# Analog Transmission System

Q

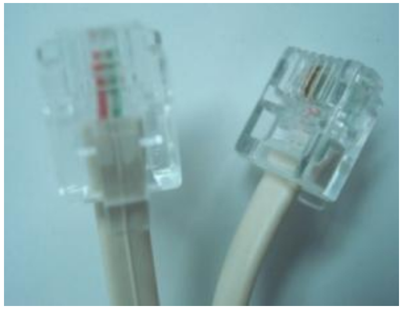
ช่องทางการส่งสัญญาณแบบใดล่ะ
ถือว่าเป็นช่องส่งสัญญาณ
**Analog**

A

ช่อง **wire** หรือ **wirelss** น๊า

# Analog Transmission Media

**WIRE**



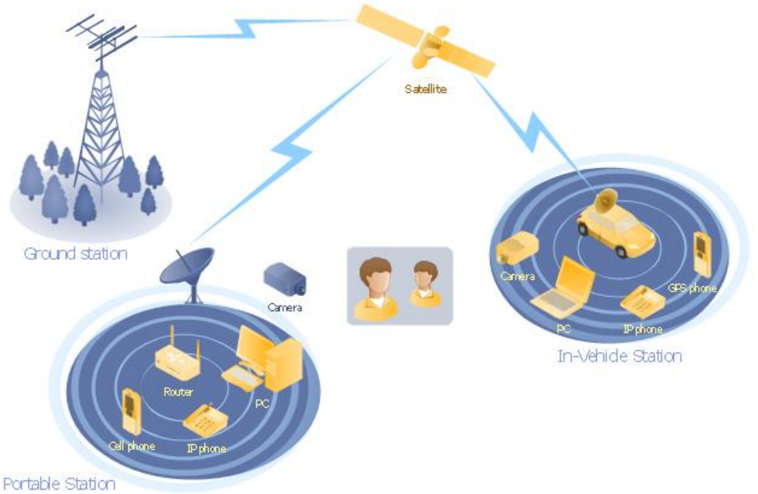

สายโทรศัพท์
(ADSL,VDSL)

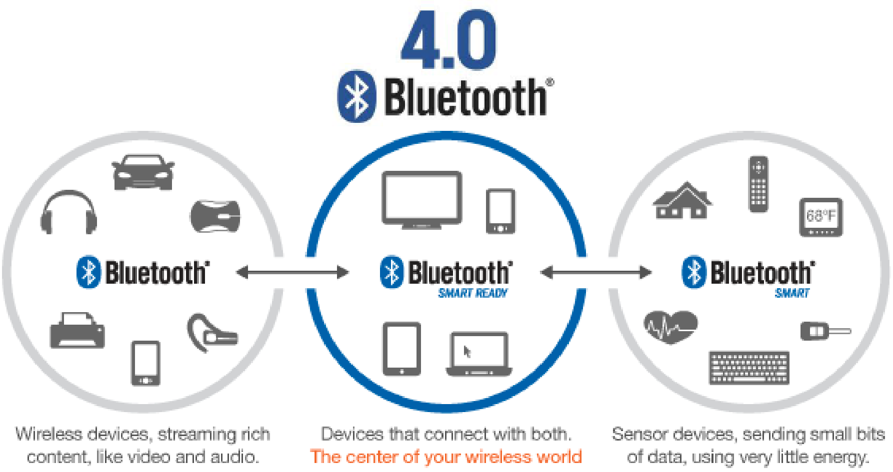
Coaxial Cable
(DOCSIS)

# Analog Transmission Media



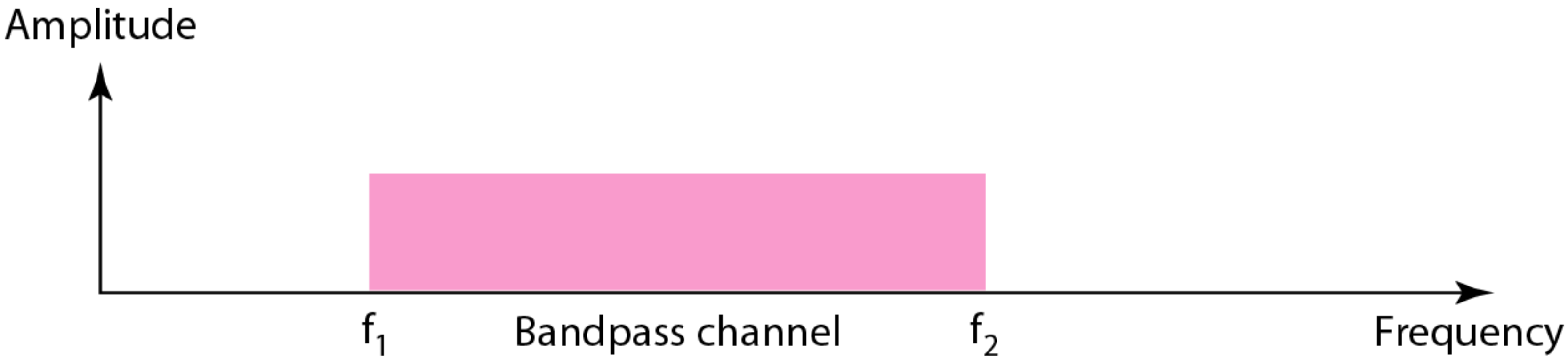
## WIRELESS



# แล้วดูอย่างไรล่ะว่าเป็นช่องส่งสัญญาณ Analog

# Bandpass Channel




- Most of Analog Transmission Media is
  - Bandpass Channel
  - Cannot transmit Digital Signal
    - Low frequency data pattern will be all lost
    - Need Signal Conversion

Q

ถ้าอยากส่งสัญญาณ **Digital** ไปบนช่องสัญญาณ **Analog** ล่ะ ทำไงดี

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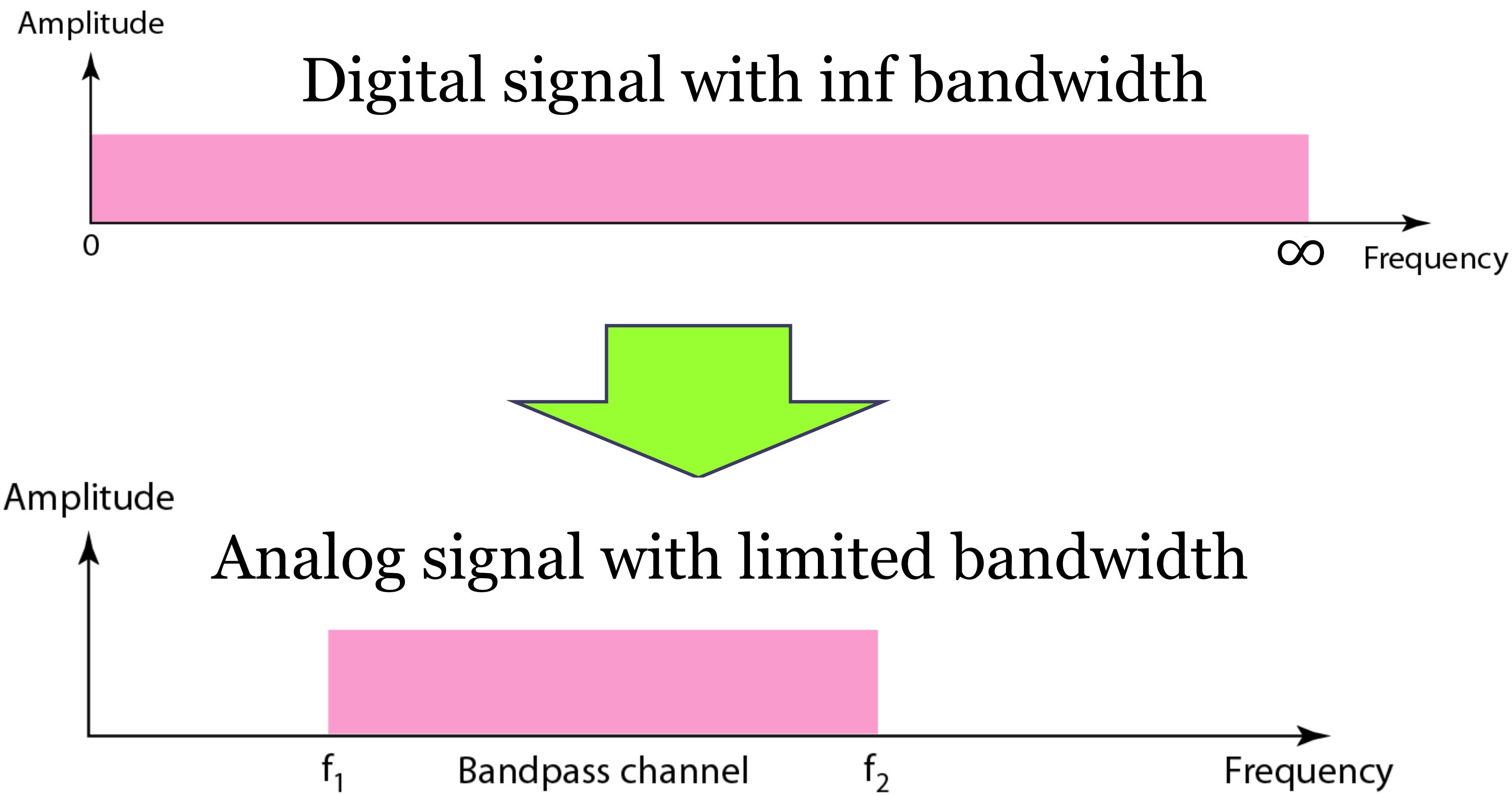
**Conversion** สิ

# Signal Conversion



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**Bandwidth ของ Analog Channel ต่าง ๆที่เราใช้งานจริงมันเป็นยังไงบ้าง**

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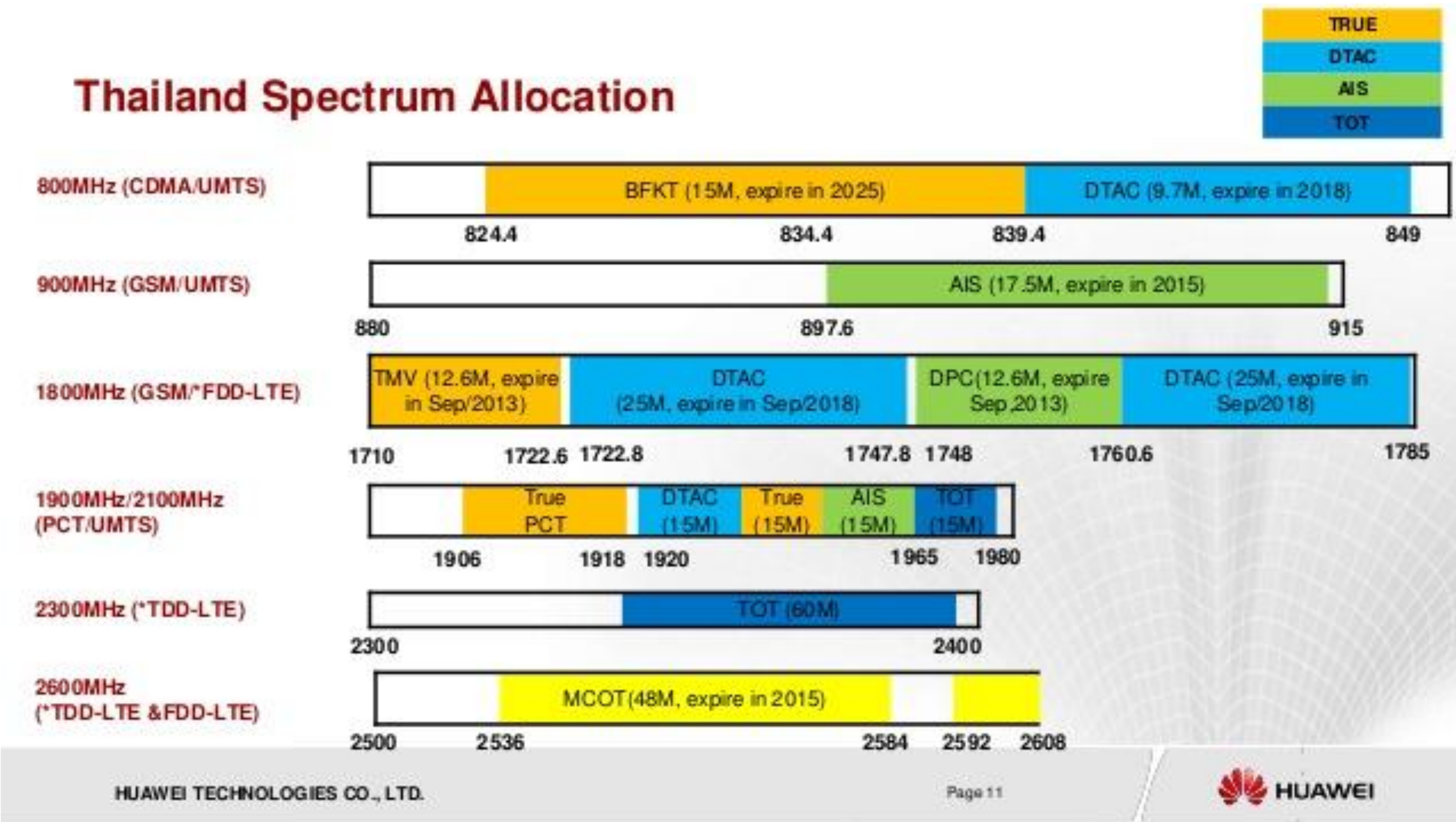
# Mobile Channel

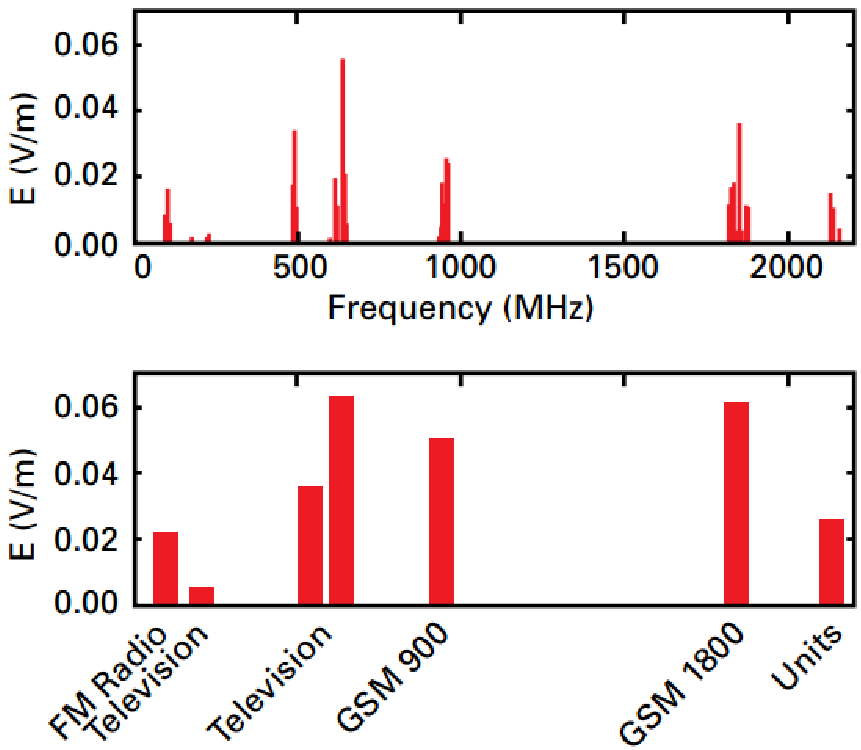
## ก่อนมั๊ย ใกล้ตัวดี

# Mobile Frequency Spectrum



# Cellular communications

**Figure 2.** Spectrum plot of typical radio communications signal levels in a community.




- GSM900 (AIS)
  - 890–915 MHz (uplink)
  - 935–960 MHz (downlink)
  - 124 RF channels (channel numbers 1 to 124) spaced at **200 kHz**
- GSM1800/CDMA1800 (DTAC/AIS/TRUE)
  - 1,710–1,785 MHz (uplink)
  - 1,805–1,880 MHz (downlink)
  - 374 channels (channel numbers 512 to 885) spaced at **200 kHz**
- CDMA2100 (3G/4G)(DTAC/AIS/TRUE)
  - 1,885-2,025 MHz (uplink)
  - 2,110-2,200 MHz(downlink)
  - Spaced at **5 MHz**

A

**TV Channel ล่ะ**

# Television Channel

## Analog VS Digital channel

| | |
|---|---|
| Frequency Band | UHF band IV/V |
| Channel Bandwidth | 1 ช่องความถี่ ➡ 8 MHz |
| Analog Channel | 1 ช่องความถี่ ➡ 1 ช่องรายการ |
| Digital Channel | 1 ช่องความถี่ (Multiplex) ➡ SDTV 10-12 ช่องรายการ |
| | 1 ช่องความถี่ (Multiplex) ➡ HDTV 2 และ SDTV 2-3 ช่อง |

# เปรียบเทียบคุณสมบัติของมาตรฐานต่าง ๆ

| | | ATSC | DVB-T | DVB-T2 | ISDB-T |
|---|---|---|---|---|---|
| Maintained by | | Advance Television System Committee | Digital Video Broadcasting Project | | Association of Radio Industries and Business |
| Compression | Video | MPEG-2 Video | MPEG-2 Video or H.264/ MPEG-4 AVC | | |
| | Audio | Dolby AC-3 | MPEG-2 Audio or AAC or HE-AAC or Dolby AC-3 | | AAC (Advanced Audio Coding) |
| System transport stream | | MPEG-2 System | MPEG-2 System | MPEG-2 System/GSE | MPEG-2 System |
| Modulation | modulation schemes | 8-VSB | COFDM (QPSK, 16QAM, 64QAM) | COFDM (QPSK, 16QAM, 64QAM, 256QAM) | BST-COFDM (QPSK, DQPSK, 16QAM, 64QAM) |
| | No. of subcarriers | Single-carrier (1) | Multi-carrier (FFT Size): 2k, 8k | Multi-carrier (FFT Size): 1k, 2k, 4k, 8k, 16k, 32k | Multi-carrier: (1) Mode 1 (1,405) (2) Mode 2 (2,809) (3) Mode 3 (5,617) |
| Channel Bandwidth | | 6 MHz (7, 8 MHz possible) | 7 or 8 MHz (6 MHz possible) | | 6 MHz (7, 8 MHz possible) |



- http://www4.nbtc.go.th/getattachment/Weblink/Hot-link

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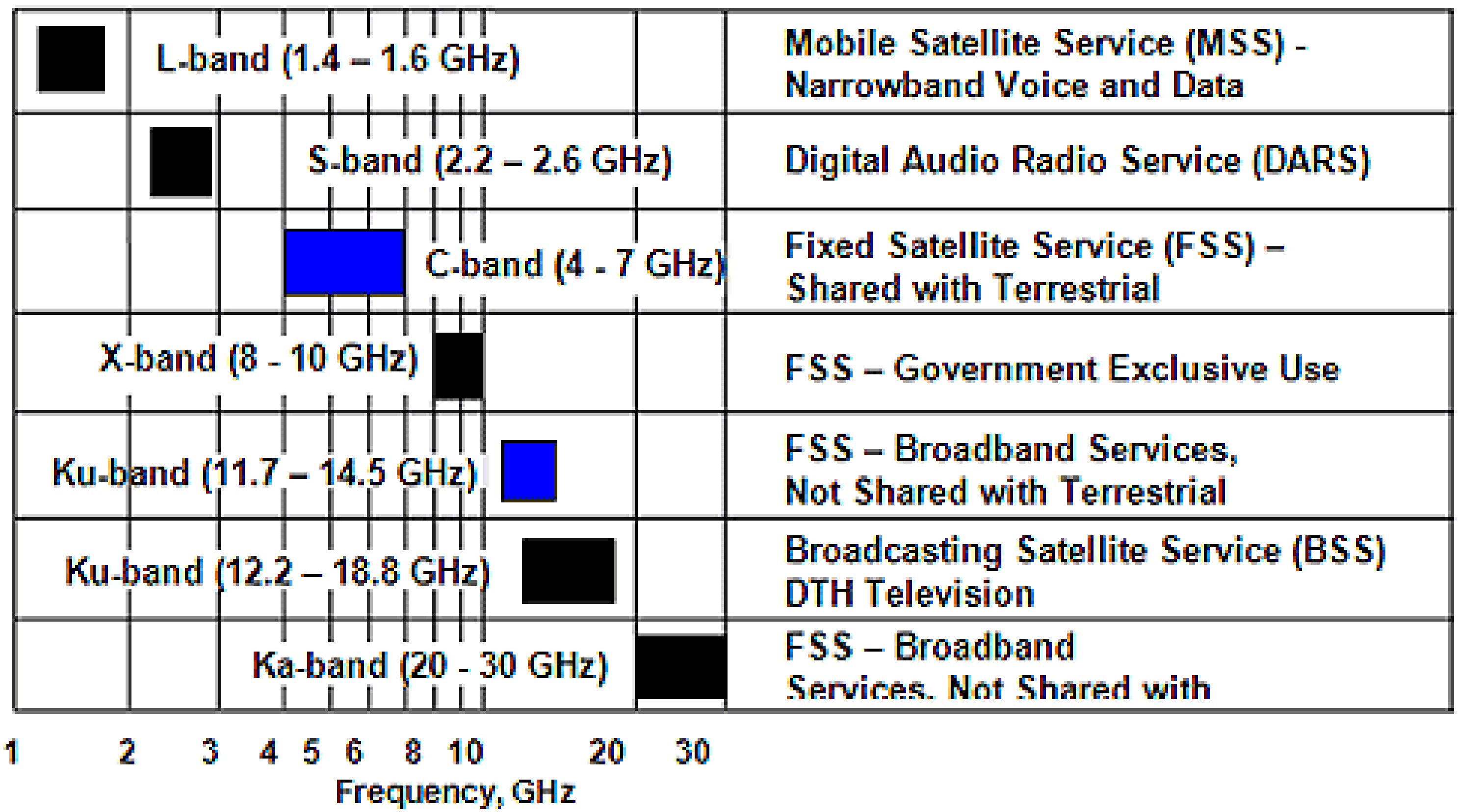
## ช่อง Satellite บ้าง

# Terrestrial / SATELLITE microwave



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ช่องนี้ๆ Bluetooth ไง
ใครๆก็ใช้

# Bluetooth

- Operate in noisy radio frequency environments
  - **2.402 GHz - 2.480** GHz
  - omni-directional
  - Point-to-multipoint
- frequency-hopping scheme
  - 79 hops (RF channels) **1 MHz apart**.
    - bandwidth is reduced in Japan, France and Spain
  - The maximum frequency hopping rate is 1600 hops/s
- link range
  - Usually 10 centimeters to 10 meters
  - Can be extended to more than 100 meters by increasing the transmit power
- Small amounts of data
  - 1Mbps over short distances (up to 10 meters).

