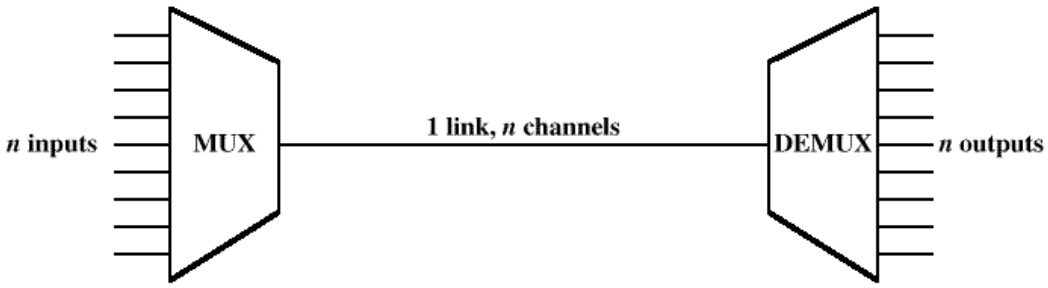
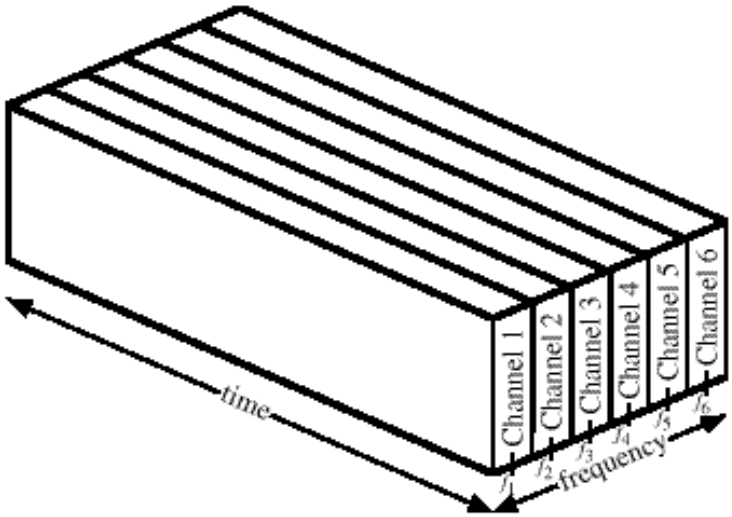
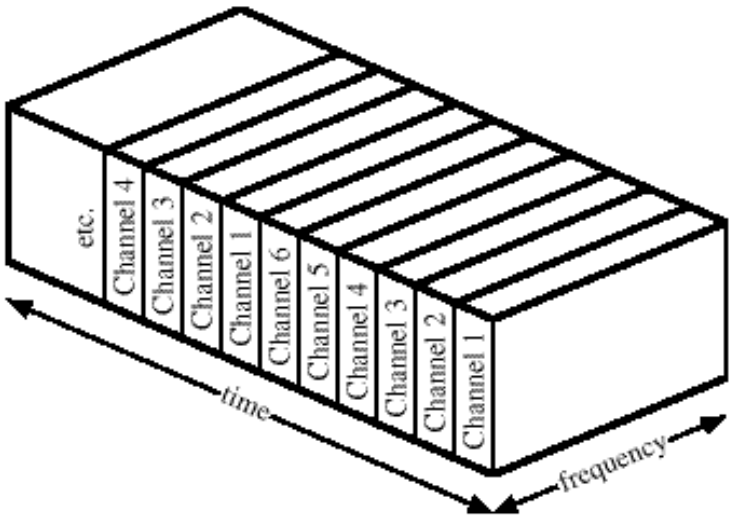
# Multiplexing




- Sharing of high capacity transmission medium between several transmissions
- Various approaches, including FDM & TDM



