BANDWIDTH UTILIZATION:

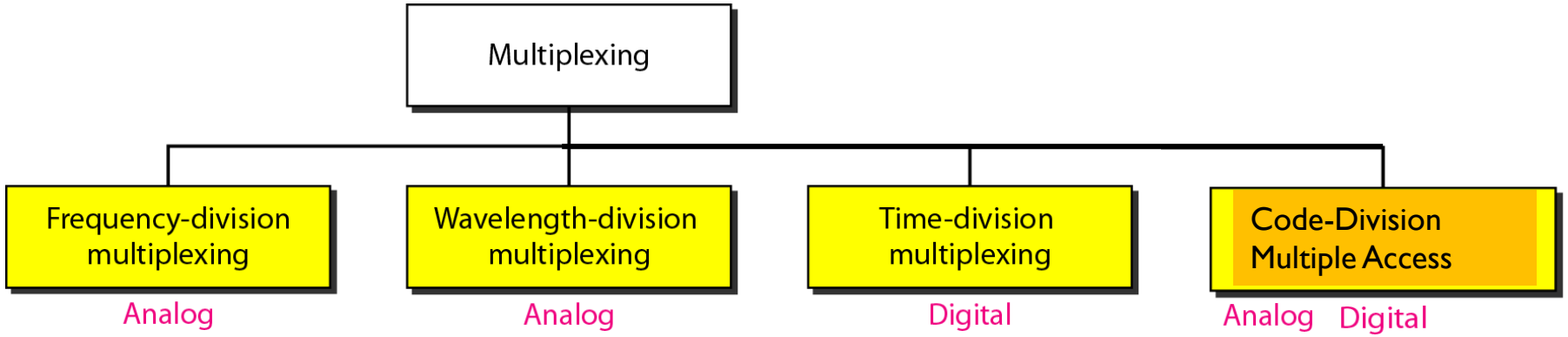
- signal ระหว่าง Tx, Rx => signal รับเข้าแผ่นไหน
  - ⇓
  - signal ออกแผ่นไหน
- signal ระหว่าง network แต่ละแผ่นไหน ขึ้นกับ channel ที่ใช้ → analog / digital
- encode data ลง transmission channel
  - digital encoding → line coding
    - → PCM + line coding
  - analog encoding → digital MOD (ASK, FSK, PSK, QAM)
    - → analog MOD (AM, FM, PM)

MULTIPLEXING AND SPREADING

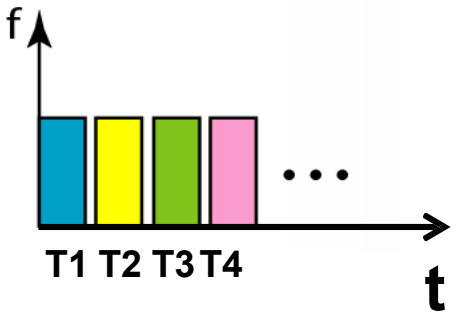
HOW CAN WE USE TRANSMISSION BANDWIDTH EFFICIENTLY?

ใน Channel ที่มี Bandwidth จำกัด เราจะแบ่งใช้งานจาก multiple devices ได้อย่างไร

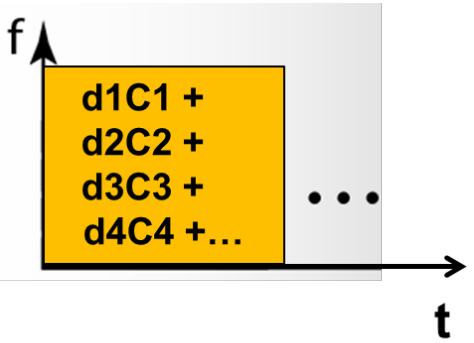
MULTIPLEXING IS THE KEY ANSWER FOR BANDWIDTH SHARING



Multiplexing through
Frequency sharing
Wavelength sharing



Multiplexing through
Time sharing

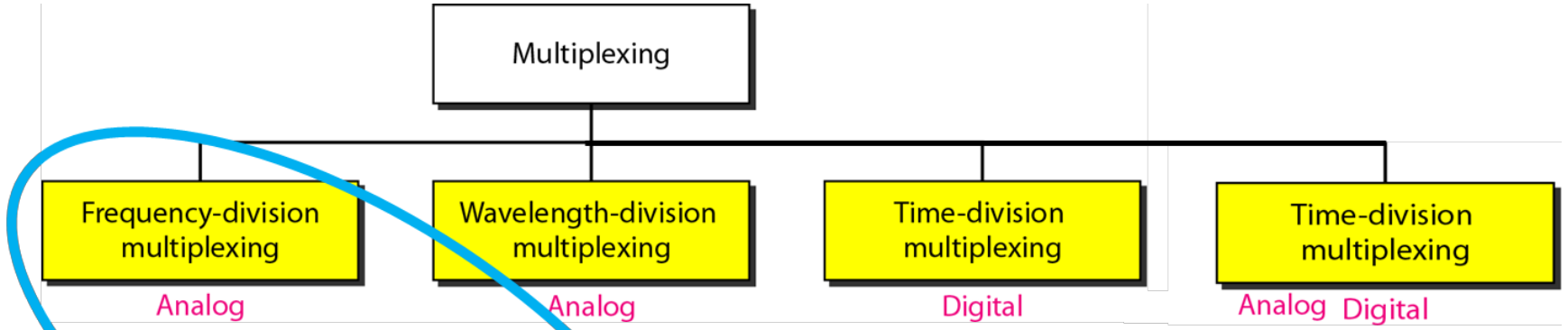


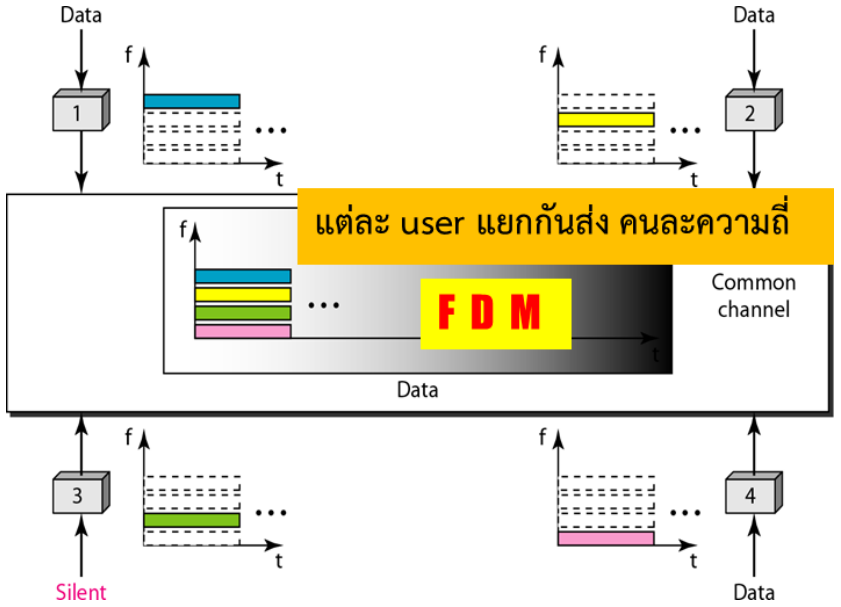
Multiplexing through
Spreading code sharing