# NFC: near-field communication

# NFC: near-field communication

## Features

- It operates within the globally available and unlicensed radio frequency band of **13.56 MHz**, with a bandwidth of **14 kHz**.
- Supported data rates: **106, 212** and **424 Kbit/s.**
- For two devices to communicate using NFC, one device must have an NFC **reader/writer** and one must have an **NFC tag.**

# NFC: near-field communication

| NFC RF STANDARDS FOR CODING, MODULATION, AND DATA RATE | | | | | |
|---|---|---|---|---|---|
| NFC-Forum standard | Polling or listening | Coding | Modulation | Data rate | Carrier frequency |
| NFC-A | Polling | Modified Miller | ASK 100% | 106 kbits/s | 13.56 MHz |
| NFC-A | Listening | Manchester | Load (ASK) | 106 kbits/s | 13.56 MHz + 848-kHz sub-carrier |
| NFC-B | Polling | NRZ-L | ASK 10% | 106 kbits/s | 13.56 MHz |
| NFC-B | Listening | NRZ-L | Load (BPSK) | 106 kbits/s | 13.56 MHz + 848-kHz sub-carrier |
| NFC-F | Polling | Manchester | ASK 10% | 212/424 kbits/s | 13.56 MHz |
| NFC-F | Listening | Manchester | Load (ASK) | 212/424 kbits/s | 13.56 MHz (no subcarrier) |

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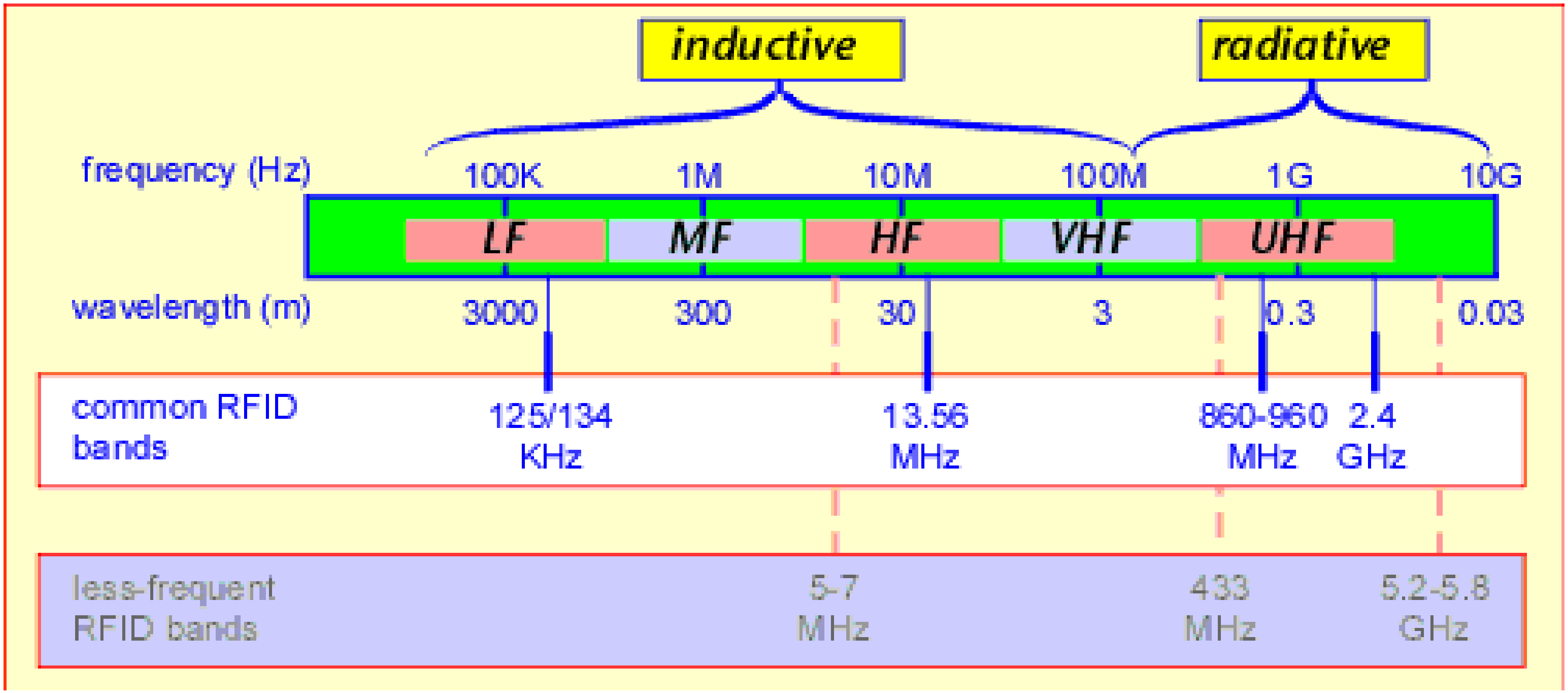
# RFID นี่ก็เคยได้ยิน

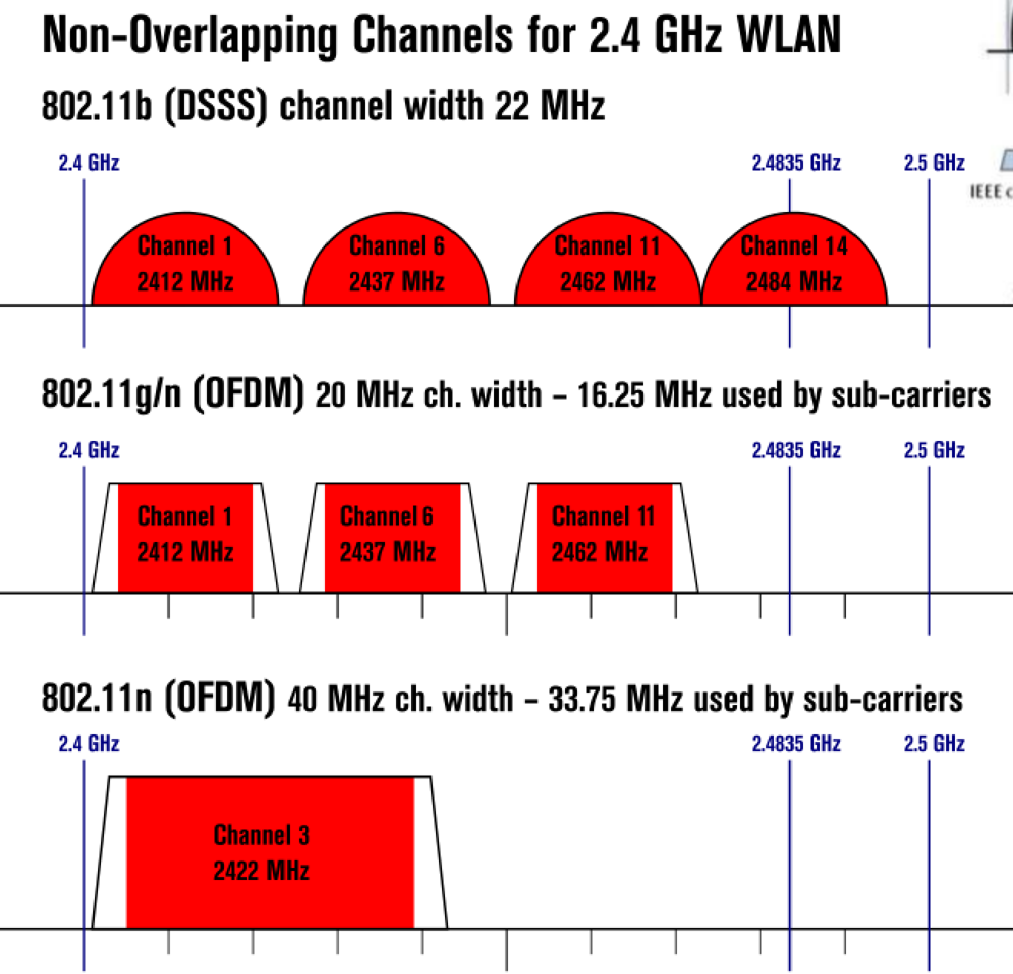
# RFID: radio frequency identification



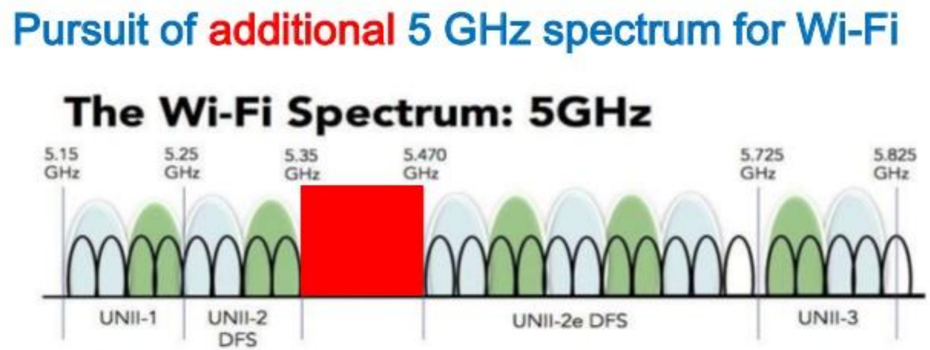
A

เอาอันนี้ด้วย ช่อง WiFi

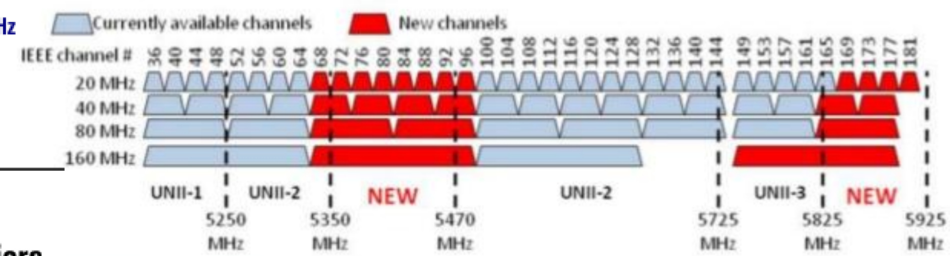
# WiFi Band



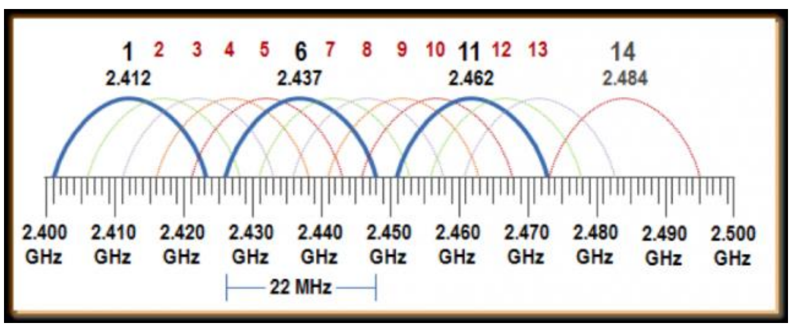
Non-Overlapping Channels for 2.4 GHz WLAN
802.11b (DSSS) channel width 22 MHz
2.4 GHz
2.4835 GHz
2.5 GHz
Channel 1
2412 MHz
Channel 6
2437 MHz
Channel 11
2462 MHz
Channel 14
2484 MHz
802.11g/n (OFDM) 20 MHz ch. width – 16.25 MHz used by sub-carriers
2.4 GHz
2.4835 GHz
2.5 GHz
Channel 1
2412 MHz
Channel 6
2437 MHz
Channel 11
2462 MHz
802.11n (OFDM) 40 MHz ch. width – 33.75 MHz used by sub-carriers
2.4 GHz
2.4835 GHz
2.5 GHz
Channel 3
2422 MHz

Pursuit of additional 5 GHz spectrum for Wi-Fi
The Wi-Fi Spectrum: 5GHz
5.15 GHz
5.25 GHz
5.35 GHz
5.470 GHz
5.725 GHz
5.825 GHz
UNII-1
UNII-2 DFS
UNII-2e DFS
UNII-3

Currently available channels
New channels
IEEE channel #
20 MHz
40 MHz
80 MHz
160 MHz
UNII-1
UNII-2
NEW
UNII-2
UNII-3
NEW
5250 MHz
5350 MHz
5470 MHz
5725 MHz
5825 MHz
5925 MHz

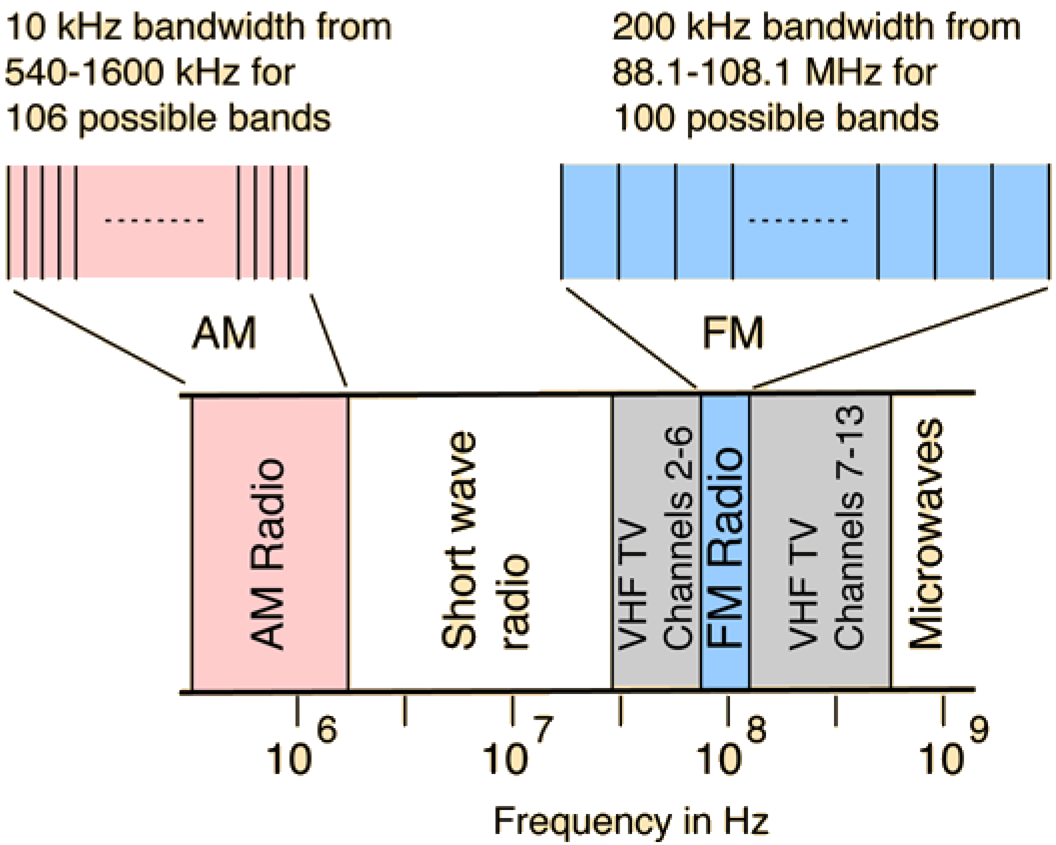



1 2 3 4 5 6 7 8 9 10 11 12 13 14
2.412
2.437
2.462
2.484
2.400 GHz
2.410 GHz
2.420 GHz
2.430 GHz
2.440 GHz
2.450 GHz
2.460 GHz
2.470 GHz
2.480 GHz
2.490 GHz
2.500 GHz
22 MHz

A

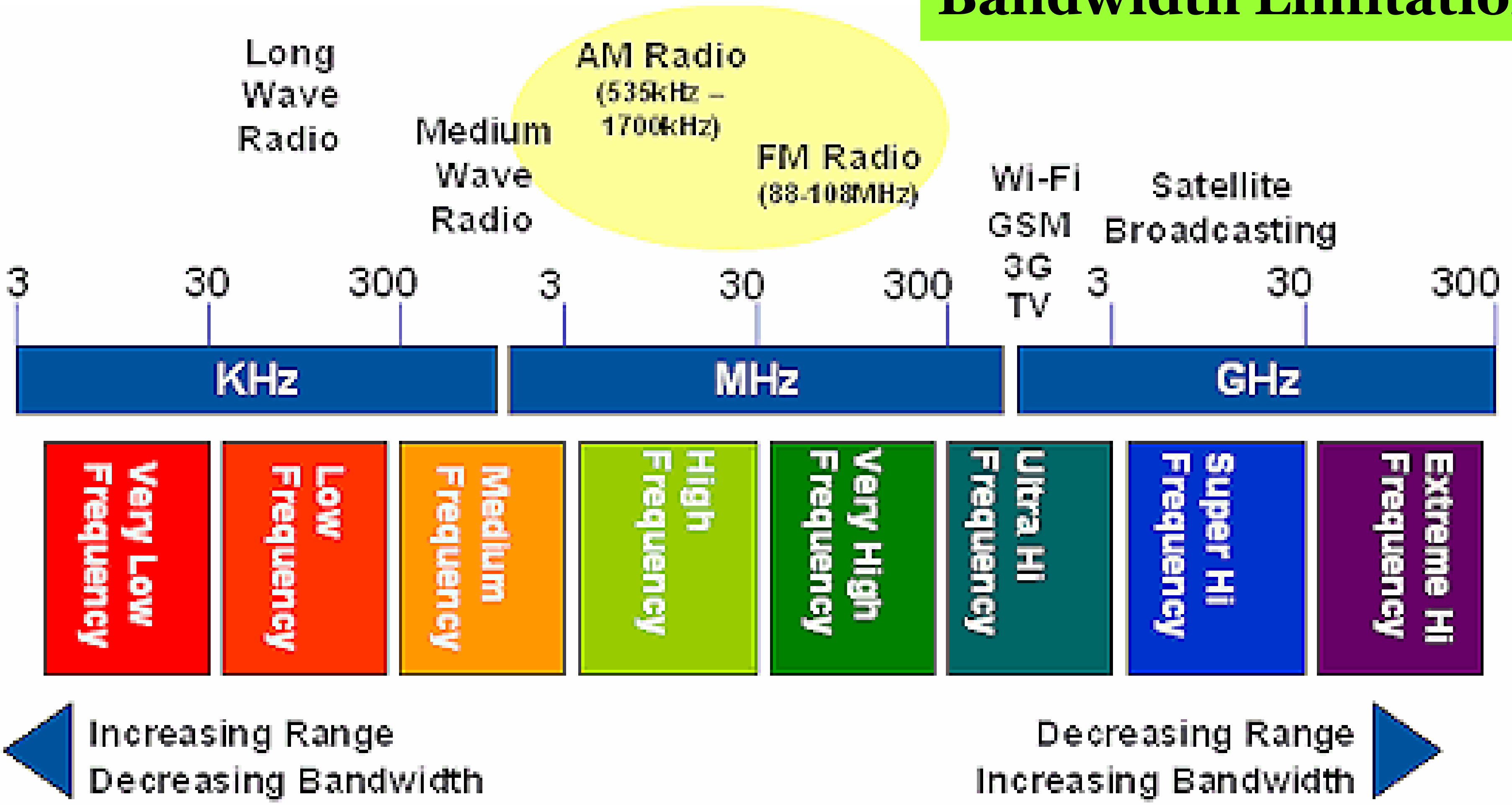
# ช่องวิทยุ (Radio Station) ล่ะ

# Radio Frequency



# Frequency Utilization

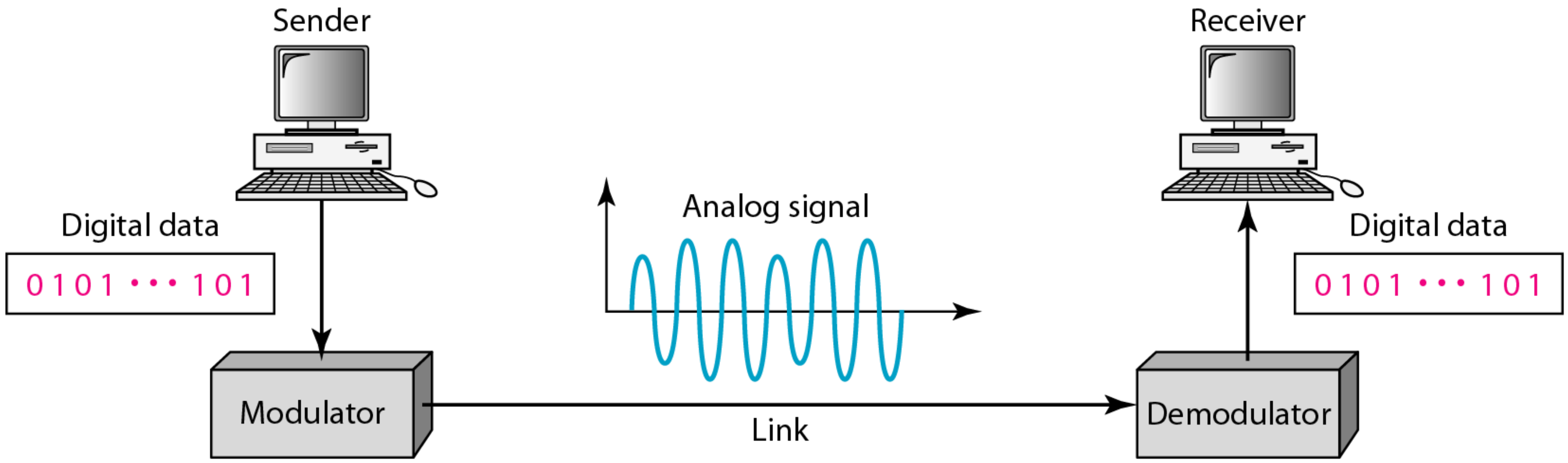
**Bandwidth Limitation**




**Transmitting Direct Digital Signal is not possible**

## Figure 5.1 *Digital-to-analog conversion*






**Analog Signal @ Selected Channel Frequency**

# Digital Modulation

- Digital to Analog Conversion

- Changing Analog Sinewave signal properties
  - to represent digital data

- What sinewave properties to be changed?
  - Amplitude
  - Frequency
  - Phase

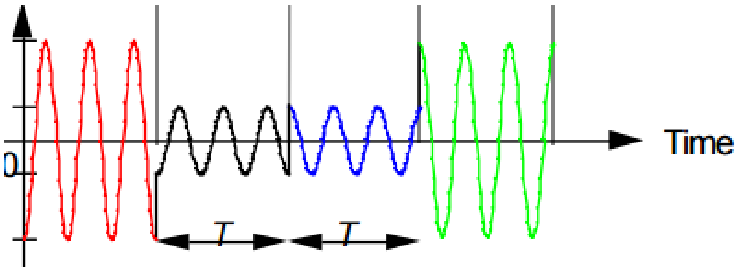
Q

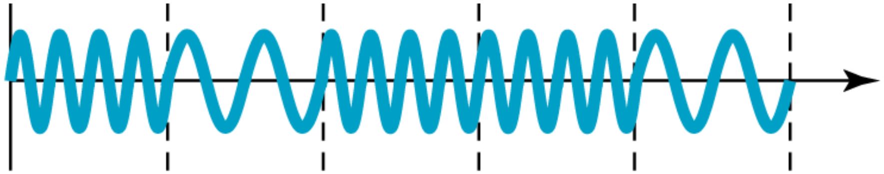
แล้วมันทำไงอ่ะ
ที่ใช้ **Analog Signal property**
มาเป็นตัวแทนข้อมูล **Digital**

