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Computer Networks

https://guilhermeir.github.io/L3Networks.html

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Computer Networks
Class 4: Physical Layer (Continued)

Class 2 Review

- Types of Transmissions
  - Guided
  - Wireless
- Fundamentals of Digital Communications
  - Medium characteristics - bandwidth
  - Receiver (sampling signal) – link capacity (max. rate)
- Today: Transmitter

Fundamentals of Communication

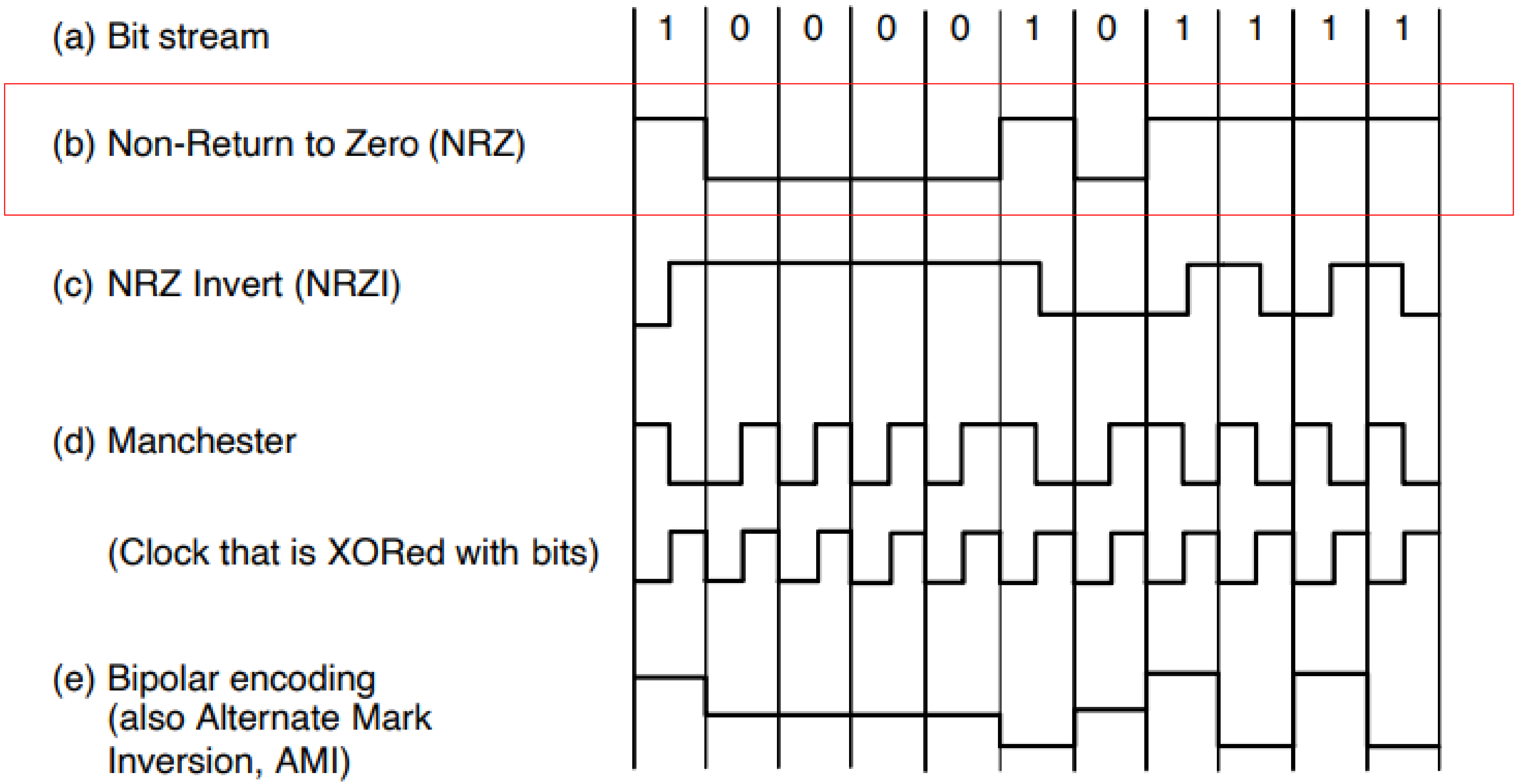
Modulation

- Baseband Transmission
- Passband Transmission

Multiplexing

- Frequency Division Multiplexing
  - Orthgonal FDM
  - Wavelength
- Time Division Multiplexing
- Spatial Division Multiplexing
- Code Division Multiplexing

