COMMUNICATION SYSTTEM REVIEW

MULTIPLEXING

Objectives

- Discuss the differences between frequency division multiplexing (FDM) and time division multiplexing (TDM).
- Discuss the various steps required to prepare a signal for TDM.
- Understand amplitude modulation (AM).
- Understand pulse code modulation (PCM).

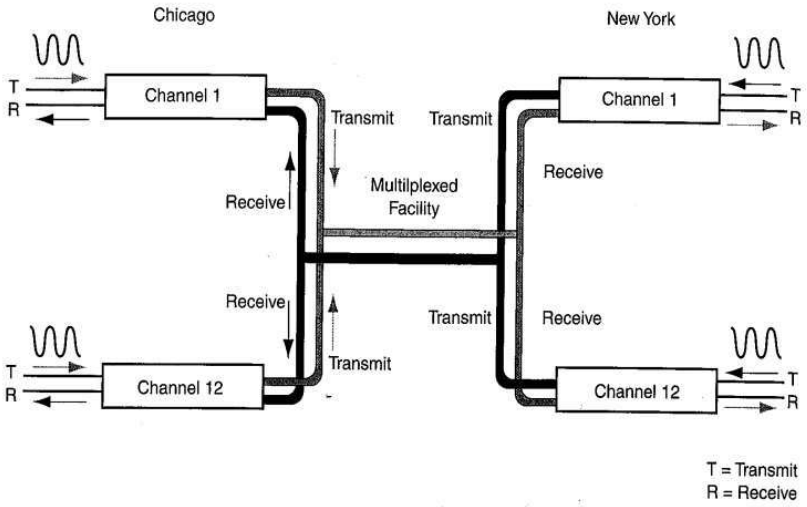
Multiplexing

- In telecommunications, multiplexing means to combine many signals (voice or data) so they can be sent over one transmission medium.
  - Space Division Multiplexing
  - Frequency Division Multiplexing (FDM)
  - Time Division Multiplexing (TDM)

Bandwidth

- Bandwidth (BW) refers to the width of a signal, which is determined by taking the difference between the highest frequency of the signal and its lowest frequency.
- A voice signal is usually though of as a signal between 0 and 4000 Hz (BW = 4000 Hz).
- In the United States, AT&T designed its FDM systems to handle the band of signals between 200 and 3400 Hz (BW = 3200 Hz).

Twelve-Channel Frequency Division Multiplexing



The Channel Unit of a FDM System

- Each signal fed to a FDM system interfaces to the multiplexer through a device called a *channel unit*.
- The channel unit makes changes to the input signal so it can be multiplexed with other signals for transmission.
  - Voice signals arrive between 0 and 4000 Hz.
  - A sharp cutoff bandpass filter passes only 200 – 3400 Hz.
  - A modulator takes the 200 – 3400 Hz signal and shifts it to another frequency.

Transmit and Receive Paths: The Four-Wire System

- The first multiplexers used four wires for the transmission medium.
  - One pair of wires was used for the signal going in one direction.
  - A separate pair of wires was used for the signal going in the opposite direction.
- Two fiber optic strands are required to connect multiplexers.
- Two microwave frequencies are required to connect multiplexers.

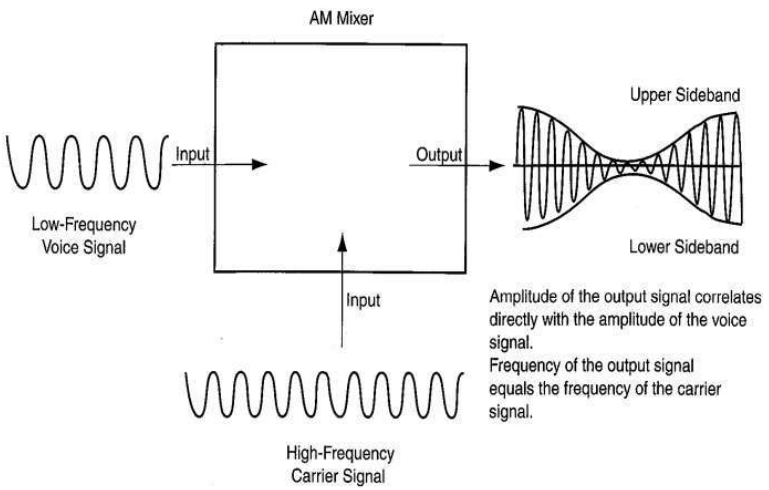
Why Use Multiplexing?

