Analog Transmission and Multiplexing

DIGITAL-TO-ANALOG CONVERSION

Digital-to-analog conversion is the process of changing one of the characteristics of an analog signal based on the information in digital data. Figure below shows the relationship between the digital information, the digital-to-analog modulating process, and the resultant analog signal.

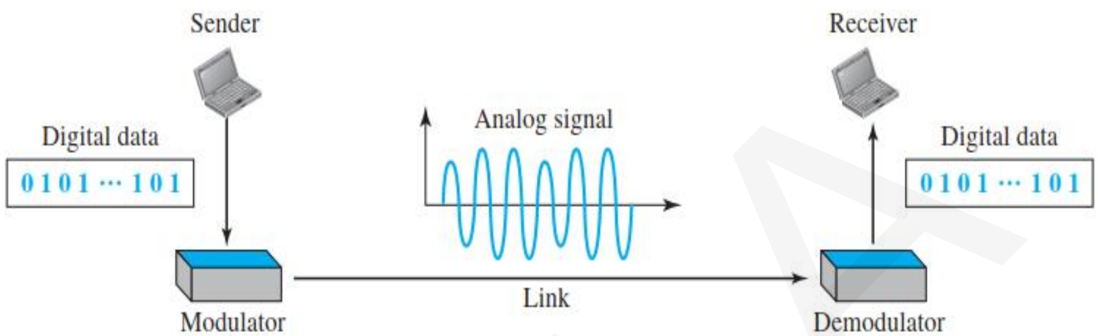


Figure Digital-to-analog conversion

-There are three Types of digital-to-analog conversion

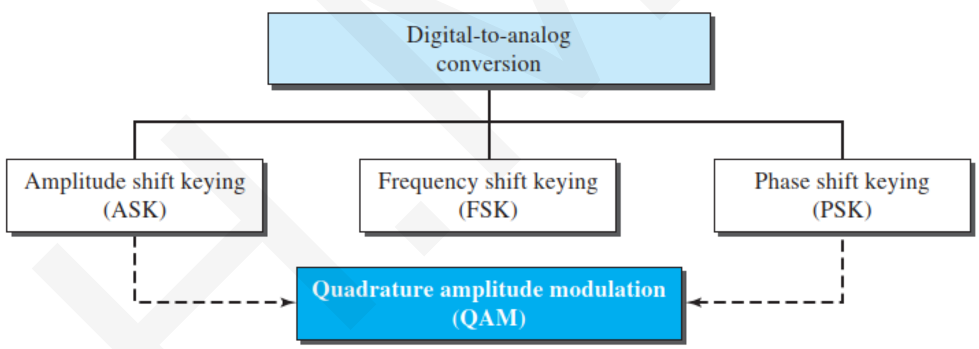


Figure Types of digital-to-analog conversion

Amplitude Shift Keying

In amplitude shift keying, the amplitude of the carrier signal is varied to create signal elements. Both frequency and phase remain constant while the amplitude changes.

Binary ASK (BASK)

Although we can have several levels (kinds) of signal elements, each with a different amplitude, ASK is normally implemented using only two levels. This is referred to as binary amplitude shift keying or on-off keying (OOK). The peak amplitude of one signal level is 0; the other is the same as the amplitude of the carrier frequency. Figure below gives a conceptual view of binary ASK.

- Bandwidth for ASK is : B = (1 + d) × S

-Where d is a factor depends on the modulation and filtering process. The value of d is between 0 and 1, S is the signal rate and the B is the bandwidth

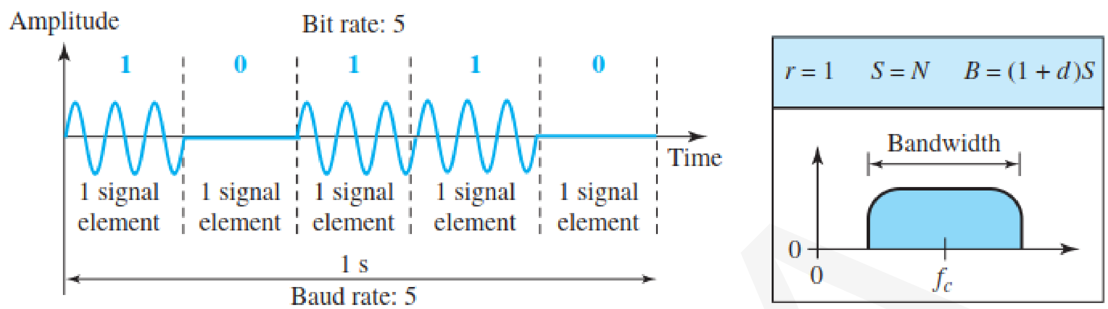


Figure Binary amplitude shift keying

Frequency Shift Keying

In frequency shift keying, the frequency of the carrier signal is varied to represent data. The frequency of the modulated signal is constant for the duration of one signal element, but changes for the next signal element if the data element changes. Both peak amplitude and phase remain constant for all signal elements.

