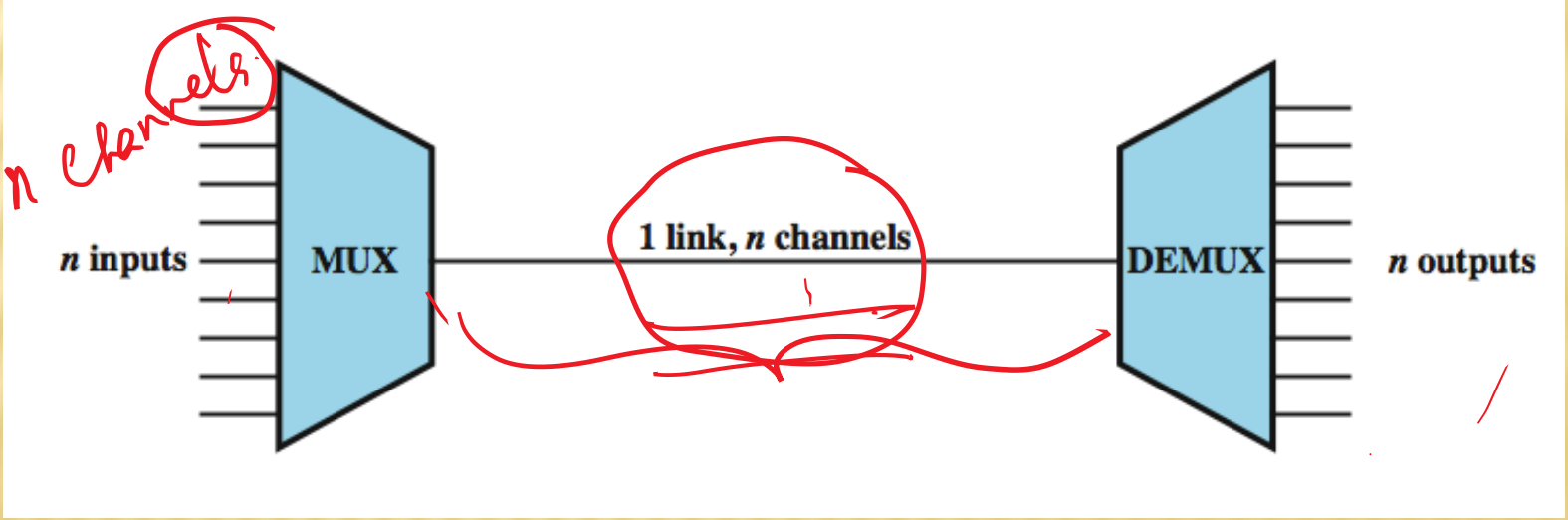
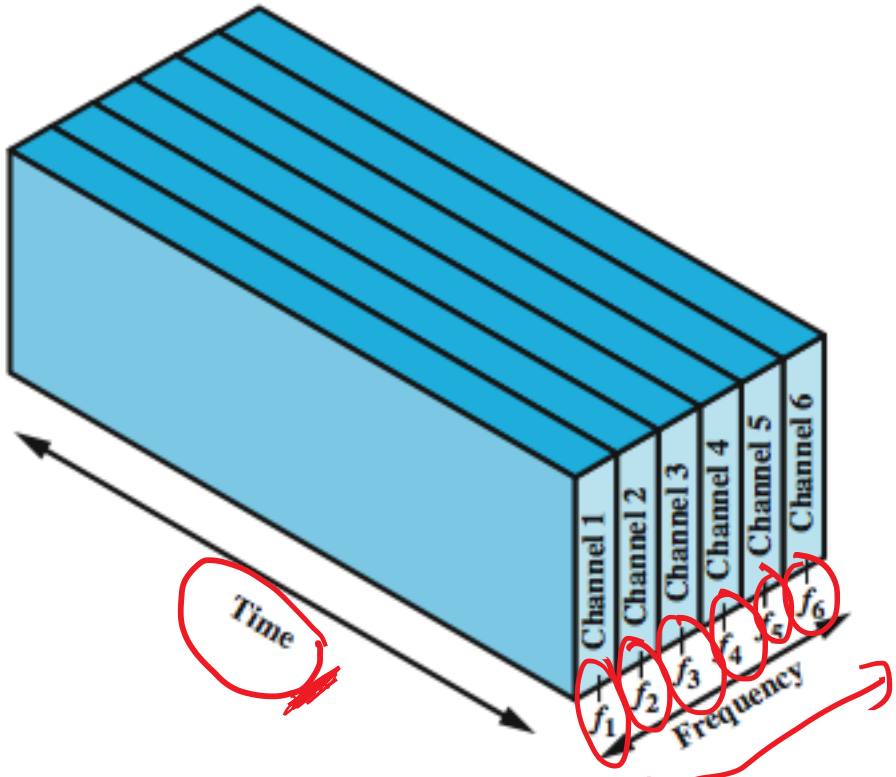
MULTIPLEXING
CHAPTER 8

MULTIPLEXING

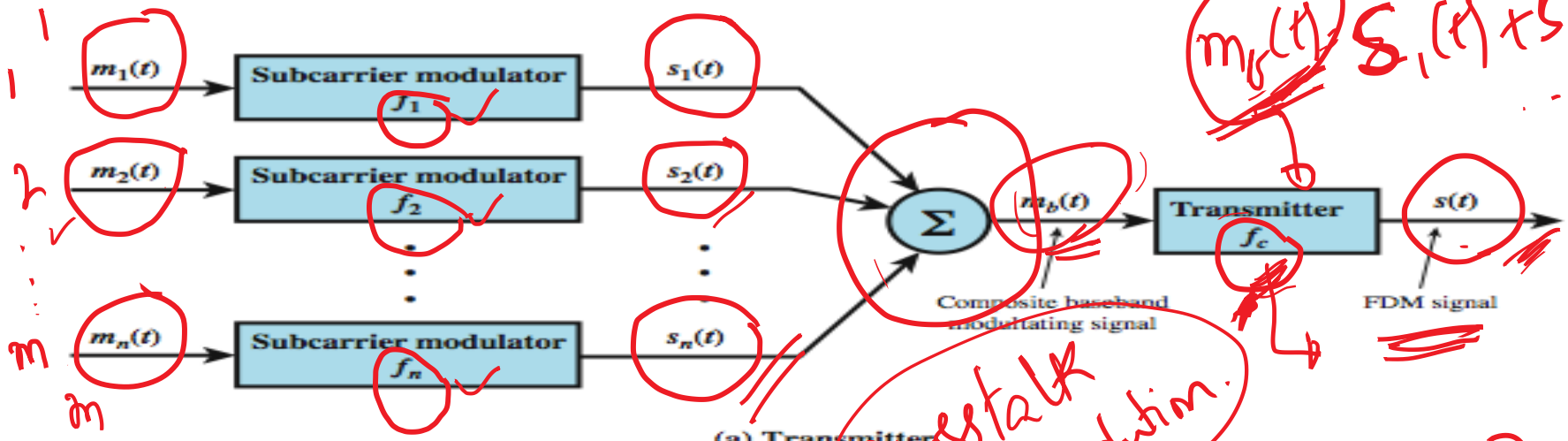
- multiple links on 1 physical line
- common on long-haul, high capacity links
- Forms of multiplexing: FDM, TDM- synchronous TDM, Statistical TDM



