The Physical Layer

Chapter 2

Theoretical Basis for Data Communication

- Fourier analysis
- Bandwidth-limited signals
- Maximum data rate of a channel

Fourier Analysis

- We model the behavior of variation of voltage or current with mathematical functions
- Fourier series is used

$$g(t) = \frac{1}{2}c + \sum_{n=1}^{\infty} a_n \sin(2\pi nft) + \sum_{n=1}^{\infty} b_n \cos(2\pi nft)$$

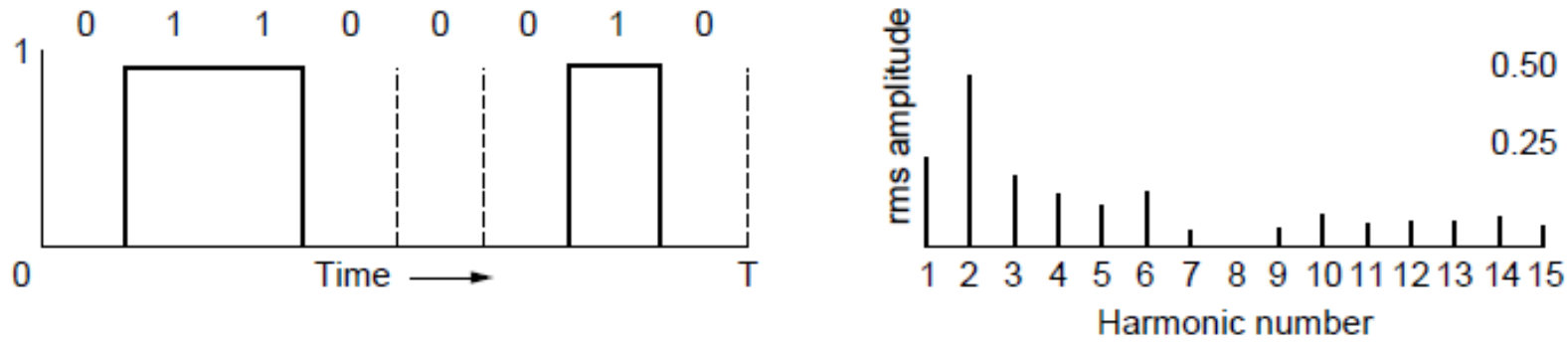
where the *n*th pair of terms is the *n*th harmonic

- Function reconstructed with

$$a_n = \frac{2}{T}\int_0^T g(t)\sin(2\pi nft)\,dt \qquad b_n = \frac{2}{T}\int_0^T g(t)\cos(2\pi nft)\,dt \qquad c = \frac{2}{T}\int_0^T g(t)\,dt$$

Bandwidth-Limited Signals (1)