Binary FSK (BFSK)

One way to think about binary FSK (or BFSK) is to consider two carrier frequencies. In Figure below, we have selected two carrier frequencies, f1 and f2. We use the first carrier if the data element is 0; we use the second if the data element is 1. However, note that this is an unrealistic example used only for demonstration purposes. Normally the carrier frequencies are very high, and the difference between them is very small.

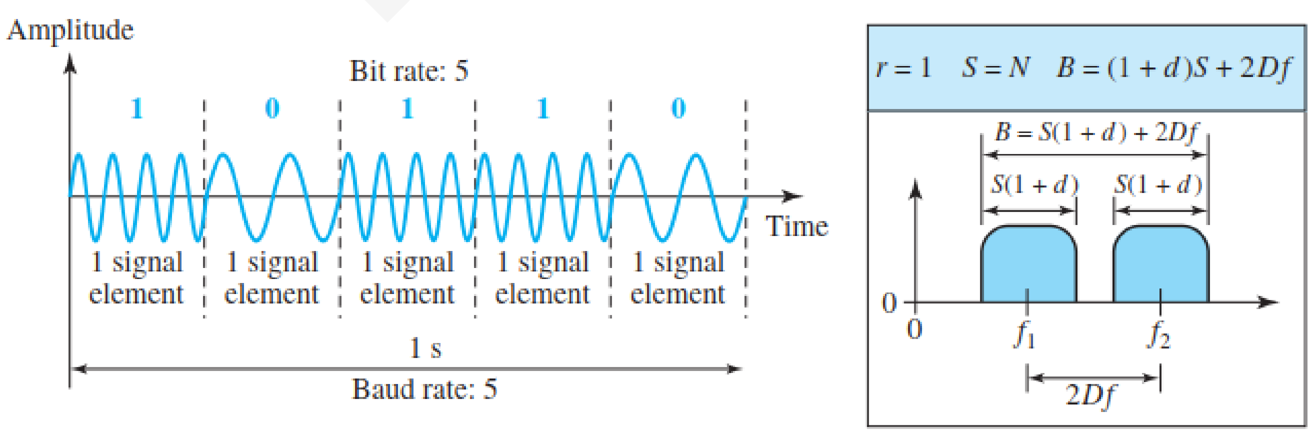


Figure Binary frequency shift keying

- As Figure above shows, the middle of one bandwidth is f1 and the middle of the other is f2. Both f1 and f2 are Δf apart from the midpoint between the two bands. The difference between the two frequencies is 2Δf.

- Bandwidth for BFSK is $B = (1 + d) \times S + 2\Delta\phi$

Phase Shift Keying

In phase shift keying, the phase of the carrier is varied to represent two or more different

signal elements. Both peak amplitude and frequency remain constant as the phase changes. Today, PSK is more common than ASK or FSK. However, we will see shortly that QAM, which combines ASK and PSK, is the dominant method of digital-to-analog modulation.

Binary PSK (BPSK)

-The simplest PSK is binary PSK, in which we have only two signal elements, one with a phase of 0°, and the other with a phase of 180°. Figure below gives a conceptual view of PSK. Binary PSK is as simple as binary ASK with one big advantage—it is less susceptible to noise.

- In other words, PSK is less susceptible to noise than ASK. PSK is superior to FSK because we do not need two carrier signals. However, PSK needs more sophisticated hardware to be able to distinguish between phases.