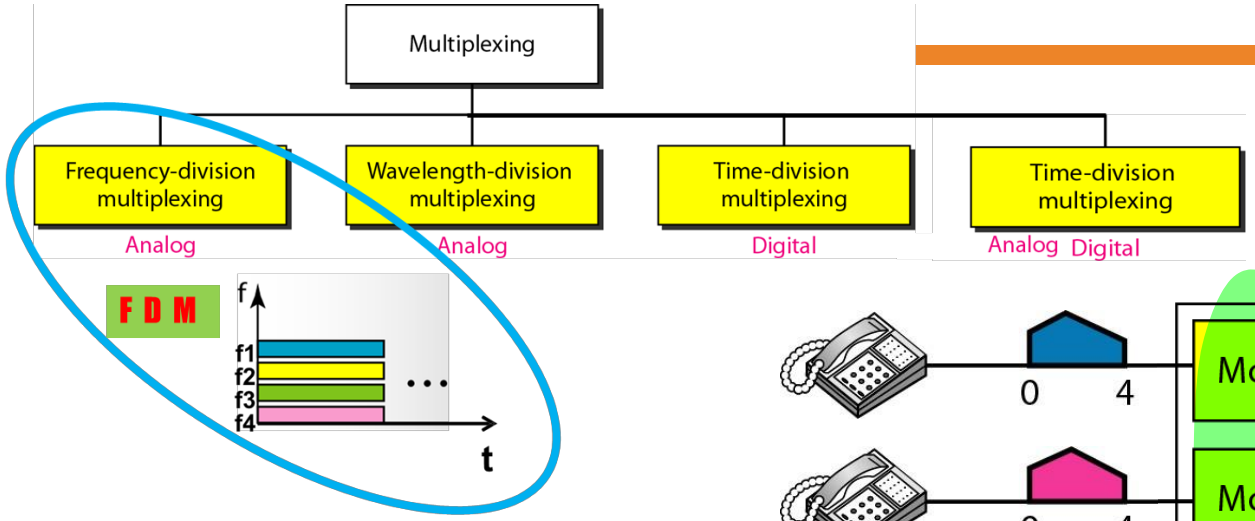
FDM

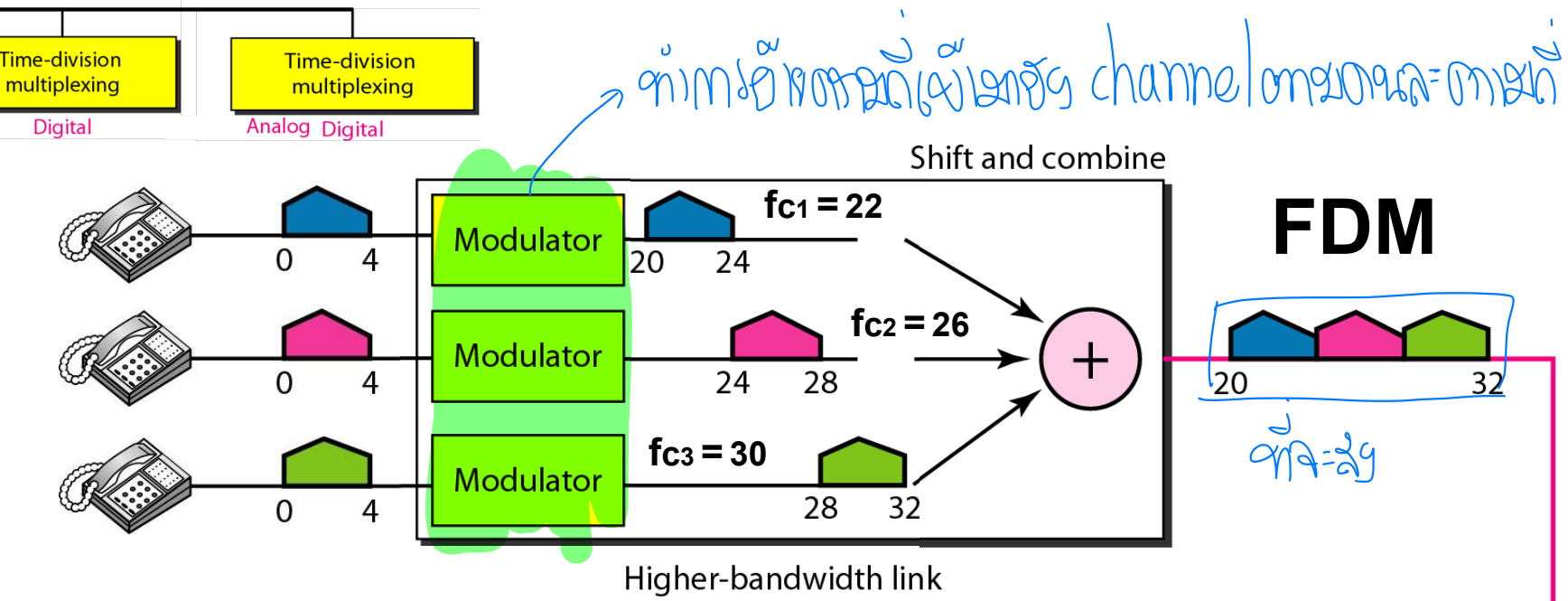
FREQUENCY DIVISION MULTIPLEXING

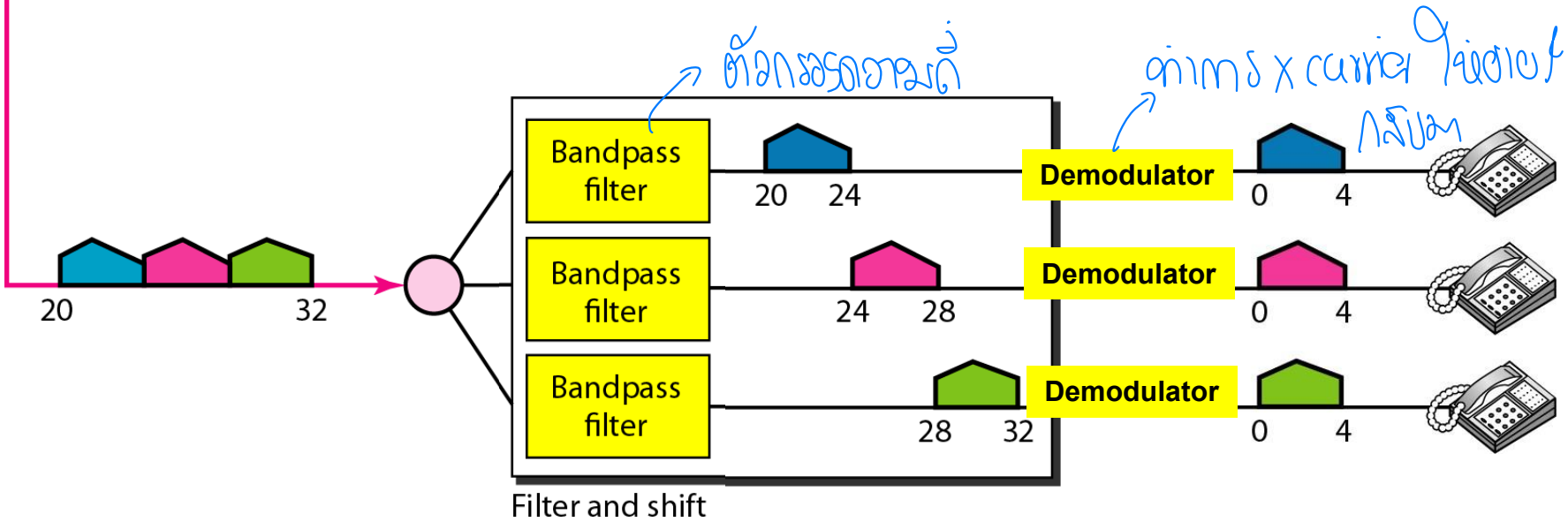
FDM: FREQUENCY DIVISION MULTIPLEXING

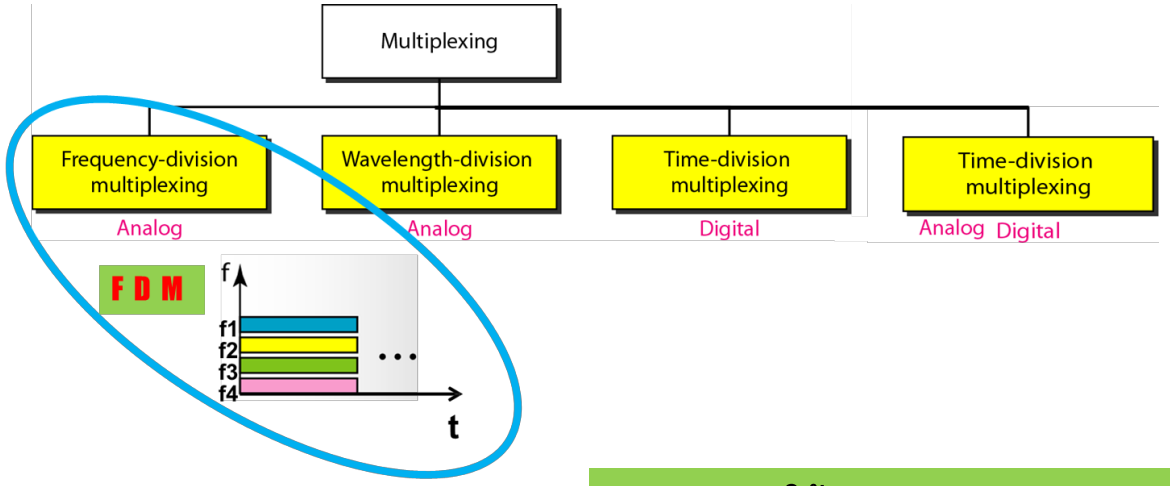





Multiplexing
Frequency-division multiplexing
Wavelength-division multiplexing
Time-division multiplexing
Time-division multiplexing
Analog
Analog
Digital
Analog Digital
FDM
f
f1
f2
f3
f4
t


Shift and combine
Modulator
Modulator
Modulator
fc1 = 22
fc2 = 26
fc3 = 30
0 4
0 4
0 4
20 24
24 28
28 32
FDM
20 32
Higher-bandwidth link

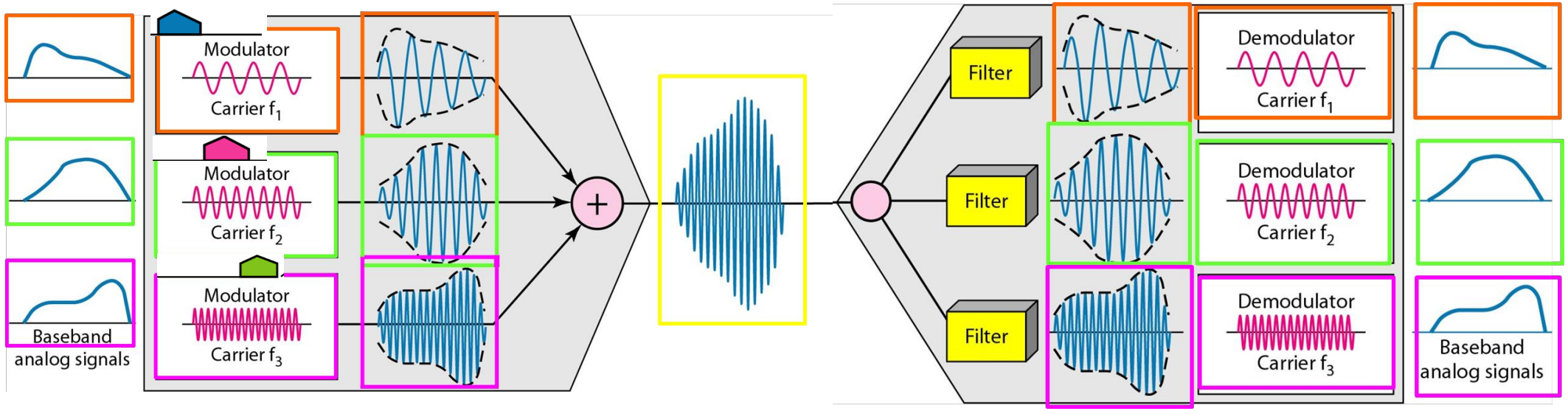

Bandpass filter
Bandpass filter
Bandpass filter
Demodulator
Demodulator
Demodulator
20 32
20 24
24 28
28 32
0 4
0 4
0 4
Filter and shift



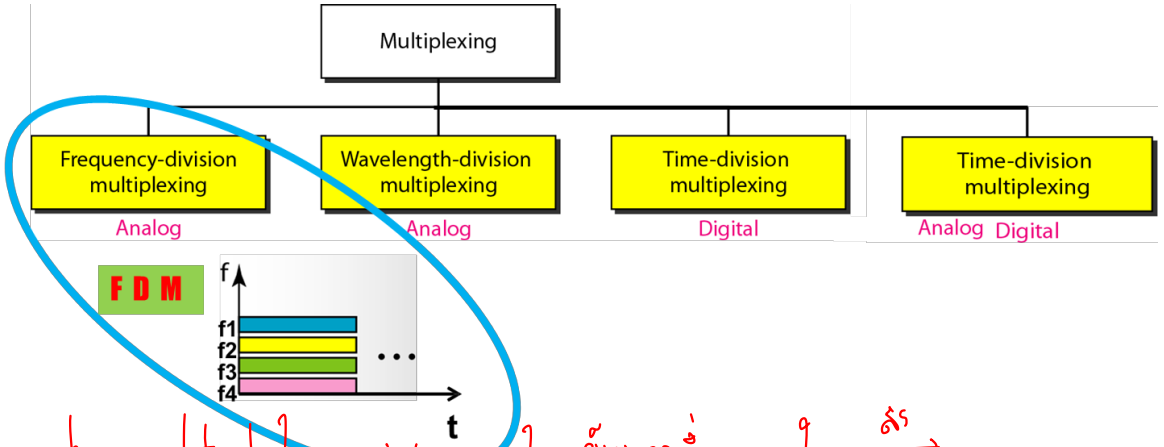
Analog Data -> FDM

แต่ละ user ใช้ carrier freq. คนละความถี่

Demultiplexing: Analog DEMOD to get data and remove carrier



Analog Data | Analog MOD | Multiplexing | De-Multiplexing | Analog De-MOD | Analog Data



Digital Data -> FDM

if we change data to digital } convert to analog signal }

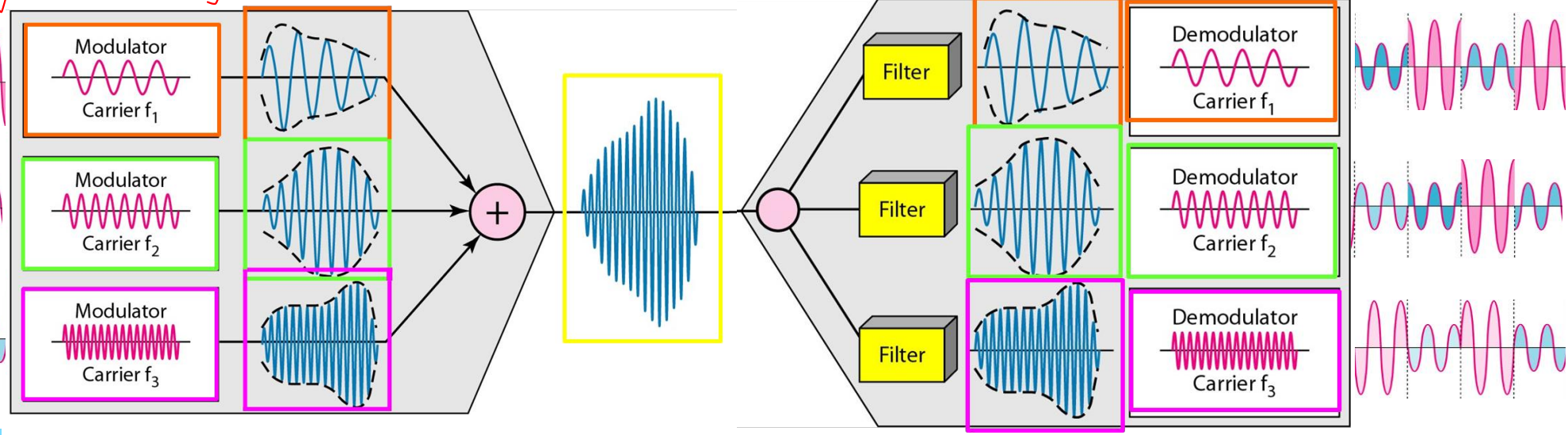
ข้อเสียคือ แต่ละ user ใช้ carrier freq. คนละความถี่