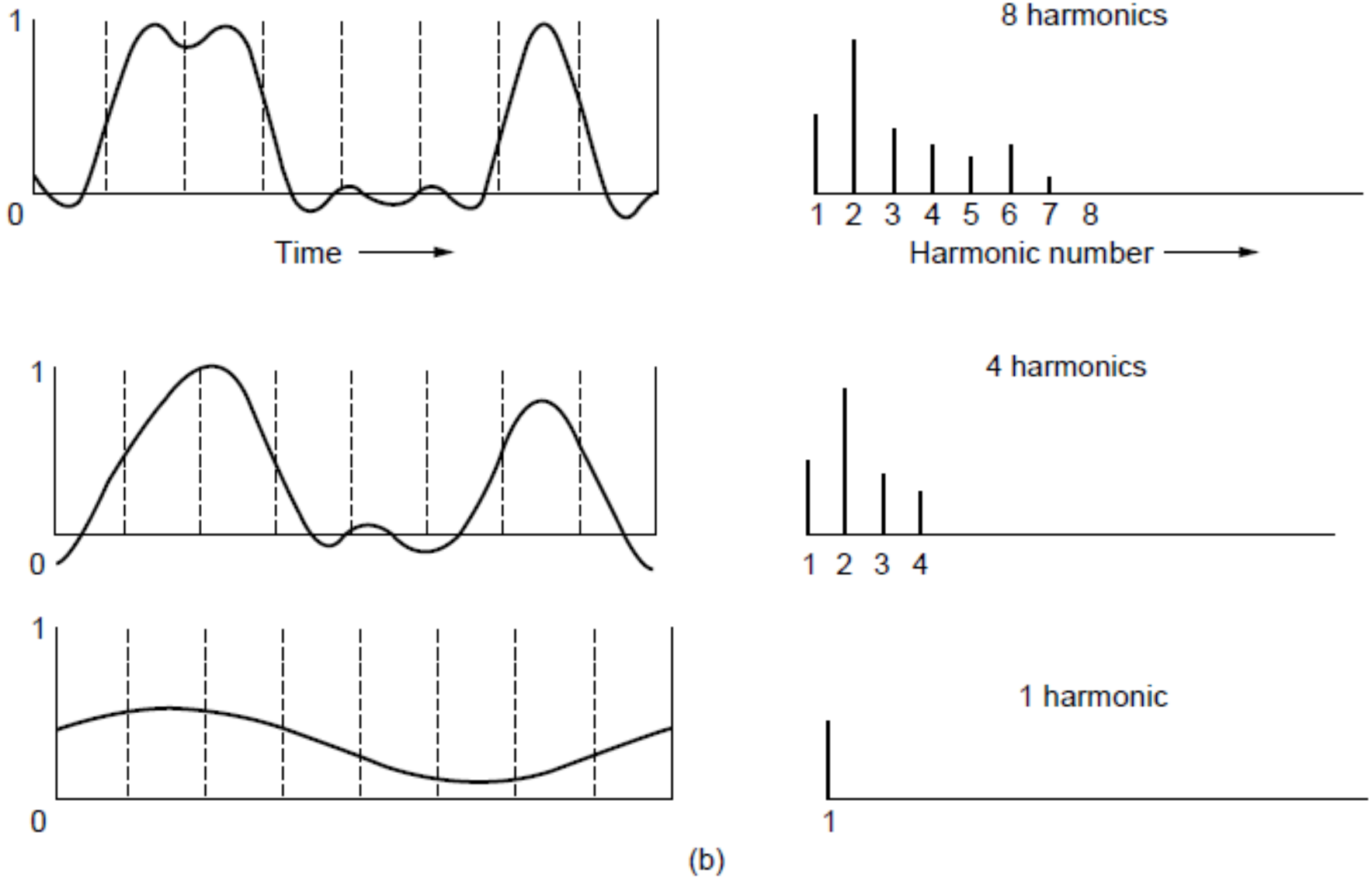
A binary signal and its root-mean-square Fourier amplitudes.



$$rms_n = \sqrt{a_n^2 + b_n^2}$$

- The root-mean-square amplitudes
  - Their square are proportional to the transmitted energy
- Signal transmission reduces harmonics amplitude differently
  - According to their frequencies

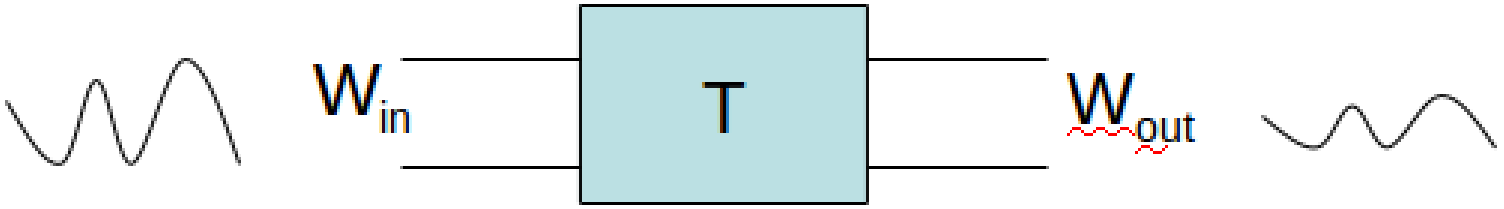
Bandwidth-Limited Signals (2)



Bandwidth-Limited Signals (3)