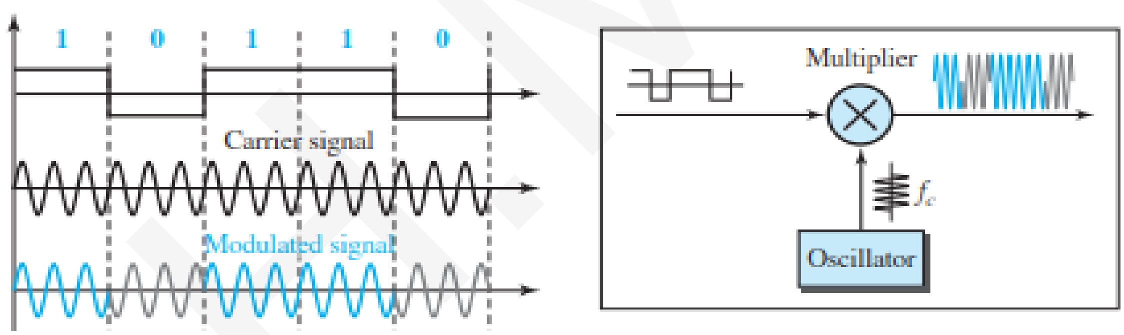


Figure Binary phase shift keying

-Bandwidth: Figure above also shows the bandwidth for BPSK. The bandwidth is the same as that for binary ASK, but less than that for BFSK. No bandwidth is wasted for separating two carrier signals

Quadrature Amplitude Modulation

The simplicity of BPSK enticed designers to use 2 bits at a time in each signal element, thereby decreasing the baud rate and eventually the required bandwidth. The scheme is called quadrature PSK or QPSK because it uses two separate BPSK modulations; one is in-phase, the other quadrature (out-of-phase). The incoming bits are first passed through a serial-to-parallel conversion that sends one bit to one modulator and the next bit to the other modulator. If the duration of each bit in the incoming signal is T, the duration of each bit sent to the corresponding BPSK signal is 2T. This means that the bit to each BPSK signal has one-half the frequency of the original signal. Figure below shows the idea.

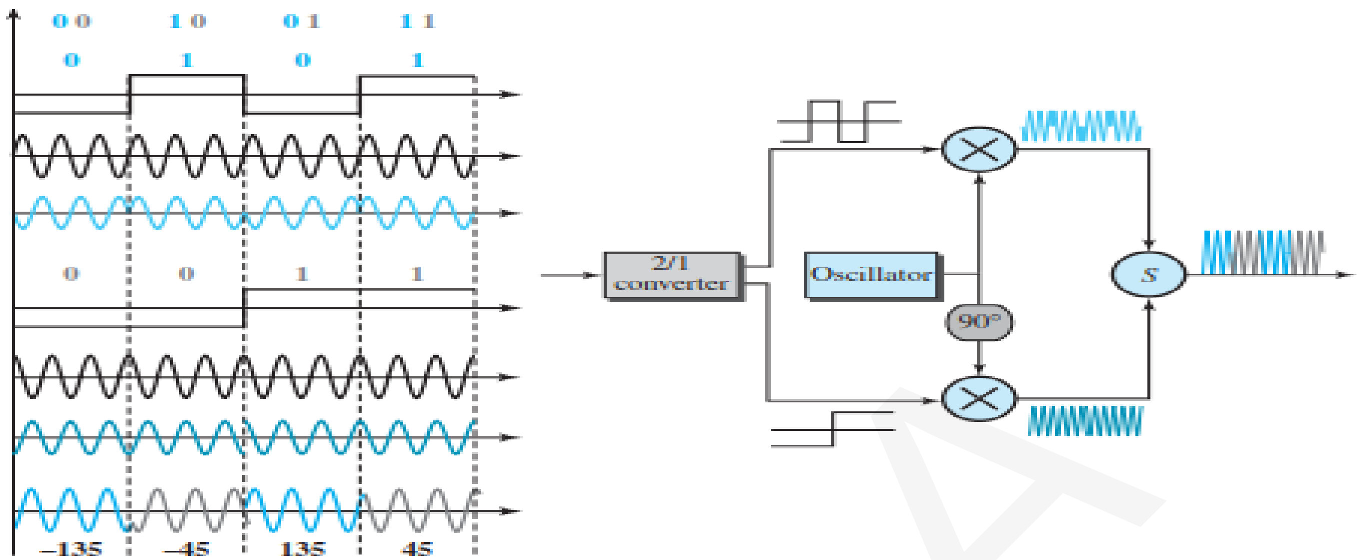


Figure QPSK and its implementation

Quadrature Amplitude Modulation

- Quadrature amplitude modulation is a combination of ASK and PSK.

-The idea of using two carriers, one in-phase and the other quadrature, with different amplitude levels for each carrier is the concept behind quadrature amplitude modulation (QAM).