- Multiplexing was first used to reduce the number of transmission media needed between cities and towns.
- This resulted in significantly reduced costs for trunk circuits.

Amplitude Modulation

- In *amplitude modulation (AM)* the amplitude of the carrier frequency coming out of the mixer will vary according to the changing amplitude of the input voice signal.
- Amplitude modulation is used by AM broadcast stations.
  - Carrier frequencies are between 540 kHz and 1,650 kHz.
  - Carrier frequencies are licensed by the FCC.

Amplitude Modulation



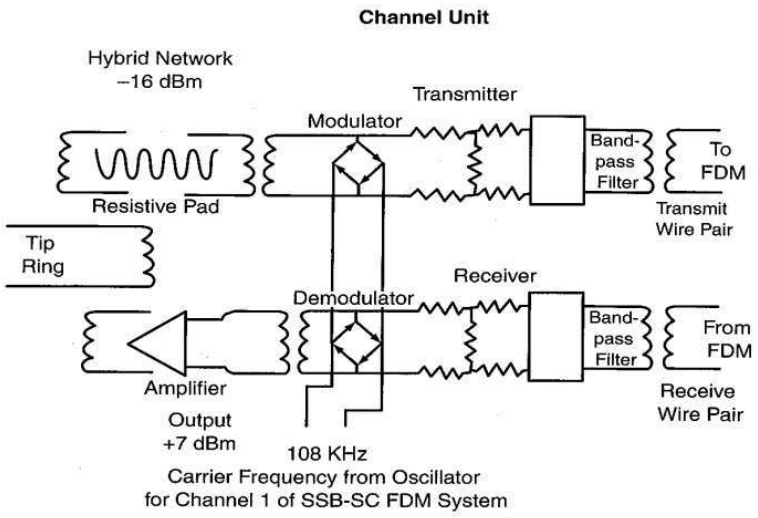
Frequency Division Multiplexing

- Using FDM, many telephone calls can be multiplexed over two pairs of wires.
- If we wish to multiplex 12 calls over two pairs of wires between cities A and B:
  - We hook up a multiplexer containing 12 transmitters to the first wire pair in city A; at the other end we attach 12 receivers in city B.
  - We hook up a multiplexer containing 12 transmitters to the second wire pair in city B; at the other end we attach 12 receivers in city A.
- The two simplex circuits make up a full-duplex circuit between A and B.

Hybrid Network

- The circuit from a telephone arrives at the input to the channel unit of a multiplexer as a two-wire circuit.
- The channel unit contains a *hybrid network* that interfaces the two-wire input to a four-wire transmit/receive path.
  - The transmit path connects to the transmitter for this channel.
  - The receive path connects to the receiver for this channel.

Channel Unit



Amplitude Modulation Technology

- Amplitude modulation is a technique in which the amplitude of the high-frequency signal changes when the high-frequency signal is mixed with a low-frequency signal in a device called a mixer or modulator.
  - The high-frequency signal is termed the *carrier frequency*.
  - The low-frequency signal is called the *modulating signal*.

Amplitude Modulation Example

- If a 64,000 Hz signal is modulated by a 4,000 Hz signal, the outputs of the modulator will be:
  - 64,000 Hz
  - 4,000 Hz
  - 68,000 Hz (64,000 + 4,000)
  - 60,000 Hz (64,000 – 4,000)
- The two additional signals generated by the mixing process are called *sidebands*.
  - The higher signal is called the *upper sideband*.
  - The lower signal is called the *lower sideband*.

Bandwidth and Single-Sideband Suppressed Carrier

- The bandwidth of an AM signal is twice the bandwidth of the modulating signal.
  - When a low-frequency signal is present as an input to the mixer, the amplitude of both sideband signals changes as the input signal changes.
  - Since both sidebands have been modulated, they both contain the frequency changes of the modulating signal.

Single-Sideband (SSB) systems

- We only need to demodulate one of the sidebands to recapture the intelligence of the modulating signal.
- Since only one sideband is needed to demodulate the modulating signal, some systems will transmit only one sideband with the carrier frequency.
- Systems that do not transmit the main carrier frequency, but transmit the sideband only, are called Single-Sideband Suppressed Carrier (SSB-SC) systems.