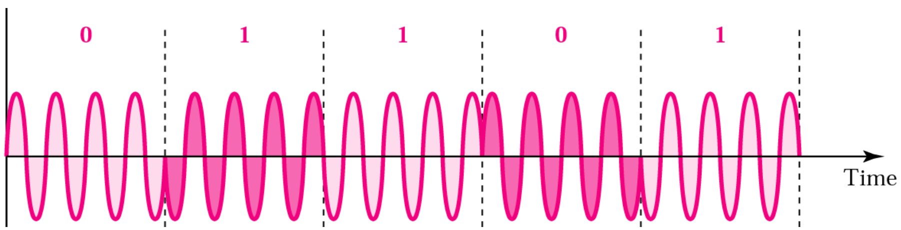
A

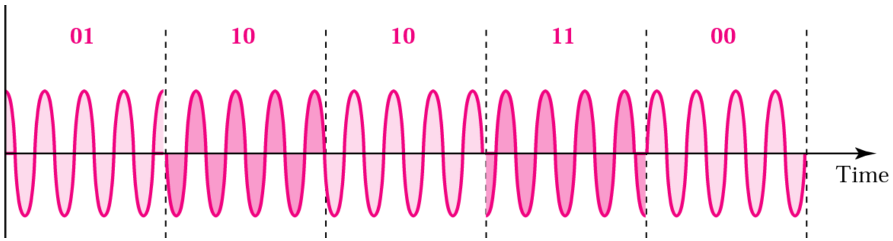
ก็ทำ **modulation** ไง

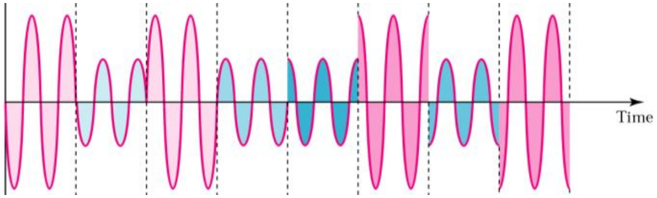
# What property has been changed?





Q

**Modulation** มันทำไงล่ะ งงอยู่ดี

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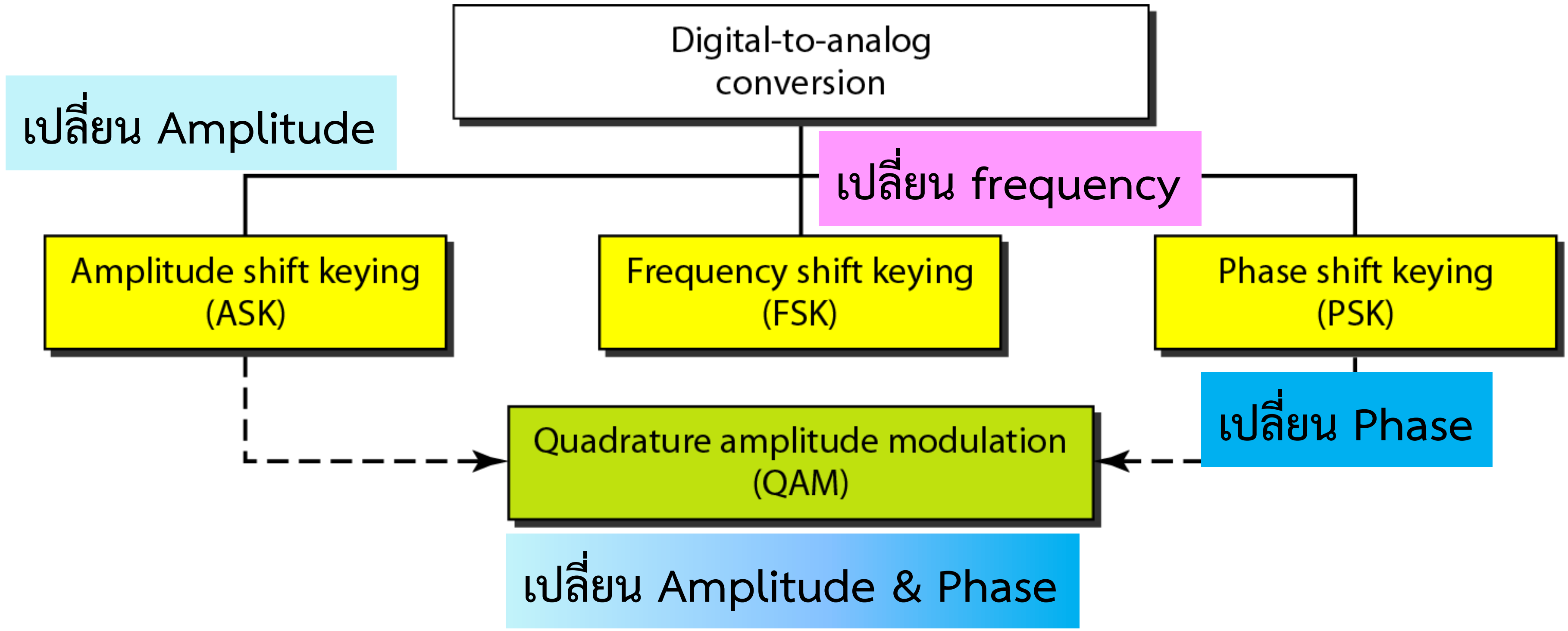
คือมันทำได้หลายแบบตาม **Analog Property**

# Figure 5.2 *Types of digital-to-analog conversion*

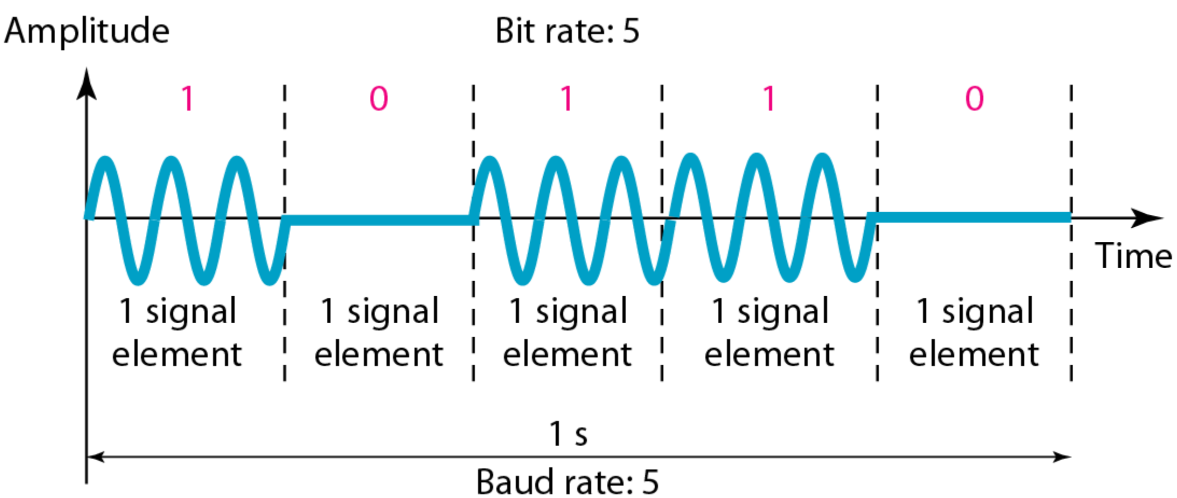


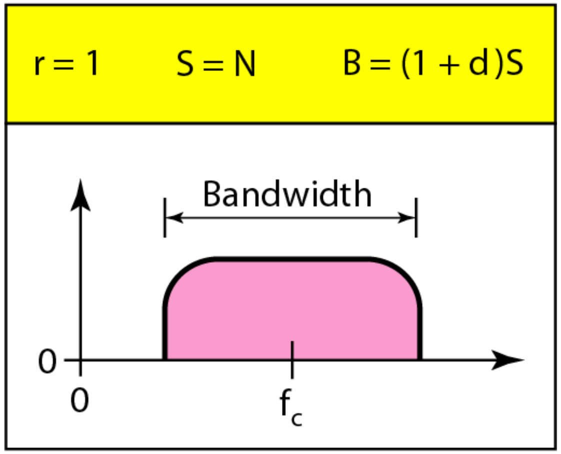


# ASK (Amplitude Shift Keying)

- Changing Amplitude of Sinewave @ channel frequency
  - 2-ASK (Binary ASK)
    - '0' -> A0
    - '1' -> A1
  - 4-ASK
    - '00' -> A0
    - '01' -> A1
    - '10' -> A2
    - '11' -> A3

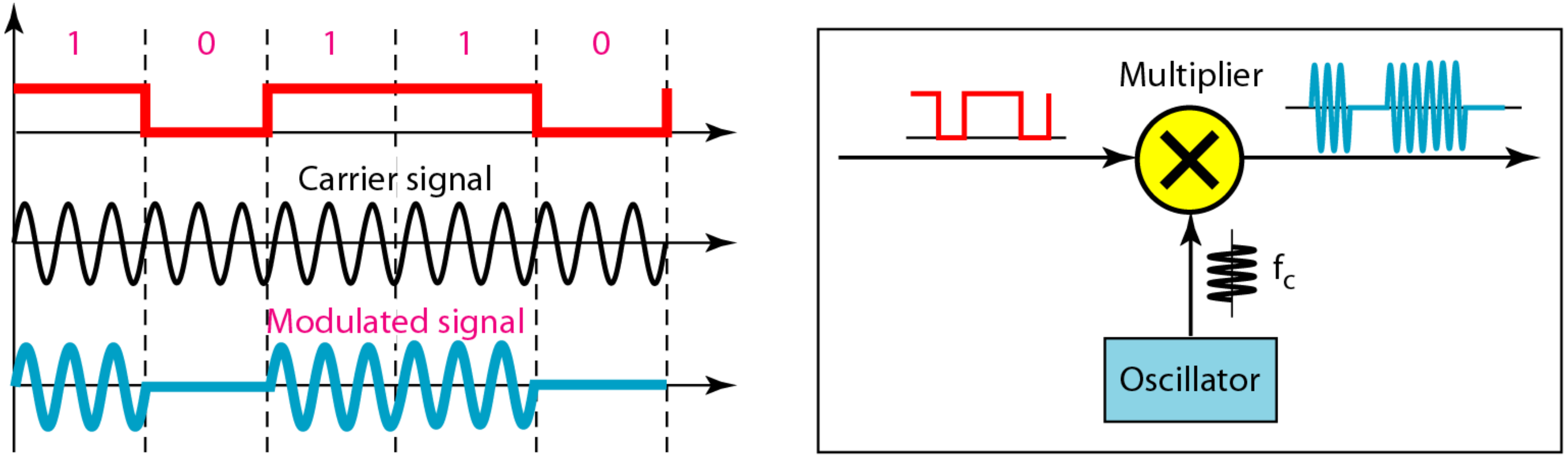
# Figure 5.3 *Binary amplitude shift keying (Binary ASK, On-Off Keying (OOK))*



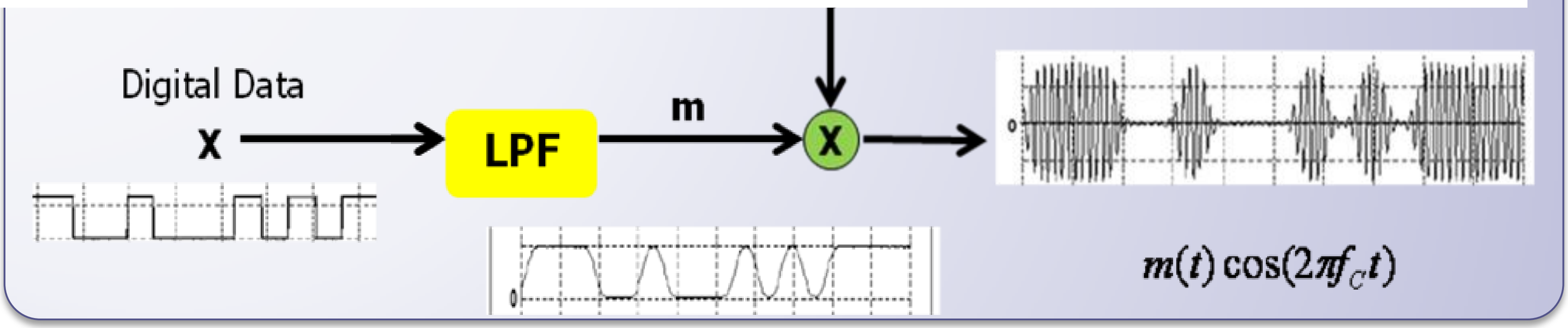

**RFID/NFC Transmission**

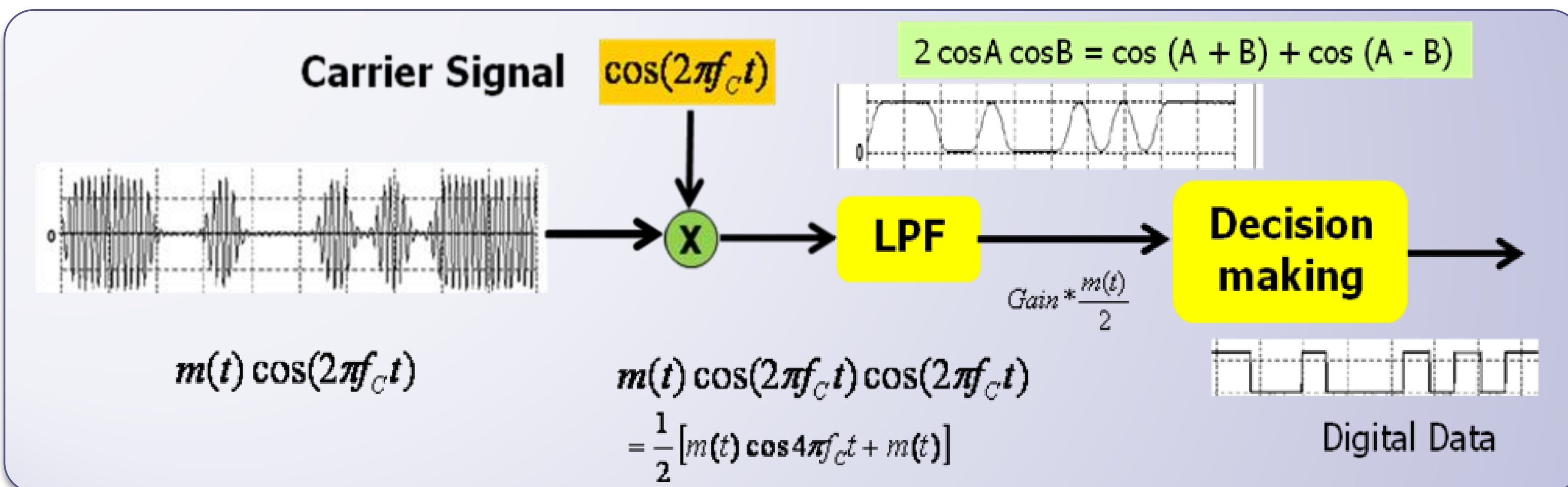
# Figure 5.4 *Implementation of binary ASK*



$$\cos\alpha\cos\beta = \tfrac{1}{2}(\cos(\alpha+\beta) + \cos(\alpha-\beta))$$

$$m(\mathrm{t})\cos(2\pi f_c t)\cos(2\pi f_c t) = \tfrac{1}{2}[m(\mathrm{t})(\cos(2\pi f_c t+2\pi f_c t)+\cos(2\pi f_c t-2\pi f_c t))]$$
$$= \tfrac{1}{2}(m(\mathrm{t})(\cos(4\pi f_c t)+\cos(0)))$$



# Signal rate / Data Rate / Bandwidth with ASK

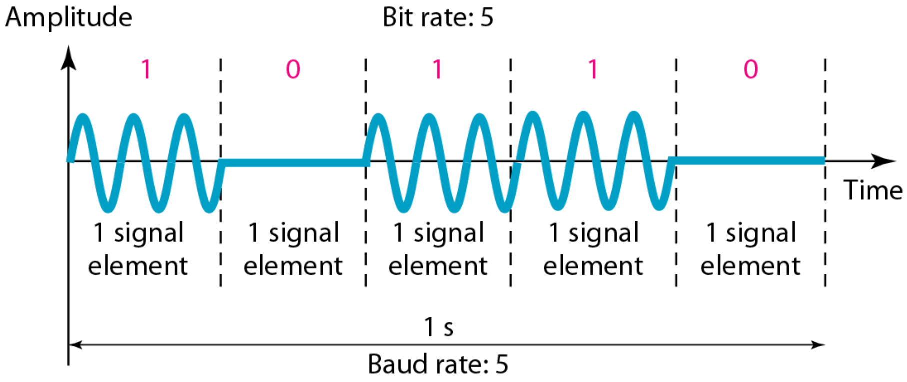
- Signal rate = # signal unit / sec (baud)

- Data Rate = #bits/sec (bps)

  N = (#bits/ signal unit) x (#signal unit/s)

  N = r x baud

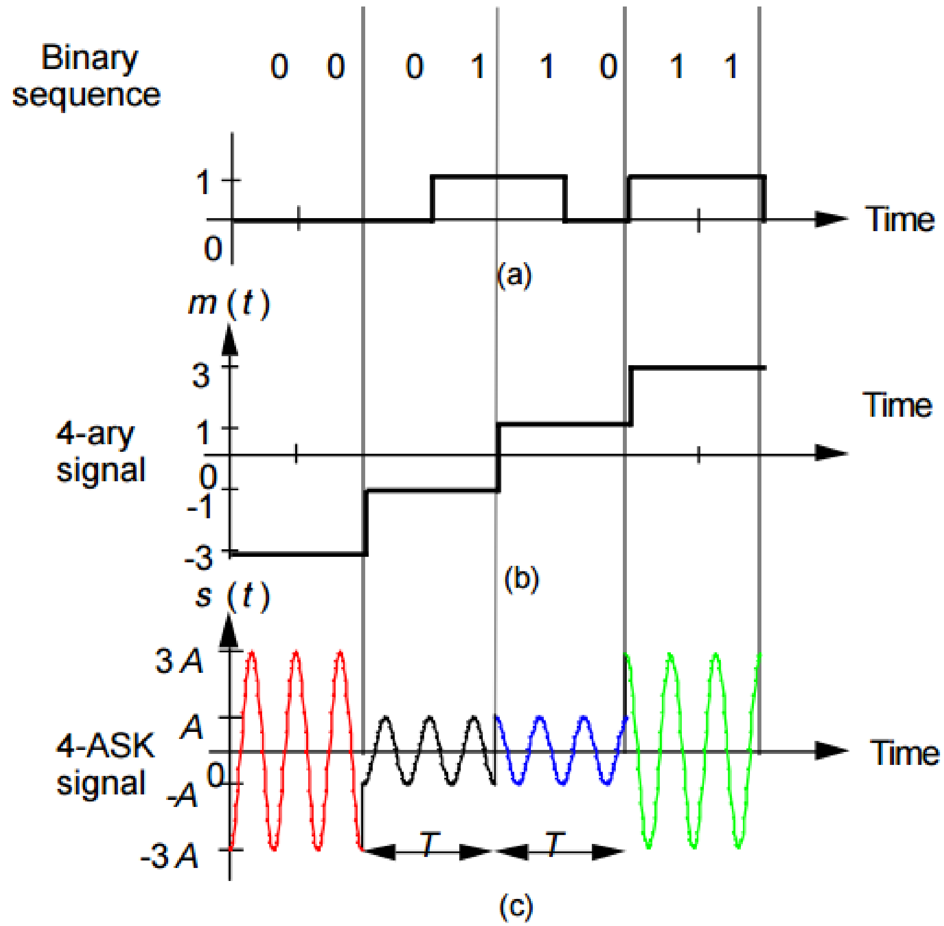
  N = r x S




- 2-ASK (OOK)
  - r = 1 (bit/signal unit)