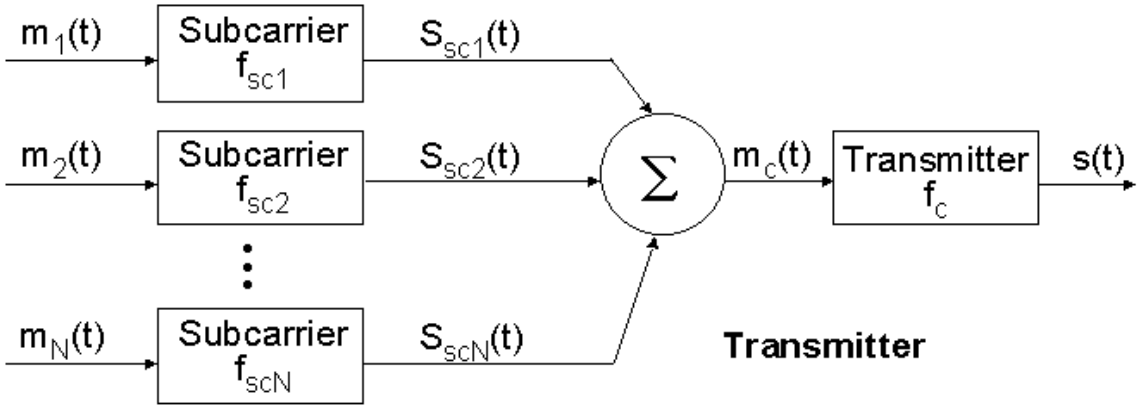

(a) Frequency-division multiplexing

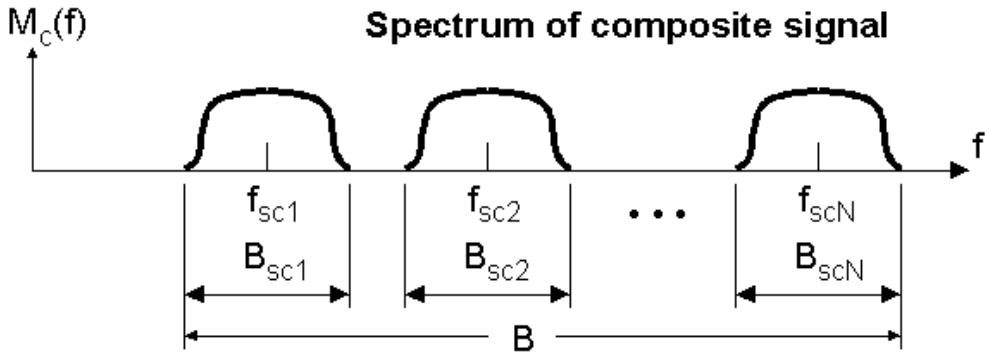


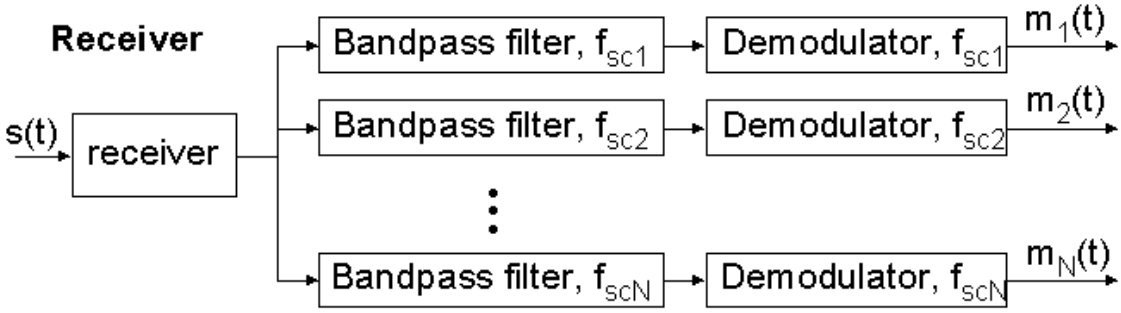

(b) Time-division multiplexing

# 1. FDM

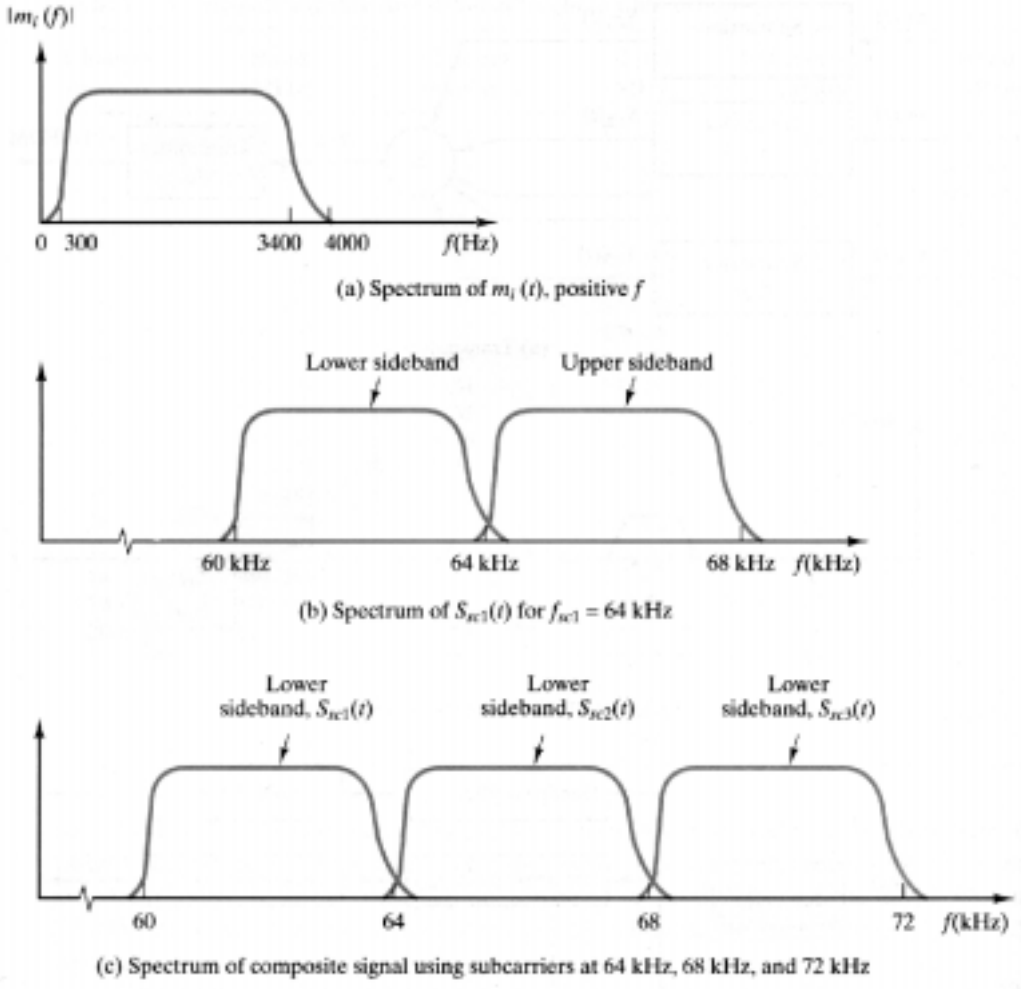
- Number of low BW analog signals simultaneously transmitted on high BW link
- Each signal is “shifted” in frequency by modulating a carrier signal
- Shifted signals can be sent simultaneously since they do not overlap in frequency