CCITT Standards for Frequency Division Multiplexing

- Telecommunications standards are set by several organizations.
- Predominant organizations:
  - American National Standards Institute (ANSI)
    - Establishes standards for North America
  - Consultative Committee on International Telegraphy and Telecommunications (CCITT)
    - Organization within the International Telecommunications Union (ITU)
    - Creates worldwide standards

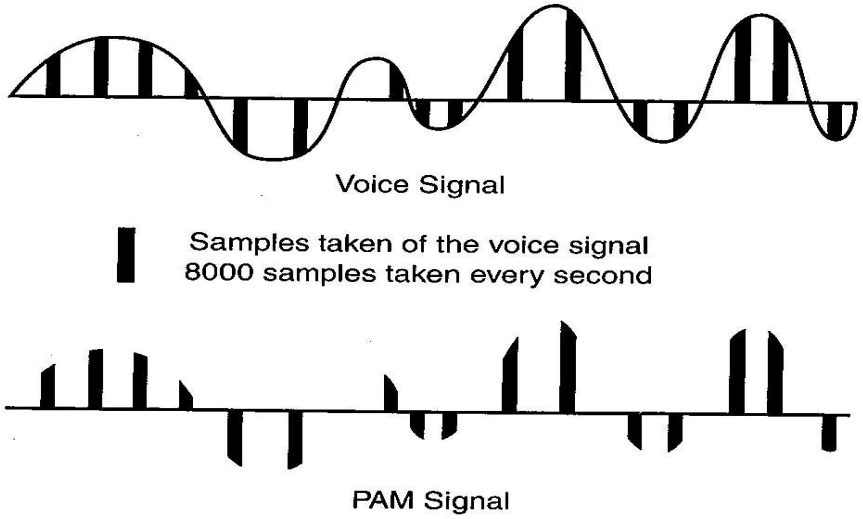
Applications for Frequency Division Multiplexing

- We now use FDM on fiber optic facilities to place multiple TDM systems on a fiber.
- Time Division Multiplexing (TDM) places each signal to be multiplexed on the medium for a brief instant of time at recurring intervals of time.
- Wave Division Multiplexing (WDM) uses many different lightwaves to connect many TDM systems on one fiber.

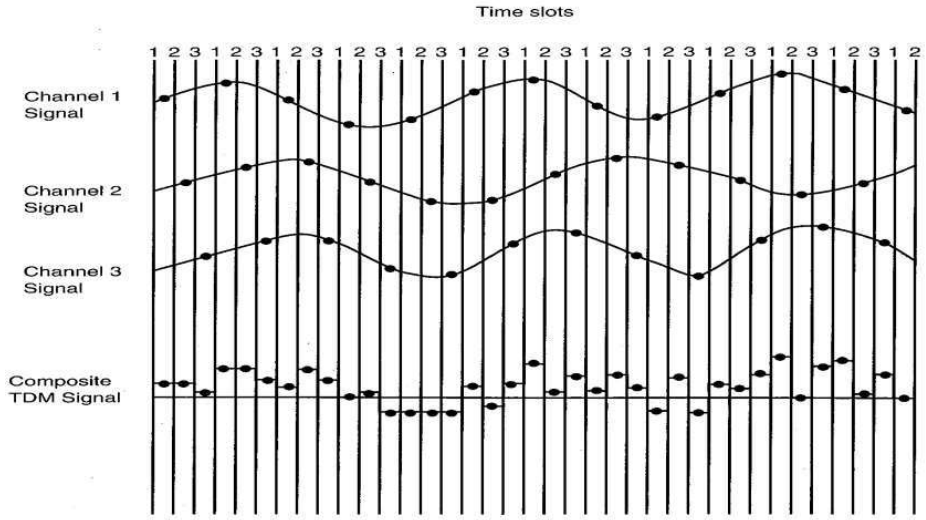
TDM Using Pulse Amplitude Modulation (PAM) Signals

- Early TDM signals multiplexed samples of the human voice from different channels over one common facility.
- Nyquist made some studies of voice sampling techniques and developed the Nyquist Theorem.
- The original signal can be reproduced if the sampling rate is at least twice the highest frequency present in the original signal.