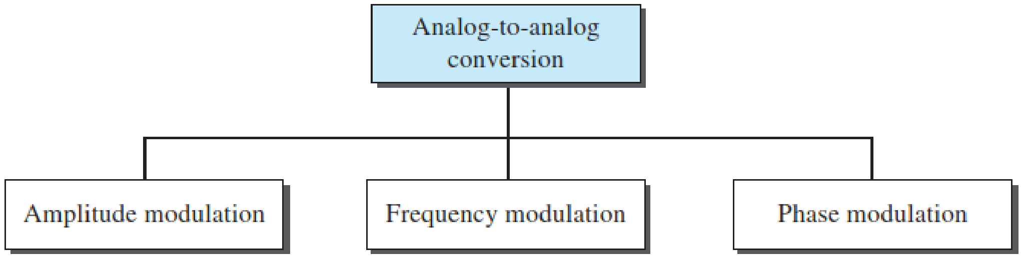
- The minimum bandwidth required for QAM transmission is the same as that required for ASK and PSK transmission. QAM has the same advantages as PSK over ASK.

ANALOG-TO-ANALOG CONVERSION

-Analog-to-analog conversion, or analog modulation, is the representation of analog information by an analog signal. One may ask why we need to modulate an analog signal; it is already analog. Modulation is needed if the medium is band pass in nature or if only a band pass channel is available to us. An example is radio. The government assigns a narrow bandwidth to each radio station. The analog signal produced by each station is a low-pass signal, all in the same range. To be able to listen to different stations, the low-pass signals need to be shifted, each to a different range.

-Analog-to-analog conversion can be accomplished in three ways: amplitude modulation (AM),

frequency modulation (FM), and phase modulation (PM).



Amplitude Modulation (AM)

-In AM transmission, the carrier signal is modulated so that its amplitude varies with the changing amplitudes of the modulating signal. The frequency and phase of the carrier remain the same; only the amplitude changes to follow variations in the information. Figure below shows how this concept works. The modulating signal is the envelope of the carrier.

-The total bandwidth required for AM can be determined from the bandwidth of the audio signal: $B_{AM} = 2B$.

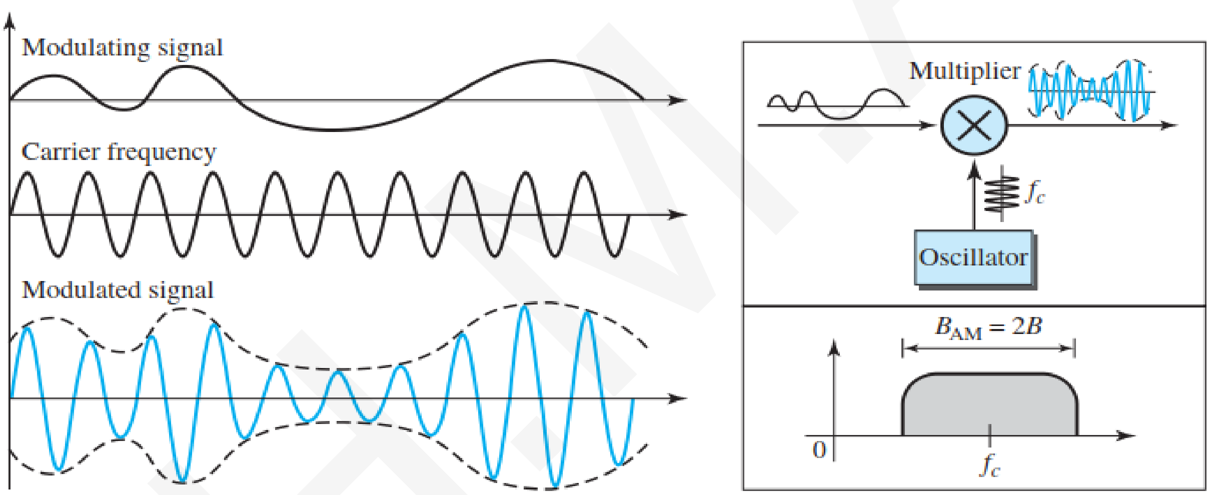


Figure Amplitude modulation

Frequency Modulation (FM)

-In FM transmission, the frequency of the carrier signal is modulated to follow the changing voltage level (amplitude) of the modulating signal. The peak amplitude and phase of the carrier signal remain constant, but as the amplitude of the information signal changes, the frequency of the carrier changes correspondingly.