- At receiver, filters separate “shifted” signals; demodulation recovers signals
- TV, radio are examples of FDM



- Analog Carrier Systems
  - Designed to transmit voiceband signals over high-capacity transmission links, based on FDM
  - A standardized FDM hierarchy




(a) Spectrum of $m_i(t)$, positive $f$

(b) Spectrum of $S_{ssc1}(t)$ for $f_{sc1} = 64$ kHz

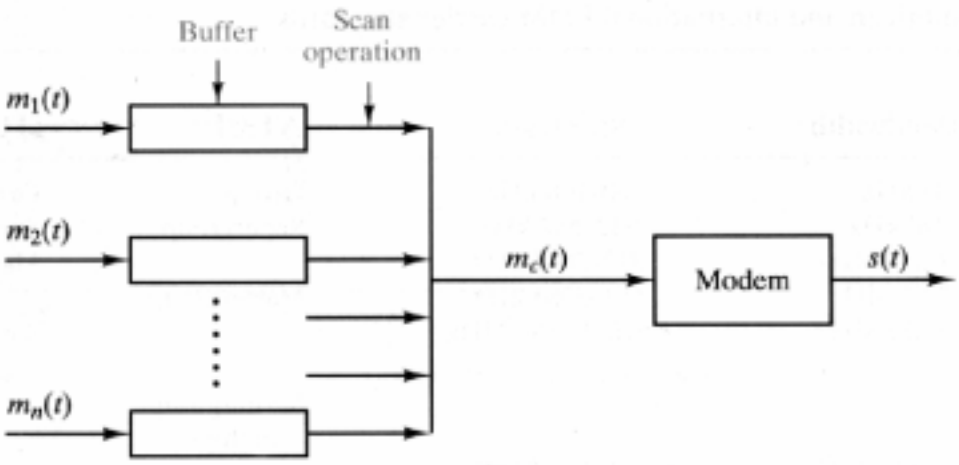
(c) Spectrum of composite signal using subcarriers at 64 kHz, 68 kHz, and 72 kHz