Demultiplexing: Analog DEMOD to get data and remove carrier

Digital data '010011110111'

Digital data '000010011110'

Digital data '101100001000'



Digital Modulation

Analog MOD

Multiplexing

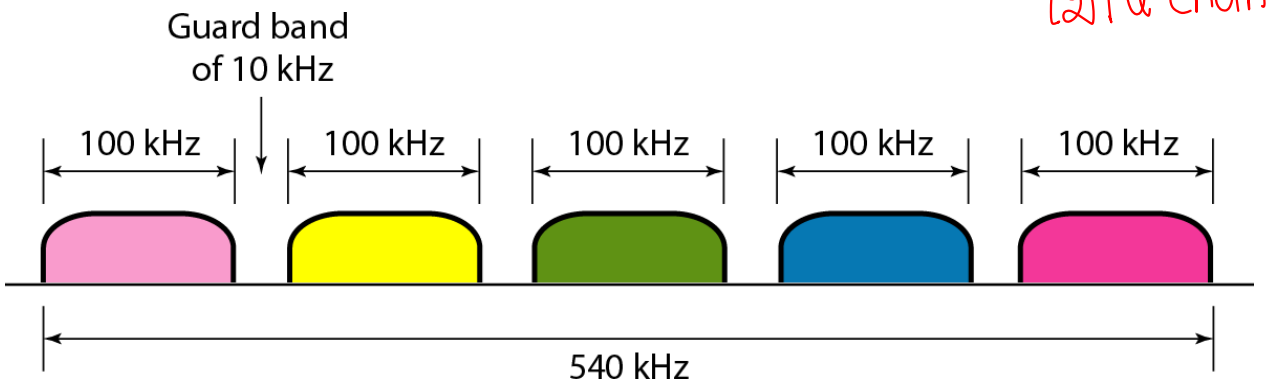
De-Multiplexing

Analog De-MOD

Digital DEModulation

EXAMPLE 6.2

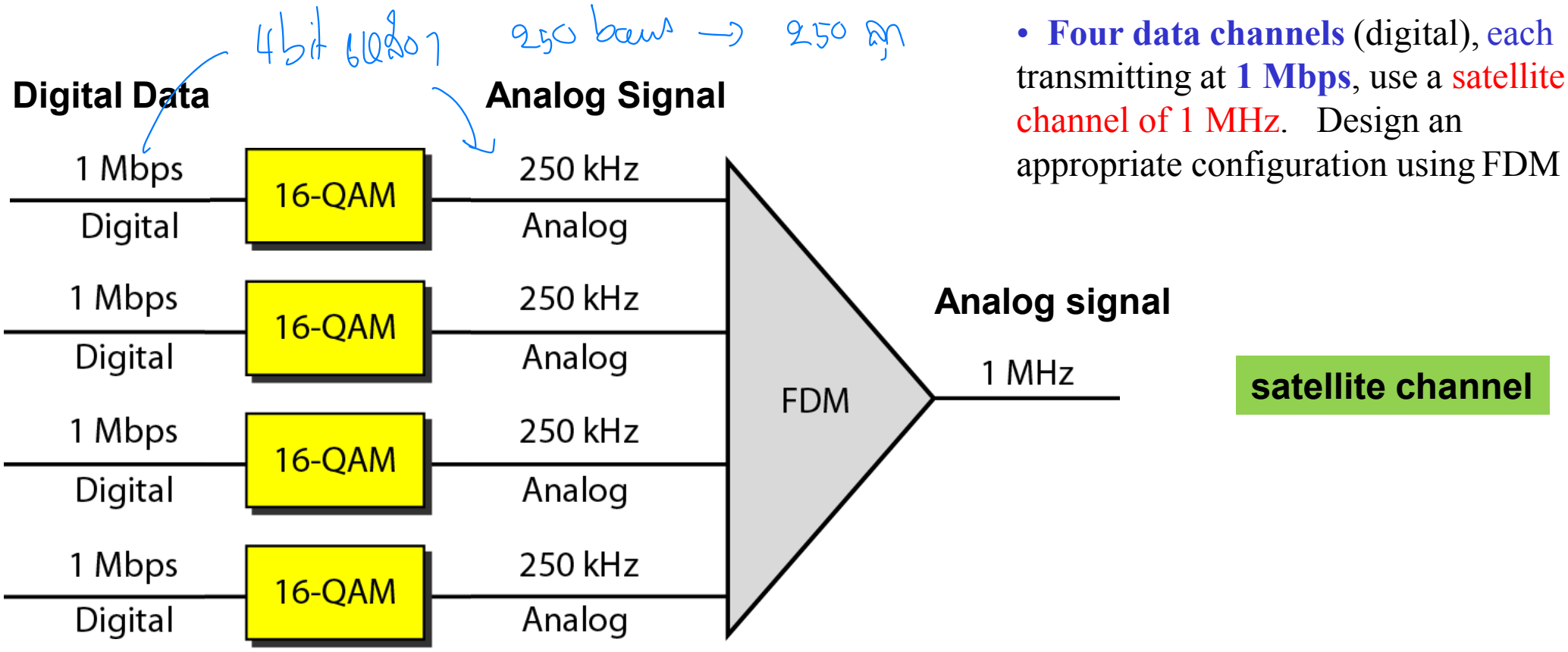
- **Five channels**, each with a **100-KHz bandwidth**, are to be multiplexed together.
- What is the **minimum bandwidth** of the link if there is a need for a **guard band of 10 KHz** between the channels to prevent interference?



Solution

For **five channels**, we need **at least four guard bands**.
This means that the required bandwidth is at least

(5 x 100) + (4 x 10) = 540 KHz,



• **Four data channels** (digital), each transmitting at **1 Mbps**, use a satellite channel of 1 MHz. Design an appropriate configuration using FDM

satellite channel

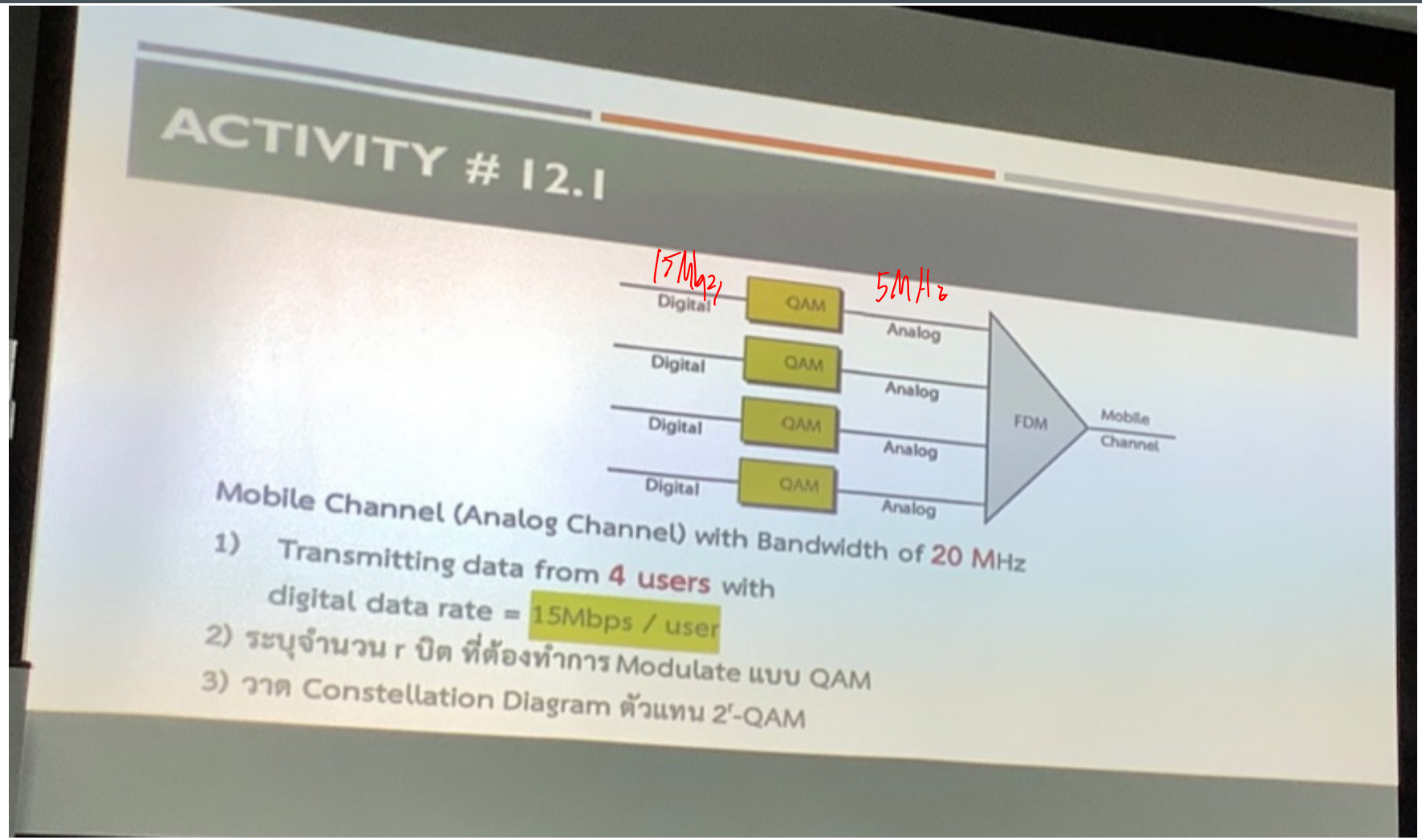
•Each digital channel of **1 Mbps** is modulated such that each r = **4 bits are modulated to 1 baud**.

- One solution is 16-QAM modulation.