Digital Modulation – Baseband Transmission: Non-Return to Zero



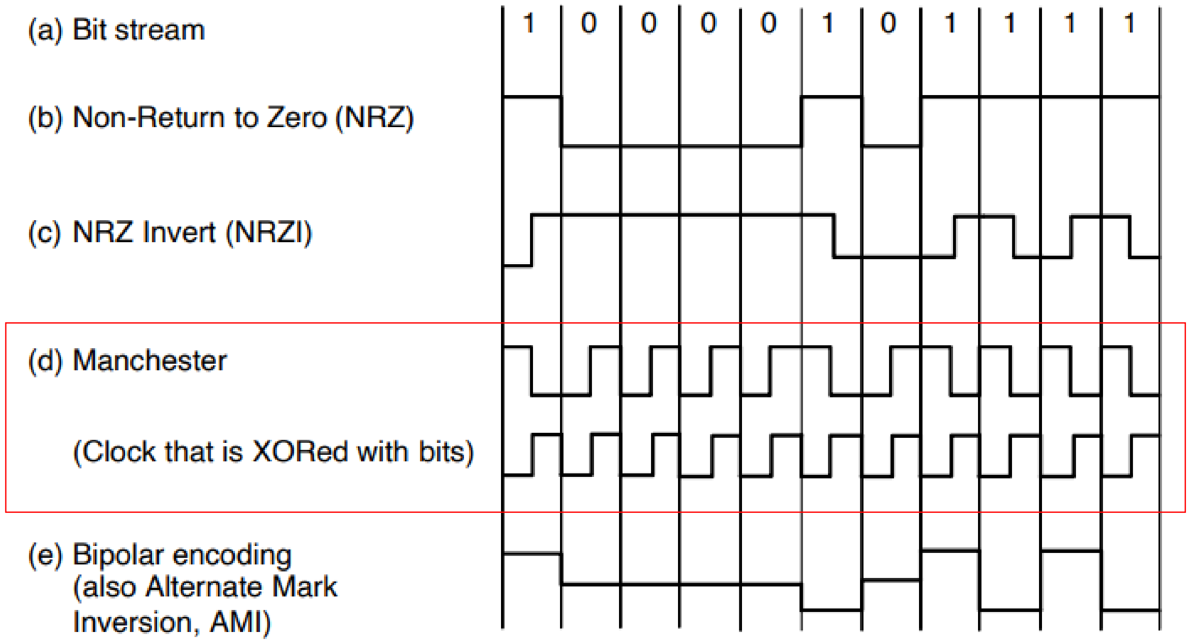
Digital Modulation – Baseband Transmission: Bandwidth Efficiency

Bandwidth Efficiency

- What is maximum rate for NRZ?
  - R=2B (Nyquist!)
- How to increase max rate?
  - B is fixed in most cases
  - Answer: Increase number of levels
    - 1 symbol carries 2 bits
  - Problem: Attenuation!