- Bandwidth: the width of the frequency range transmitted without attenuation
  - Convention: from 0 to the frequency at which the received power has fallen by half
- Bandwidth depends on:
  - material, thickness, and length of a wire or fiber
- Signals types:
  - Baseband signals: bandwidth from 0 to Max
  - Passband signals: bandwidth from Min (≠0) to Max

Gain Index



- Gain (or loss) misured in decibel (dB)

$$W_{dB} = 10 \log_{10} \frac{W}{W_{rif}}$$

- In electrical circuits, since $W \propto V^2$

$$V_{dB} = 20 \log_{10} \frac{V}{V_{rif}}$$

The Maximum Data Rate of a Channel

- Nyquist's theorem of noiseless channel

  $$\text{maximum data rate} = 2B \log_2 V \text{ bits/sec}$$

  V: number of signal discrete levels
- Shannon's formula for capacity of noisy channel

  $$\text{maximum number of bits/sec} = B \log_2 (1 + S/N)$$

  S/N: *signal to noise ratio (SNR)*
- *An S /N ratio of:*
  - *0.5 is -3dB, 10 is 10 dB, 100 is 20 dB, 1000 is 30 dB*

Bandwidth-Limited Signals (6)

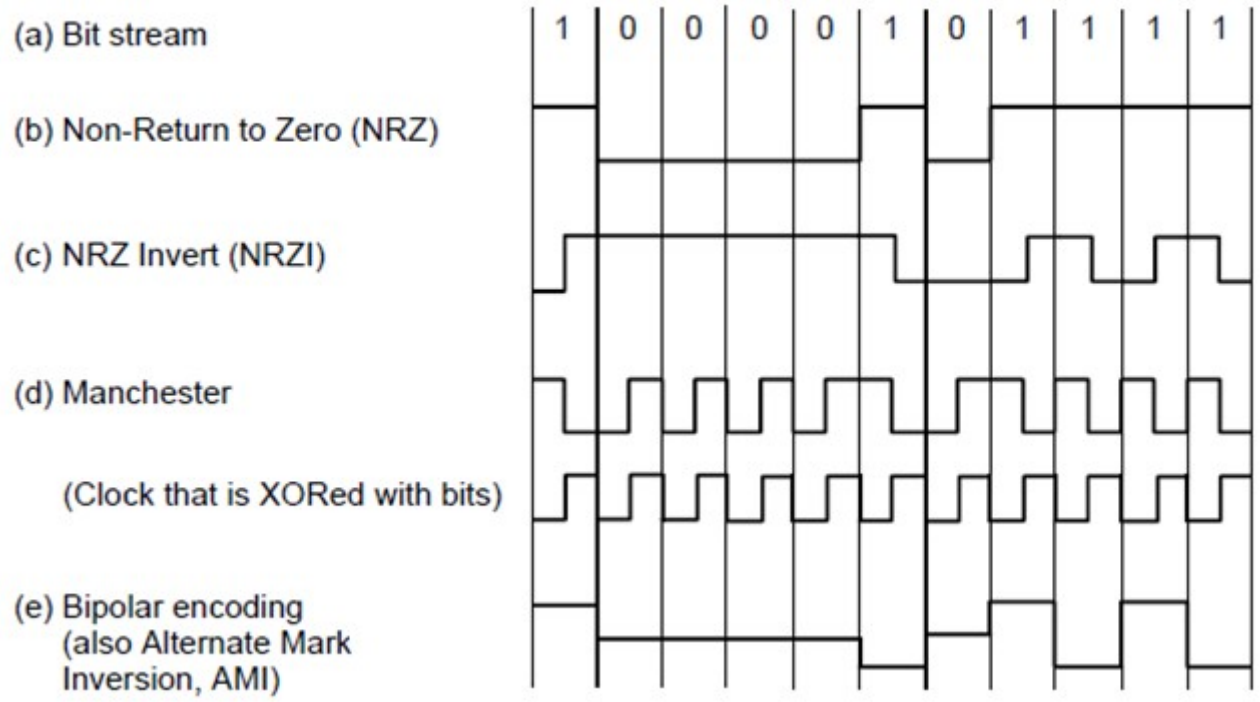
bps	T of Byte (msec)	First harmonic (Hz)	# Harmonics sent
300	26.67	37.5	80
600	13.33	75	40
1200	6.67	150	20
2400	3.33	300	10
4800	1.67	600	5
9600	0.83	1200	2
19200	0.42	2400	1
38400	0.21	4800	0