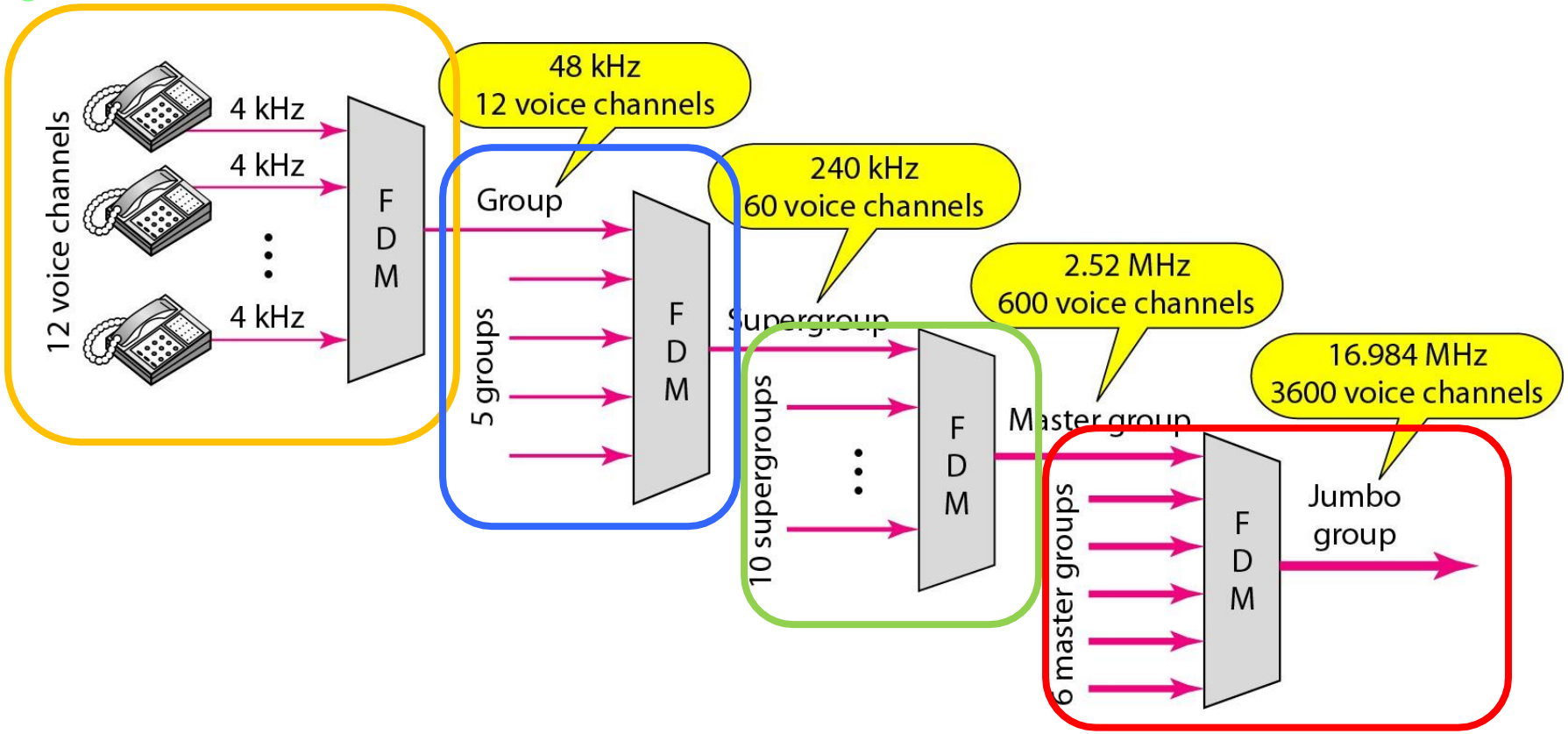
•The **satellite channel is analog**.

- We divide it into **four channels**, each channel having a **250-KHz** bandwidth.

ACTIVITY # 12.1

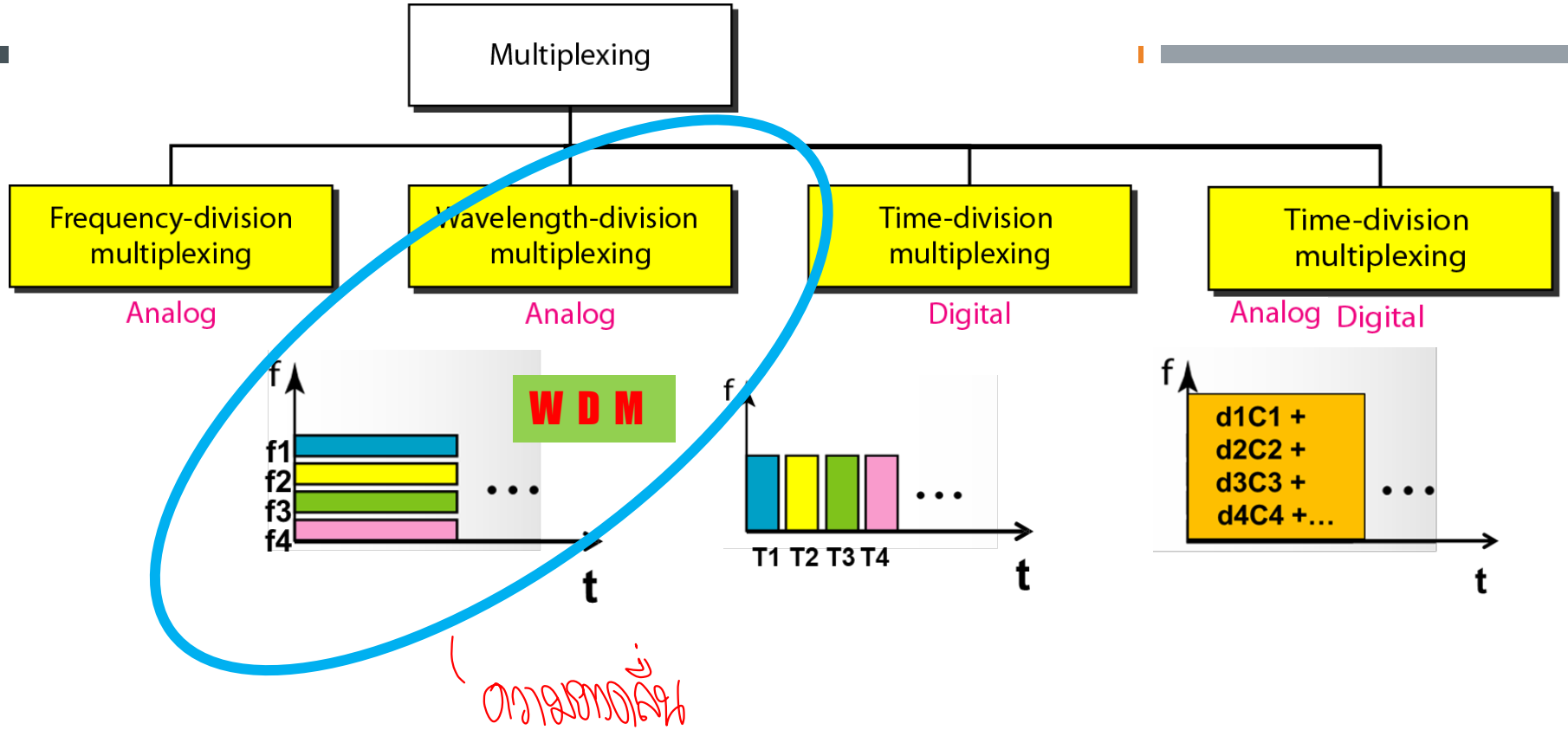


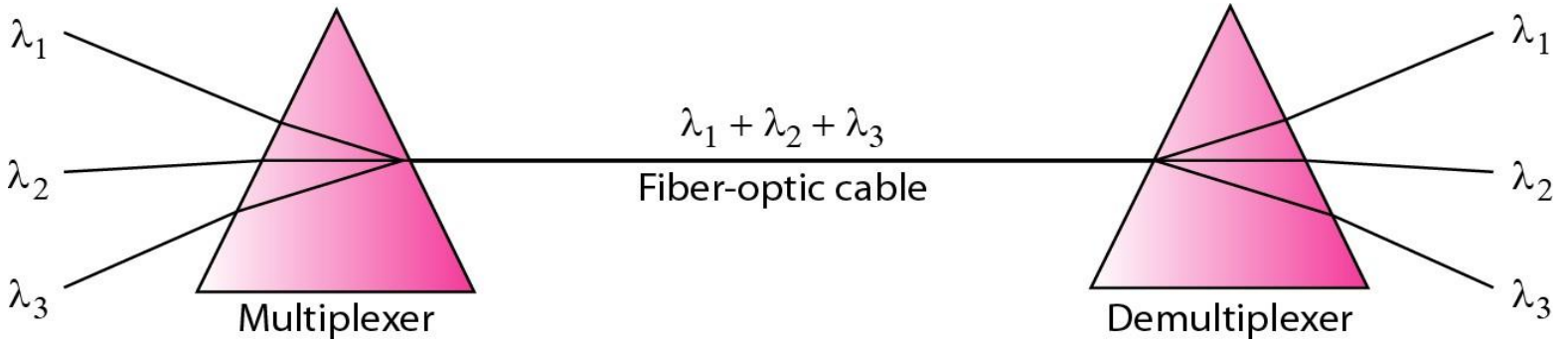
HIERARCHICAL FDM

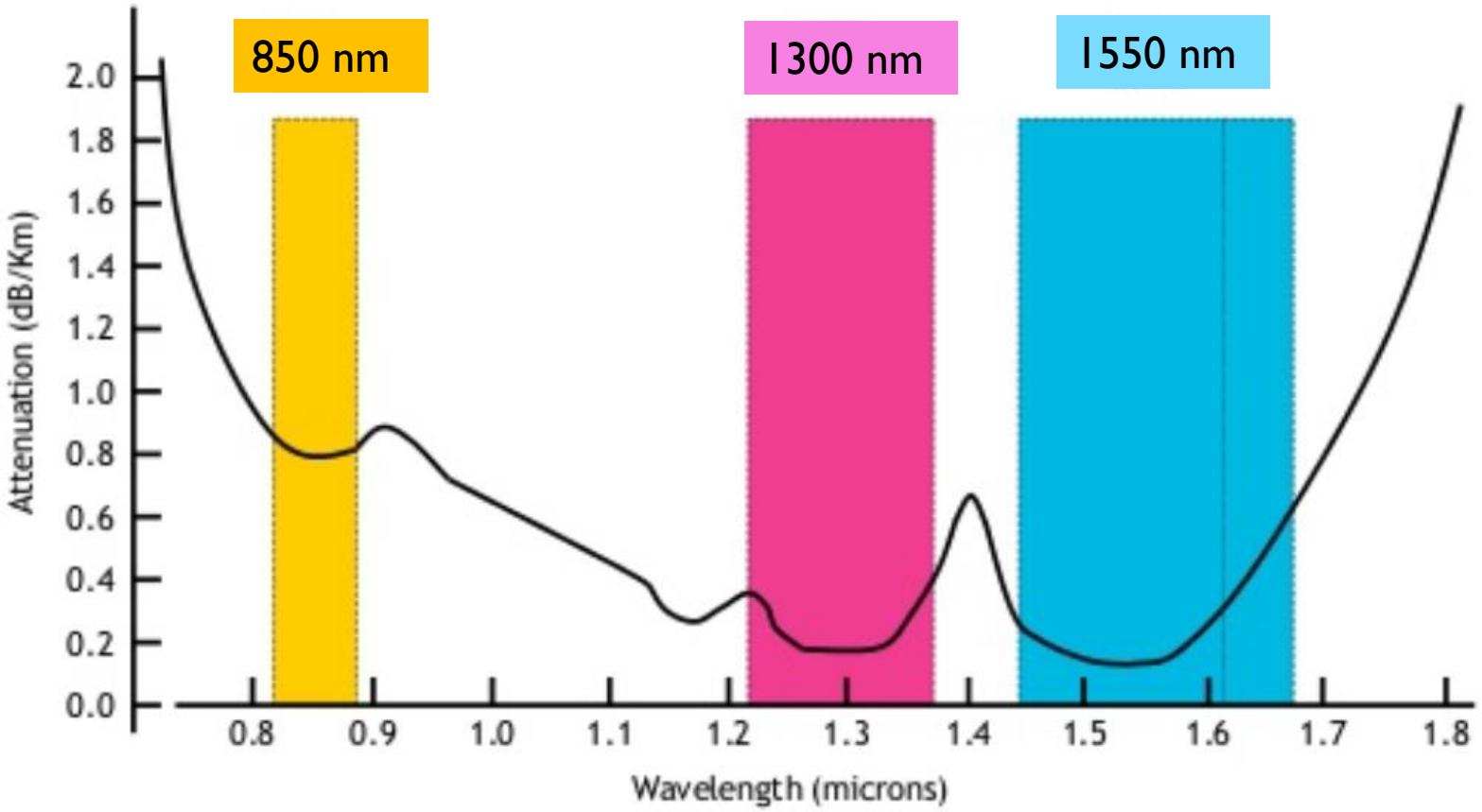


WDM

WAVE DIVISION MULTIPLEXING


Multiplexing
Frequency-division multiplexing
Wavelength-division multiplexing
Time-division multiplexing
Time-division multiplexing
Analog
Analog
Digital
Analog
Digital
f
f1
f2
f3
f4
t
W D M
f
T1 T2 T3 T4
t
f
d1C1 +
d2C2 +
d3C3 +
d4C4 +...
t