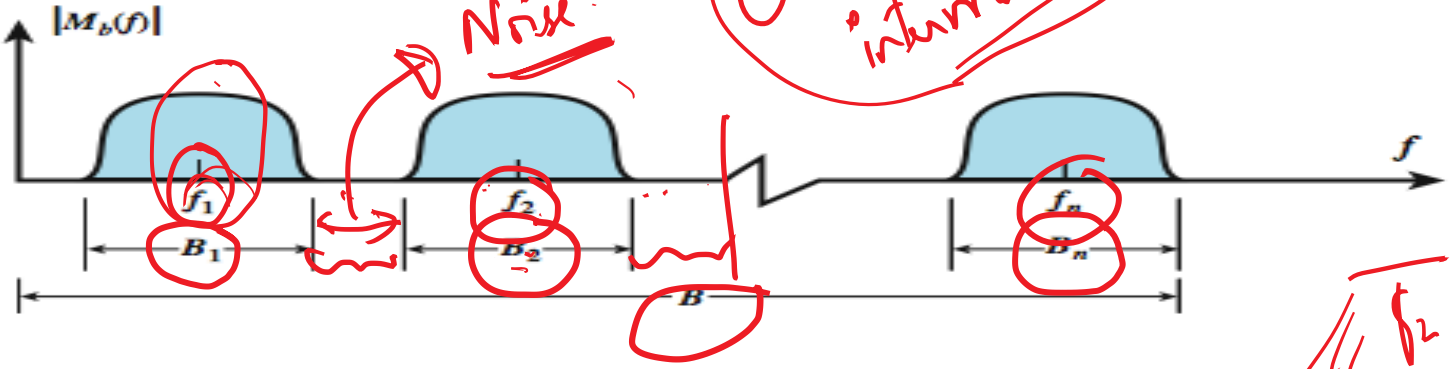
FREQUENCY DIVISION MULTIPLEXING



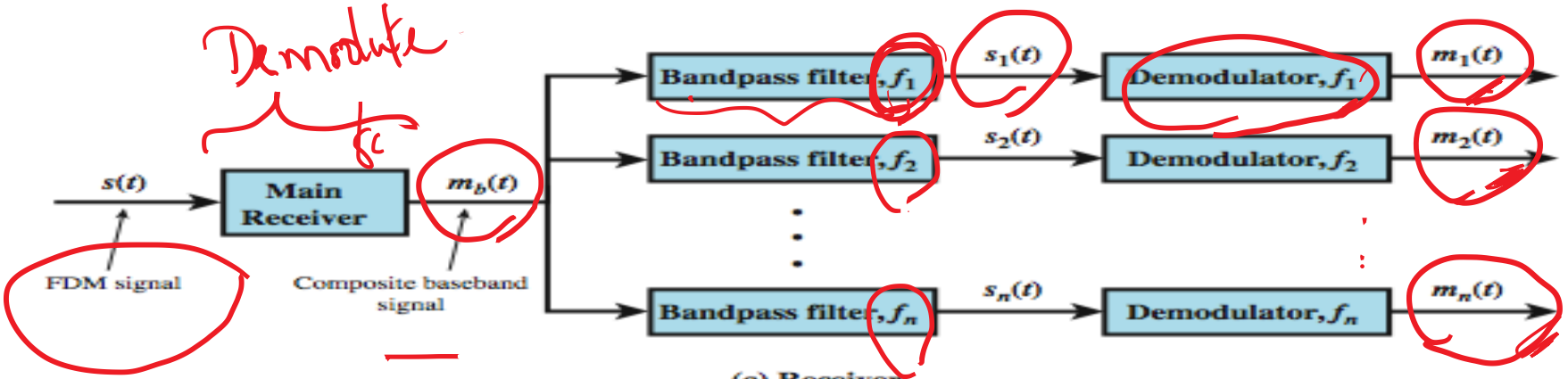
(a) Frequency division multiplexing



(a) Transmitter

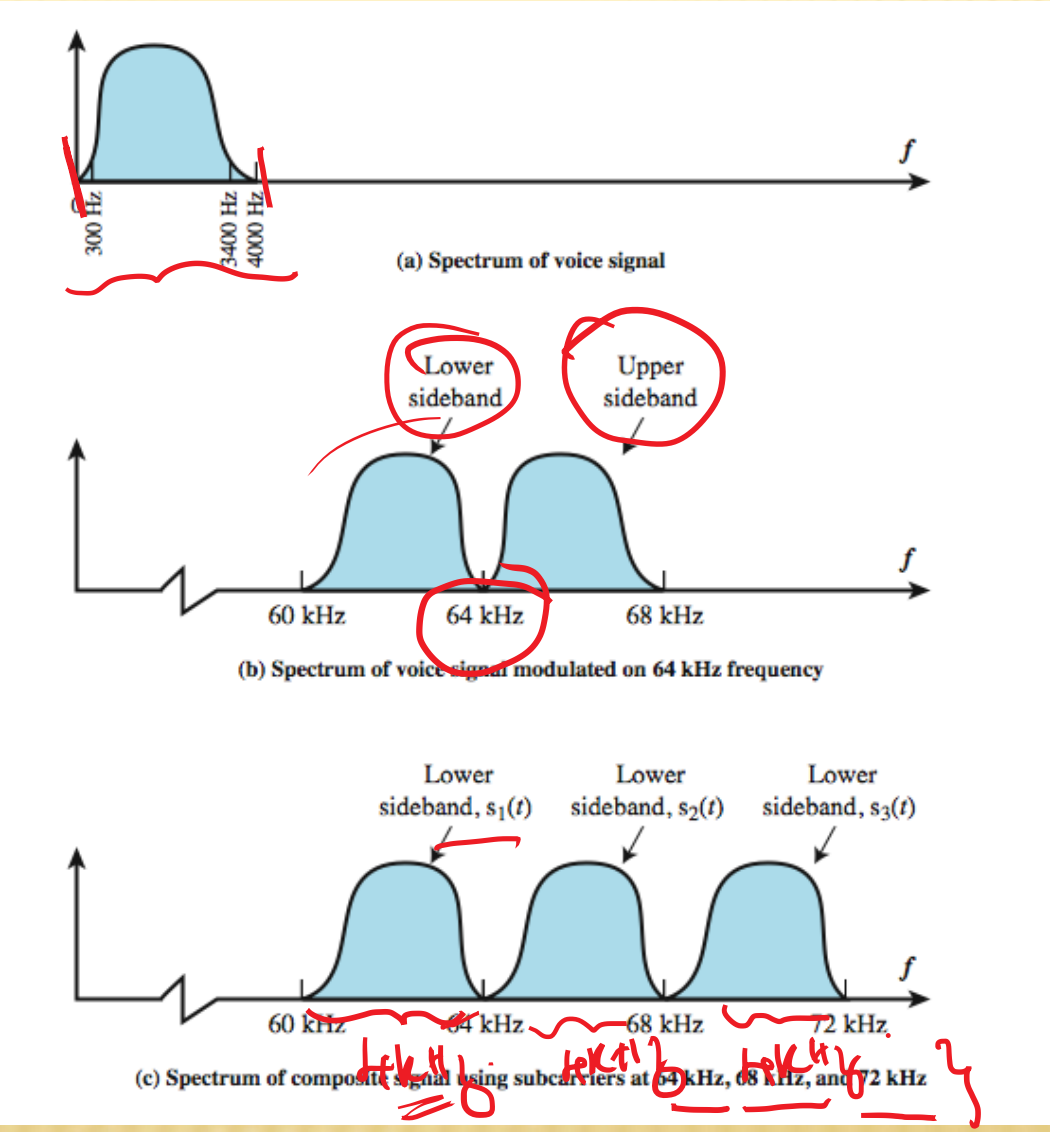


(b) Spectrum of composite baseband modulating signal



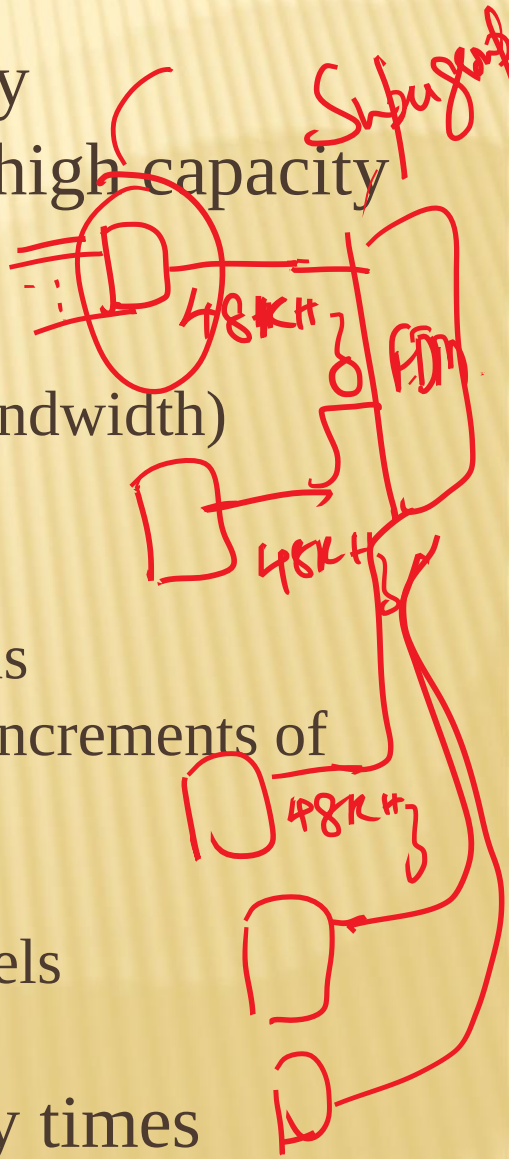
(c) Receiver

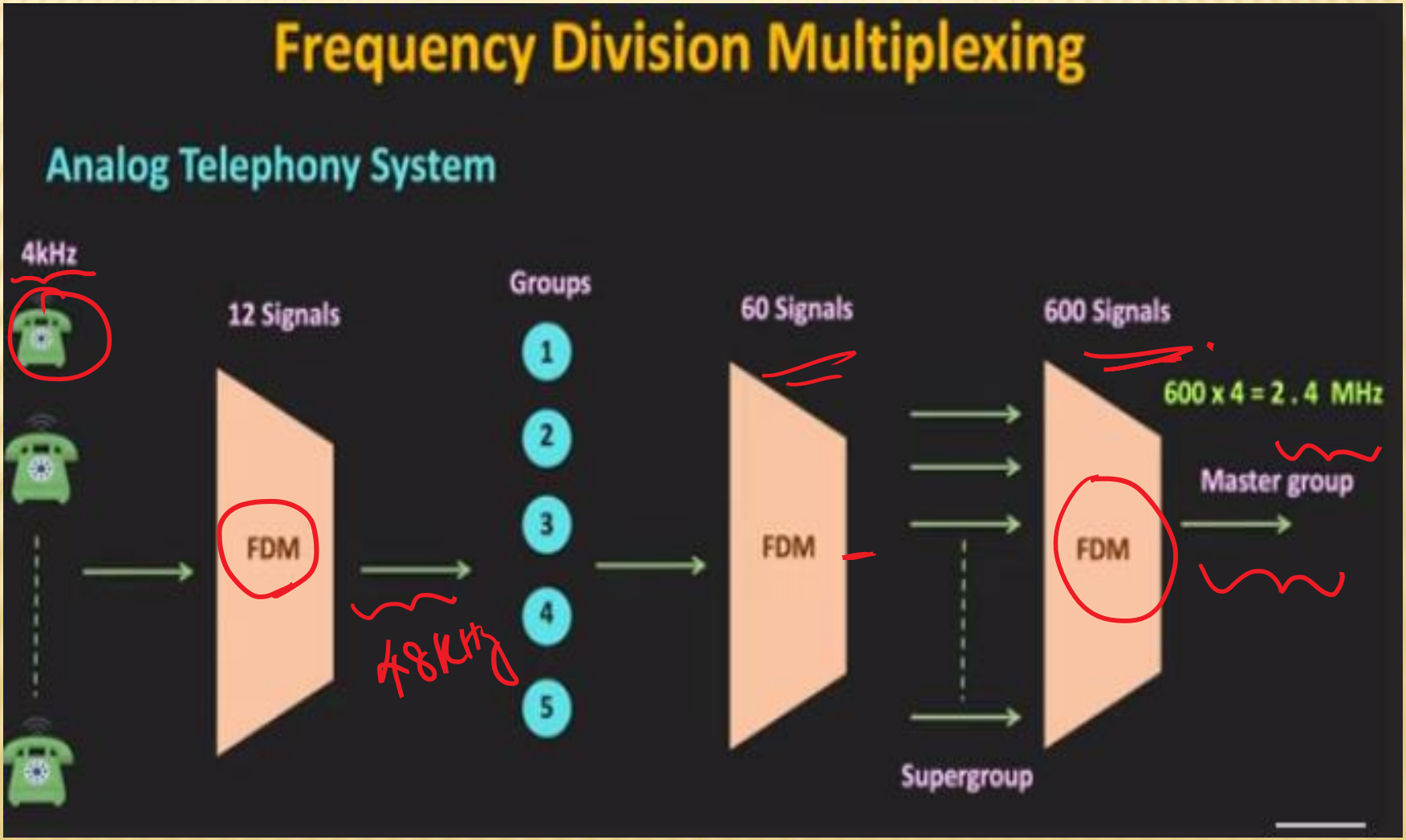
FDM VOICEBAND EXAMPLE



ANALOG CARRIER SYSTEMS

- long-distance links use an FDM hierarchy
- Used to transmit voiceband signals over high-capacity transmission links.
- Group- 1st level