Relation between data rate and harmonics in a 3KHz bandwidth channel

Digital Modulation and Multiplexing

- Baseband Transmission
- Passband Transmission
- Frequency Division Multiplexing
- Time Division Multiplexing
- Code Division Multiplexing

Baseband Transmission



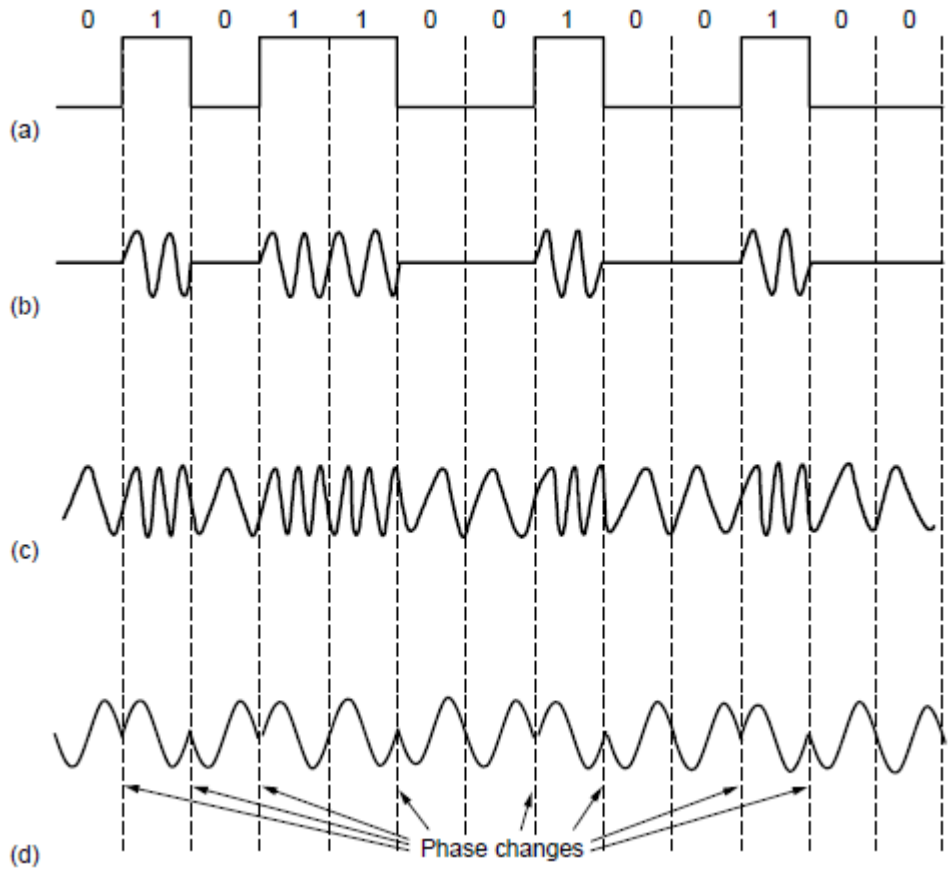
Line codes: (a) Bits, (b) NRZ, (c) NRZI, (d) Manchester, (e) Bipolar or AMI.

Clock Recovery

Data (4B)	Codeword (5B)	Data (4B)	Codeword (5B)
0000	11110	1000	10010
0001	01001	1001	10011
0010	10100	1010	10110
0011	10101	1011	10111
0100	01010	1100	11010
0101	01011	1101	11011
0110	01110	1110	11100
0111	01111	1111	11101