-The total bandwidth required for FM can be determined from the bandwidth of the audio signal: $B_{FM} = 2(1 \times \beta)B$. where β is a factor that depends on modulation technique with a common value of 4

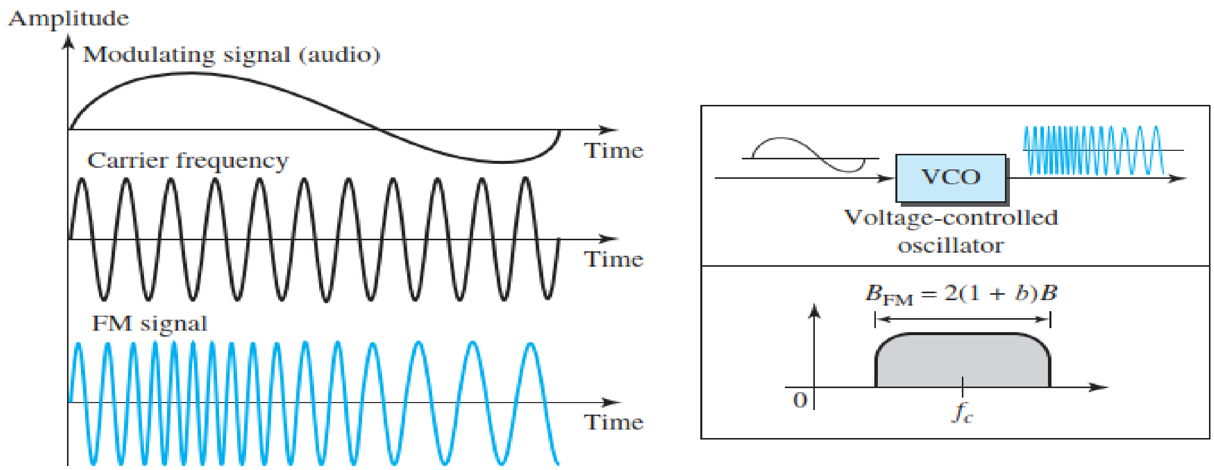


Figure   Frequency modulation

Phase Modulation (PM)

In PM transmission, the phase of the carrier signal is modulated to follow the changing voltage level (amplitude) of the modulating signal. The peak amplitude and frequency of the carrier signal remain constant, but as the amplitude of the information signal changes, the phase of the carrier changes correspondingly. In FM, the instantaneous change in the carrier frequency is proportional to the amplitude of the modulating signal; in PM the instantaneous change in the carrier frequency is proportional to the derivative of the amplitude of the modulating signal.

-The total bandwidth required for PM can be determined from the bandwidth and

maximum amplitude of the modulating signal: $B_{PM} = 2(1 + \beta)B$.

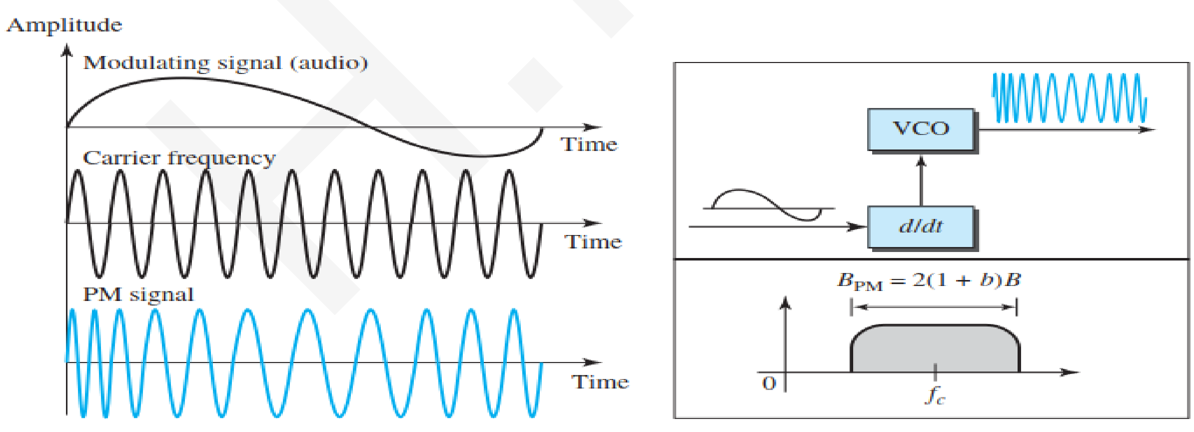


Figure   Phase modulation

MULTIPLEXING

-Whenever the bandwidth of a medium linking two devices is greater than the bandwidth

needs of the devices, the link can be shared.