  - 12 voice channels (4kHz each) = 48kHz(Bandwidth)
  - in range 60kHz to 108kHz
- Supergroup
  - FDM of 5 group signals supports 60 channels
  - on carriers between 420kHz to 612 kHz in increments of 48kHz.
- Mastergroup
  - FDM of 10 supergroups supports 600 channels
  - Bandwidth of 2.52MHz
- so original signal can be modulated many times

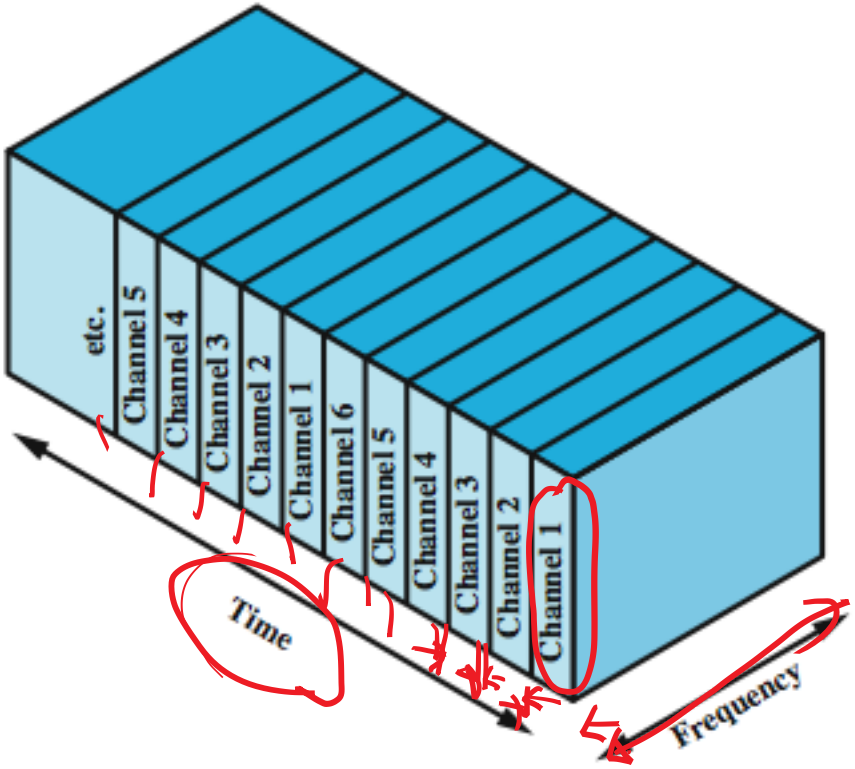



Frequency Division Multiplexing
Analog Telephony System
4kHz
12 Signals
FDM
48KHz
Groups
1
2
3
4
5
60 Signals
FDM
600 Signals
FDM
600 x 4 = 2 . 4 MHz
Master group
Supergroup