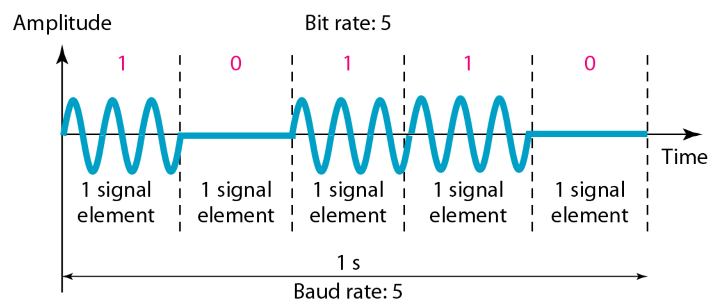
# 4-ASK

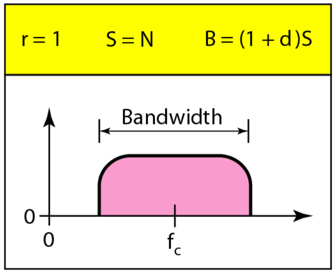
- r = 2 (bits/signal unit)



# Signal rate / Data Rate / Bandwidth with ASK

- Signal rate = # signal unit / sec (baud)
- ขึ้นกับ Channel Bandwidth
- $BW = (1+d)S$
  - $0 <= d <= 1$
  - $S <= BW <= 2S$
  - $(BW/2) <= S <= BW$



# Example 5.3

*We have an available bandwidth of 100 kHz which spans from 200 to 300 kHz. What are the carrier frequency and the bit rate if we modulated our data by using ASK with d = 1?*

## Solution

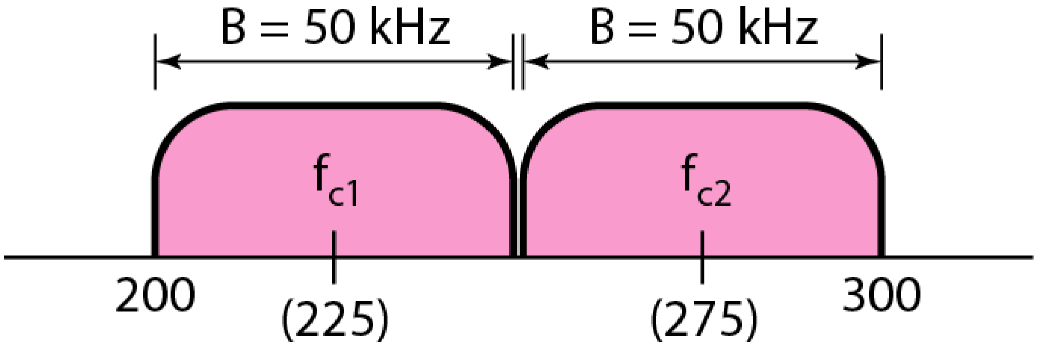
*The middle of the bandwidth is located at 250 kHz. This means that our carrier frequency can be at $f_c = 250$ kHz. We can use the formula for bandwidth to find the bit rate (with d = 1 and r = 1).*

N = r x S

$$B = (1 + d) \times S = 2 \times N \times \frac{1}{r} = 2 \times N = 100 \text{ kHz} \rightarrow N = 50 \text{ kbps}$$

# *Example 5.4*

*In data communications, we normally use* ***full-duplex links*** *with communication in both directions. We need to* ***divide the bandwidth into two with two carrier frequencies****, as shown in Figure 5.5. The figure shows the positions of two carrier frequencies and the bandwidths. The available bandwidth for each direction is now 50 kHz, which leaves us with a data rate of 25 kbps in each direction.*



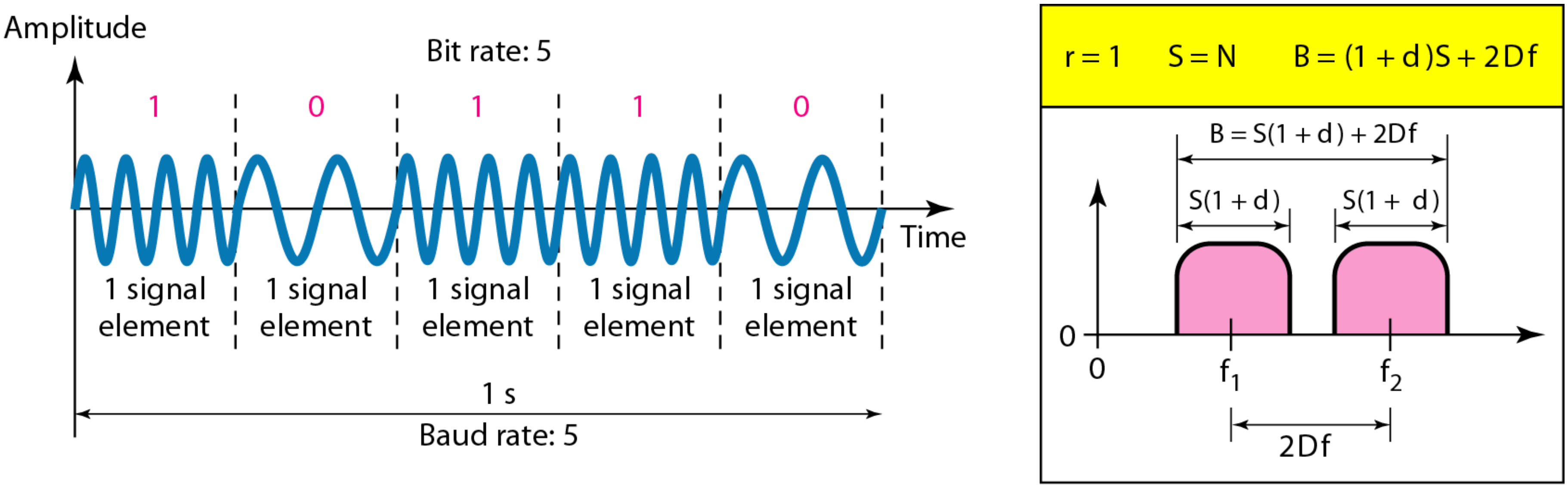
# Summarize: Amplitude Shift Keying

- Bit representation
  - Changing Amplitude of Carrier Signal
- Benefit
  - Simple (normally used for fiber optic / RFID)
  - Require Less Bandwidth
- Disadvantage
  - Easily effected by noise

# FSK (Frequency Shift Keying)

- Changing Frequency of Sinewave @ channel frequency
  - 2-FSK (Binary FSK)
    - '0' -> f0
    - '1' -> f1
  - 4-FSK
    - '00' -> f0
    - '01' -> f1
    - '10' -> f2
    - '11' -> f3

# Figure 5.6 *Binary frequency shift keying*




S <= Sub-carrier spacing (2Df) <= 2S

# Example 5.5

*We have an available bandwidth of 100 kHz which spans from 200 to 300 kHz. What should be the carrier frequency and the bit rate if we modulated our data by using FSK with d = 1?*

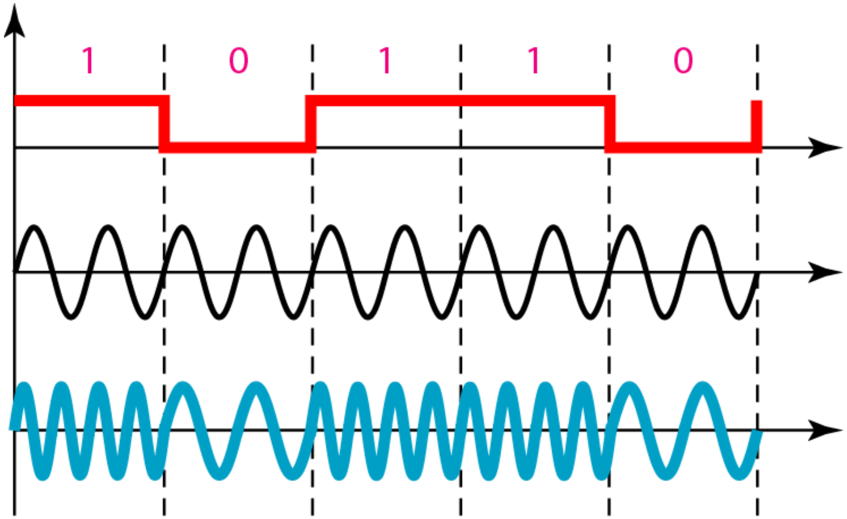
## Solution

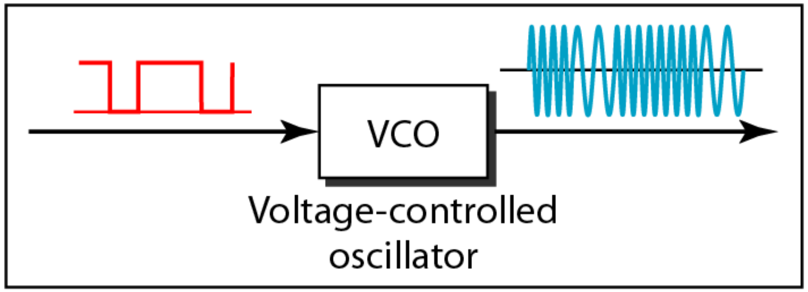
*This problem is similar to Example 5.3, but we are modulating by using FSK. The midpoint of the band is at 250 kHz. We choose 2Δf to be 50 kHz; this means*

$$B = (1 + d) \times S + 2\Delta f = 100 \quad \rightarrow \quad 2S = 50 \text{ kHz} \quad S = 25 \text{ kbaud} \quad N = 25 \text{ kbps}$$

S <= Sub-channel spacing (2Df) <= 2S
0<= d <= 1

# Figure 5.7 *Bandwidth of MFSK used in Example 5.6*



# Example 5.6

*We need to send data 3 bits at a time at a bit rate of 3 Mbps. The carrier frequency is 10 MHz. Calculate the number of levels (different frequencies), the baud rate, and the bandwidth.*

## Solution

*We can have L = 2^3 = 8. The baud rate is*

$$S = N/r = 3\ \text{Mbps}/3\ (\text{bps / bit-per-signal unit})$$

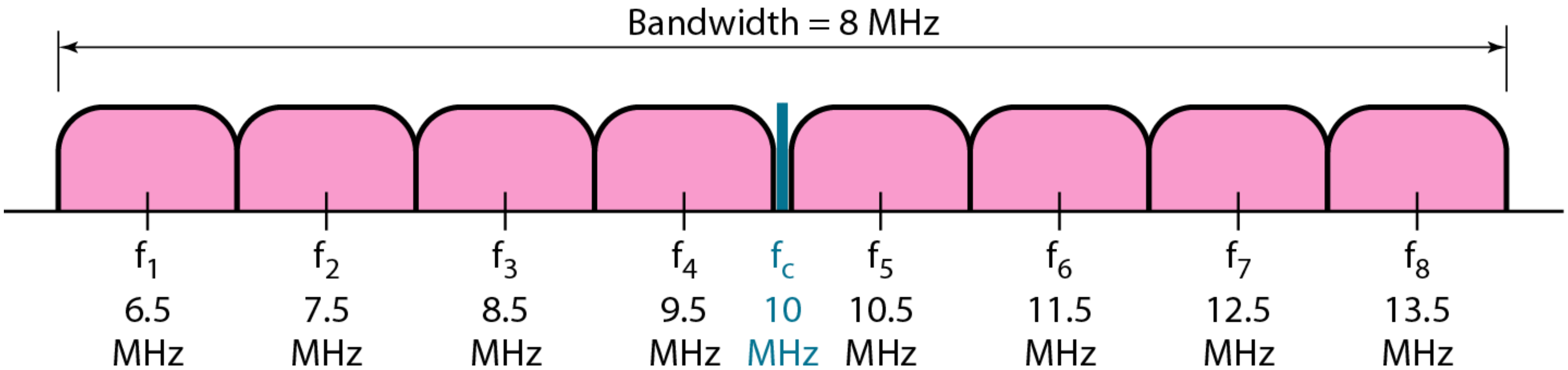
$$= 1\ \text{Mbaud}.$$

$$S <= \text{sub-channel spacing} <= 2S$$

*Choose d=0 -> (2Δf = S = 1 MHz)*

*This means that the carrier frequencies must be 1 MHz apart.*

# Figure 5.8 *Bandwidth of MFSK used in Example 5.6*

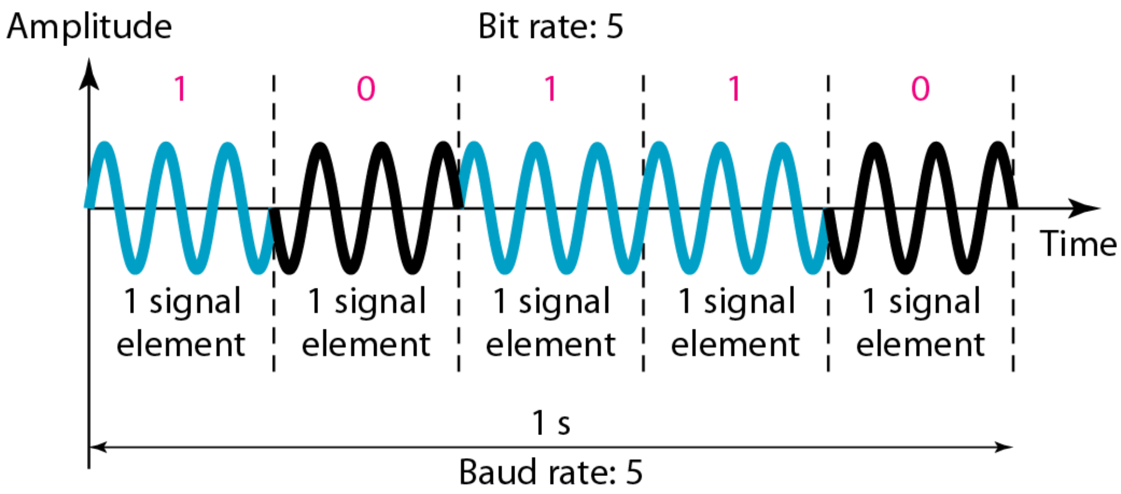


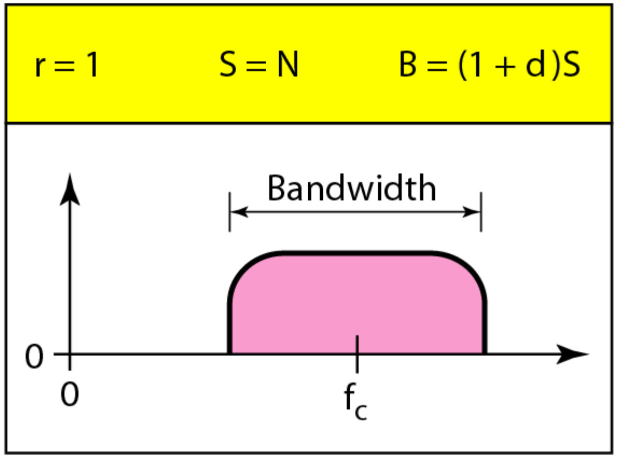

*The bandwidth is B = 8 × 1000 = 8000.*
*Figure 5.8 shows the allocation of frequencies and bandwidth.*

# PSK (Phase Shift Keying)

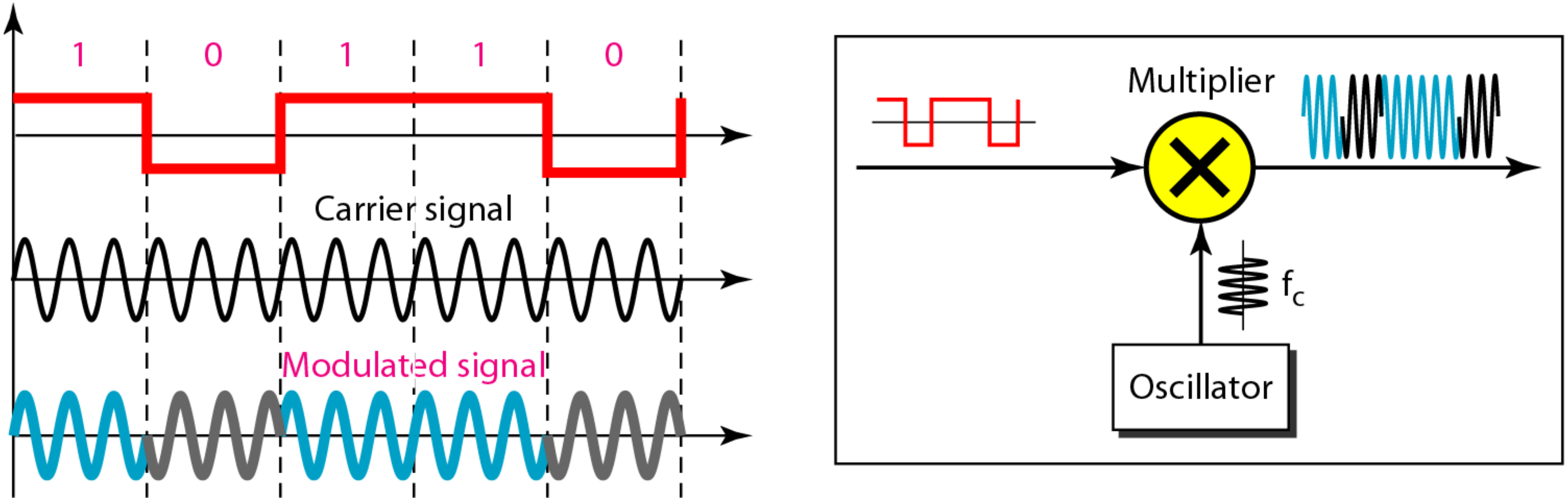
- Changing Frequency of Sinewave @ channel frequency
  - 2-PSK (Binary PSK)
    - ‘0’ -> zeta_0
    - ‘1’ -> zeta_1
  - 4-PSK
    - ‘00’ -> zeta_0
    - ‘01’ -> zeta_1
    - ‘10’ -> zeta_2
    - ‘11’ -> zeta_3

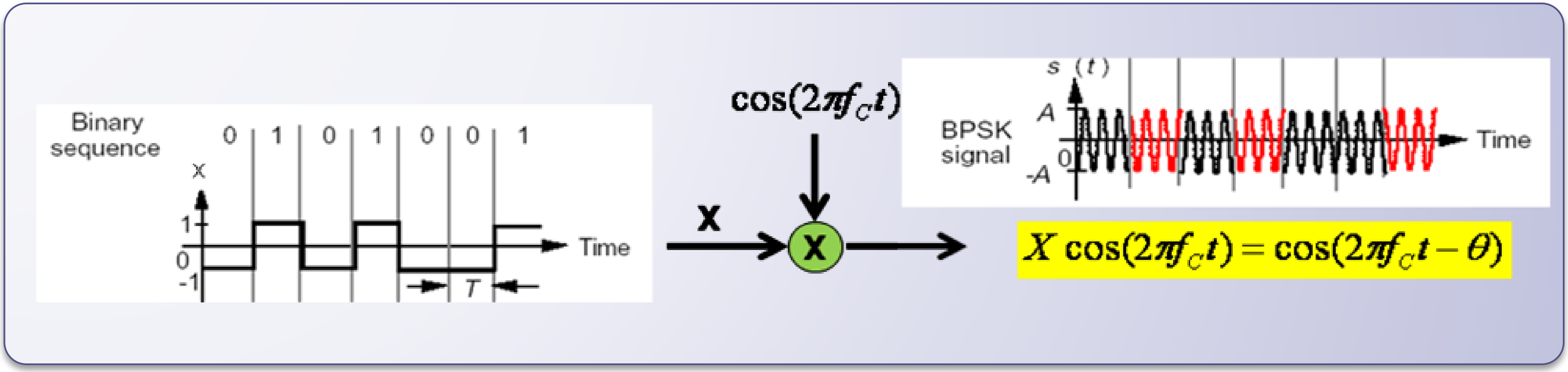
# Figure 5.9 *Binary phase shift keying*



# Figure 5.10 *Implementation of BPSK*

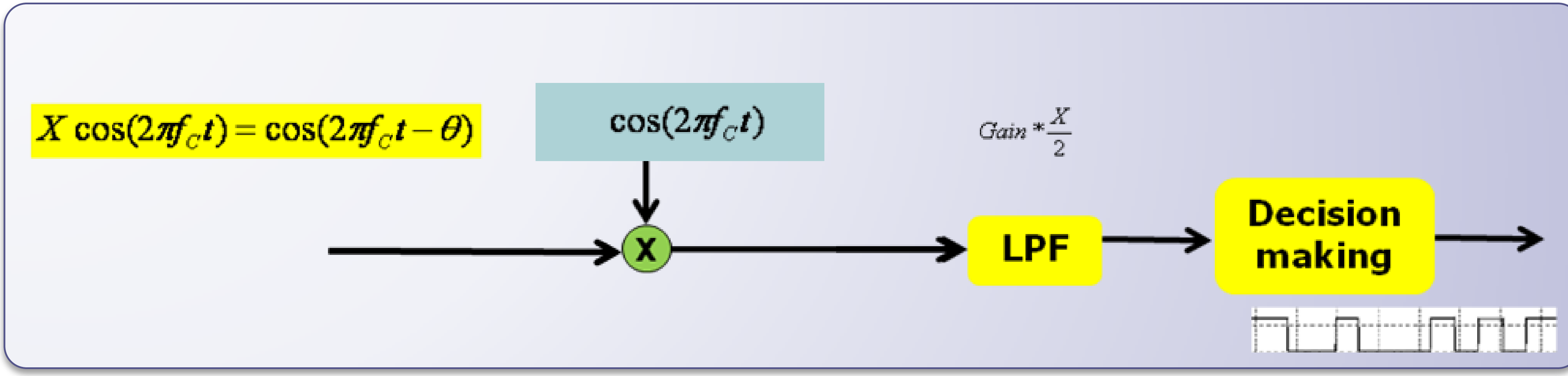





$$s(t) = \begin{cases} A\cos(2\pi f_c t - \pi); & binary \quad '0' \\ A\cos(2\pi f_c t); & binary \quad '1' \end{cases}$$

$$X\cos(2\pi f_C t) = \cos(2\pi f_C t - \theta)$$

| **Binary Data** **[0, 1]** | **X（Digital Signal）** **[-1, 1]** | $X\cos(2\pi f_C t)$ | $\cos(2\pi f_C t - \theta)$ |
|---|---|---|---|
| 0 | -1 | | |
| 1 | 1 | | |