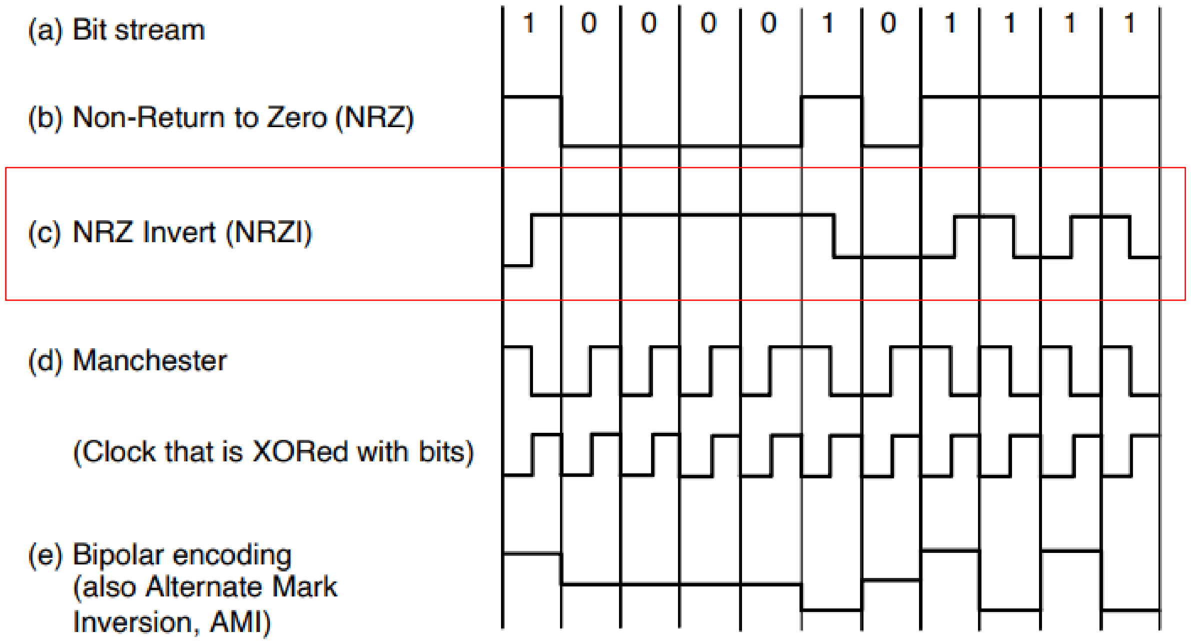
- *Symbol rate*: rate at which bits change
- Bit rate = Symbol rate x bits/symbol

Digital Modulation – Baseband Transmission: Manchester Encoding



- NRZ: Hard to detect bounds
- Clock Recovery
- Clock = 2 x Bit Rate
- Encoded Signal = Clock $\oplus$ Data

Digital Modulation – Baseband Transmission: NRZ Inverted Encoding



- Manchester: Requires 2x bandwidth
- Transitions are easier to detect
- Encoding:
  - 1-bit: transition
  - 0-bit: no transition

Digital Modulation – Baseband Transmission: 4B/5B Encoding

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

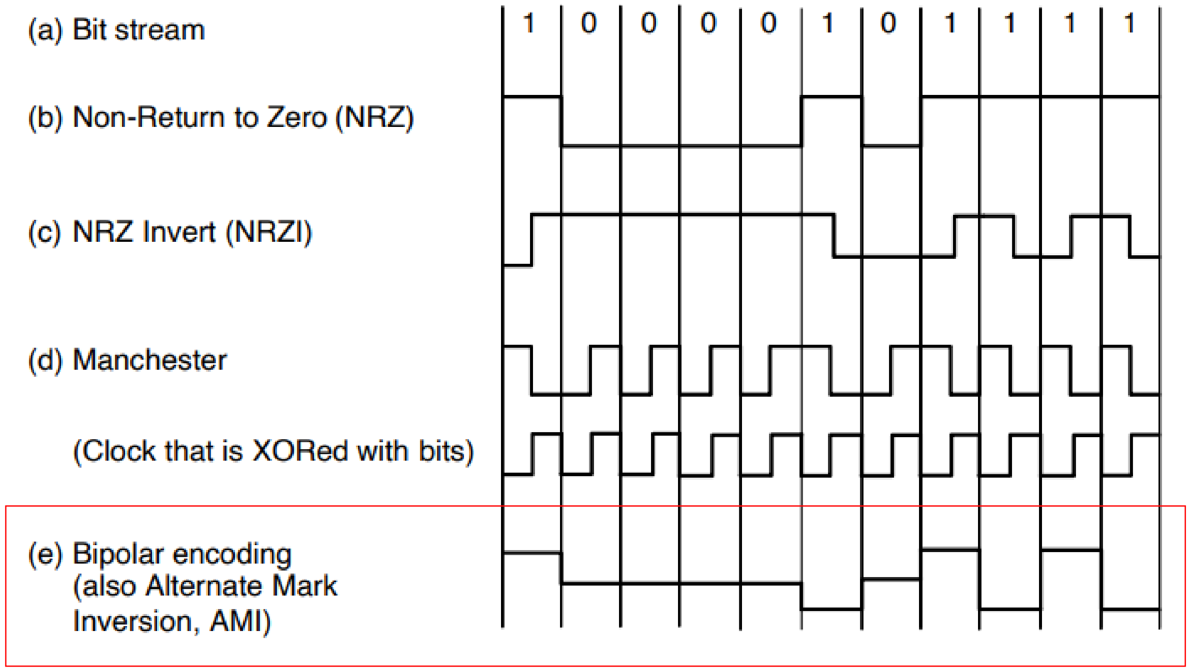
- NRZI: Long streams of zeros
- 4 bits maps to unique 5 bits
  - No more than 3 zeros in a row
- 25% overhead
- 16 combinations are not used for data
  - Control codes:
    - 11111: iddle line
    - 11000: start of a frame