WAVELENGTH DIVISION MULTIPLEXING

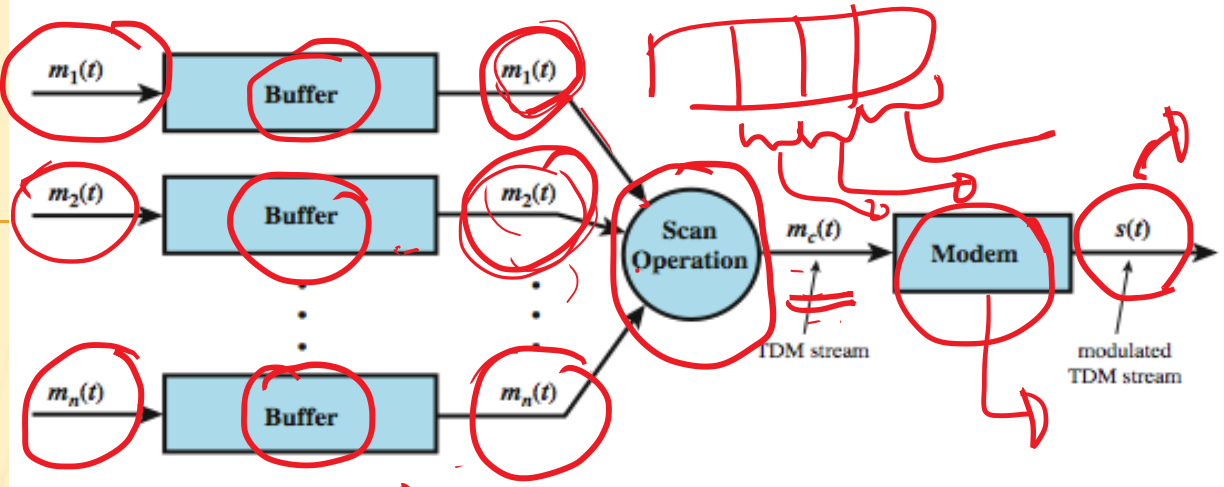
- FDM with multiple beams of light at different wavelength.
- carried over optical fiber links
  - commercial systems with 160 channels of 10 Gbps
  - lab demo of 256 channels 39.8 Gbps a total of 10.1Tbps over a 100Km space.
- architecture similar to other FDM systems
  - multiplexer consolidates laser sources (1550nm) for transmission over single fiber
  - Optical amplifiers amplify all wavelengths spaced 10Km apart.
  - Demux separates channels at the destination
- also have Dense Wavelength Division Multiplexing (DWDM) channel spacing of 200GHz or less.