-Multiplexing is the set of techniques that allow the simultaneous transmission of multiple signals across a single data link.

-As data and telecommunications use increases, so does traffic. We can accommodate this increase by continuing to add individual links each time a new channel is needed; or we can install higher-bandwidth links and use each to carry multiple signals.

-In a multiplexed system, n lines share the bandwidth of one link. Figure below shows the basic format of a multiplexed system.

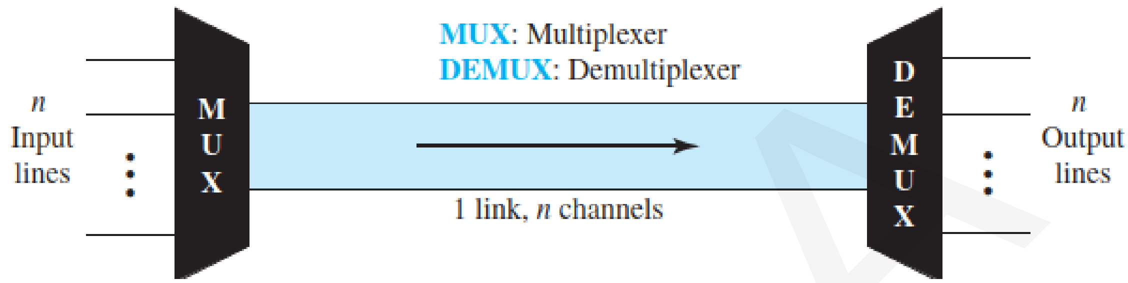


Figure Dividing a link into channels

-The lines on the left direct their transmission streams to a multiplexer (MUX), which combines them into a single stream (many-to one).

-At the receiving end, that stream is fed into a demultiplexer (DEMUX), which separates the stream back into its component transmissions (one-to-many) and directs them to their corresponding lines.

-In the figure, the word link refers to the physical path.

-The word channel refers to the portion of a link that carries a transmission between a given pair of lines.

-One link can have many (n) channels.

-There are three basic multiplexing techniques: frequency-division multiplexing, wavelength-division multiplexing, and time-division multiplexing. The first two are techniques designed for analog signals, the third, for digital signals

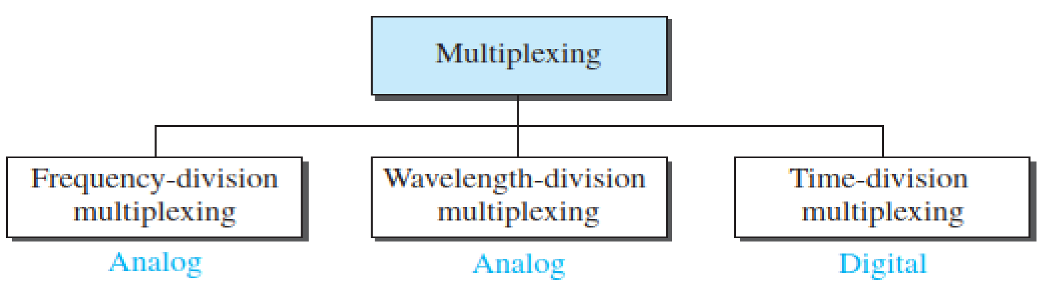


Figure Categories of multiplexing

Frequency-Division Multiplexing

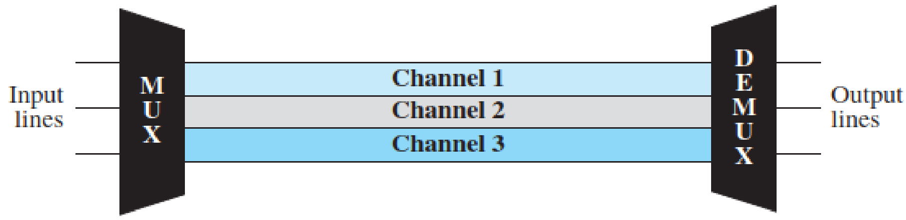


Figure Frequency-division multiplexing

-Frequency-division multiplexing (FDM) is an analog technique that can be applied when the bandwidth of a link (in hertz) is greater than the combined bandwidths of the signals to be transmitted.

-In FDM, signals generated by each sending device modulate different carrier frequencies. These modulated signals are then combined into a single composite signal that can be transported by the link.

-Carrier frequencies are separated by sufficient bandwidth to accommodate the modulated signal.

-These bandwidth ranges are the channels through which the various signals travel. Channels can be separated by strips of unused bandwidth-guard bands-to prevent signals from overlapping.