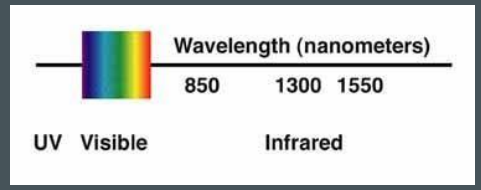

λ_1
λ_2
λ_3
Multiplexer
$\lambda_1 + \lambda_2 + \lambda_3$
Fiber-optic cable
Demultiplexer
λ_1
λ_2
λ_3

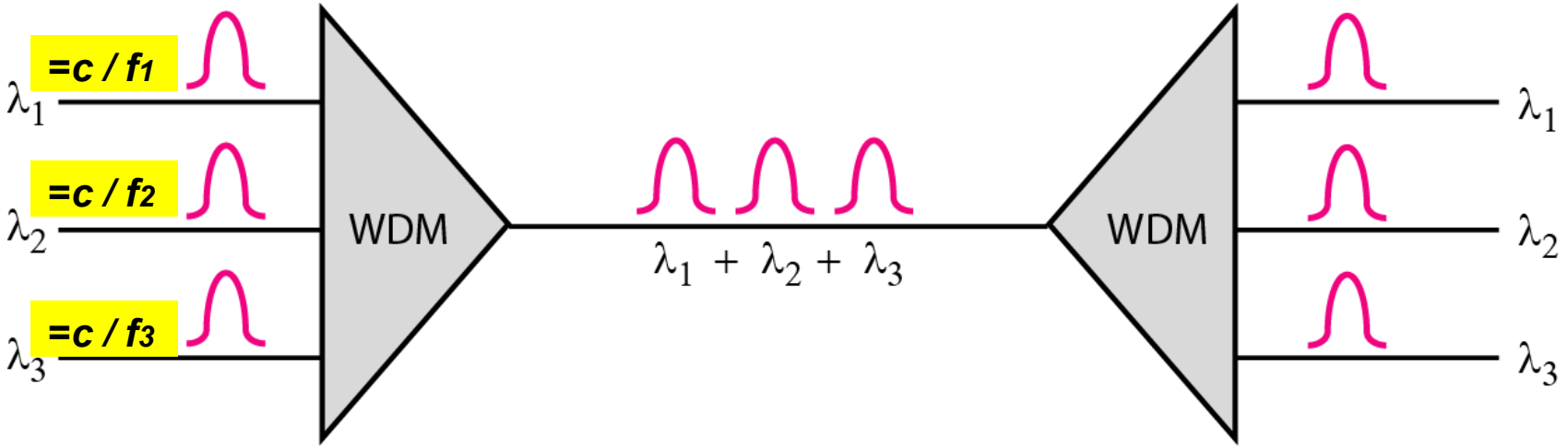


NONLINEAR ATTENUATION

(LOSS / DISTANCE)

WDM





λ= c / f

λ=wavelength

c = Light Speed

- ช่วง wavelength ที่ใช้งาน 1550 nm
- Channel space:
  - SDH/SONET -> 50 GHz/ channel, 32 channels -> 2.5 Gbps x 32 = 80 Gbps
  - (1999)Bell LAB: 10 GHz/ channel, 1022 channels -> 2.5 Gbps x 1022 = 2.555 Tbps
  - (2002) NEC: 10 GHz/ channel, 273 channels -> 40 Gbps x 273 = 10.9 Tbps
  - (2011) NEC: 10 GHz/ channel, 370 channels -> 274 Gbps x 370 = 101.7 Tbps