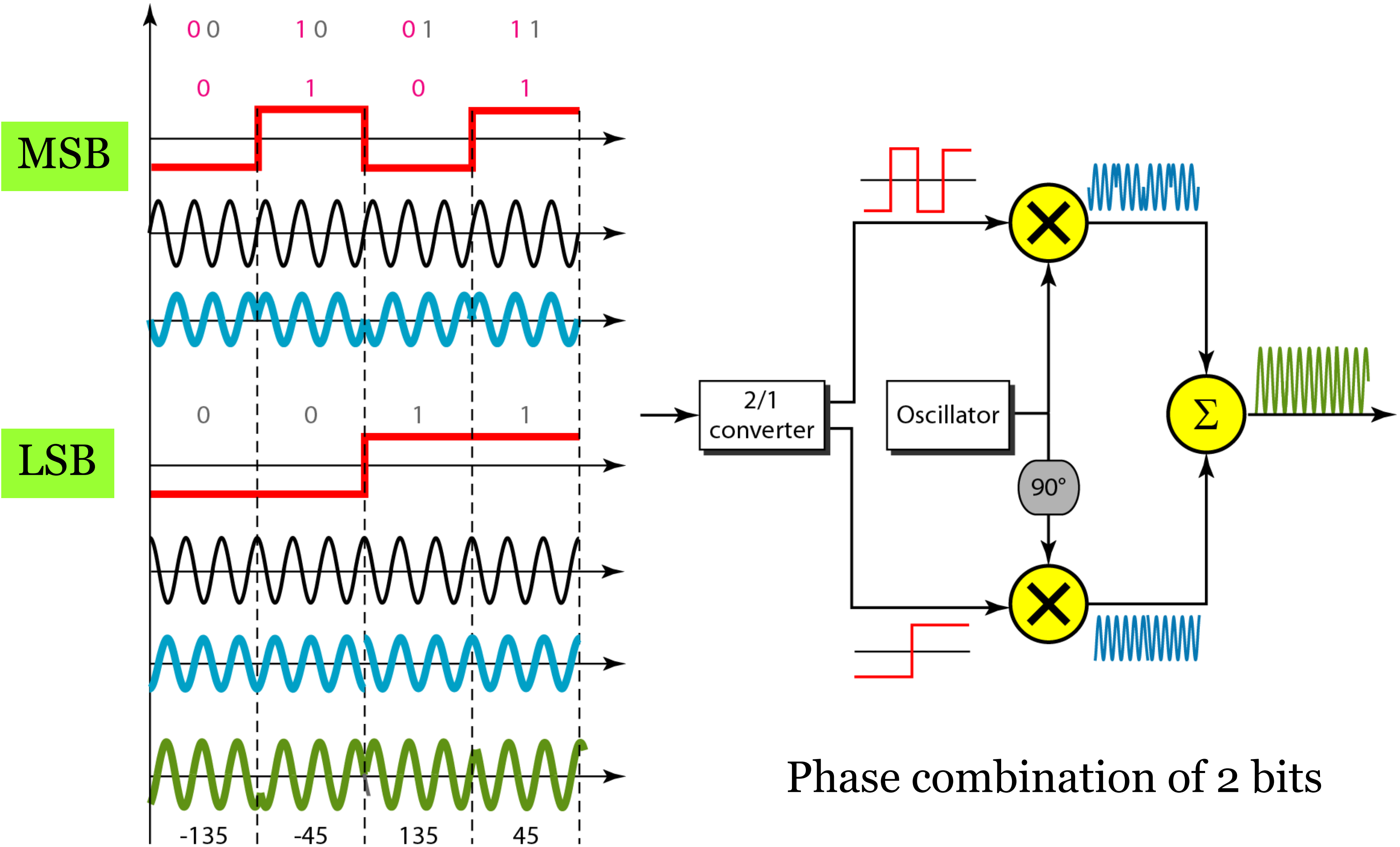



$$X\cos(2\pi f_C t)\cos(2\pi f_C t) = X\left(\frac{1}{2}\left[\cos(2\pi f_C t + 2\pi f_C t) + \cos(2\pi f_C t - 2\pi f_C t)\right]\right)$$

$$= \frac{1}{2}\left[X\cos\left(4\pi f_C t\right) + X\right]$$

# Figure 5.11 *QPSK and its implementation*






Phase combination of 2 bits

# *Example 5.7*

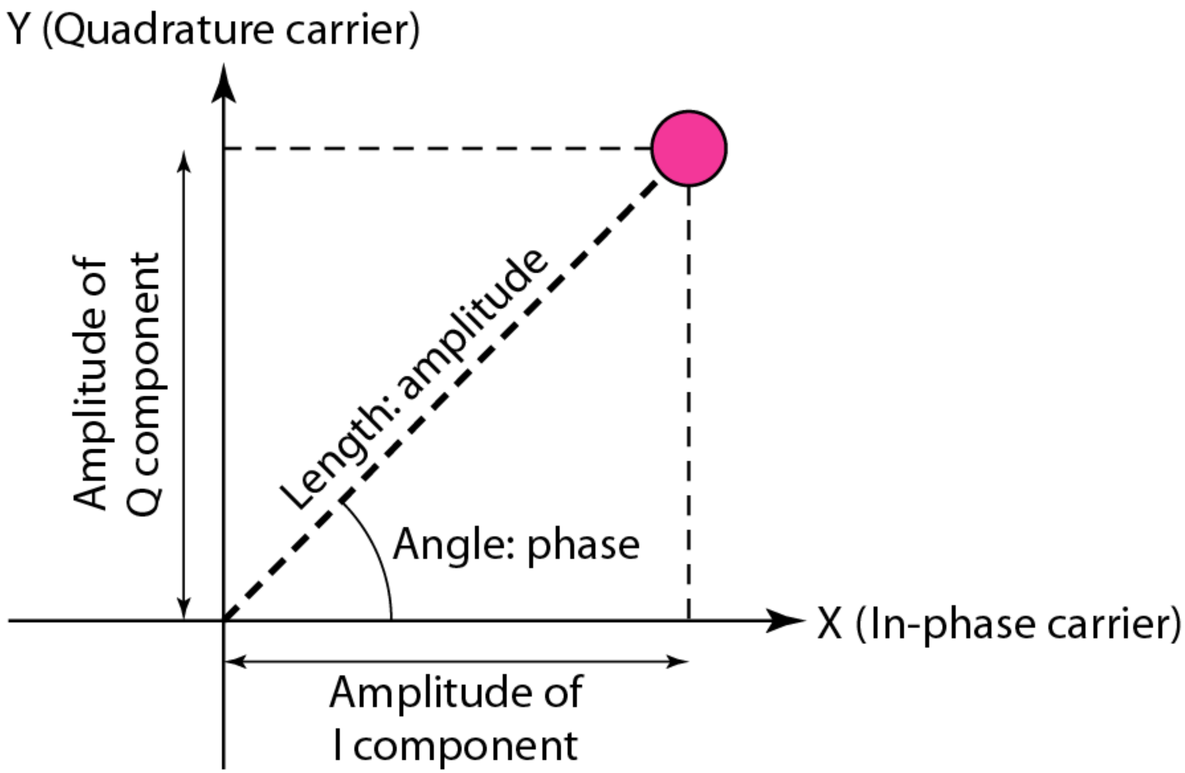


*Find the bandwidth for a signal transmitting at 12 Mbps for QPSK. The value of d = 0.*

## *Solution*

*For QPSK, 2 bits is carried by one signal element. This means that r = 2. So the signal rate (baud rate) is S = N × (1/r) = 6 Mbaud. With a value of d = 0, we have B = S = 6 MHz.*

# Figure 5.12 *Concept of a* ***constellation diagram***



# Example 5.8

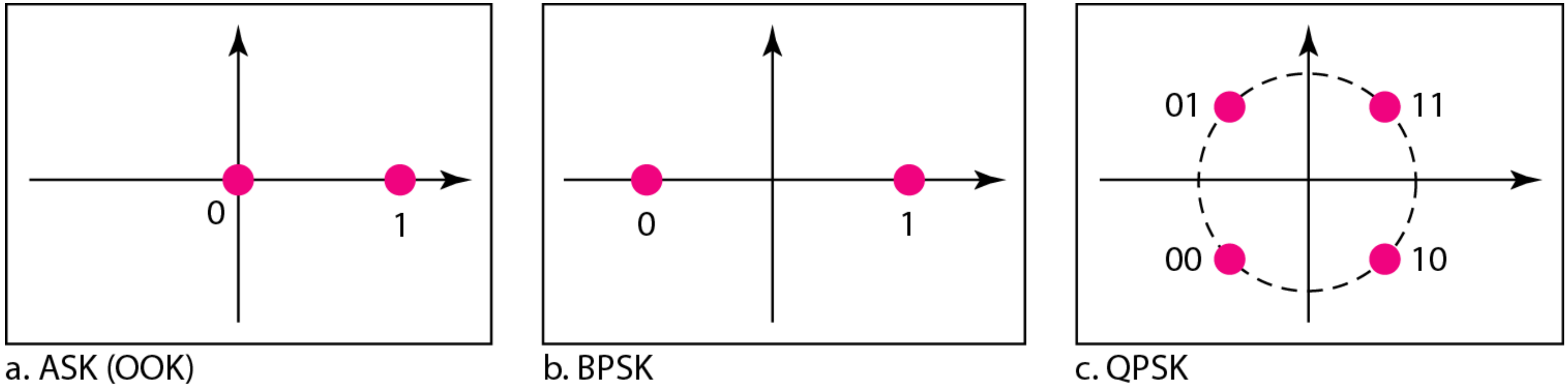


*Show the constellation diagrams for an ASK (OOK), BPSK, and QPSK signals.*

## Solution

*Figure 5.13 shows the three constellation diagrams.*

# Figure 5.13 *Three constellation diagrams*



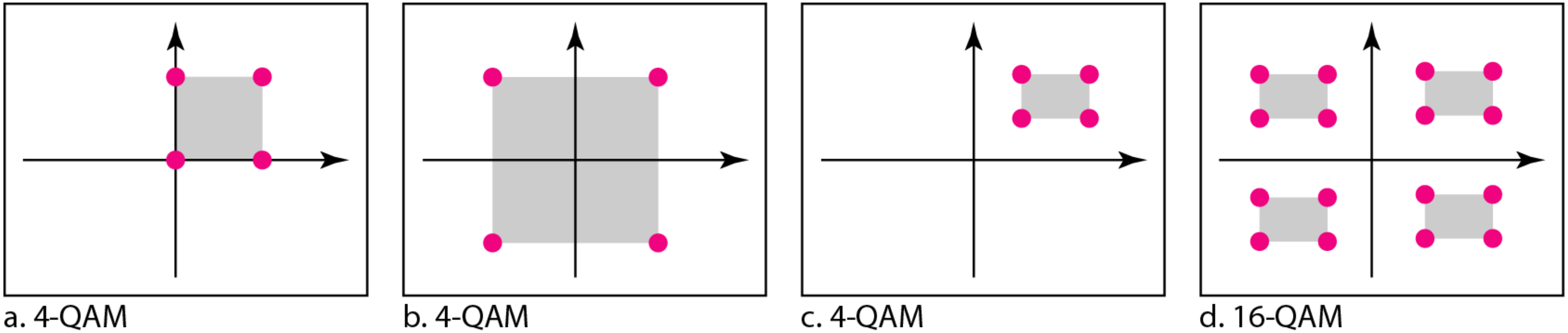
# Quadrature Amplitude Modulation

- Bit representation
  - Combination of ASK and PSK
  - Changing Amplitude & Phase of Career Signal
  - One bit, One signal unit
- Benefit
  - Less effected by noise compared to ASK
  - Require less bandwidth
- Disadvantage
  - Complex demodulation technique

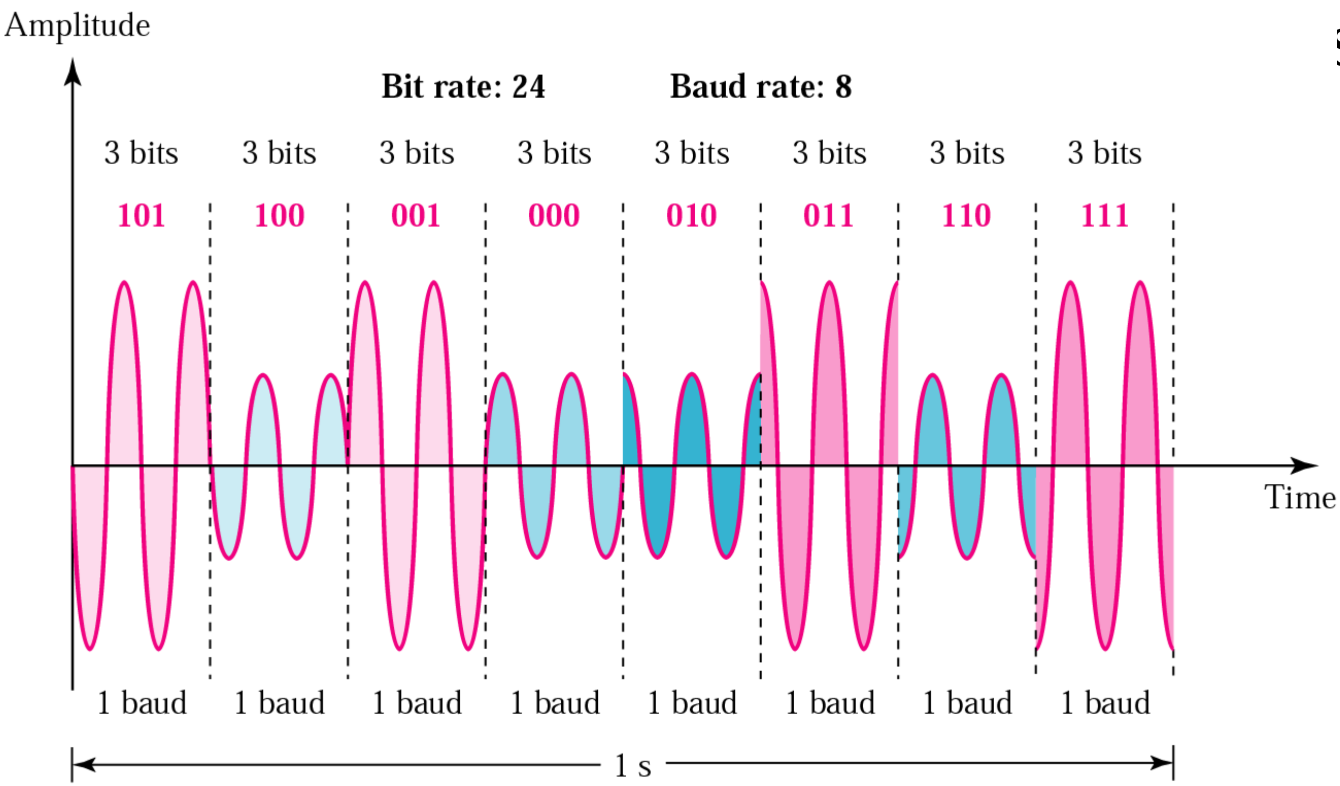
*Note*

Quadrature amplitude modulation is a combination of ASK and PSK.