SYNCHRONOUS TIME DIVISION MULTIPLEXING

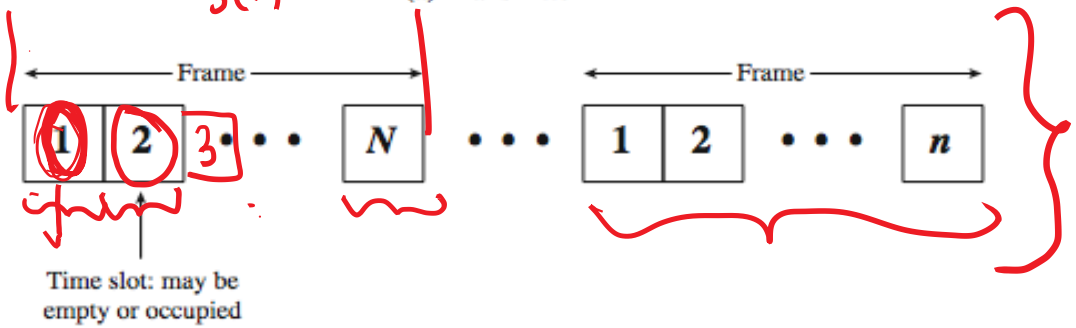


(b) Time division multiplexing

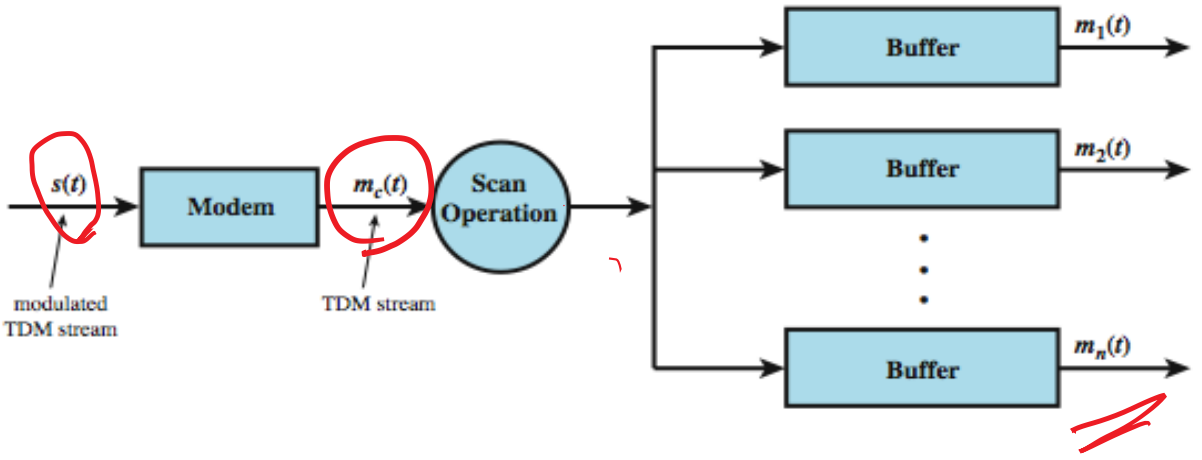
TDM SYSTEM OVERVIEW



(a) Transmitter

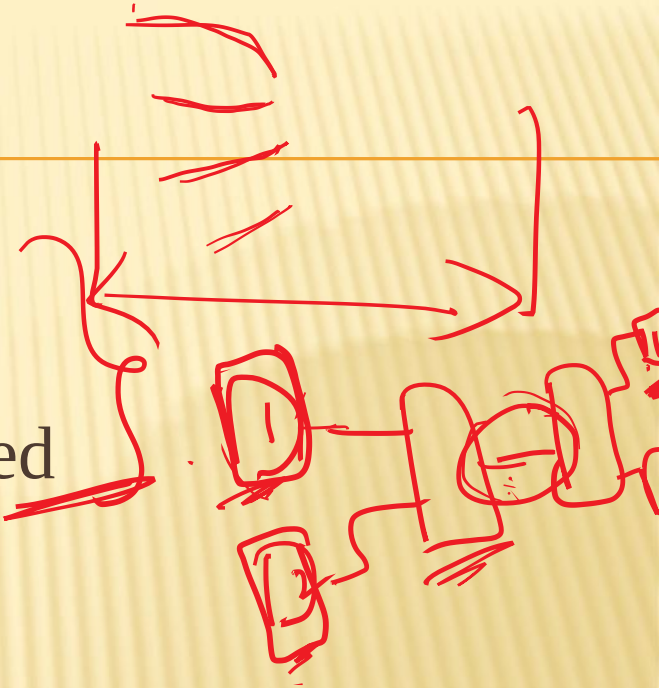


(b) TDM Frames



(c) Receiver

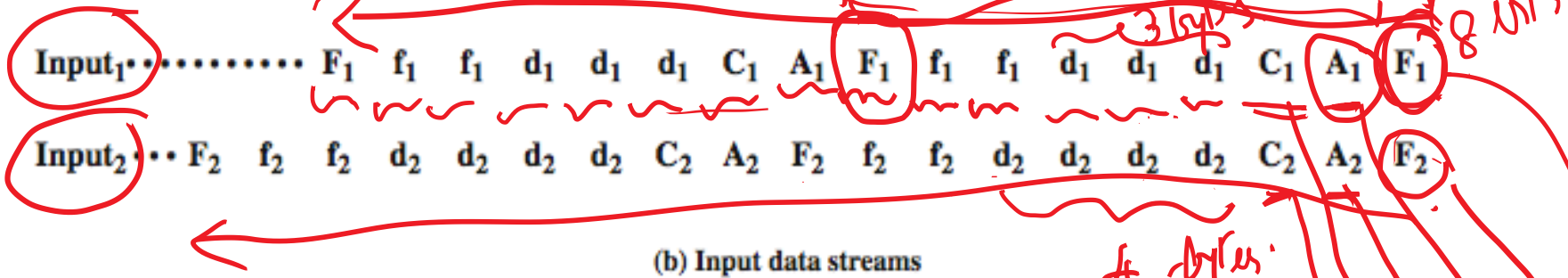
TDM LINK CONTROL



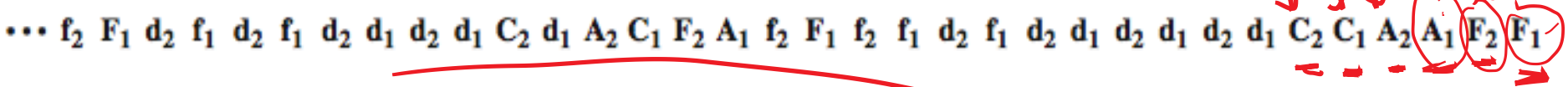
- no headers and trailers
- data link control protocols not needed
- flow control
  - data rate of multiplexed line is fixed
  - if one channel receiver can not receive data, the others must carry on
  - leaving empty slots
- error control
  - errors detected & handled on individual channel

DATA LINK CONTROL ON TDM

(a) Configuration



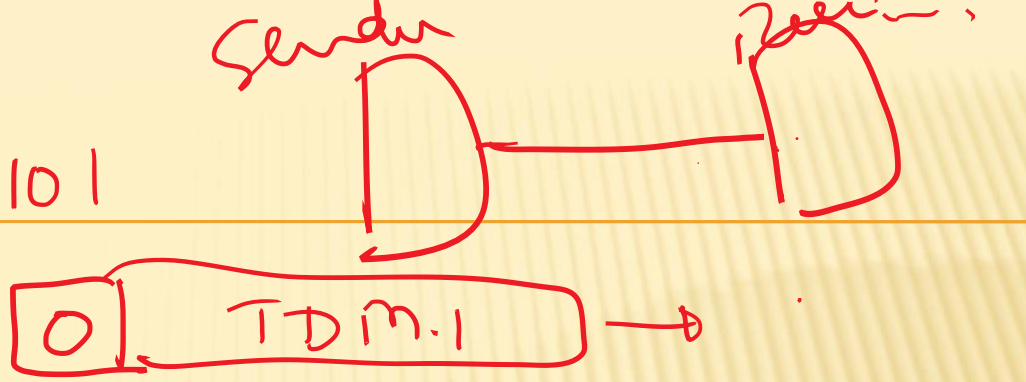
(b) Input data streams



(c) Multiplexed data stream

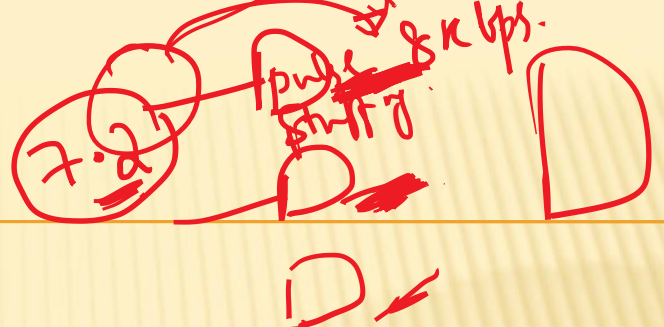
Legend: F = flag field; A = address field; C = control field; d = one octet of data field; f = one octet of FCS field

FRAMING



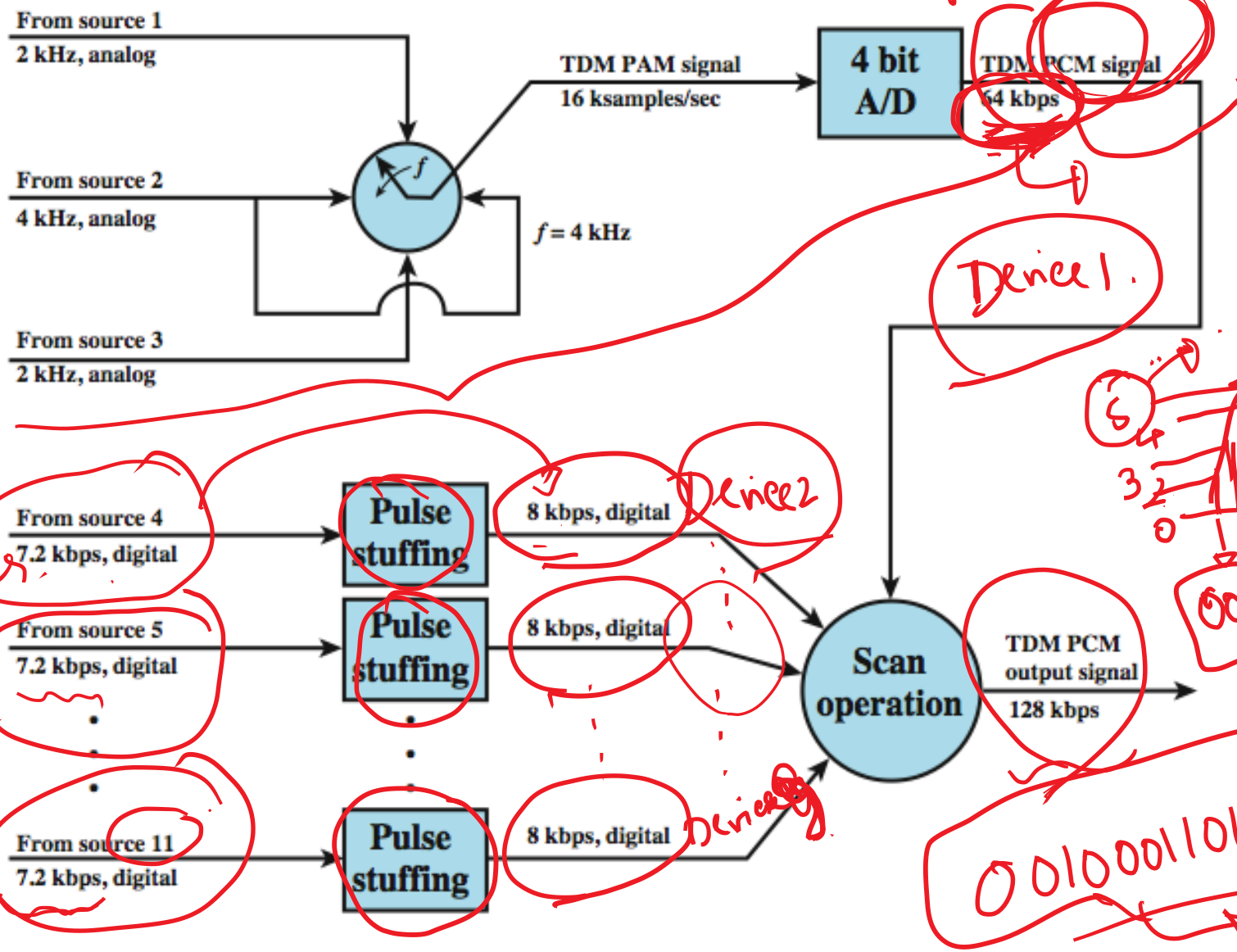
- no flag or SYNC characters bracketing TDM frames
- must still provide synchronizing mechanism between source and destination
- Added- digit framing
  - one control bit added to each TDM frame
  - identifiable bit pattern used on control channel
  - eg. alternating 01010101…
  - compare incoming bit patterns on each channel with known sync pattern