TDM

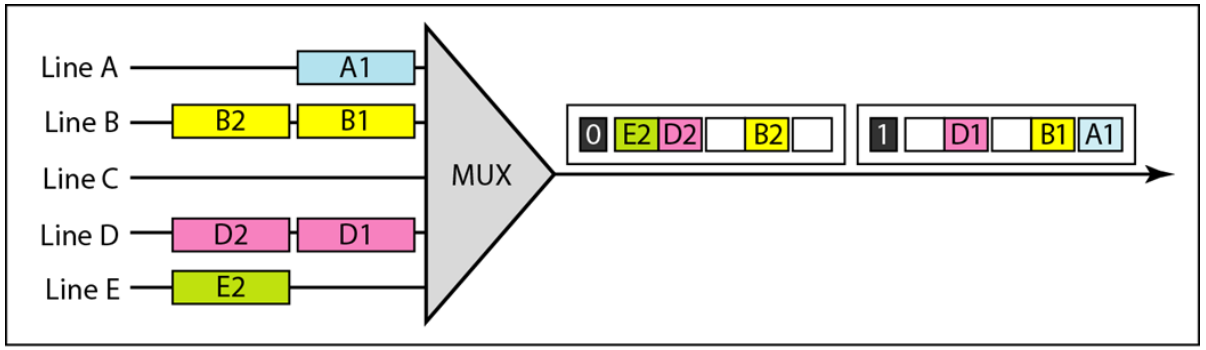
TIME DIVISION MULTIPLEXING

SYNCHRONOUS TDM

STATISTICAL TDM

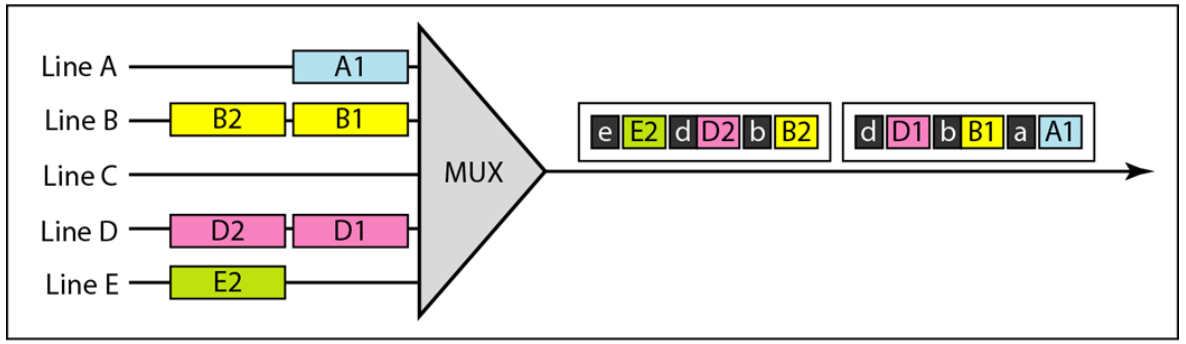
SYNCHRONOUS TDM VS STATISTICAL TDM

- **Synchronous TDM**



a. Synchronous TDM

- **Statistical TDM**



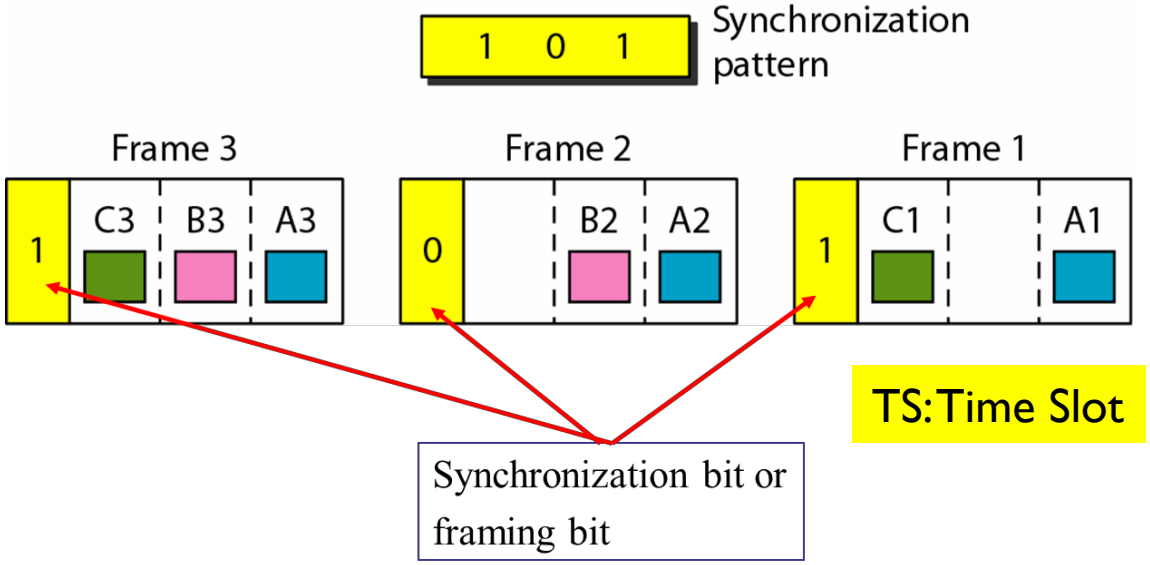
b. Statistical TDM

Fixed Time Slot Allocation

Flexible Time Slot Allocation

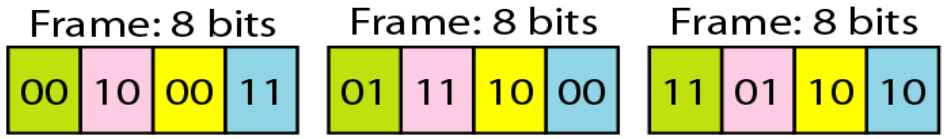
TDM: INTERLEAVING UNIT / TIME SLOT

Framing bits

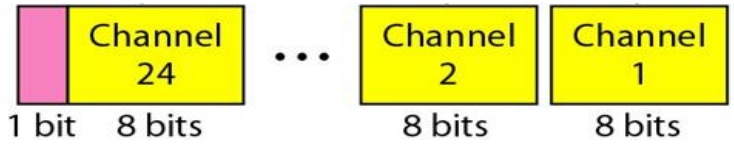


TS: Time Slot

TS: Time Slot

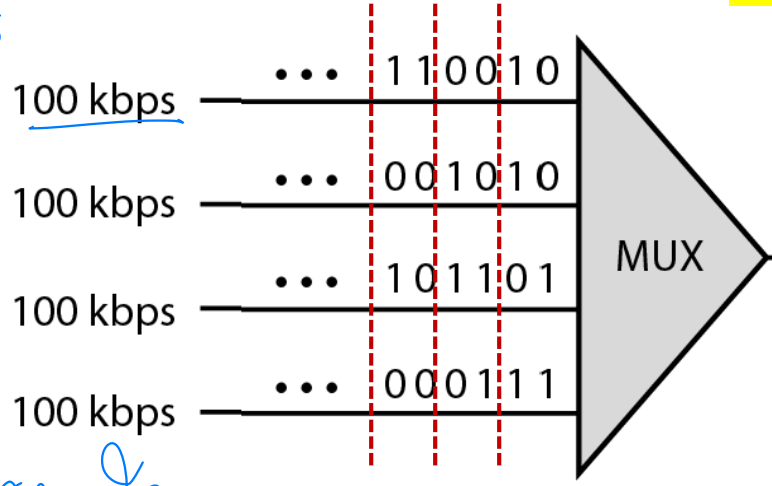


Interleaving Unit / Time slot -> **2 bits** / timeslot

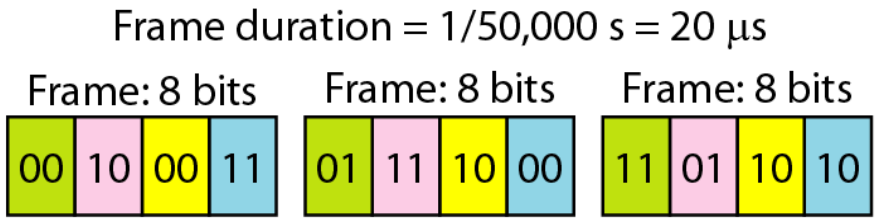


Interleaving Unit / Time slot -> **8 bits** / timeslot

No Synchronization Bit



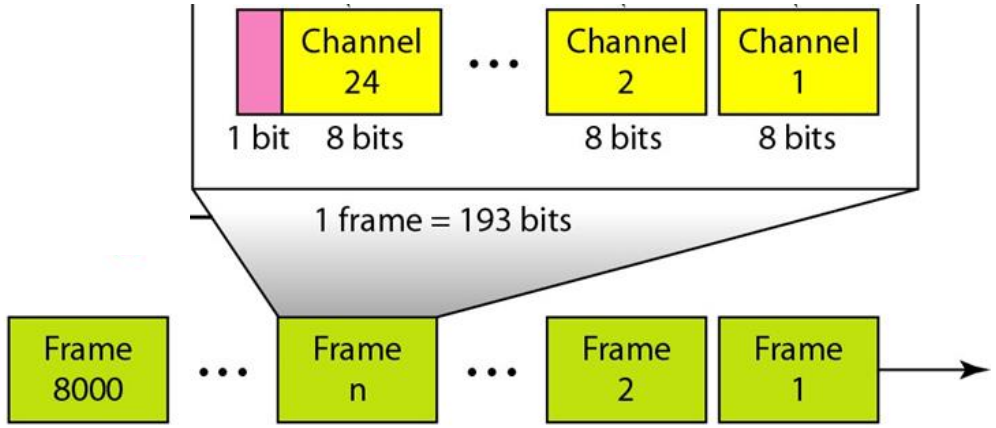
TDM: 2bits/slot Interleaving Unit = 2 bits



Frame rate = 100 kbps / (2 bits / frame)
= 50 kframes / s

Bit rate = 4 x 100 kbps
= 50,000 frame/s x 8 bits/frame
= 400 kbps

With Synchronization Bit

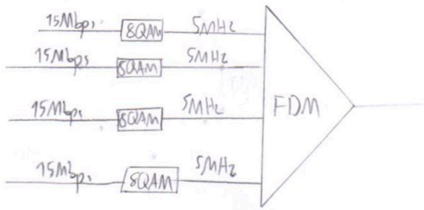


Frame rate = 8000 frames / s

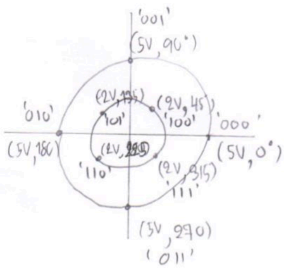
Bit rate = 8000 frames / s x (24 x 8 + 1) bits/ frame
= 8000 x 193
= 1.544 Mbps

ACTIVITY # 12.2

61011483



$r = \frac{15}{(20/4)} = 3$ bit



2.1 4 user

2.2 user data rate = 5 Mbps

2.3 bit duration $= \frac{1}{5M} = 200$ nS

2.4 bit/time slot = 8

2.5 framerate $= \frac{5M}{8} = 625$ frame/s

2.6 fram duration $\frac{1}{625} = 1.6\ \mu S$

(คิดแบบของคนเดียว)