# Figure 5.14 *Constellation diagrams for some QAMs*

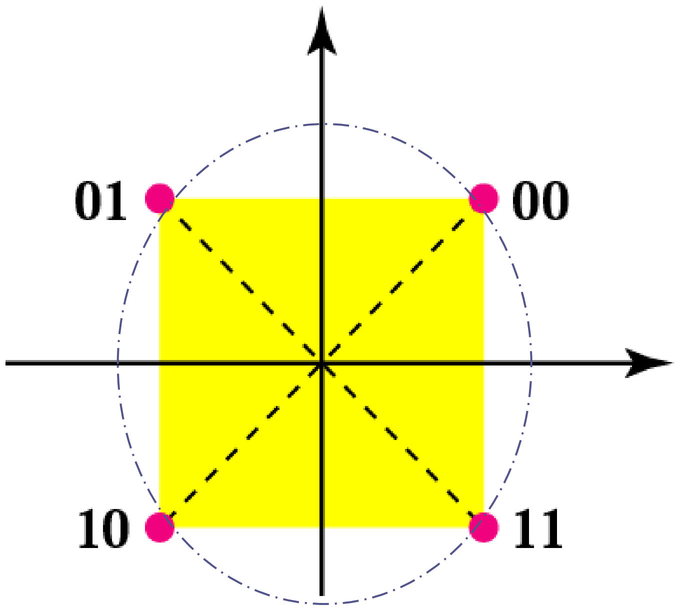


# Quadrature Amplitude Modulation

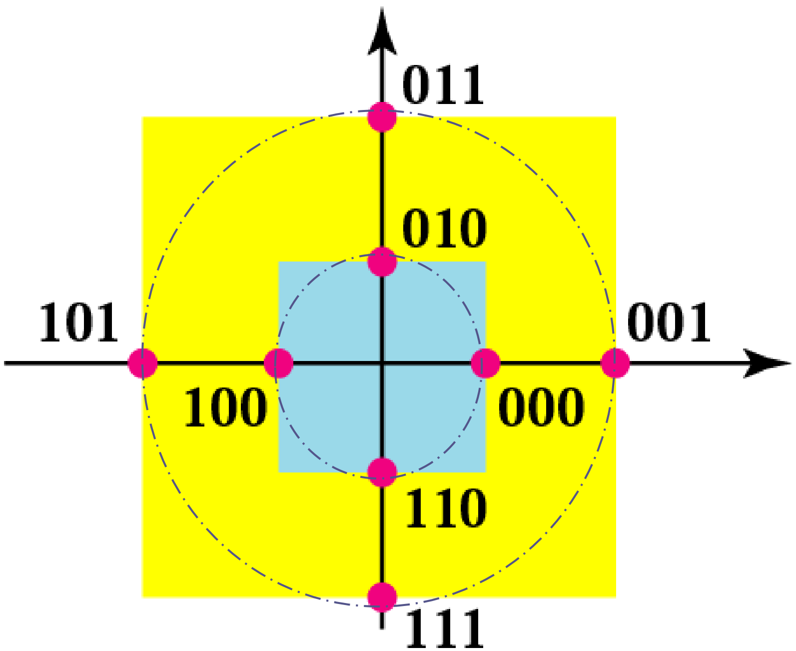



s a

# Quadrature Amplitude Modulation



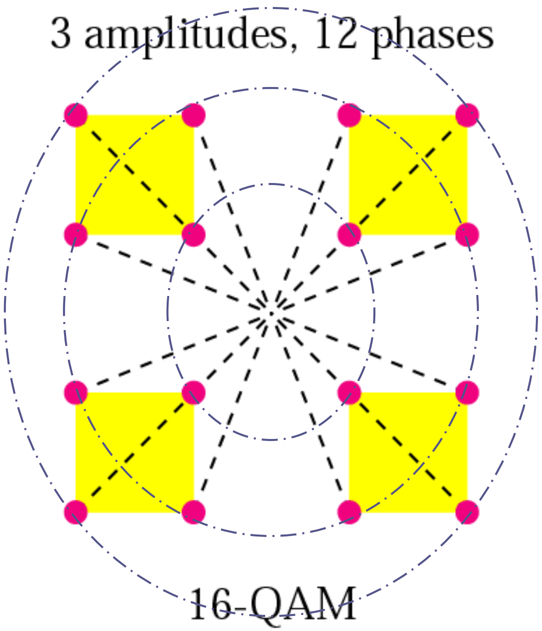

4-QAM
1 amplitude, 4 phases




8-QAM
2 amplitudes, 4 phases

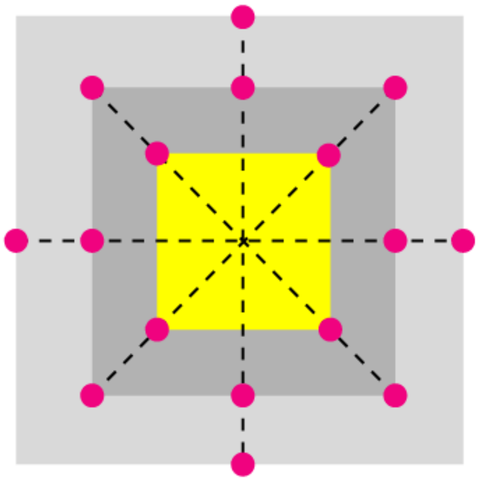
# Quadrature Amplitude Modulation

3 amplitudes, 12 phases



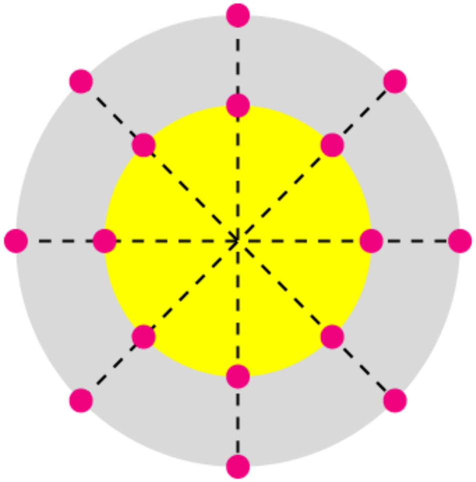
16-QAM

4 amplitudes, 8 phases



16-QAM

2 amplitudes, 8 phases

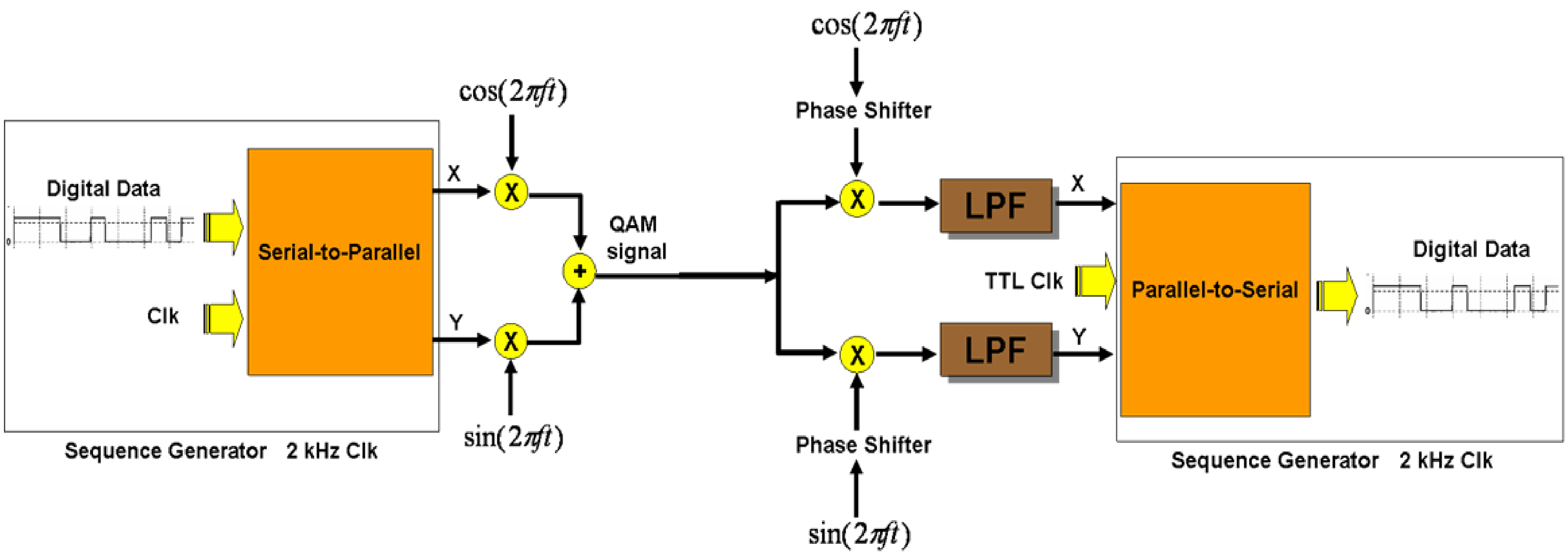


16-QAM

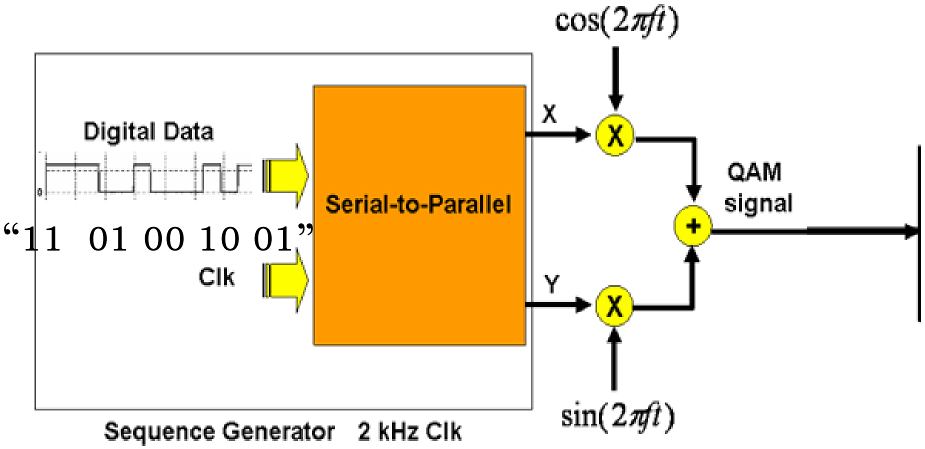
ITU-T recommendation

OSI recommendation

# Quadrature Amplitude Modulation



# Quadrature Amplitude Modulation

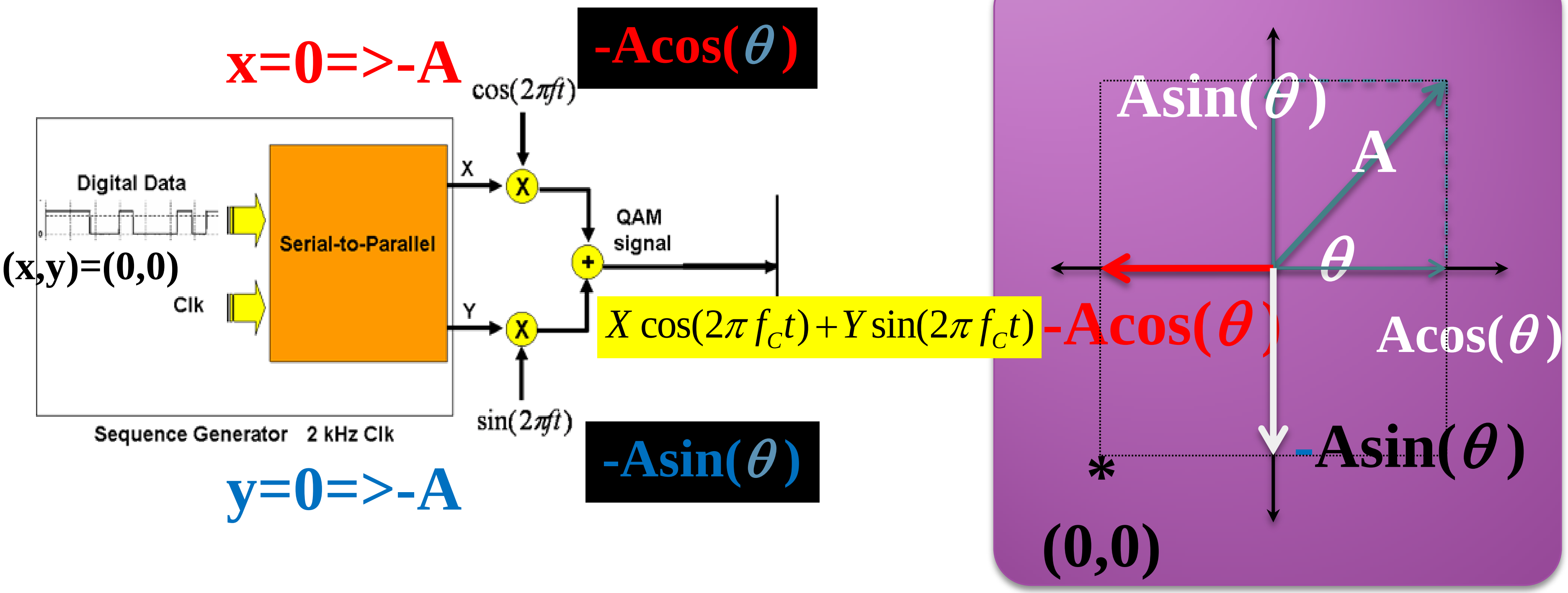



$$X\cos(2\pi f_C t) + Y\sin(2\pi f_C t)$$
$$\Rightarrow \cos B\cos A + sinB\sin A$$
$$= \cos(A - B)$$

| X Binary Data [0, 1] | X (Digital Signal) [-1, 1] | Y Binary Data [0, 1] | Y (Digital Signal) [-1, 1] | Xcosω + Ysinω<br>cosθcosω+sinθsinω | =cos(ω−θ) | θ |
|---|---|---|---|---|---|---|
| 0 | -1 | 0 | -1 | -1 cosω + -1 sinω | cos(ω+135) | -135 |
| 0 | -1 | 1 | 1 | -1 cosω + 1 sinω | cos(ω-135) | +135 |
| 1 | 1 | 0 | -1 | 1 cosω + -1 sinω | cos(ω+45) | -45 |
| 1 | 1 | 1 | 1 | 1 cosω + 1 sinω | cos(ω-45) | +45 |

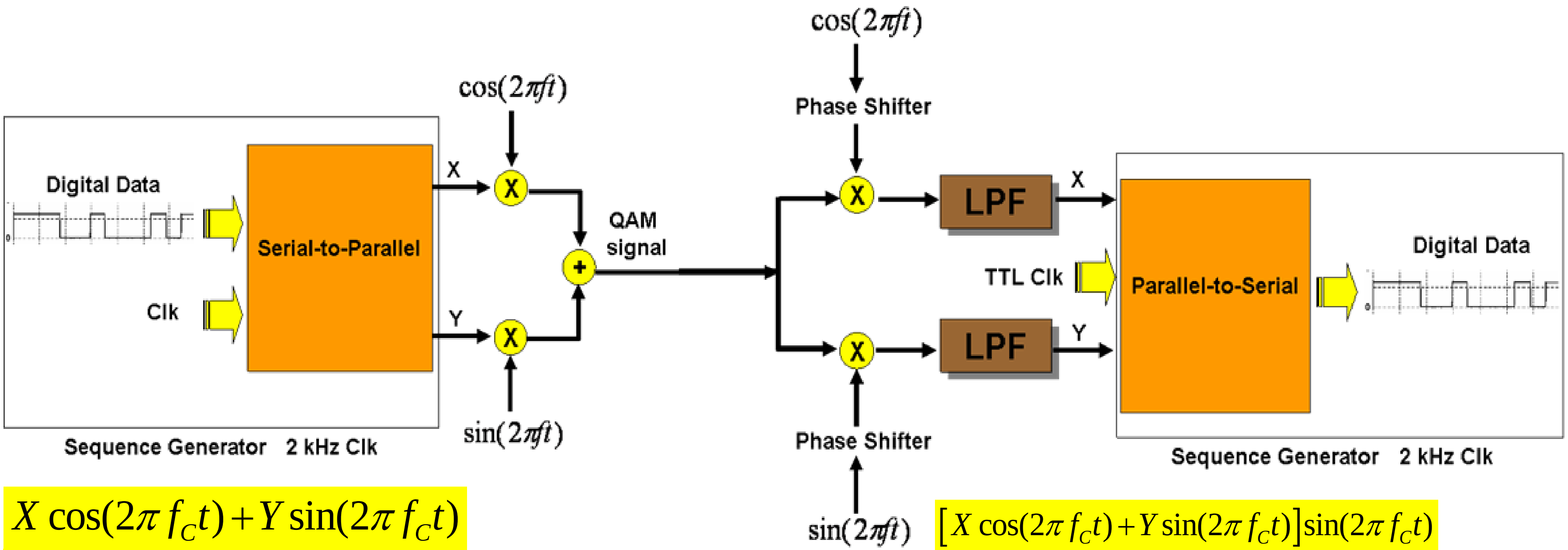
+ β))

# Quadrature Amplitude Modulation



# QAM

$$\left[X\cos(2\pi f_C t)+Y\sin(2\pi f_C t)\right]\cos(2\pi f_C t)$$
$$=X\cos(2\pi f_C t)\cos(2\pi f_C t)+Y\sin(2\pi f_C t)\cos(2\pi f_C t)$$
$$=X\left(\frac{1}{2}\left[\cos(0)+\cos(4\pi f_C t)\right]\right)+Y\left(\frac{1}{2}\sin(4\pi f_C t)\right)$$
$$=\frac{1}{2}\left[X+X\cos(4\pi f_C t)+\sin(4\pi f_C t)\right]$$




$$X\cos(2\pi f_C t)+Y\sin(2\pi f_C t)$$
$$\Rightarrow \cos B\cos A+sinB\sin A$$
$$=\cos(A-B)$$

$$\left[X\cos(2\pi f_C t)+Y\sin(2\pi f_C t)\right]\sin(2\pi f_C t)$$
$$=X\cos(2\pi f_C t)\sin(2\pi f_C t)+Y\sin(2\pi f_C t)\sin(2\pi f_C t)$$
$$=X\left(\frac{1}{2}\sin(4\pi f_C t)\right)+Y\left(\frac{1}{2}\left[\cos(0)-\cos(4\pi f_C t)\right]\right)+$$
$$=\frac{1}{2}\left[X\sin(4\pi f_C t)+Y-Y\cos(4\pi f_C t)\right]$$

Q

ถ้า **Amplitude** ของ **subCarrier** ไม่เท่ากันล่ะ จะเกิดอะไรขึ้น

A

ลองทำดูสิ

# SubCarrier Amplitude difference

- วาด Constellation Diagram
- 4-QAM: 4 subcarriers (2 amplitudes / 4 phases

  - A1=1, A2=2
  - A1=2, A2=1

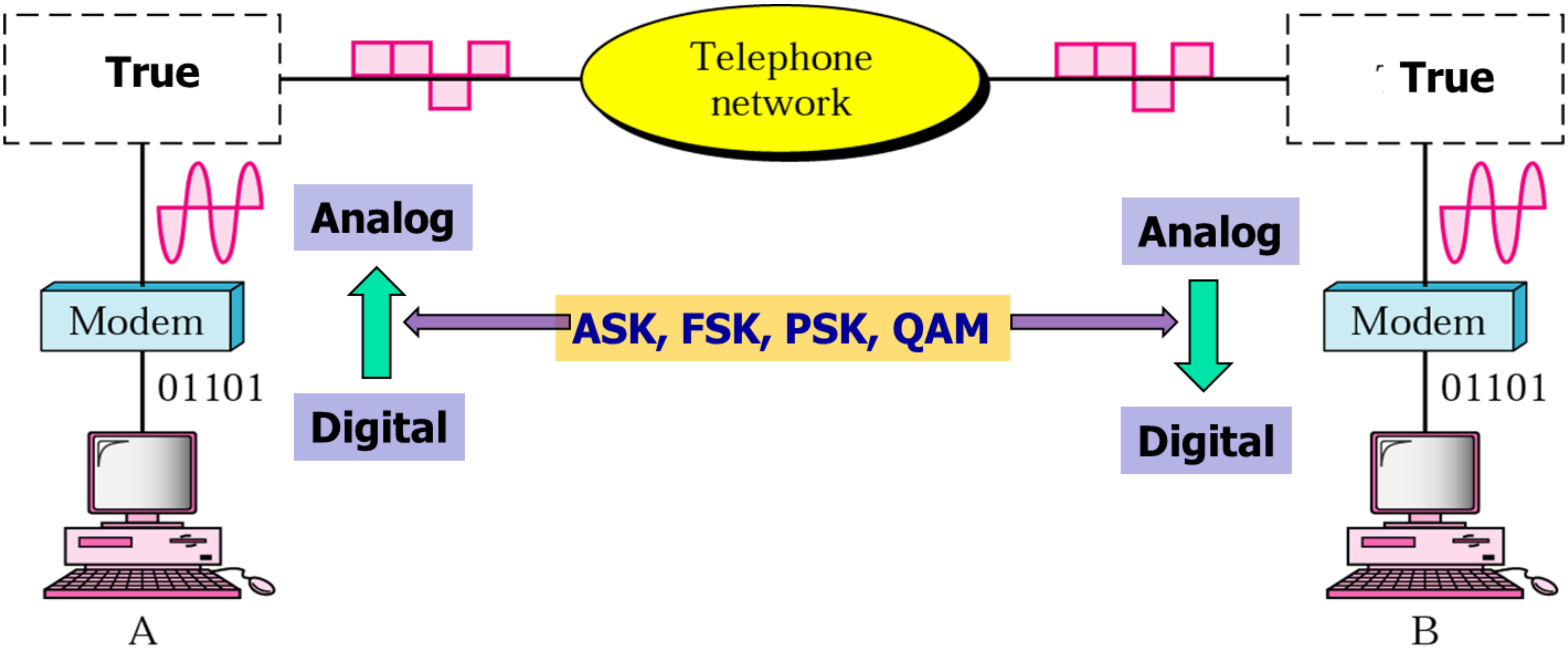
Q

ถ้า **Amplitude** ของ **subCarrier** ไม่เท่ากันล่ะ จะเกิดอะไรขึ้น

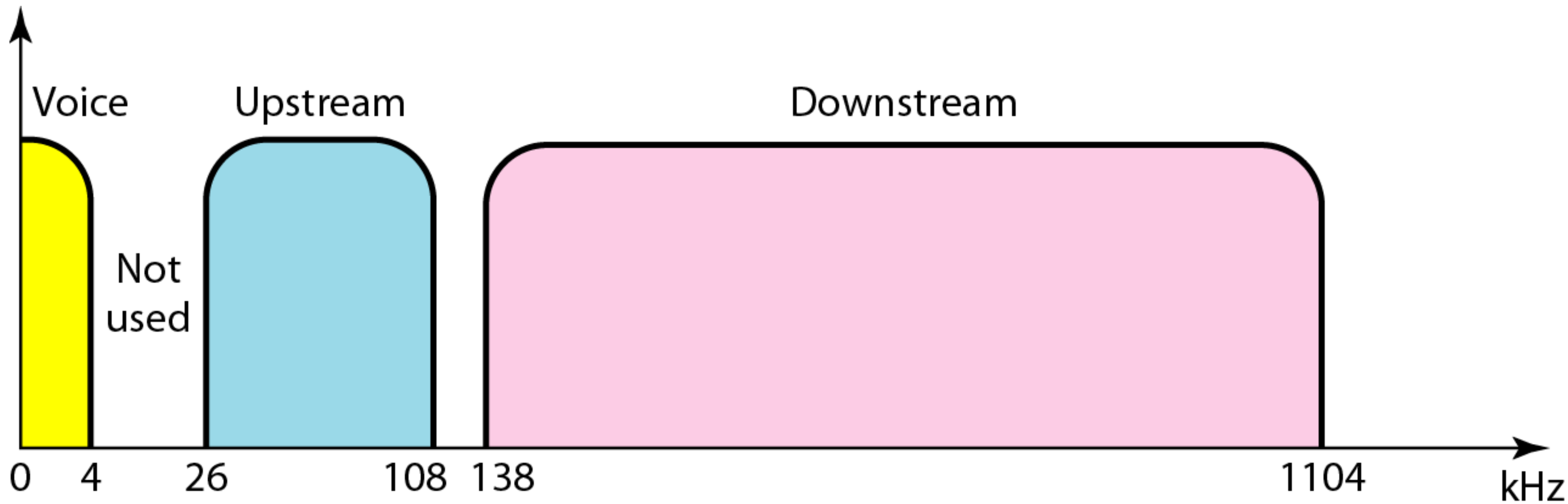
A

ลองทำดูสิ

# Data Communications through a telephone line

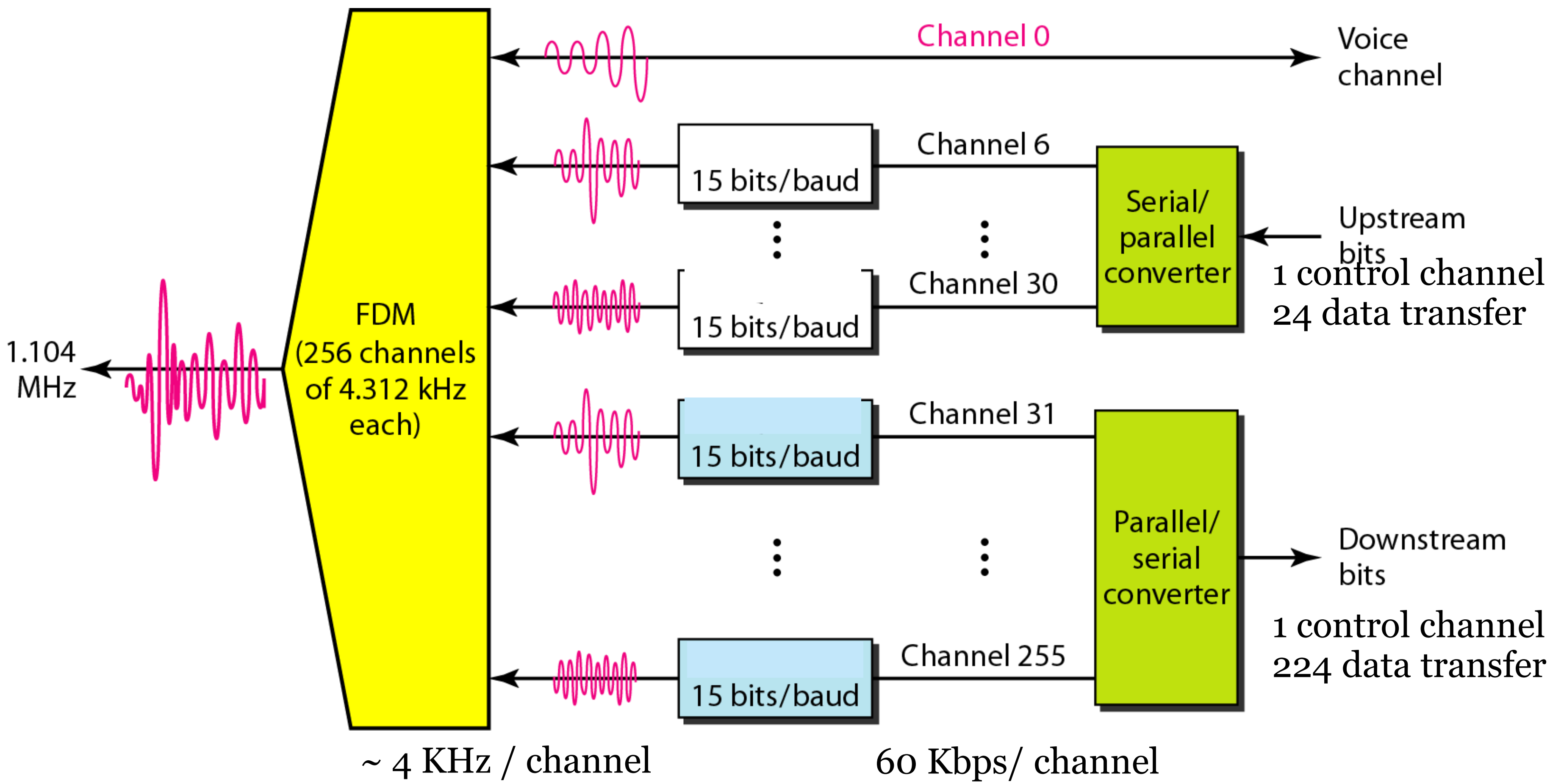


## Figure 9.11 *Bandwidth division in ADSL*




- Transmission: twisted-pair (1 pair)
  - Divides 1.104 MHz bandwidth into three bands (256 channels; 4.312 KHz per channel)
    - POT (voice) (channel 0)
    - Upstream (channel 6-30; 25 channels),
    - Downstream (channel 31-255; 225 channels)