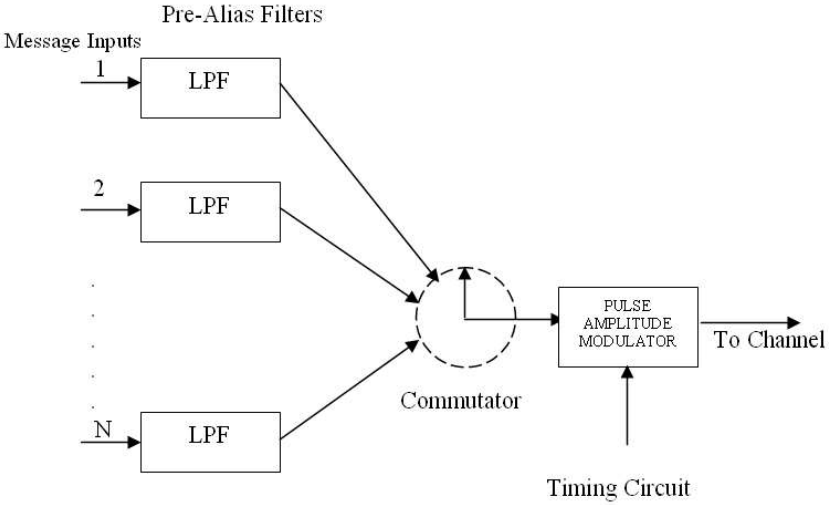
Pulse Amplitude Modulation Samples



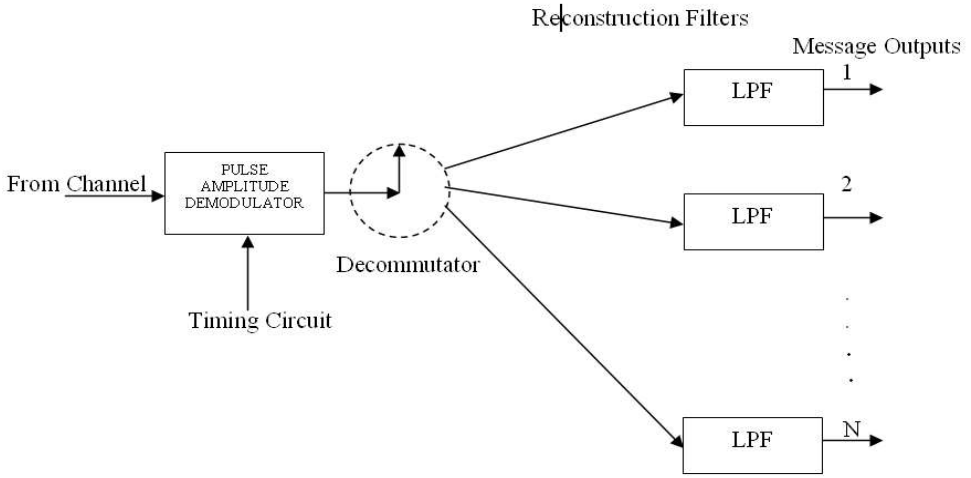
Creation of a Time Division Multiplexing Signal