→ เขากำหนดให้ 4 user bandwidth รวม 20M

1 user = 5Mbps

$\frac{1}{5M}$ = bit duration

bit/timeslot = 8

framerate $= \frac{5M}{8} = 625$ fr

8 bit → 1 f

5M bit →

คิดของคนทั้งหมด

bit/timeslot = 8 x 4 → 32

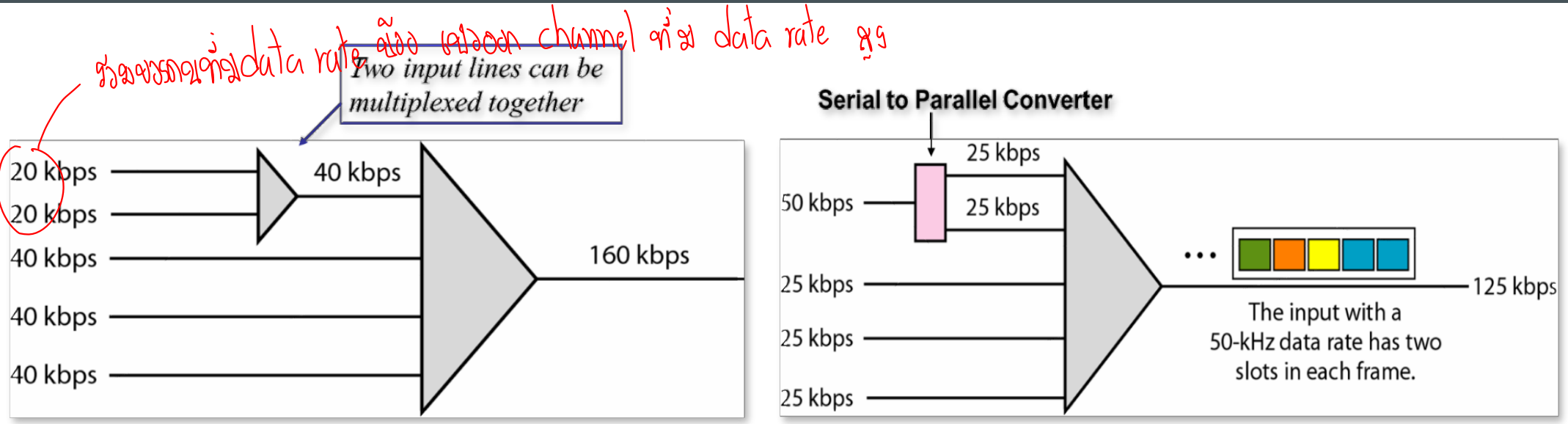
framerate ⇒ 32 → 1 frame

20M → $\frac{20M}{32}$ = 625 frame/s

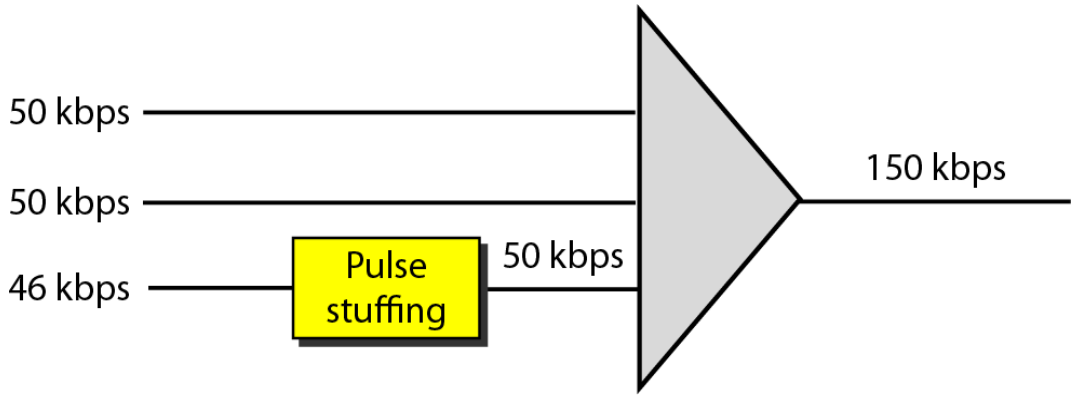
เท่ากัน

ภูต่อม นันทสิงห์

MULTILEVEL MULTIPLEXING

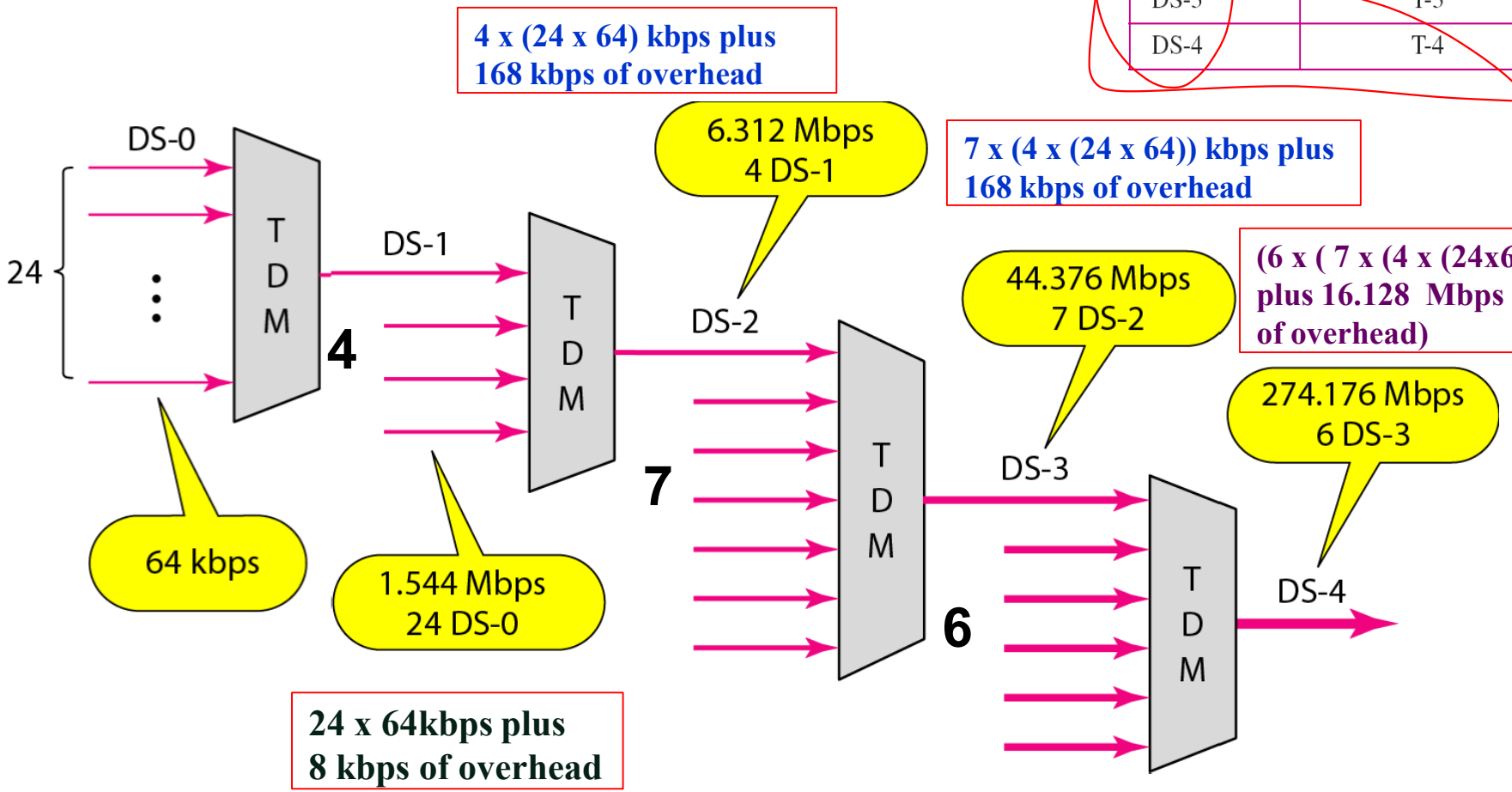


Pulse stuffing



HIERARCHICAL TDM

Service	Line	Rate (Mbps)	Voice Channels
DS-1	T-1	1.544	24
DS-2	T-2	6.312	96
DS-3	T-3	44.736	672
DS-4	T-4	274.176	4032

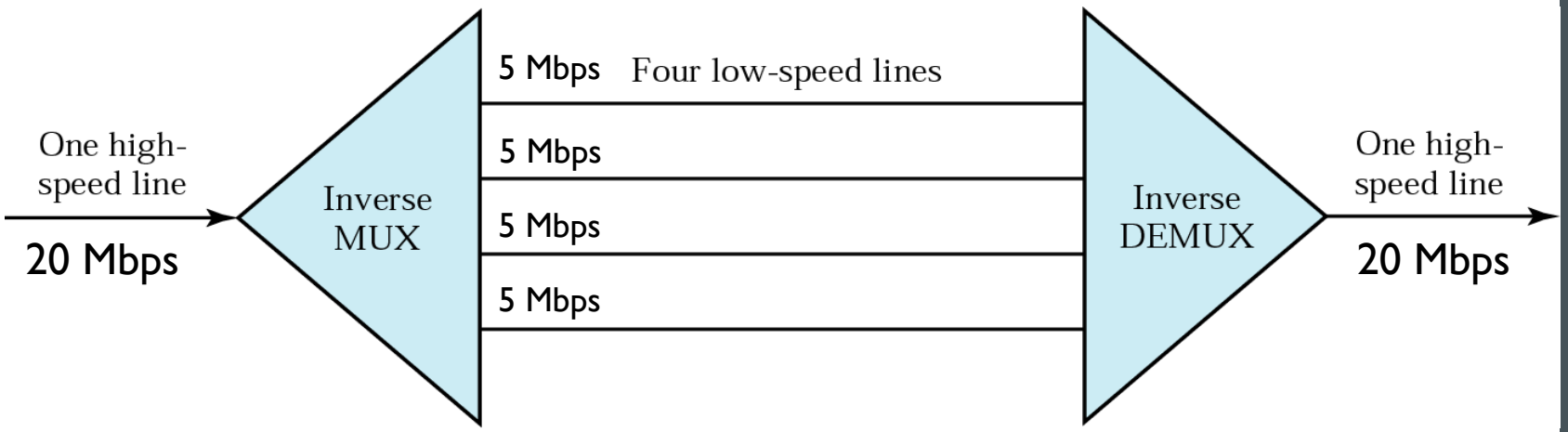


Line	Rate (Mbps)	Voice Channels
E-1	2.048	30
E-2	8.448	120
E-3	34.368	480
E-4	139.264	1920

DS-1 (T1): 24x64 kbps = 1536 kbps = 1.536 Mbps

INVERSE TDM

กรณีที่ data rate สูงกว่า channel ตัวใด
เช่า channel เพิ่มแล้ว



CDMA

CODE DIVISION MULTIPLE ACCESS

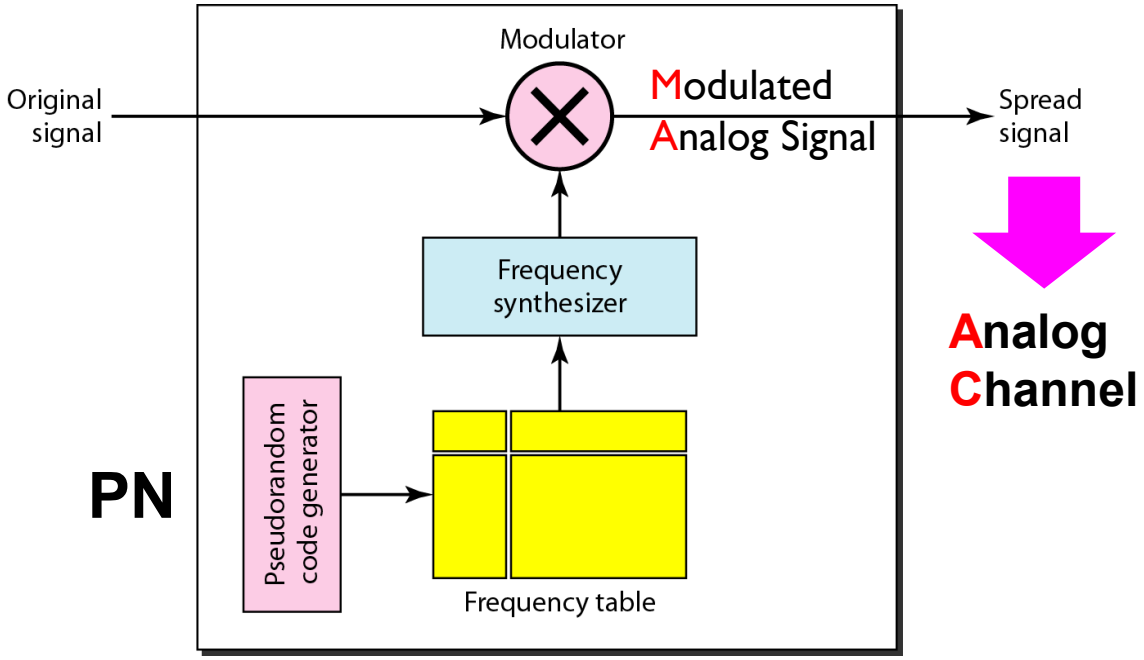
แล้วแต่เลขตัวรวมไหล ?