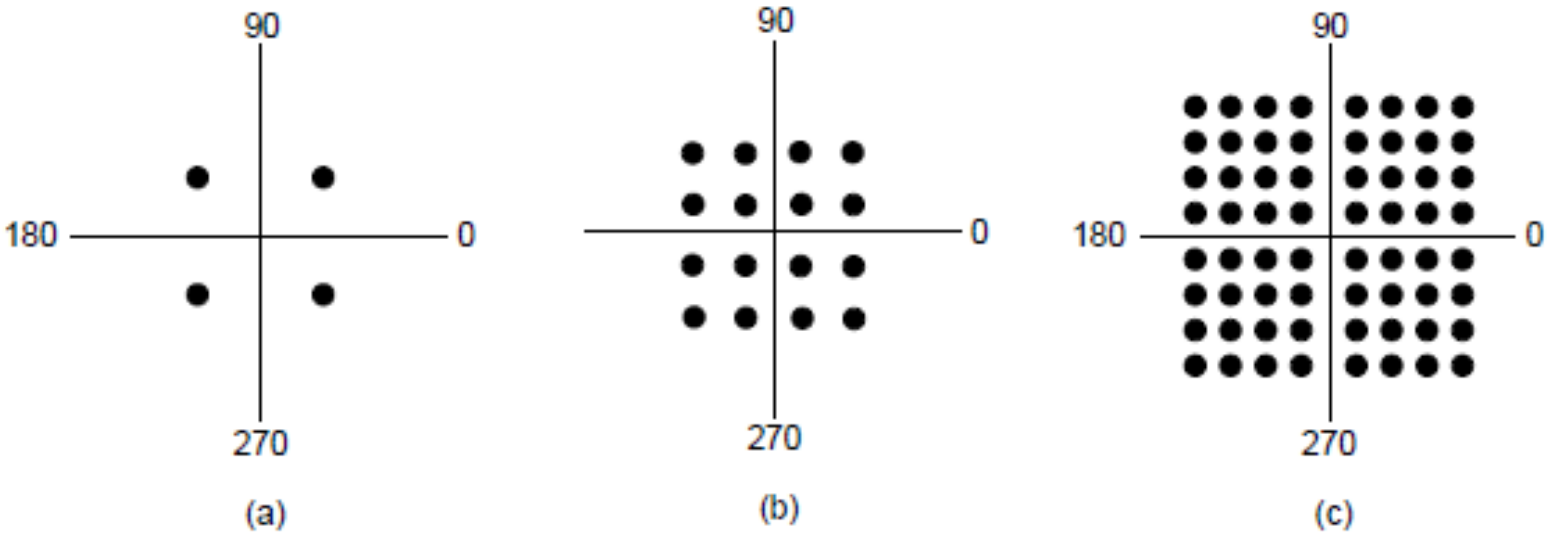
4B/5B mapping.

Passband Transmission (1)