North American and int'l FDM carrier standards

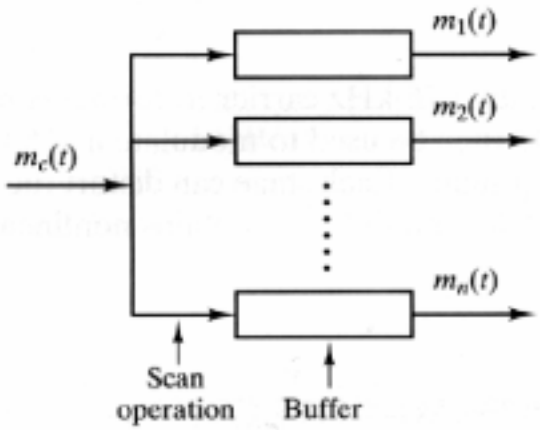
| Number of voice channels | Bandwidth | Spectrum | AT&T | ITU-T |
|---|---|---|---|---|
| 12 | 48 kHz | 60–108 kHz | Group | Group |
| 60 | 240 kHz | 312–552 kHz | Supergroup | Supergroup |
| 300 | 1.232 MHz | 812–2044 kHz | | Mastergroup |
| 600 | 2.52 MHz | 564–3084 kHz | Mastergroup | |
| 900 | 3.872 MHz | 8.516–12.388 MHz | | Supermaster group |
| $N \times 600$ | | | Mastergroup multiplex | |
| 3,600 | 16.984 MHz | 0.564–17.548 MHz | Jumbogroup | |
| 10,800 | 57.442 MHz | 3.124–60.566 MHz | Jumbogroup multiplex | |

# 2. Synchronous TDM

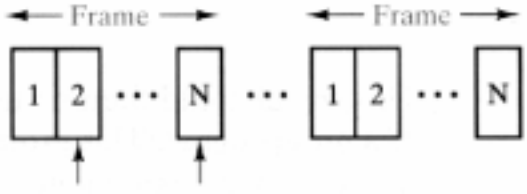
- High data rate of digital transmission medium used to simultaneously transmit a number of lower data rate digital signals
- Sources are scanned in round-robin fashion; each source has fixed slot for transmission
- At destination, the received stream is distributed to the corresponding receivers