แบบ คนเดิม จะไม่อยู่ตามที่เดิมเลย

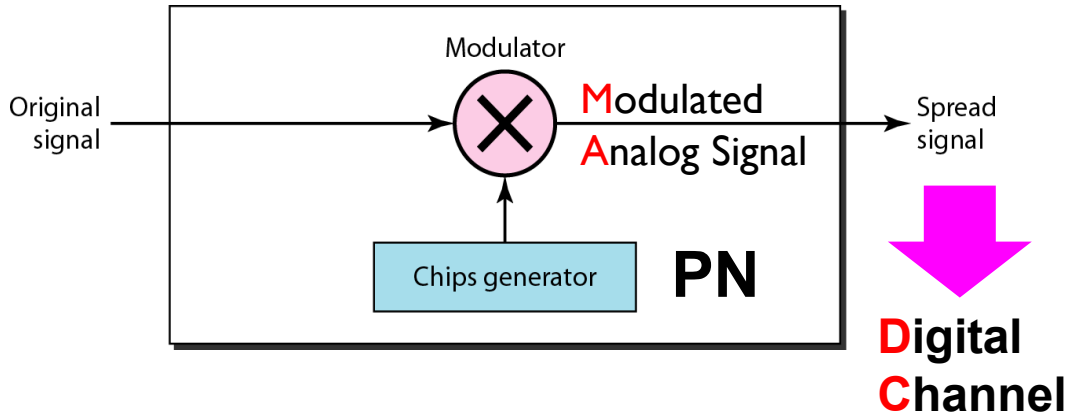
FREQUENCY HOPPING SPREAD SPECTRUM

DIRECT SEQUENCE SPREAD SPECTRUM

FREQUENCY HOPPING VS DIRECT SEQUENCE



Frequency Hopping



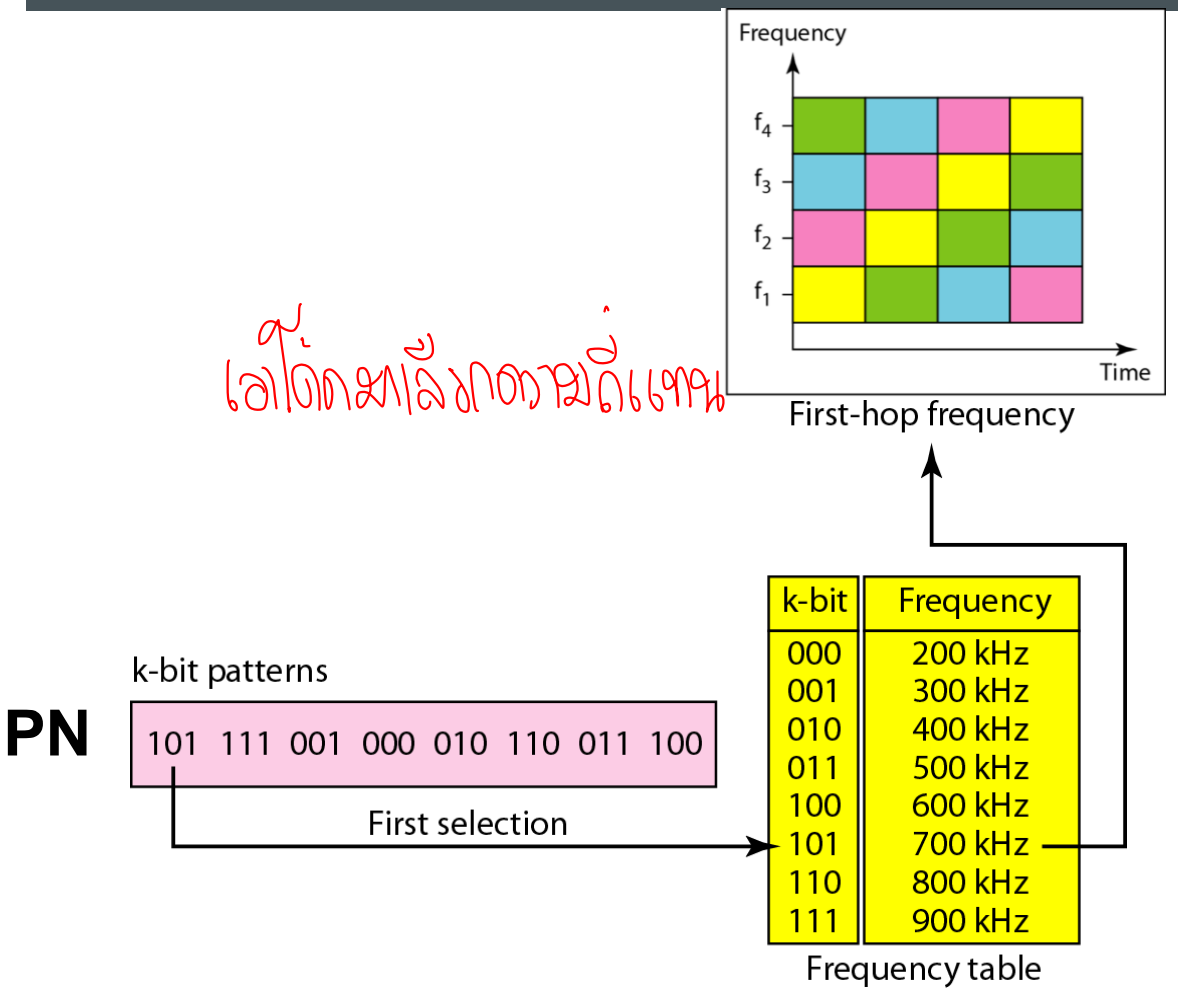
Direct Sequency

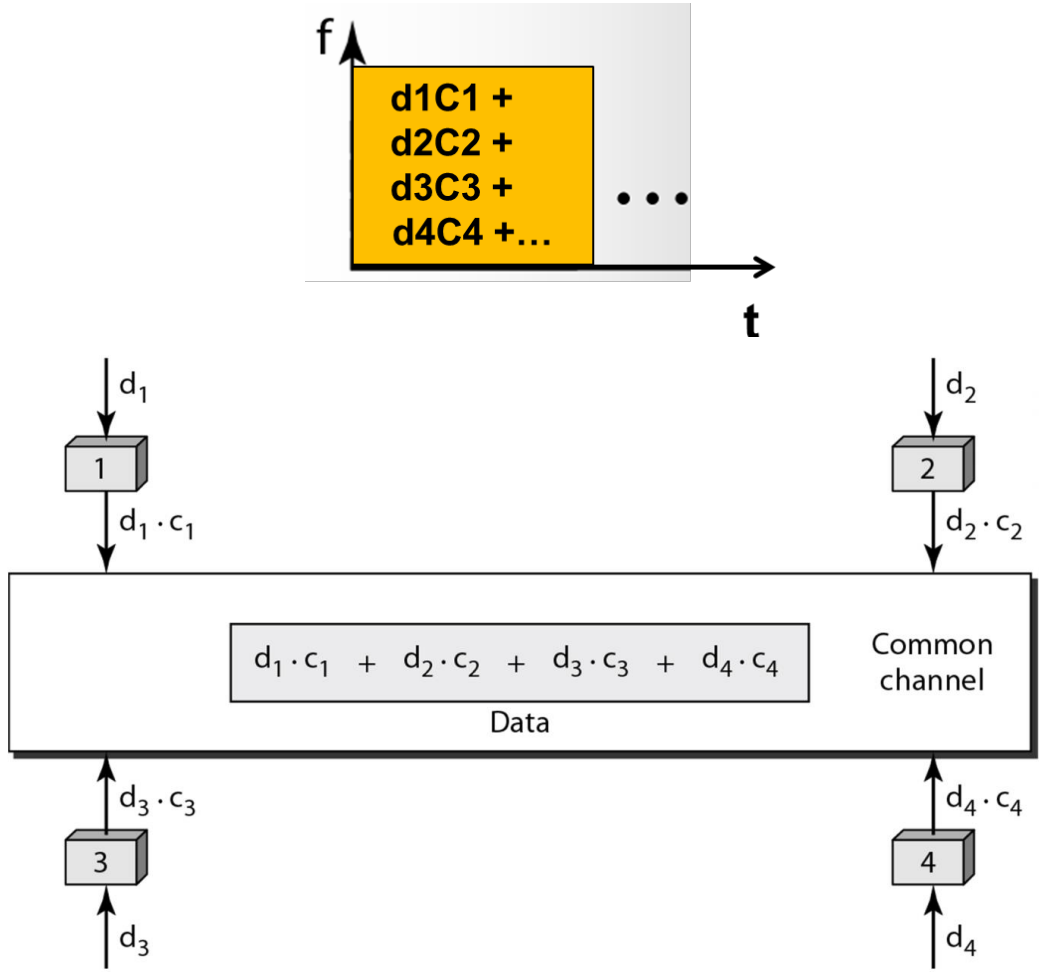
ที่จะเราใช้ในเทอมนี้

PN: Pseudo Random Number

each user has his own code

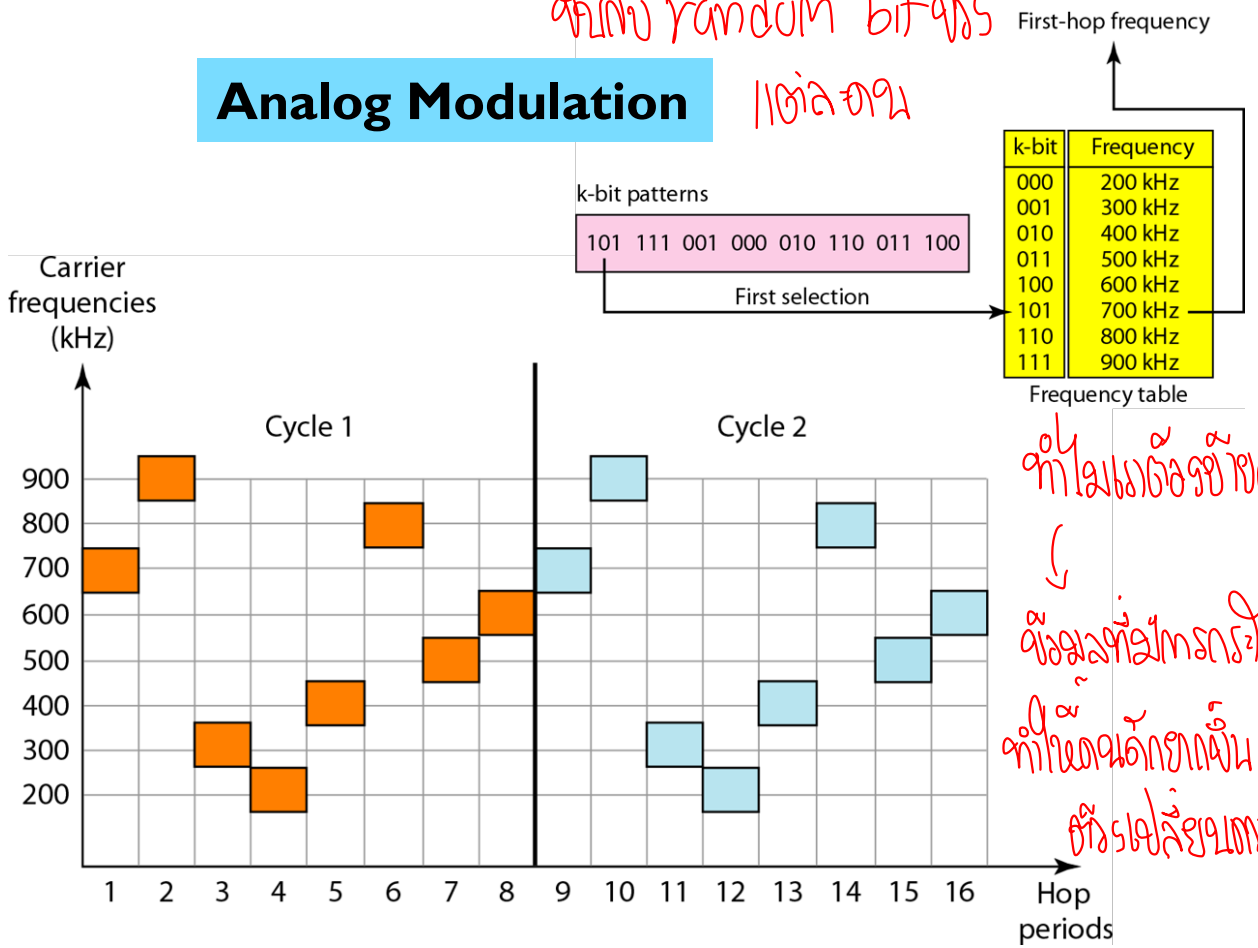
FREQUENCY HOPPING VS DIRECT SEQUENCE



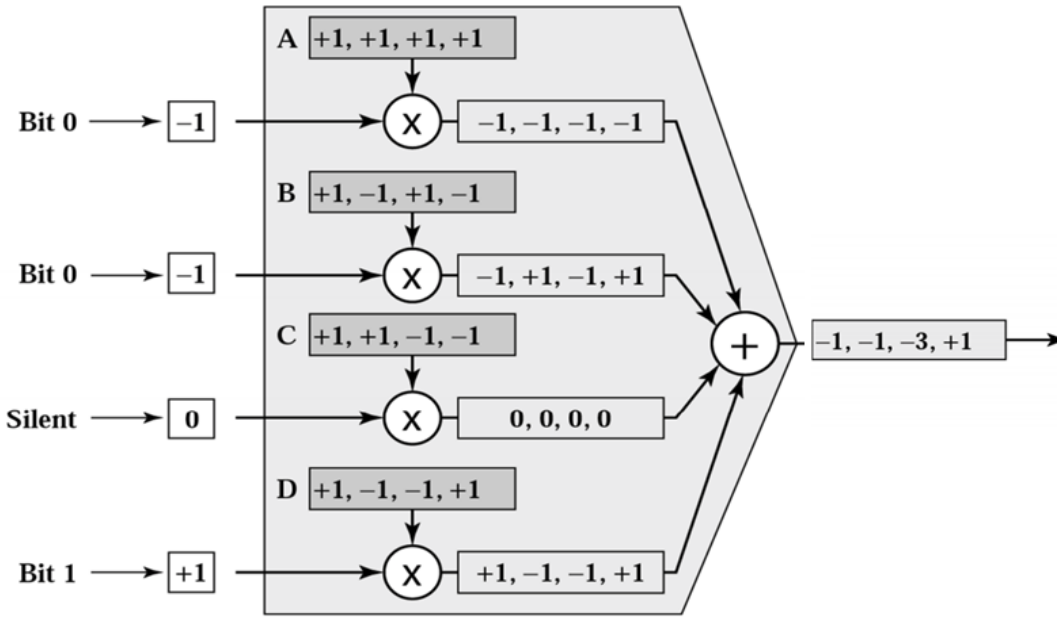


FREQUENCY HOPPING VS DIRECT SEQUENCE

Analog Modulation



Code Modulation



WALSH CODE FOR PN (PSEUDO RANDOM NUMBER)

Sequence generation

การสร้างรูปแบบ

$$\begin{bmatrix} W_{2n} & W_{2n} \\ W_{2n} & \overline{W}_{2n} \end{bmatrix}$$

Element

$$W_1 = \begin{bmatrix} +1 \end{bmatrix}$$

N=1

$$W_2 = \begin{bmatrix} +1 & +1 \\ +1 & -1 \end{bmatrix}$$

$$W_4 = \begin{bmatrix} +1 & +1 & +1 & +1 \\ +1 & -1 & +1 & -1 \\ +1 & +1 & -1 & -1 \\ +1 & -1 & -1 & +1 \end{bmatrix}$$

W_2 W_2 W_2 $\overline{W}_2$

N=2