-In addition, carrier frequencies must not interfere with the original data frequencies.

Multiplexing Process

Each source generates a signal of a similar frequency range. Inside the multiplexer, these similar signals modulate different carrier frequencies (f1, f2, and f3). The resulting modulated signals are then combined into a single composite signal that is sent out over a media link that has enough bandwidth to accommodate it.

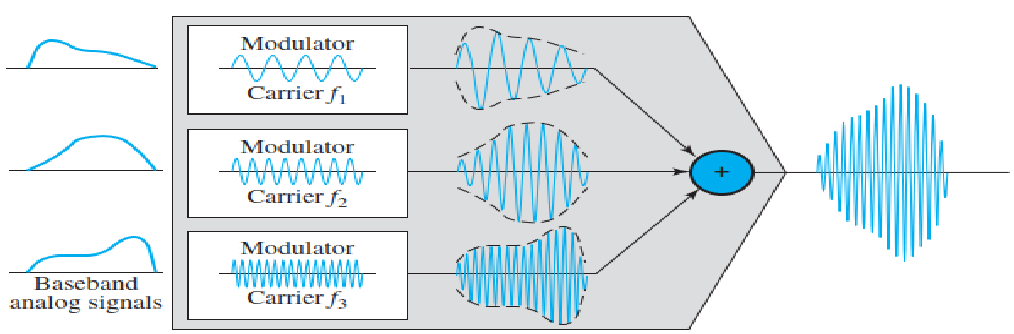


Figure FDM process

Demultiplexing Process

The de-multiplexer uses a series of filters to decompose the multiplexed signal into its constituent component signals. The individual signals are then passed to a demodulator that separates them from their carriers and passes them to the output lines.

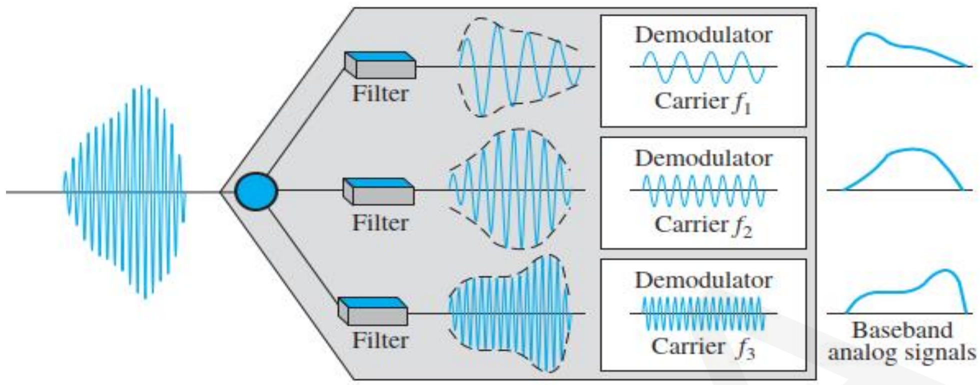


Figure FDM demultiplexing example

Wavelength-Division Multiplexing

-Wavelength-division multiplexing (WDM) is designed to use the high-data-rate capability of

fiber-optic cable. The optical fiber data rate is higher than the data rate of metallic transmission cable. Using a fiber-optic cable for one single line wastes the available bandwidth. Multiplexing allows us to combine several lines into one.

-WDM is conceptually the same as FDM, except that the multiplexing and de-multiplexing involve optical signals transmitted through fiber-optic channels. The idea is the same: We are combining different signals of different frequencies. The difference is that the frequencies are very high.