(a) Transmitter



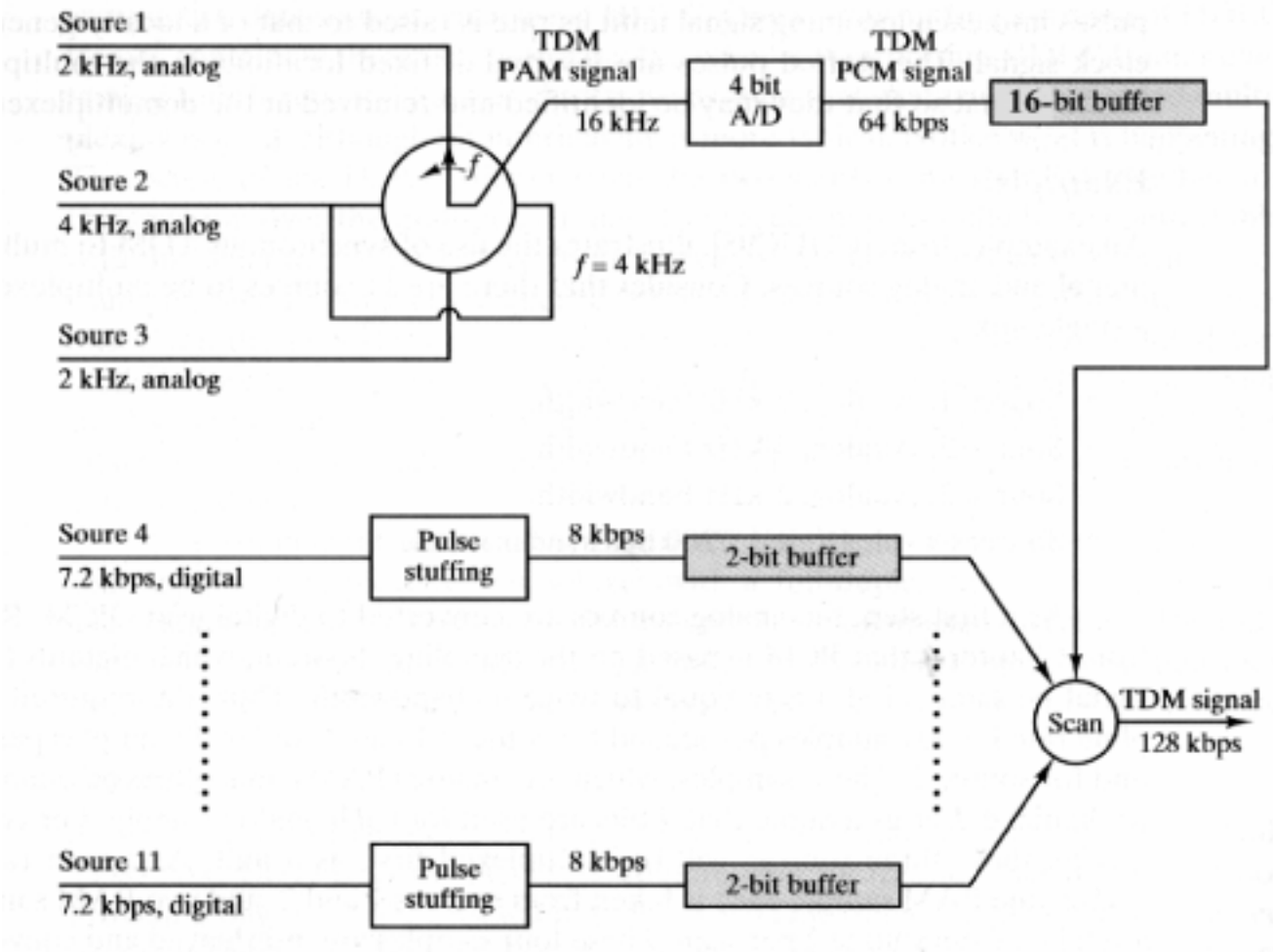

(c) Receiver




Time slot: may be empty or occupied

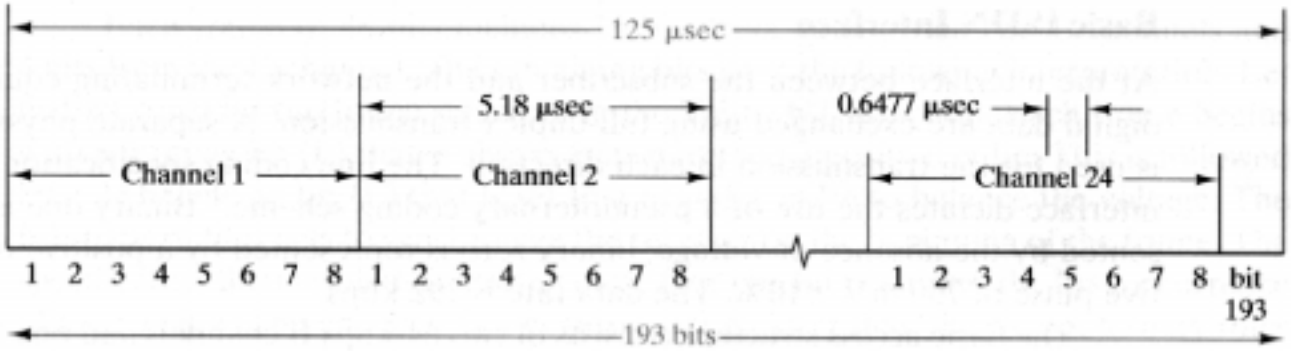
(b) TDM frames

- Pulse stuffing
  - Used when data rate of sources are not related by a simple rational number.
  - e.g.
    - One source at 8 kbps and another at 7.2 kbps. The slower is “pulse stuffed” with extra dummy pulses to send out on link at same rate. Since 8/7.2 = 10/9, every nine real samples, one dummy bit is sent out for the slower channel. Reverse at receiver: every 10th pulse is thrown away.