TDM-PAM: Transmitter

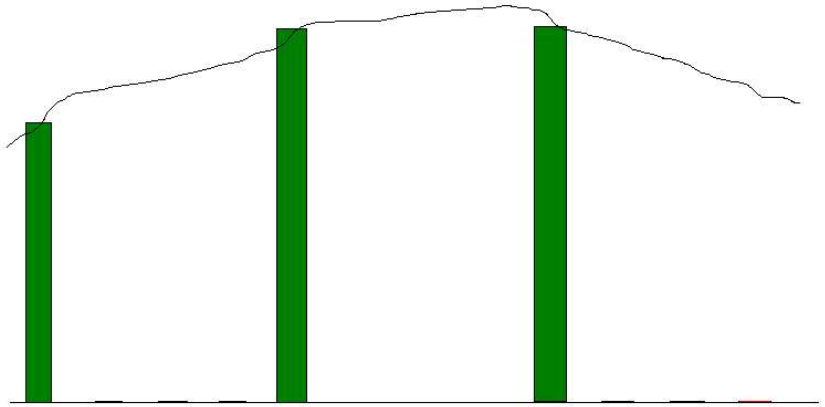


TDM-PAM: Receiver



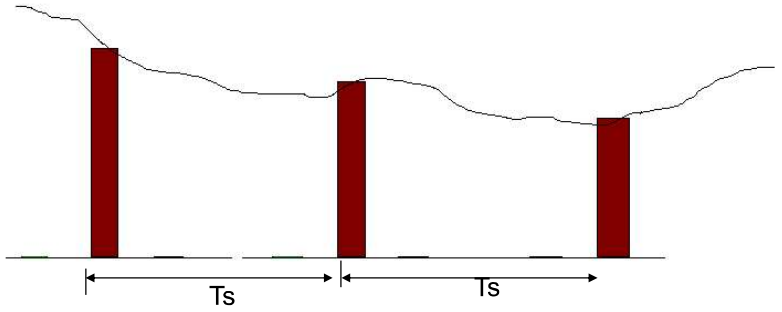
Example

Samples of Signal -1



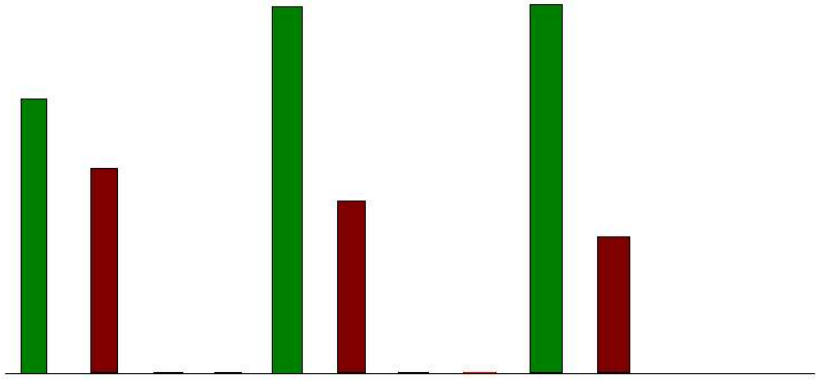
Example

Samples of signal - 2



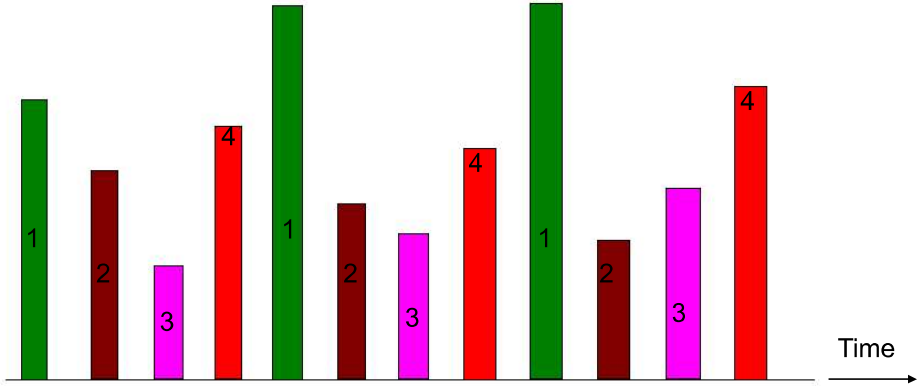
Example

Multiplexing of TWO signals



Example

TDM-PAM for 4 signals.



Time Division Multiplexing Using PCM Signals

- TDM systems using PAM are susceptible to noise interference.
- The industry standard for converting an analog signal into a digital signal is called *Pulse Code Modulation* (PCM).
- PCM/TDM has many advantages over FDM and PAM/TDM
  - Digital signals are less susceptible to noise.
  - Digital circuitry lends itself readily to integrated circuit design, which makes digital circuits cheaper than analog circuits.
  - Digital-to-digital interface is easily achieved.

Pulse Code Modulation

- The industry standard method for converting one analog voice signal into a digital signal is PCM.
- There are five basic steps to PCM:
  - Sampling
  - Quantization
  - Companding
  - Encoding
  - Framing

Sampling

- *Sampling* refers to how often measurements are taken of the input analog signal.
- The *Nyquist Theorem* states that an analog signal should be sampled at a rate at least twice its highest frequency.
- In telecommunications, the network was designed to handle signals between 0 and 4000 Hz.
- Every 1/8000 of a second (125 μs) a voltage measurement is taken of the input signal.

Quantization

- In PCM, each voltage measurement is converted to an 8-bit code, and the 8-bit coded is sent instead of the actual voltage.
  - The input signal can be any level.
  - The 8-bit coded limits the conversion process to the recognition of 256 ($2^8 = 256$) levels.
- *Quantization* is the process to convert the input level to one of the 256 discrete codes available.

Companding

- Quantizing a signal will result in some distortion because we do not code the exact voltage of the input signal.
- This distortion is called *quantizing noise*, it is greater for low-amplitude signals.
- *Companding* is used to reduce quantizing noise.
  - The signal is compressed at the transmitter to divide low-amplitude signals into more levels.
  - When the signal is decoded at the receiving system, it is expanded by reversing the compression process.

Encoding

- After compression and quantization of the input signal, it will be one of the 256 discrete signal levels that can be assigned an 8-bit code.
- The process of assigning an 8-bit code to represent the signal level is known as *encoding*.