# Figure 9.10 *Discrete Multitone Technique (DMT) : modulation technique standard for ADSL*



# ANSI standard for ADSL

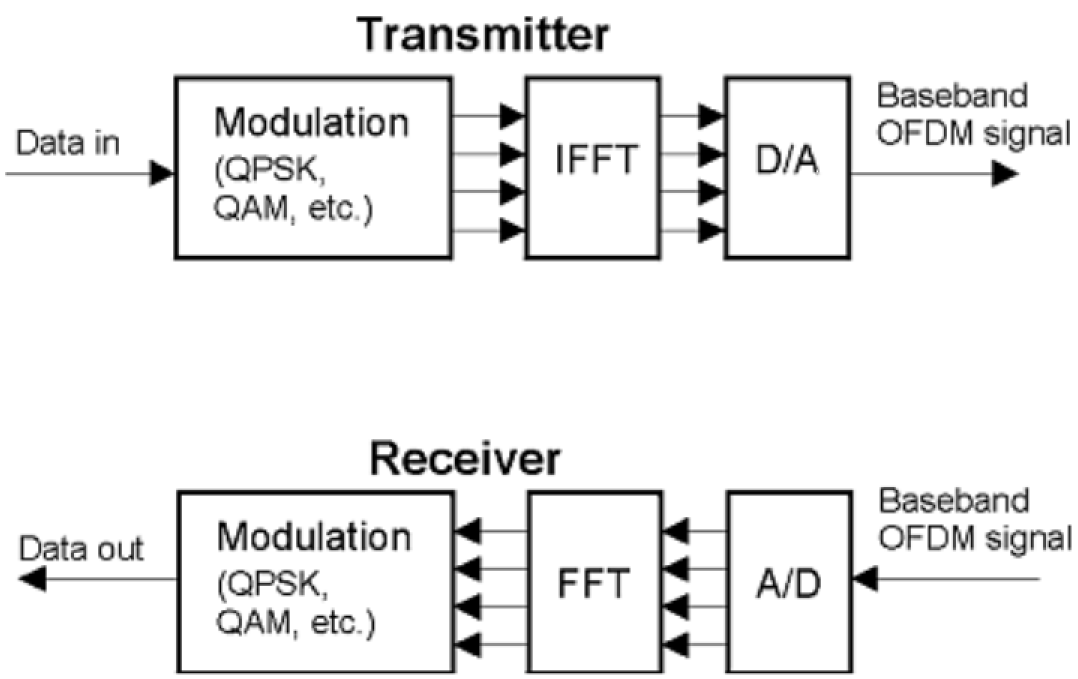
- Upstream (25-200 KHz -> 25 channels)
  - Each FDM sub channel: 4 KHz
  - Discrete Multitone Technique (DMT): 15 bits per baud
  - Data rate: 60 Kbps / channel
  - Upstream data rate (no noise): 25 x 60Kbps = 1.5 Mbps
  - data rate (with noise) : 64 Kbps – 1 Mbps

- Downstream (250-100 KHz -> 200 channels)
  - Downstream data rate: 200 x 60 Kbps = 12 Mbps
  - data rate (with noise): 500 Kbps – 8 Mbps

# Mobile Data Modulation

- PSK, QAM
- OFDM

## OFDM Transmitter and Receiver



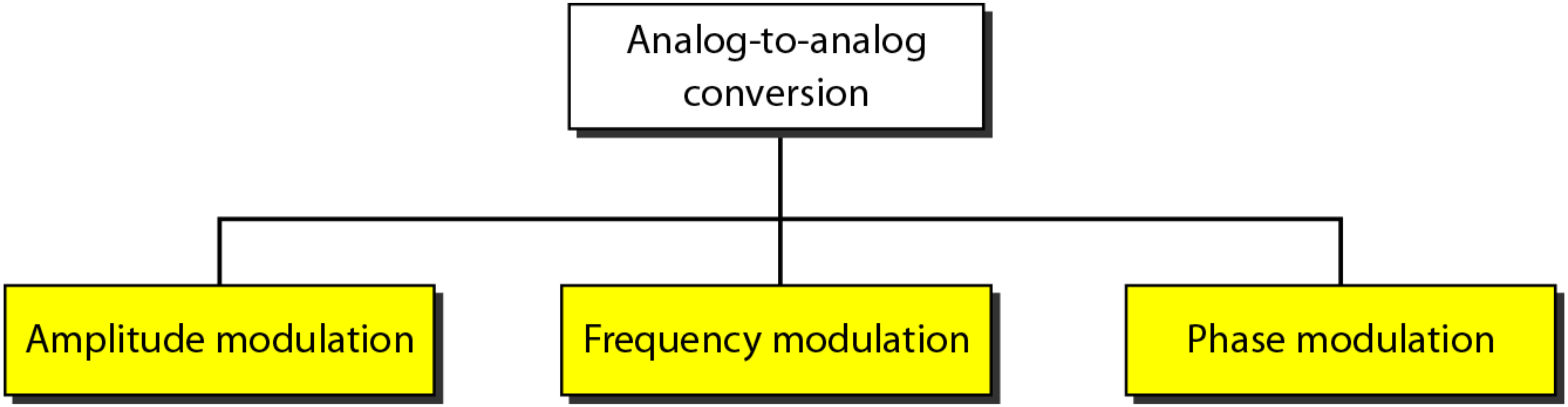
## 5-2 ANALOG AND DIGITAL

*Analog-to-analog conversion 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 bandpass in nature or if only a bandpass channel is available to us.*

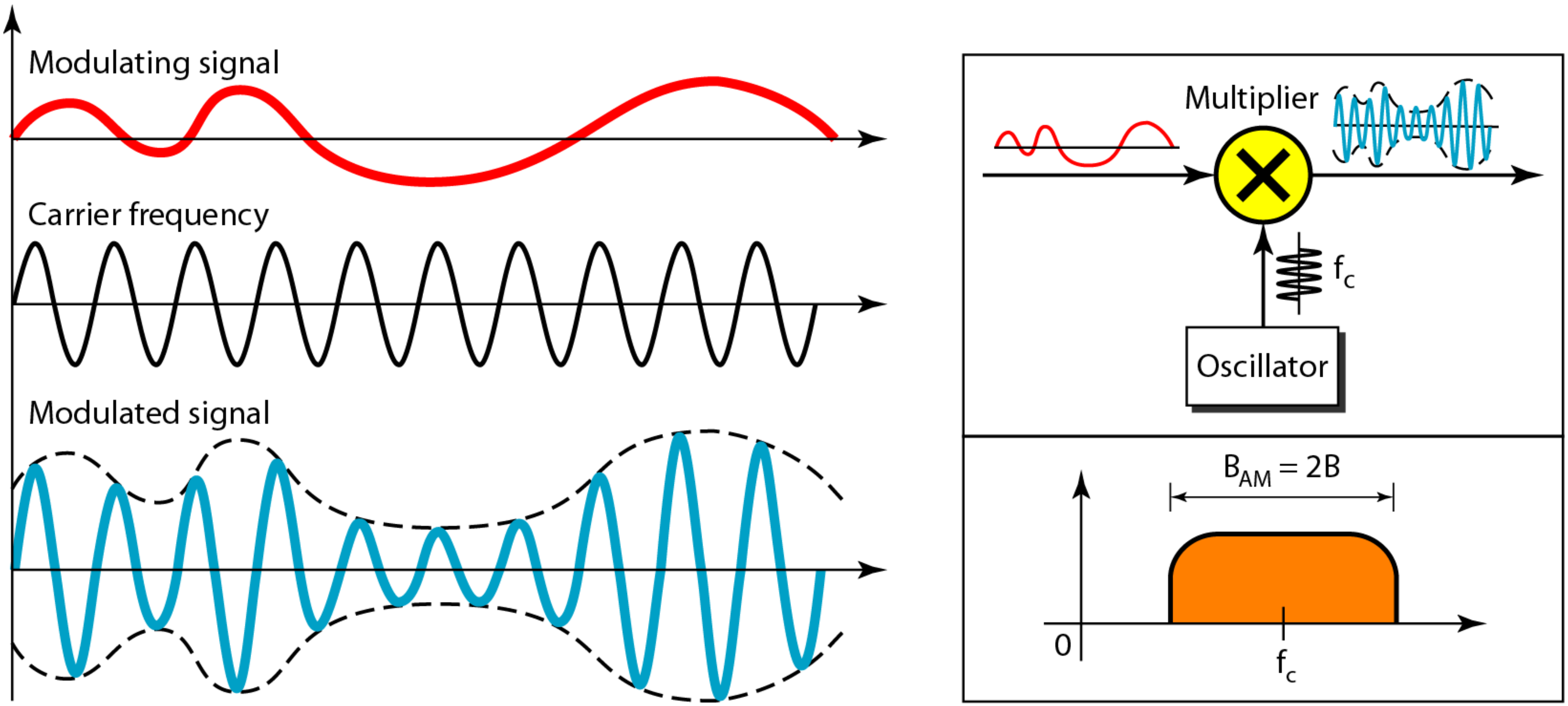
*Topics discussed in this section:*

Amplitude Modulation
Frequency Modulation
Phase Modulation

# Figure 5.15 *Types of analog-to-analog modulation*



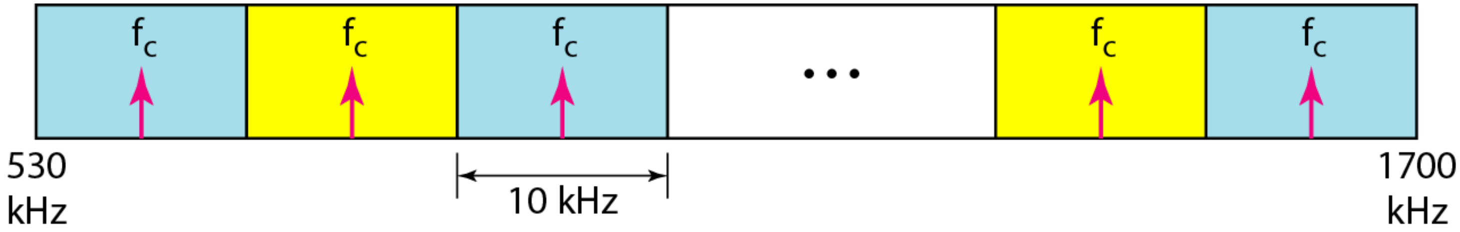
# Figure 5.16 *Amplitude modulation*



*Note*

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

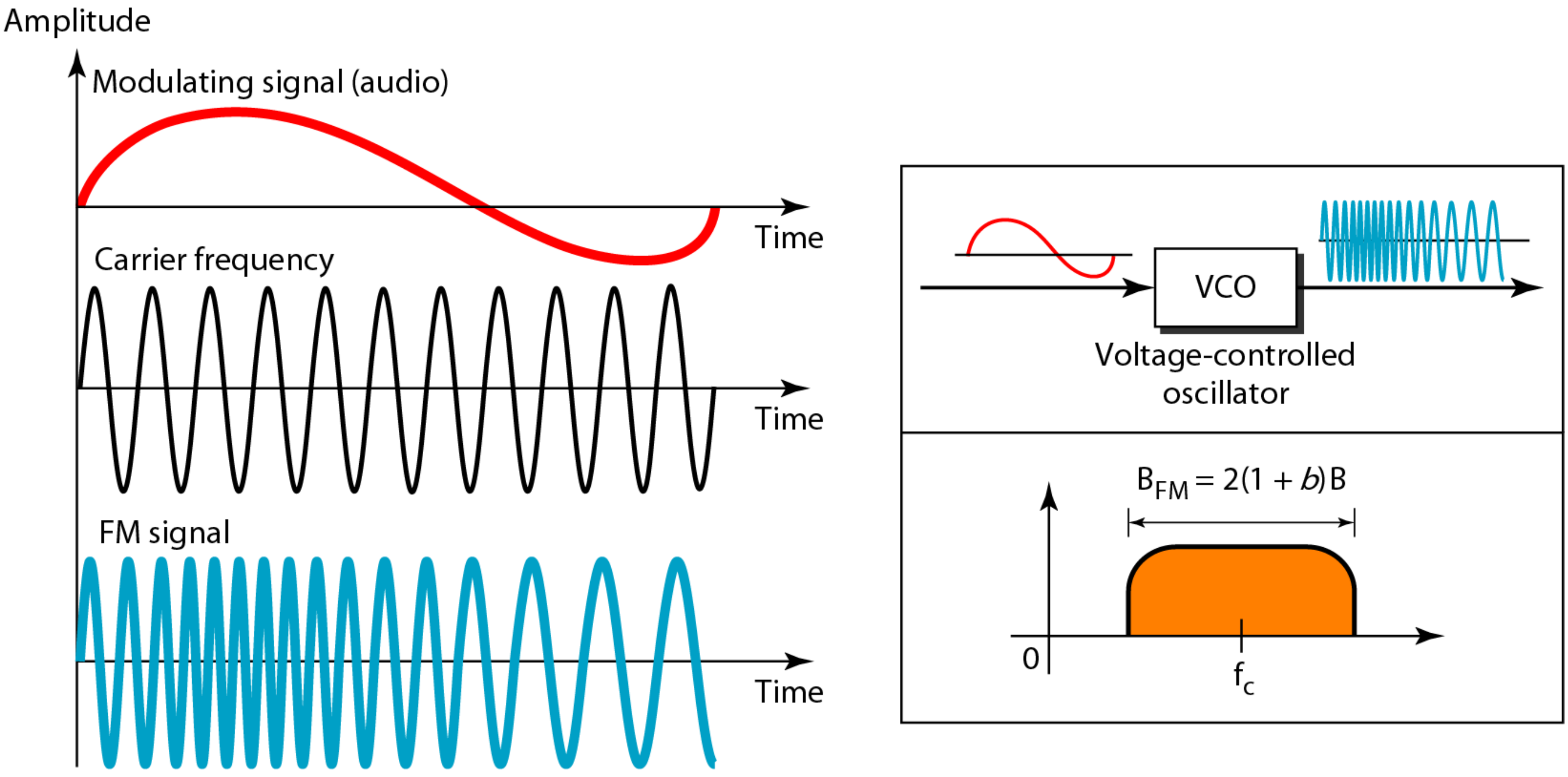
# Figure 5.17 *AM band allocation*



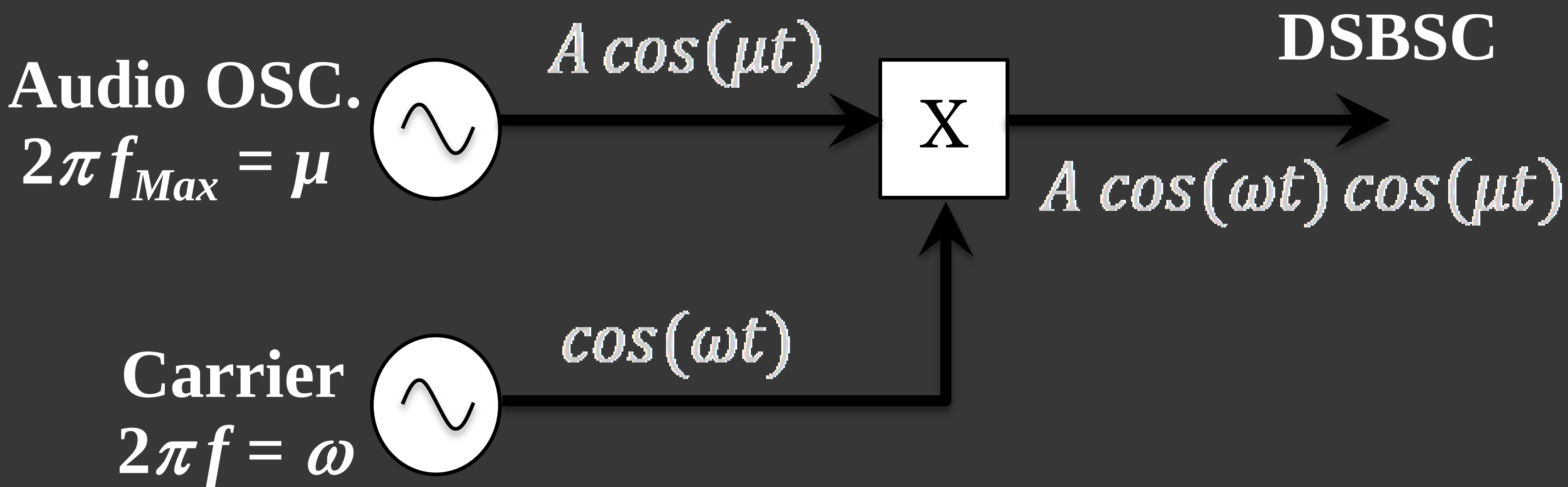
**Note**

The total bandwidth required for FM can be determined from the bandwidth of the audio signal: $B_{FM} = 2(1 + \beta)B$.

# Figure 5.18 *Frequency modulation*

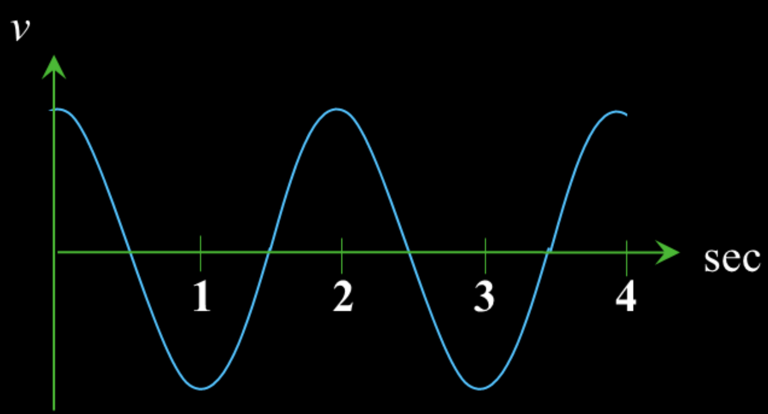


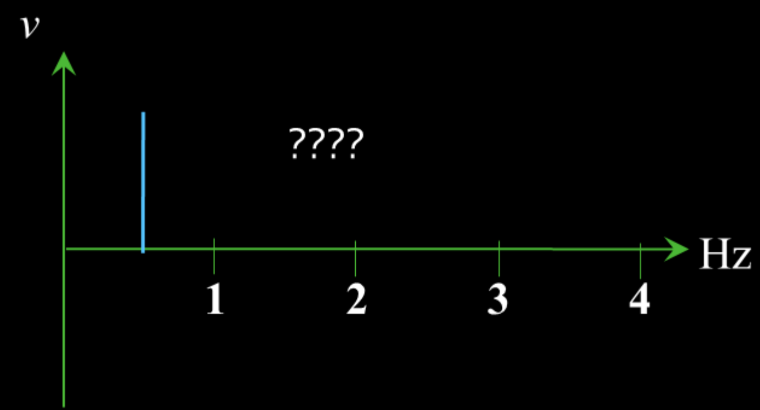
# DSBSC (Double Sideband Suppressed Carrier)




$$A\,cos(\omega t)\,cos(\mu t)$$
$$= \left(\frac{A}{2}\right) cos(\omega - \mu)t + \left(\frac{A}{2}\right) cos(\omega + \mu)t$$