- Digital Carrier Systems
  - designed to transmit voice signals over high-capacity transmission links, based on synchronous TDM
  - DS-1 : basic frame format of the TDM hierarchy (in North America)

## DS-1 frame format




Notes:

1. Bit 193 is a framing bit, used for synchronization.
2. Voice channels:
   - 8-bit PCM used on five of six frames.
   - 7-bit PCM used on every sixth frame. Bit 8 of each channel is a signaling bit.
3. Data channels:
   - Channel 24 used for signaling only in some schemes.

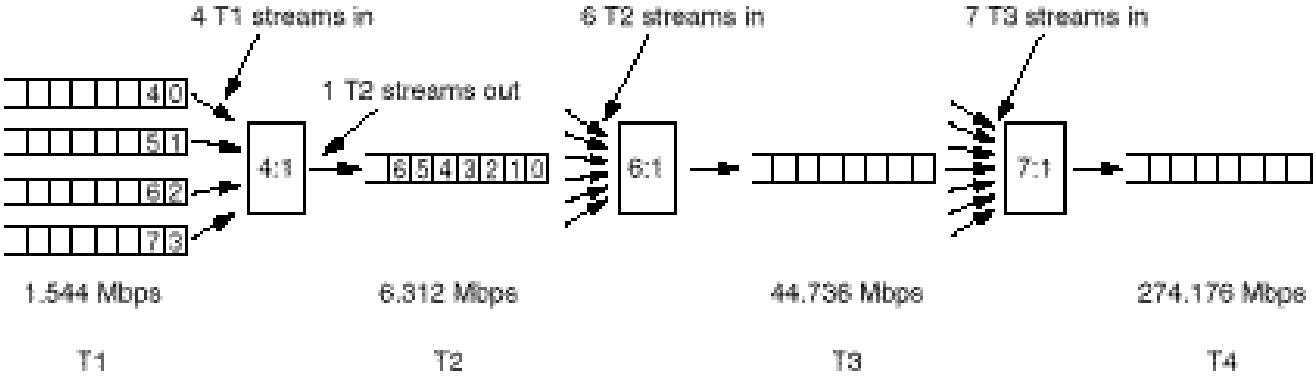
☆ Framing bit for frame synchronization and alignment. Every 12 frames form a multiframe. The F bits in the odd numbered frames have the pattern 101010 and are used for frame sync. F bits in the even numbered frames have a pattern of 001110, and are used for multiframe synchronization

✸ When T1 system is used for entirely for data, only 23 channels are used for data. The 24th one is used for a special synchronization pattern, to allow faster and more reliable reframing (recovery) following a framing error

## TDM carrier standards

| North American | | | | International | | |
|---|---|---|---|---|---|---|
| Carrier system | Frame format | Number of voice channels | Data rate (Mbps) | Level number | Number of voice channels | Data rate (Mbps) |
| T-1 | DS-1 | 24 | 1.544 | 1 | 30 | 2.048 |
| T-1C | DS-1C | 48 | 3.152 | 2 | 120 | 8.448 |
| T-2 | DS-2 | 96 | 6.312 | 3 | 480 | 34.368 |
| T-3 | DS-3 | 672 | 44.736 | 4 | 1920 | 139.264 |
| T-4 | DS-4 | 4032 | 274.176 | 5 | 7680 | 565.148 |

## Multiplexing T1 streams onto higher carriers



# 3. Statistical TDM

- With synchronous TDM, channel capacity wasted when sources transmit intermittently (Due to fixed assignment of channel)
- Statistical TDM (also known as asynchronous TDM and intelligent TDM) does not use fixed assignment; a source gets a time slice only if it is active.