PULSE STUFFING



- have problem of synchronizing data sources
- with clocks in different sources drifting
- Pulse Stuffing a common solution
  - have outgoing data rate (excluding framing bits) higher than sum of incoming rates
  - stuff extra dummy bits or pulses into each incoming signal until it matches local clock
  - stuffed pulses inserted at fixed locations in frame and removed at demultiplexer

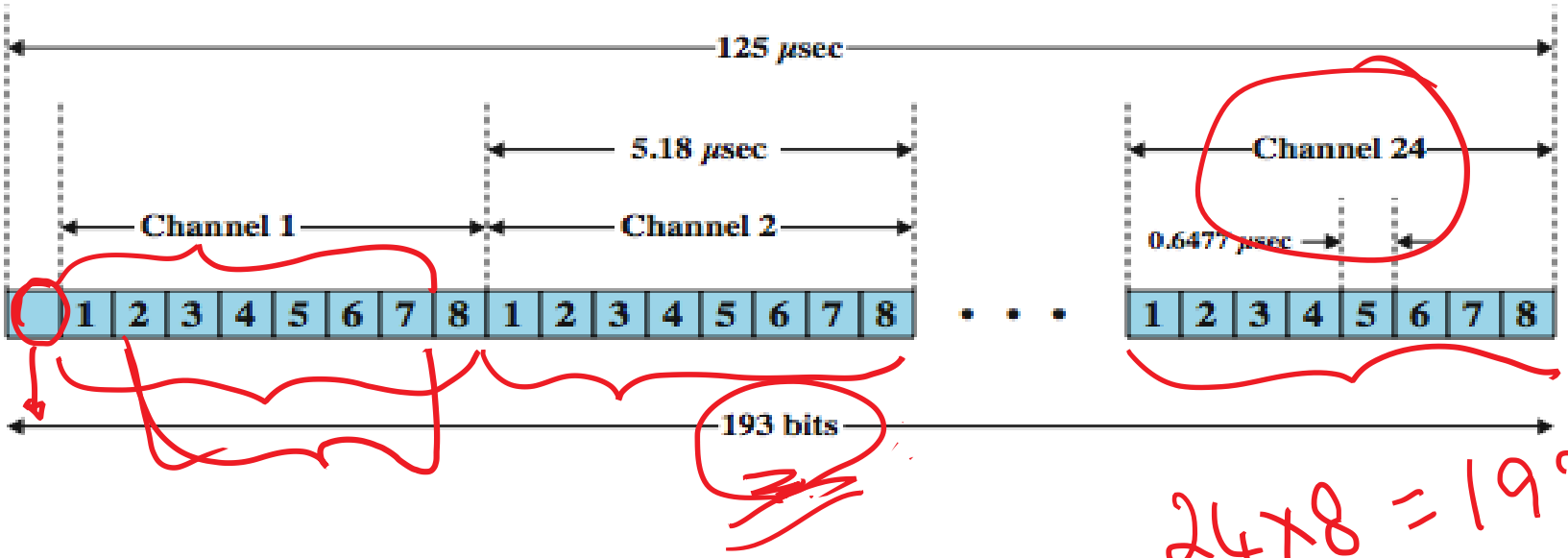
TDM EXAMPLE


From source 1
2 kHz, analog
From source 2
4 kHz, analog
From source 3
2 kHz, analog
f
f = 4 kHz
TDM PAM signal
16 ksamples/sec
4 bit
A/D
TDM PCM signal
64 kbps
From source 4
7.2 kbps, digital
From source 5
7.2 kbps, digital
From source 11
7.2 kbps, digital
Pulse stuffing
Pulse stuffing
Pulse stuffing
8 kbps, digital
8 kbps, digital
8 kbps, digital
Scan operation
TDM PCM output signal
128 kbps

DIGITAL CARRIER SYSTEMS

- long-distance links use an TDM hierarchy
- AT&T (USA) and ITU-T (International) variants
- US system based on DS-1 format
- can carry mixed voice and data signals
- 24 channels used for total data rate of 1.544Mbps
- each voice channel contains one word of digitized data (PCM, 8000 samples per sec)
- same format for 56kbps digital data
- can interleave DS-1 channels for higher rates
  - DS-2 is four DS-1 at 6.312Mbps

DS-1 TRANSMISSION FORMAT

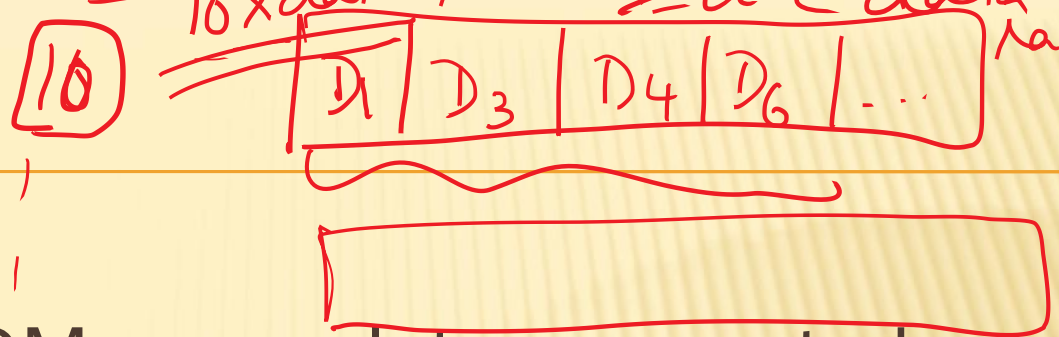


24x8 = 192

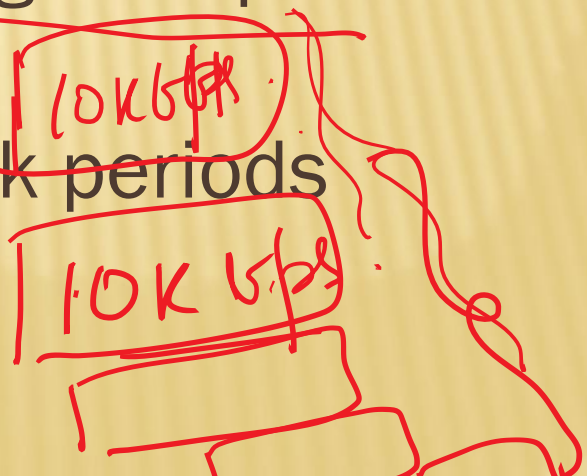
Notes:

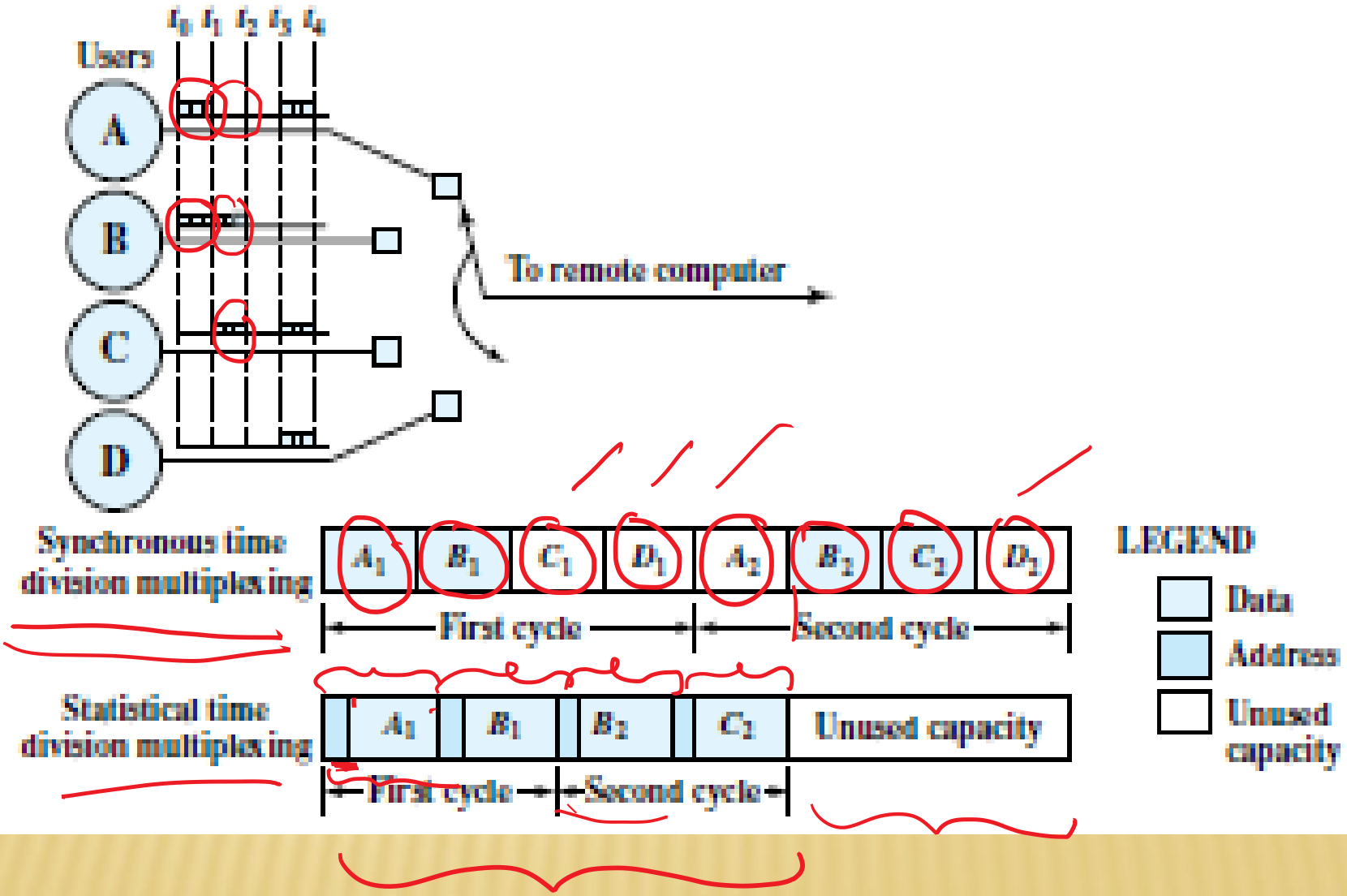
1. The first bit is a framing bit, used for synchronization.
2. Voice channels:
   - 8-bit PCM used on five of six frames.
   - 7-bit PCM used on every sixth frame; bit 8 of each channel is a signaling bit.
3. Data channels:
   - Channel 24 is used for signaling only in some schemes.
   - Bits 1-7 used for 56 kbps service
   - Bits 2-7 used for 9.6, 4.8, and 2.4 kbps service.

STATISTICAL TDM



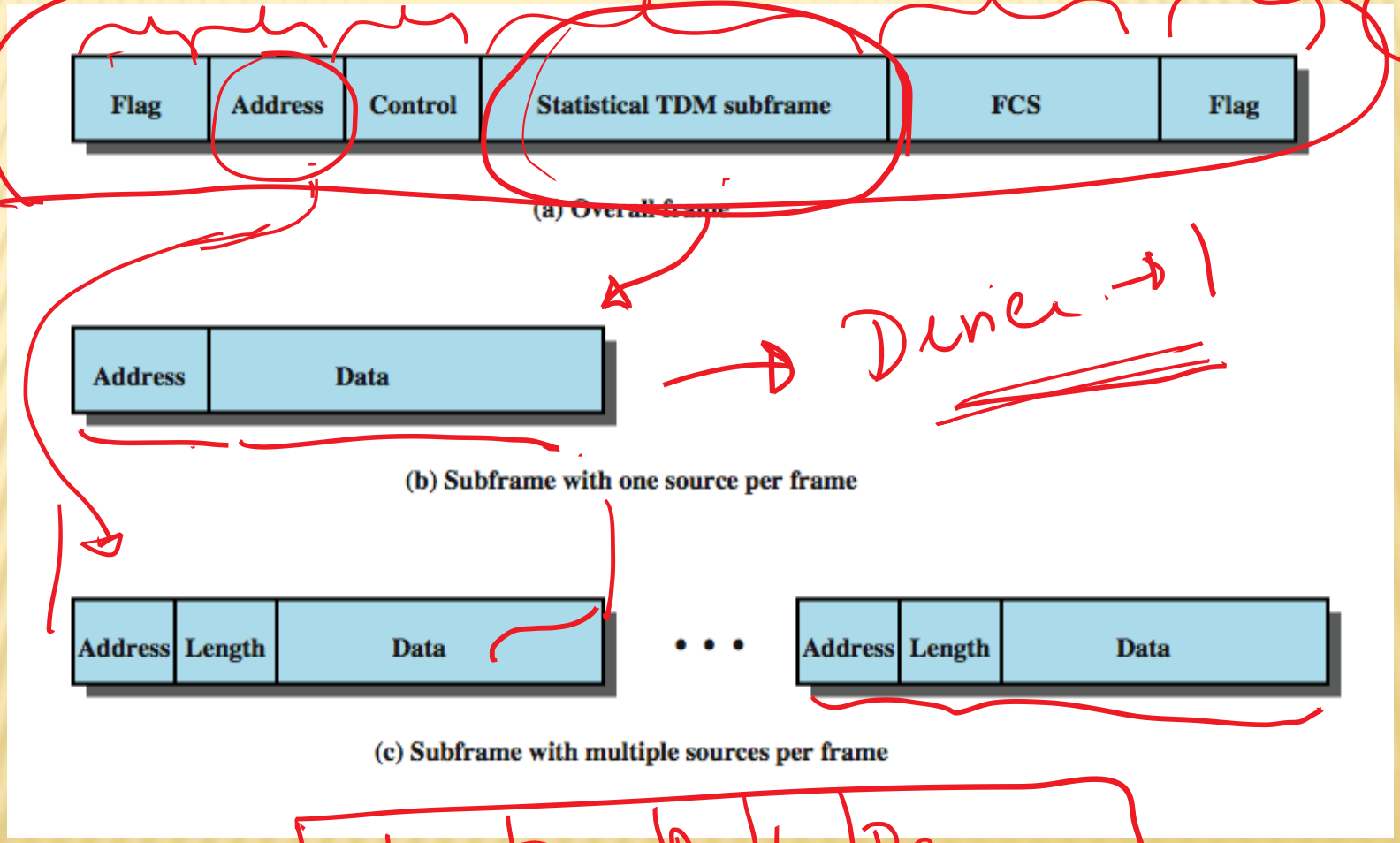
- in Synchronous TDM many slots are wasted
- Statistical TDM allocates time slots dynamically based on demand
- multiplexer scans input lines and collects data until frame full
- line data rate lower than aggregate input line rates
- may have problems during peak periods
  - must buffer inputs




t_0 t_1 t_2 t_3 t_4
Users
A
B
C
D
To remote computer
Synchronous time division multiplexing
A_1 B_1 C_1 D_1 A_2 B_2 C_2 D_2
First cycle
Second cycle
Statistical time division multiplexing
A_1 B_1 B_2 C_2 Unused capacity
First cycle
Second cycle
LEGEND
Data
Address
Unused capacity

STATISTICAL TDM FRAME FORMAT

HDLC



PERFORMANCE

I = number of input sources

R = data rate of each source, bps

M = effective capacity of multiplexed line, bps

α = mean fraction of time each source is transmitting, $0 < \alpha < 1$

$K = \frac{M}{IR}$ = ratio of multiplexed line capacity to total maximum input

$$\lambda = \alpha I R$$

$$T_s = \frac{1}{M}$$

$$\rho = \lambda T_s = \frac{\alpha I R}{M} = \frac{\alpha}{K} = \frac{\lambda}{M}$$

$K < 1$

Synch TDM $\Rightarrow K = 1$

$\lambda \Rightarrow$ average arrival rate

$\alpha =$ fraction of time

Service time.