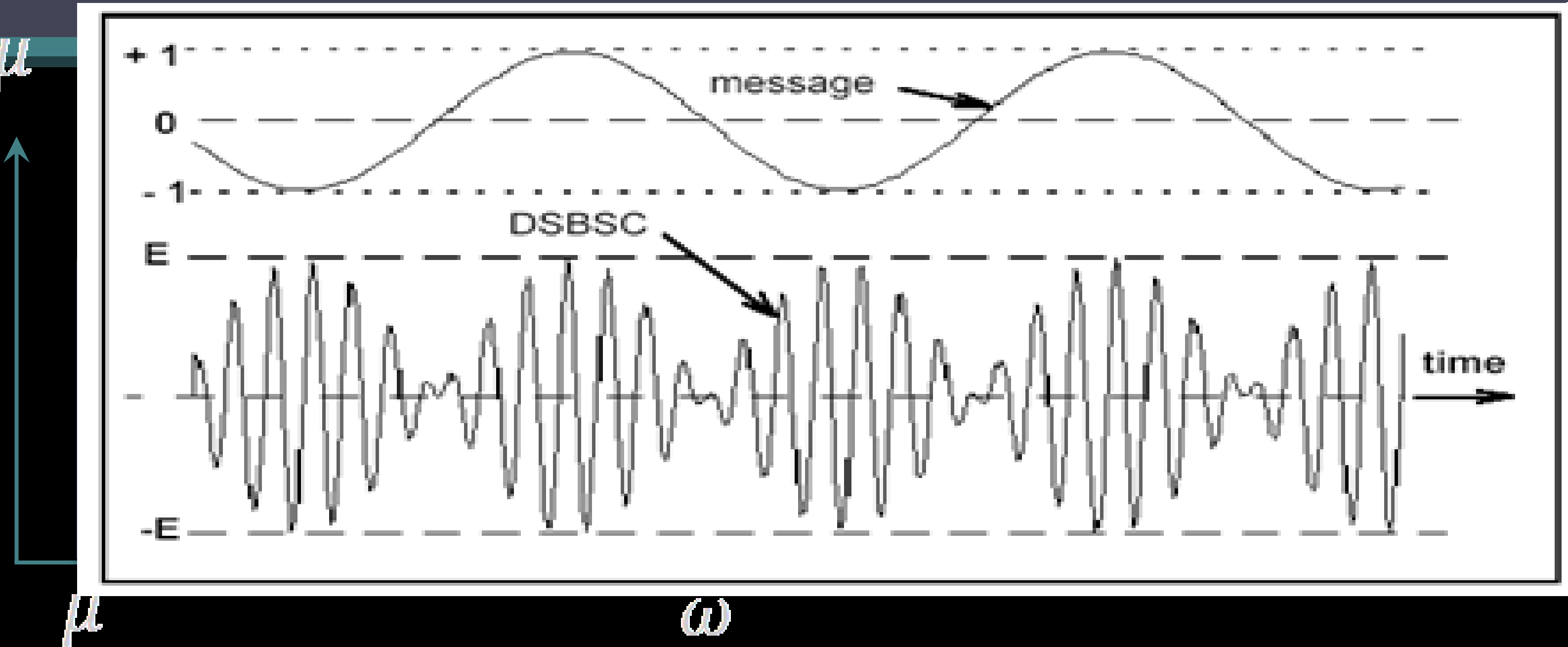
# DSBSC (Double Sideband Suppressed Carrier)



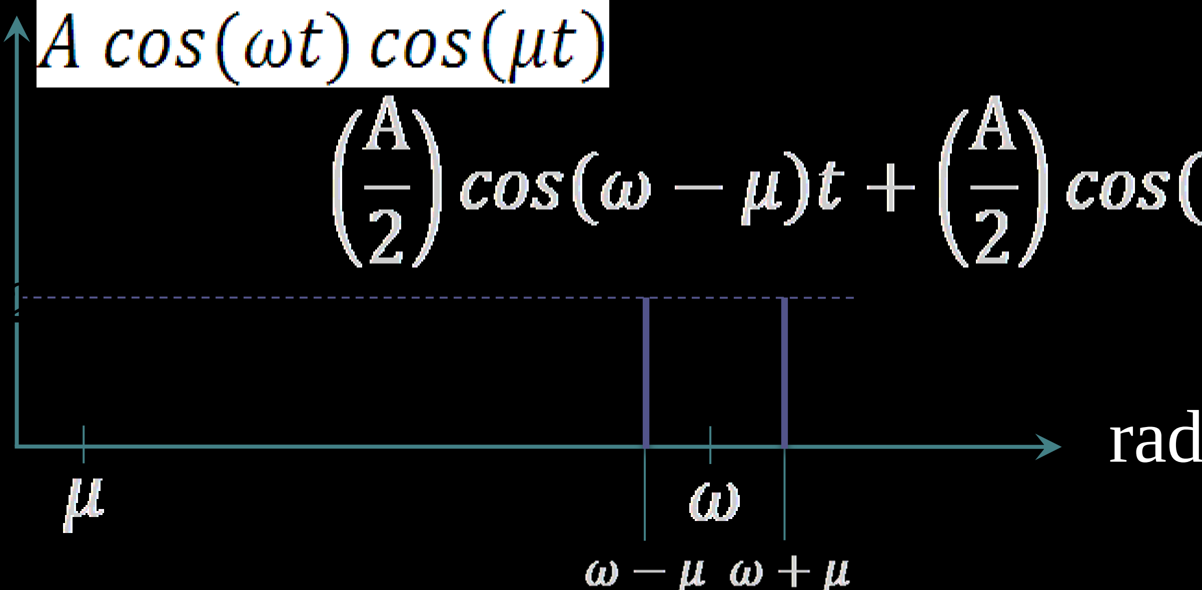

T=2 $f$=0.5

# $\omega \gg \mu$




$$A\cos(\omega t)\cos(\mu t)$$

$$\left(\frac{A}{2}\right)\cos(\omega-\mu)t+\left(\frac{A}{2}\right)\cos(\omega+\mu)t$$



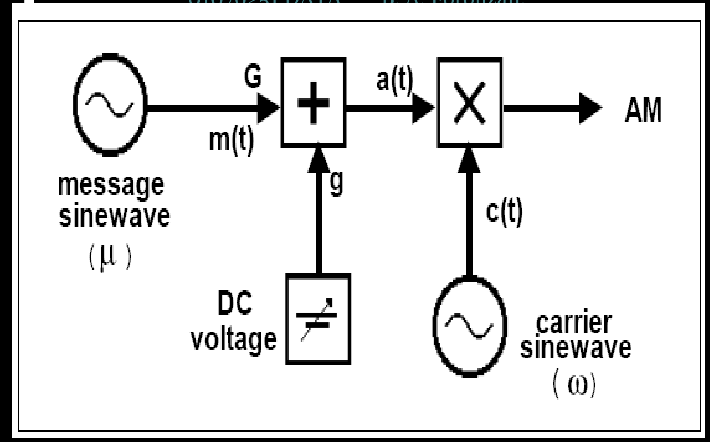
# Amplitude Modulation

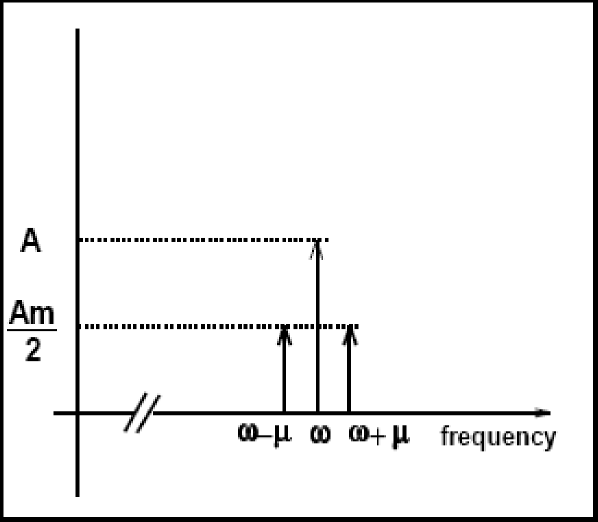
$$AM = \{G[m(t)] + g\}c(t)$$

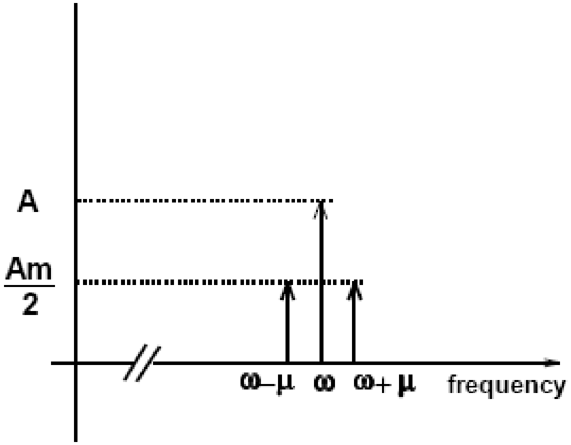
$$= \{G[\cos(\mu t)] + g\}\cos(\omega t)$$

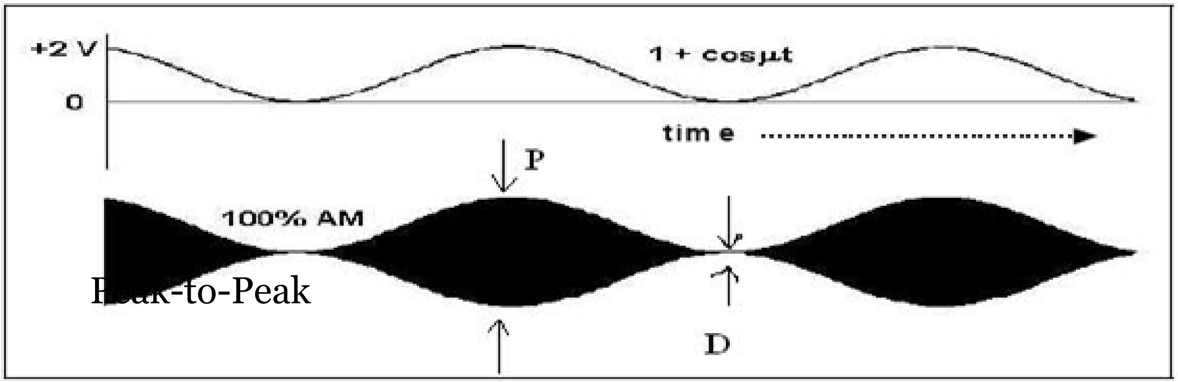
$$= G\cos(\mu t)\cos(\omega t) + g\cos(\omega t)$$

$$= \frac{G}{2}\cos(\omega t + \mu t) + \frac{G}{2}\cos(\omega t - \mu t) + g\cos(\omega t)$$

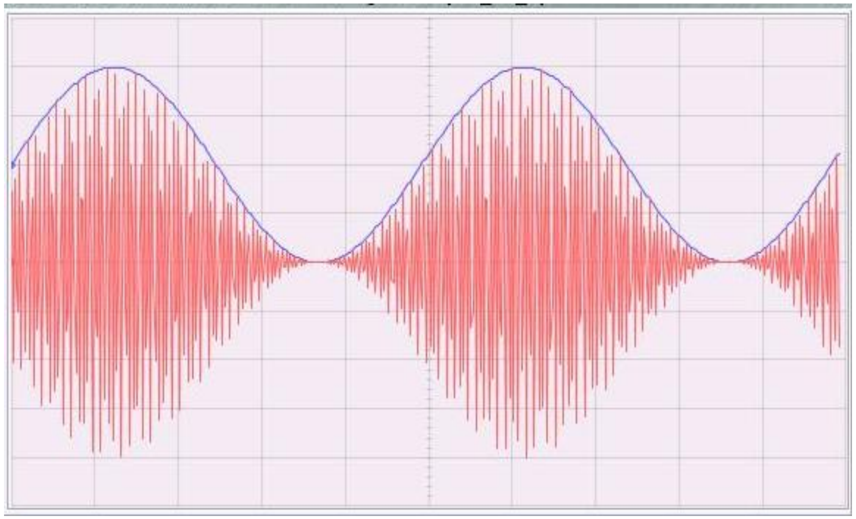


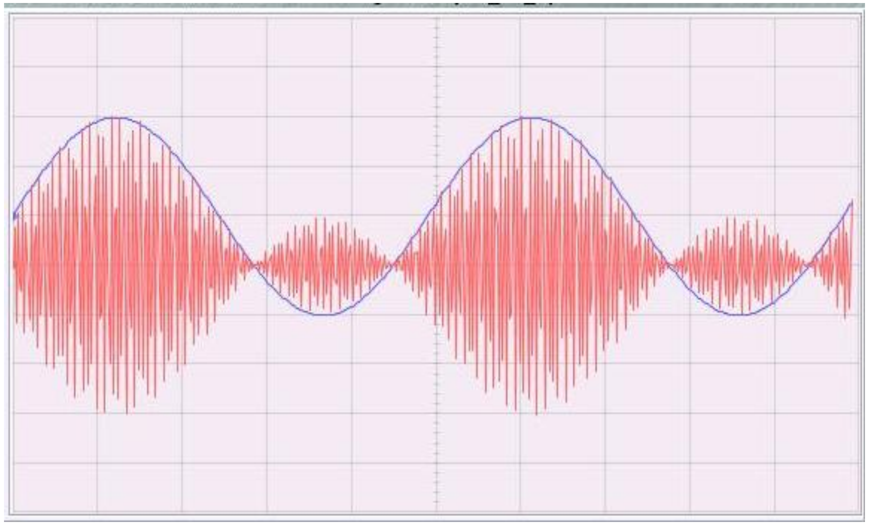






$$m = \frac{P-D}{P+D}$$ m=1 : 100% AM





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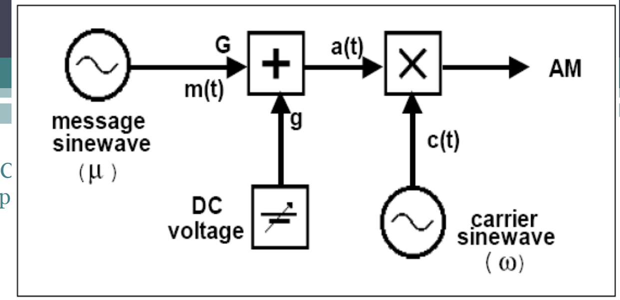
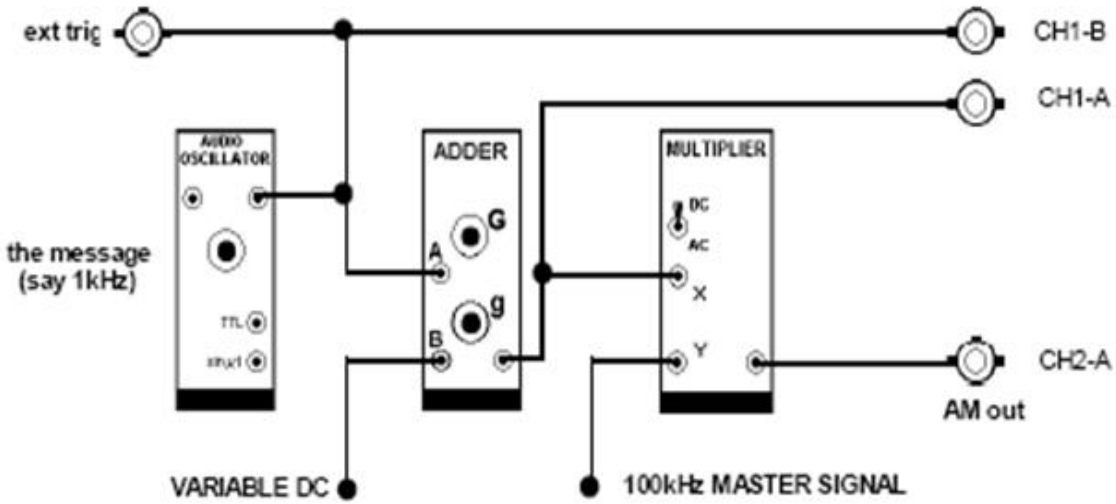
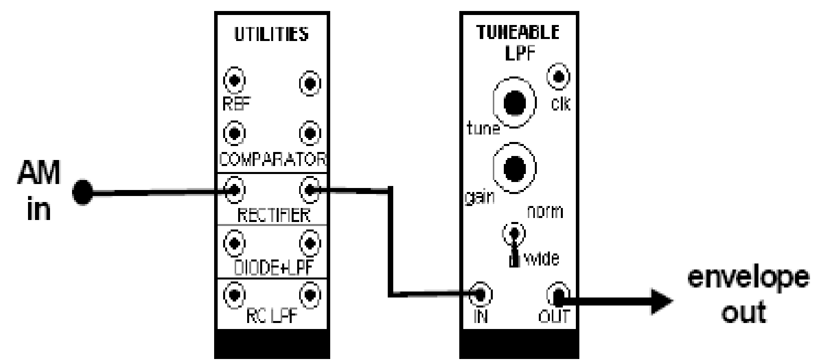
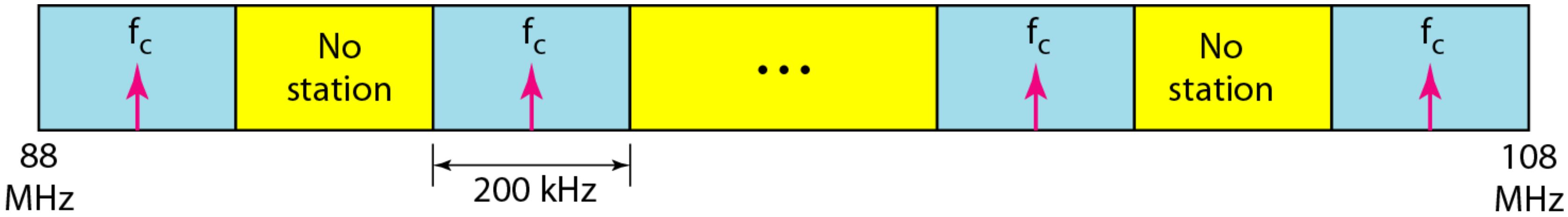
Dep


G
a(t)
AM
m(t)
g
message
sinewave
( μ )
c(t)
DC
voltage
carrier
sinewave
( ω)

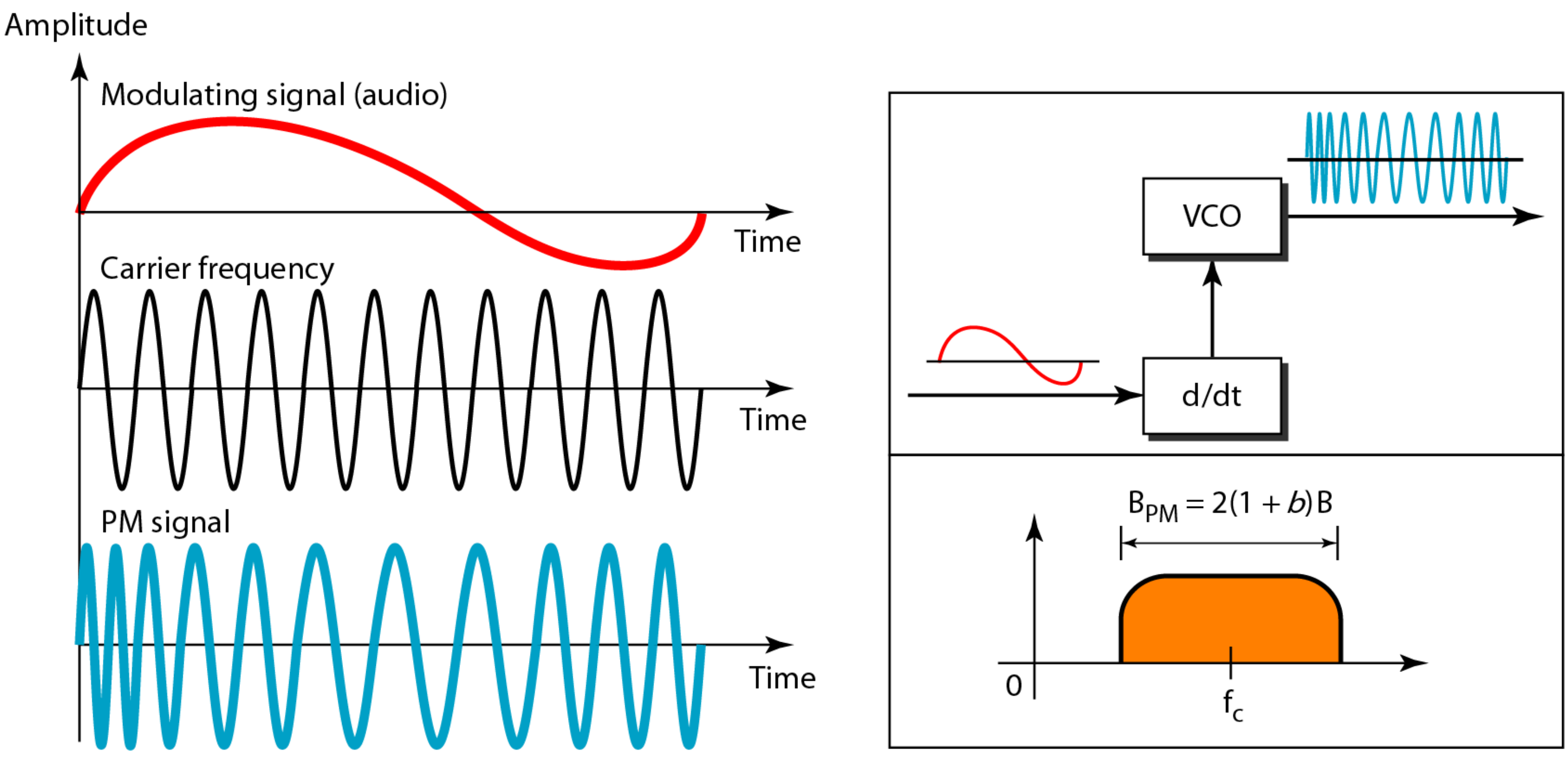

ext trig
CH1-B
CH1-A
AUDIO
OSCILLATOR
ADDER
MULTIPLIER
DC
AC
G
g
A
B
X
Y
the message
(say 1kHz)
TTL
CH2-A
AM out
VARIABLE DC
100kHz MASTER SIGNAL


AM
in
UTILITIES
REF
COMPARATOR
RECTIFIER
DIODE+LPF
RC LPF
TUNEABLE
LPF
clk
tune
gain
norm
wide
IN
OUT
envelope
out

# Figure 5.19 *FM band allocation*



# Figure 5.20 *Phase modulation*



*Note*

The total bandwidth required for PM can be determined from the bandwidth and maximum amplitude of the modulating signal:

$$B_{PM} = 2(1 + \beta)B.$$