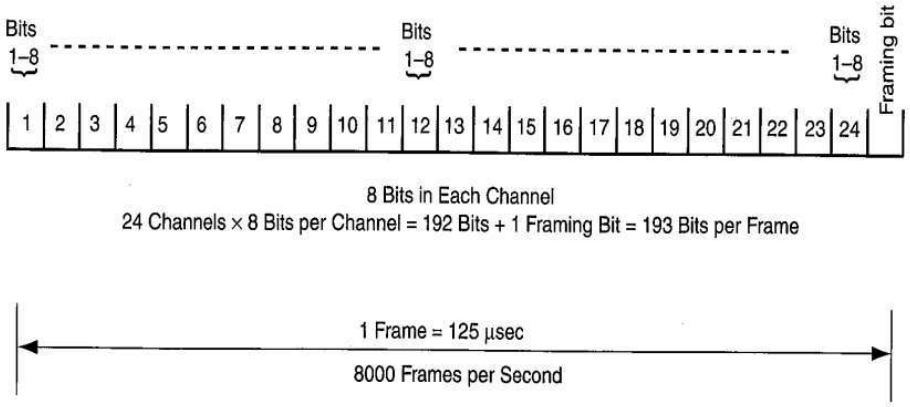
Framing

- The encoded 8-bit signal is time division multiplexed with 23 other 8-bit signals to generate 192 bits for 24 signals.
- A single framing bit is added to these 192 bits to make a 193-bit frame.
- Framing Bits
  - Follow an established pattern of 1s and 0s for 12 frames (1,0,0,0,1,1,0,1,1,1,0,0) and then repeat in each of the succeeding 12 frames.
  - This pattern is used by the receiving terminal to stay synchronized with the received frames.

North American DS1 System

- The basic building block for digital transmission standards begins with the DS0 signal level.
  - One voice equivalent
  - 8 bits/sample x 8,000 samples/second
- The DS1 signal has 24 voice equivalents
  - 193 bits per frame
    - 24 x 8 bits per channel
    - 1 framing bit

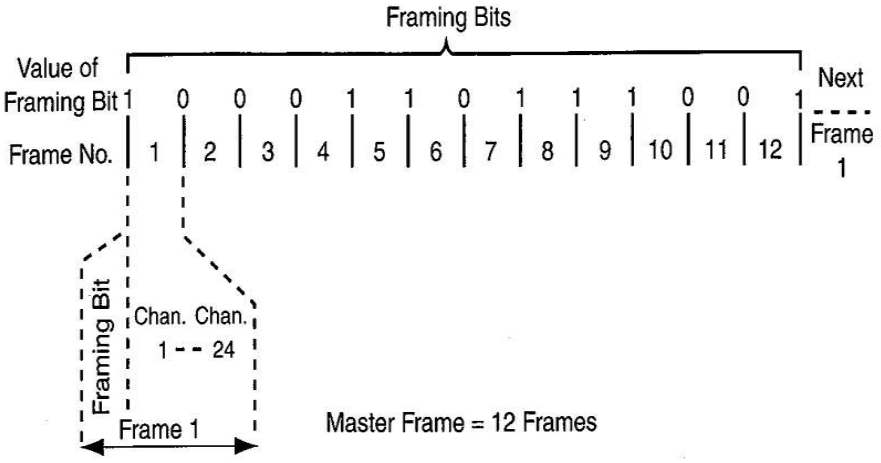
One Frame of a DS1 Signal



T1 Carrier Systems

- The multiplexing system of choice to connect two central offices in a North American DS1 system is called T1 carrier.
- It is necessary to remove load coils from pairs being used for T1 to improve high-frequency response.
- Repeaters (pulse regenerators) are placed where the load coils were and at each central office.

Superframe



European TDM 30 + 2 System

- The European TDM system multiplexes 32 DS0 channels together.
  - Channel 0 is used for synchronizing (framing) and signaling.
  - Channels 1-15 and 17-31 are used for voice.
  - Channel 16 is reserved for future use as a signaling channel.
- The total signal rate is 2.048 Mbps (64 kbps * 32 channels)

Statistical Time Division Multiplexing (STDM)

- The T1 and E1 systems are referred to as *synchronous time division multiplexing systems*.
- The *statistical time division multiplexer* improves the efficiency of a TDM system.
  - Channel units do not have reserved time slots.
  - Time slots are dynamically assigned.
- Also called *stat muxs*, *intelligent multiplexers*, and *asynchronous multiplexers*.