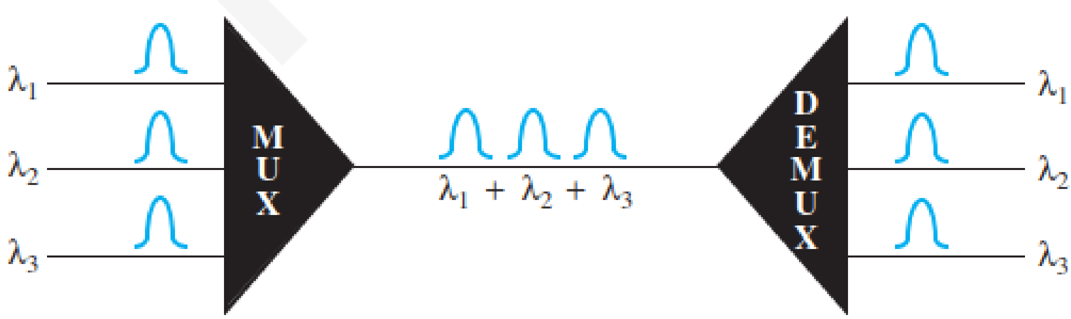


Figure Wavelength-division multiplexing

-A new method, called dense WDM (DWDM), can multiplex a very large number of

channels by spacing channels very close to one another

Time-Division Multiplexing

Time-division multiplexing (TDM) is a digital process that allows several connections to share the high bandwidth of a link Instead of sharing a portion of the bandwidth as in FDM, time is shared. Each connection occupies a portion of time in the link.

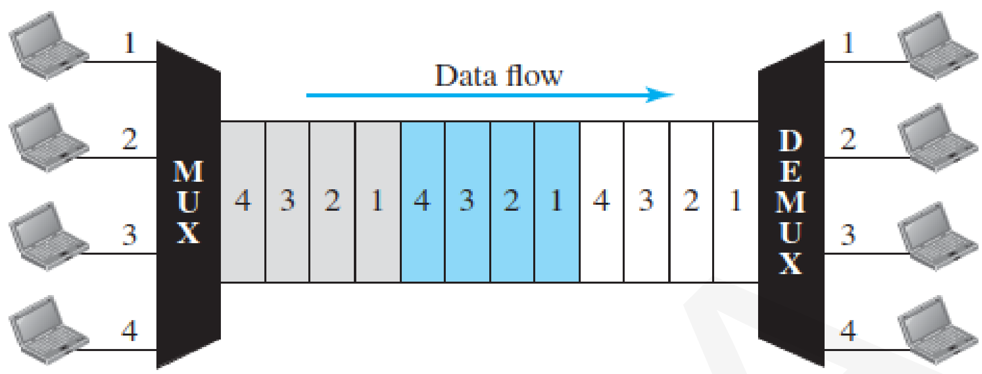


Figure TDM

-We can divide TDM into two different schemes: **synchronous** and **statistical**.

-in synchronous TDM, each input has a reserved slot in the output frame. This can be inefficient if some input lines have no data to send.

-In statistical time-division multiplexing, slots are dynamically allocated to improve bandwidth

efficiency. Only when an input line has a slot's worth of data to send is it given a slot in the output frame.

-In statistical multiplexing, the number of slots in each frame is less than the number of input lines.

Figure below shows a synchronous and a statistical TDM example.

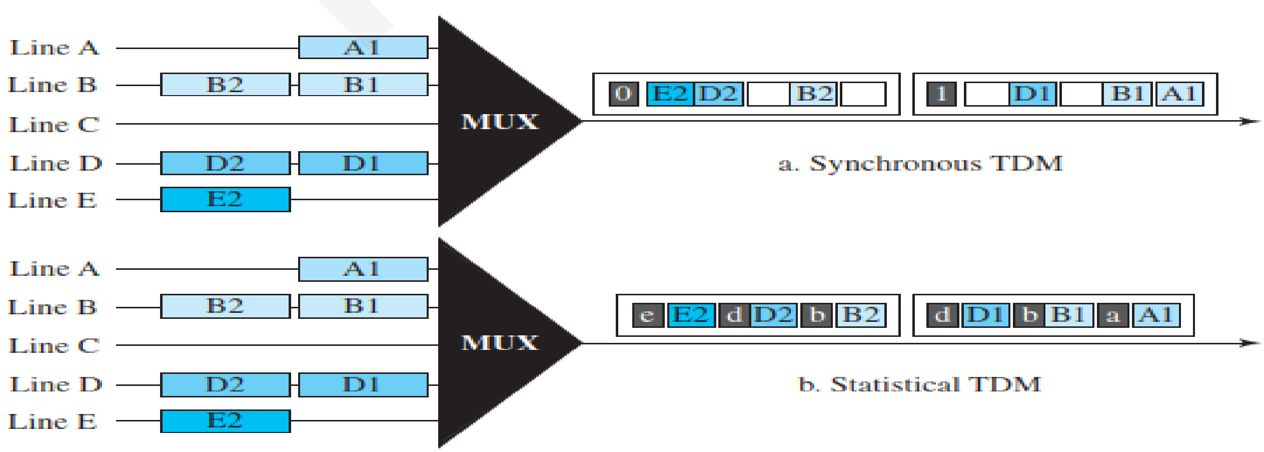


Figure TDM slot comparison