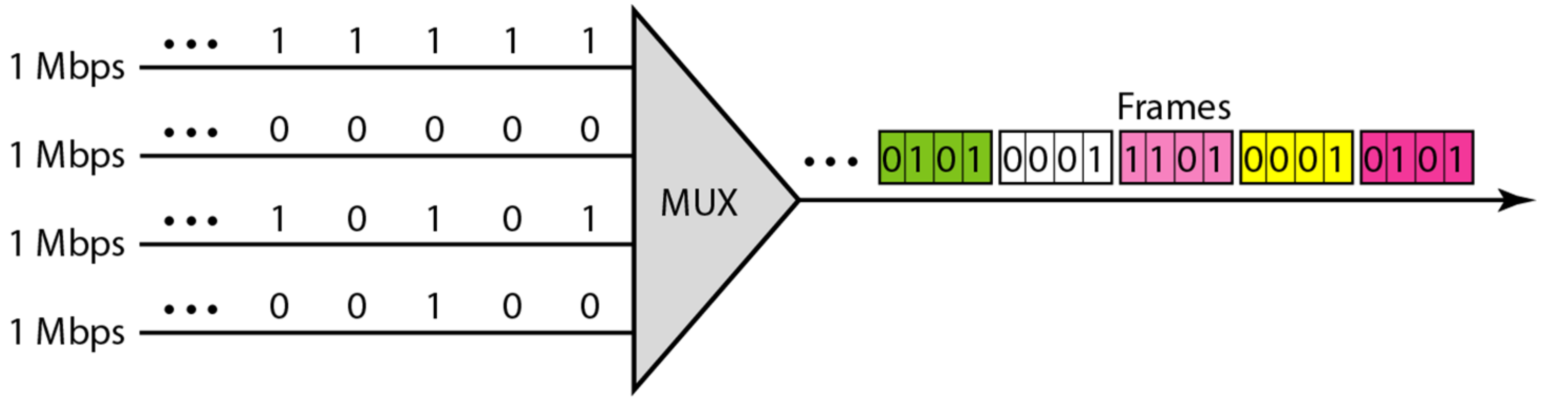


Bandwidth Utilization

Example: Time-Division Multiplexing

Figure below shows synchronous TDM with 4, each1Mbps data stream inputs and one data stream for the output. The unit of data is 1 bit. Find

(a) the input bit duration, (b) the output bit duration,
(c) the output bit rate, (d) the output frame rate.



Bandwidth Utilization

Example: Time-Division Multiplexing

Solution

a. The input bit duration is the inverse of the bit rate: 1/1 Mbps = 1 μs.

b. The output bit duration is one-fourth of the input bit duration, or ¼ μs.

c. The output bit rate is the inverse of the output bit duration or 1/(4μs) or 4 Mbps. This can also be deduced from the fact that the output rate is 4 times as fast as any input rate; so the output rate = 4 × 1 Mbps = 4 Mbps.

d. The frame rate is always the same as any input rate. So the frame rate is 1,000,000 (1 M)frames per second. Because we are sending 4 bits in each frame. We can verify the result of the previous question by multiplying the frame rate by the number of bits per frame.