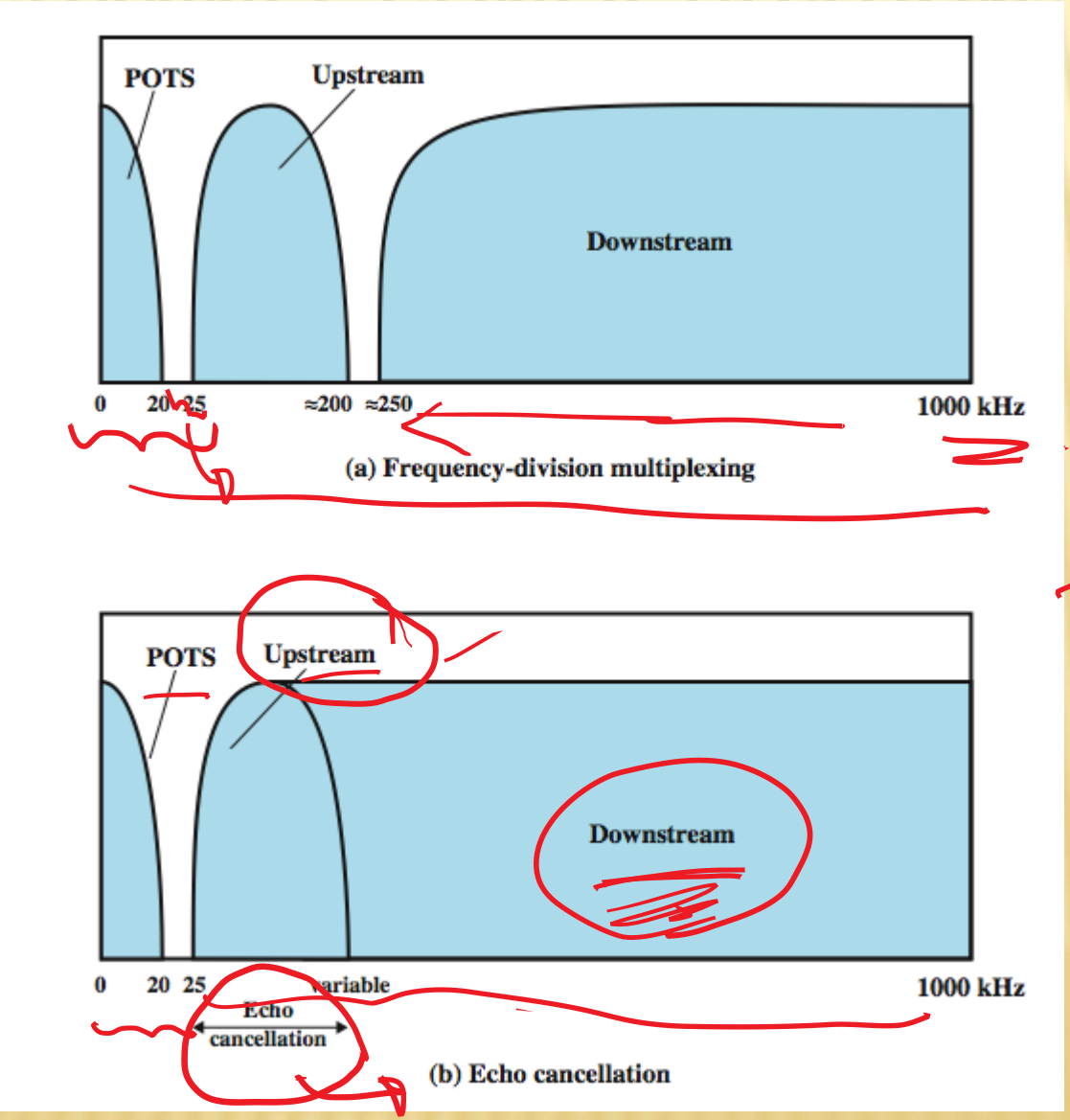
$T_s =$

$\rho \Rightarrow$ Utilization $\Rightarrow$ total link Capacity

ASYMMETRICAL DIGITAL SUBSCRIBER LINE (ADSL)

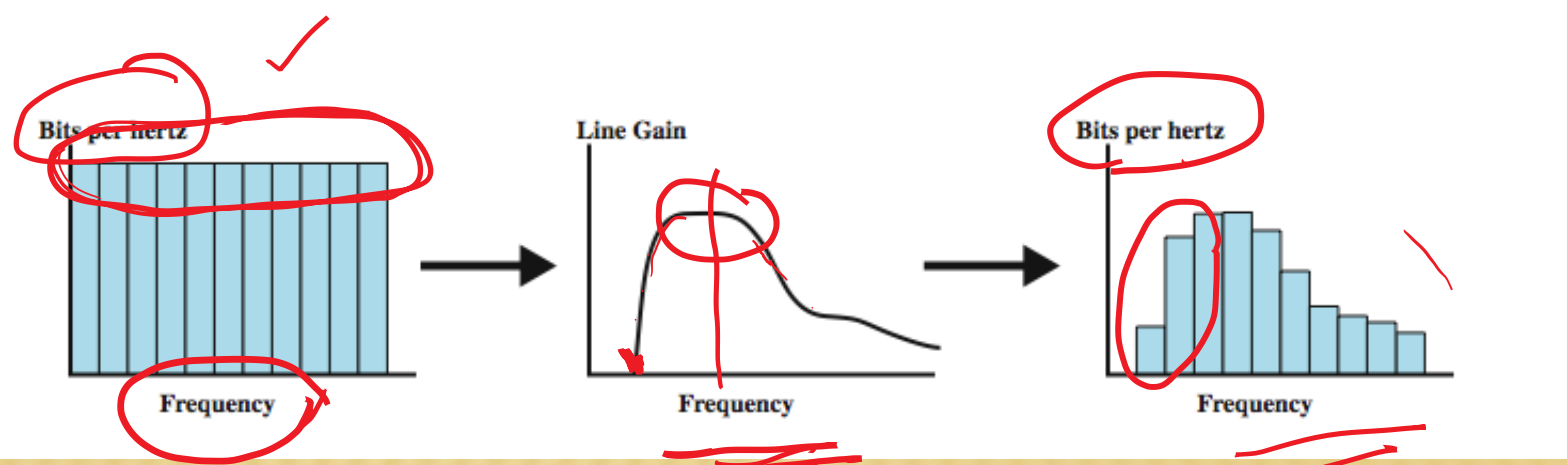
- link between subscriber and network
- uses currently installed twisted pair cable
- is Asymmetric – larger capacity for downstream than up stream
- uses Frequency division multiplexing
  - reserve lowest 25kHz for voice (POTS-plain old telephone service)
  - uses echo cancellation or FDM to give two bands
- has a range of up to 5.5km

ADSL CHANNEL CONFIGURATION



DISCRETE MULTITONE (DMT)

- multiple carrier signals at different frequencies
- divide into 4kHz subchannels
- test and use subchannels with better SNR
- 256 downstream subchannels at 4kHz (60kbps)
  - in theory 15.36Mbps, in practice 1.5-9Mbps



DMT TRANSMITTER