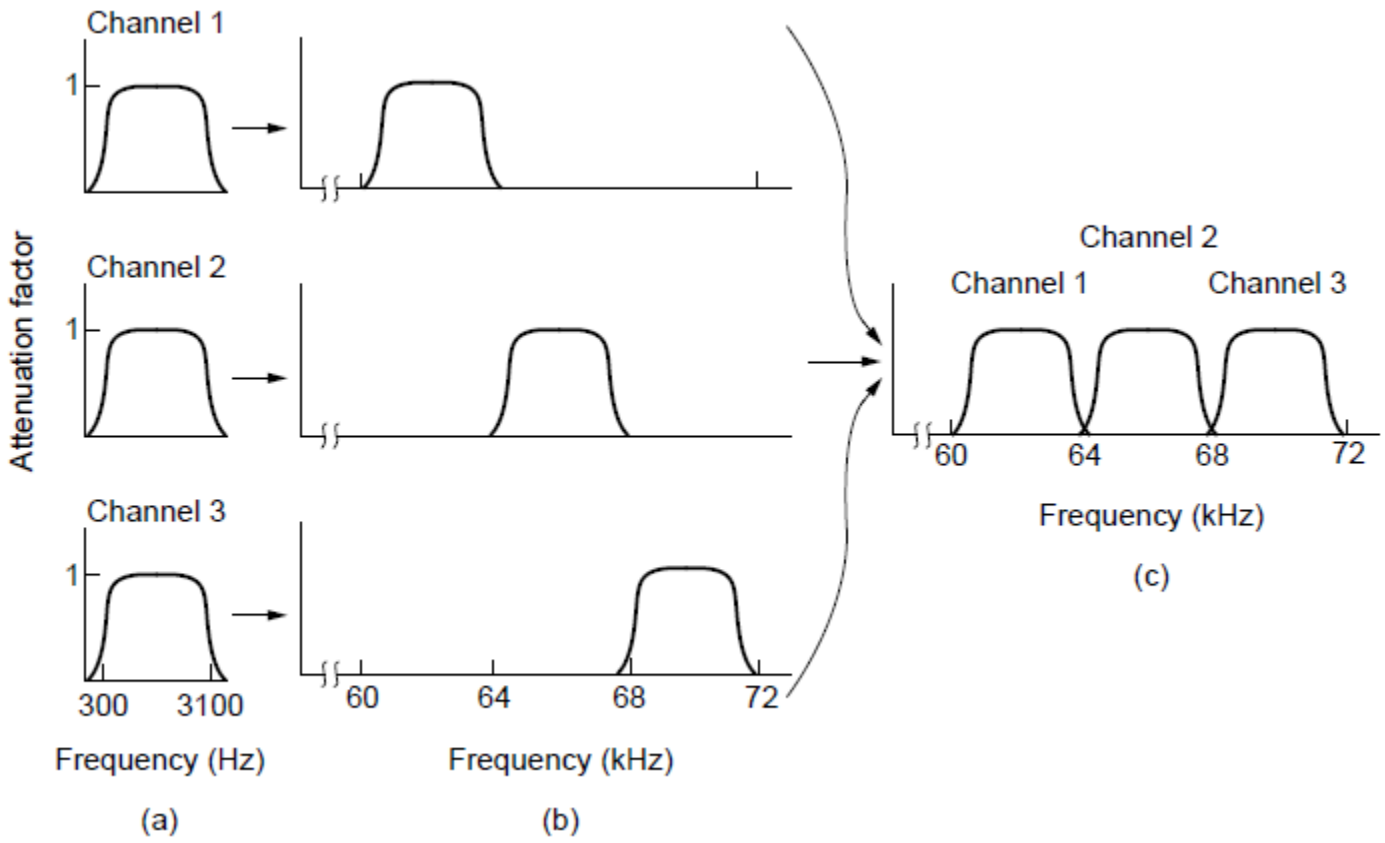
(a) A binary signal. (b) Amplitude shift keying. (c) Frequency shift keying. (d) Phase shift keying (BPSK).

Passband Transmission (2)



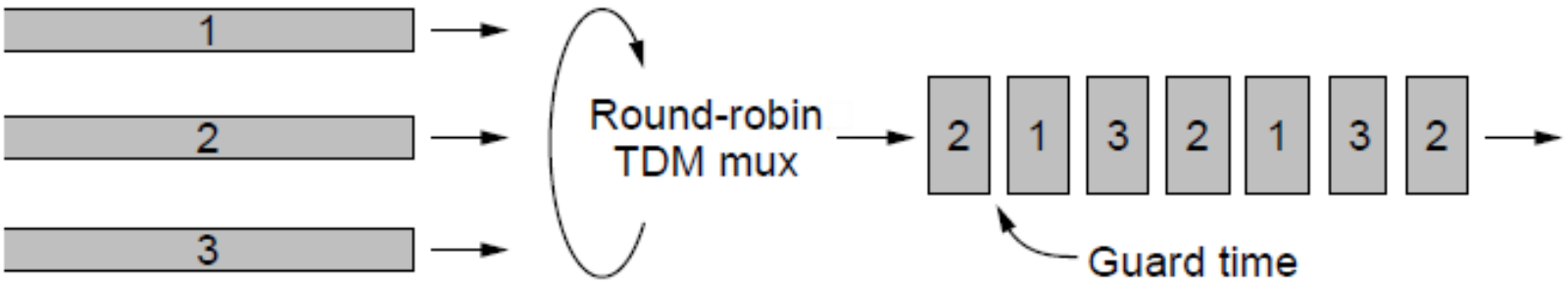
(a) QPSK. (b) QAM-16. (c) QAM-64.

Frequency Division Multiplexing (2)



Frequency division multiplexing. (a) The original bandwidths. (b) The bandwidths raised in frequency. (c) The multiplexed channel.

Time Division Multiplexing



Time Division Multiplexing (TDM).

End

Chapter 2