Digital Modulation – Baseband Transmission: 4B/5B “Scrambling”

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: Easy to intercept (unsafe)
- Shared pseudorandom (PR) sequence
- Signal = Data $\oplus$ PR
- Advantages:
  - No overhead
  - No additional bandwidth needed
- Disadvantege: sequence of zeros!

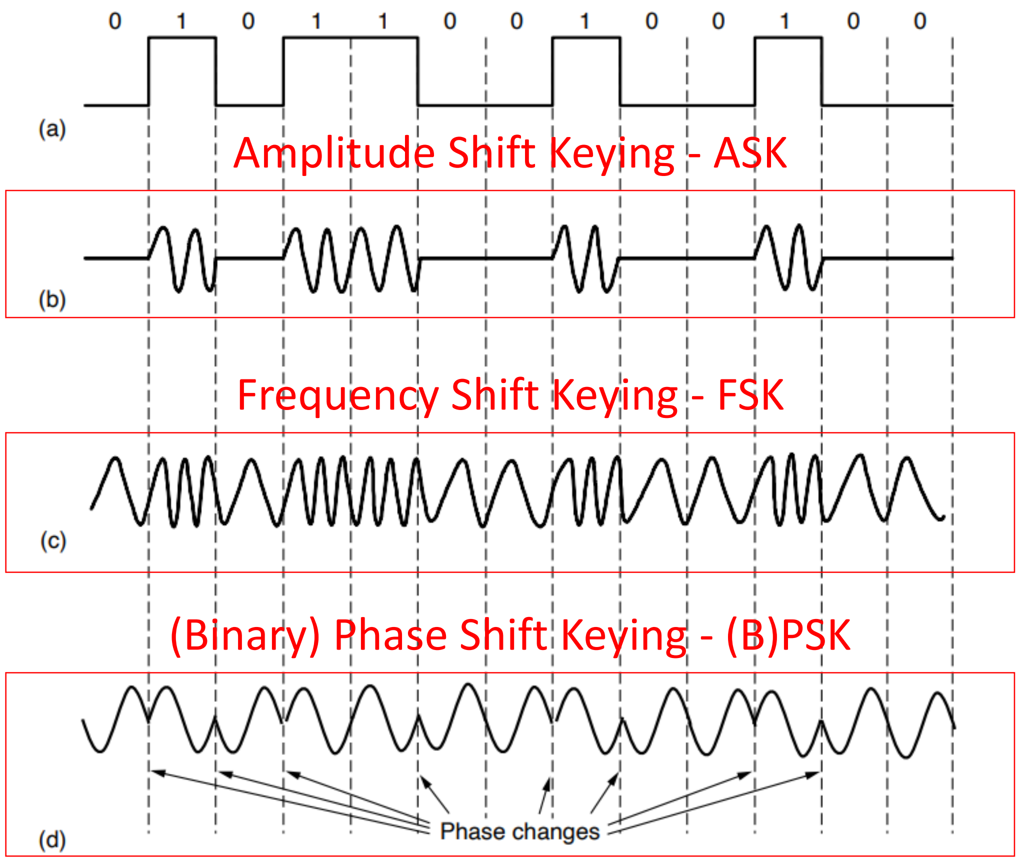
Digital Modulation – Baseband Modulation: Bipolar Encoding



- Previous coding: unbalanced voltage
- 3-voltage-level Encoding:
  - 0-bit = 0V
  - 1-bit = +1V or -1V (alternating)
- 8B/10B Mapping:
  - 8 bits -> 10 bits (80% efficiency)
  - 5 first bits -> 6 bits
  - 3 last bits -> 4 bits
  - Help balance: at most 2 disparity bits
  - Clock recovery: at most 5 consecutive 1s/0s

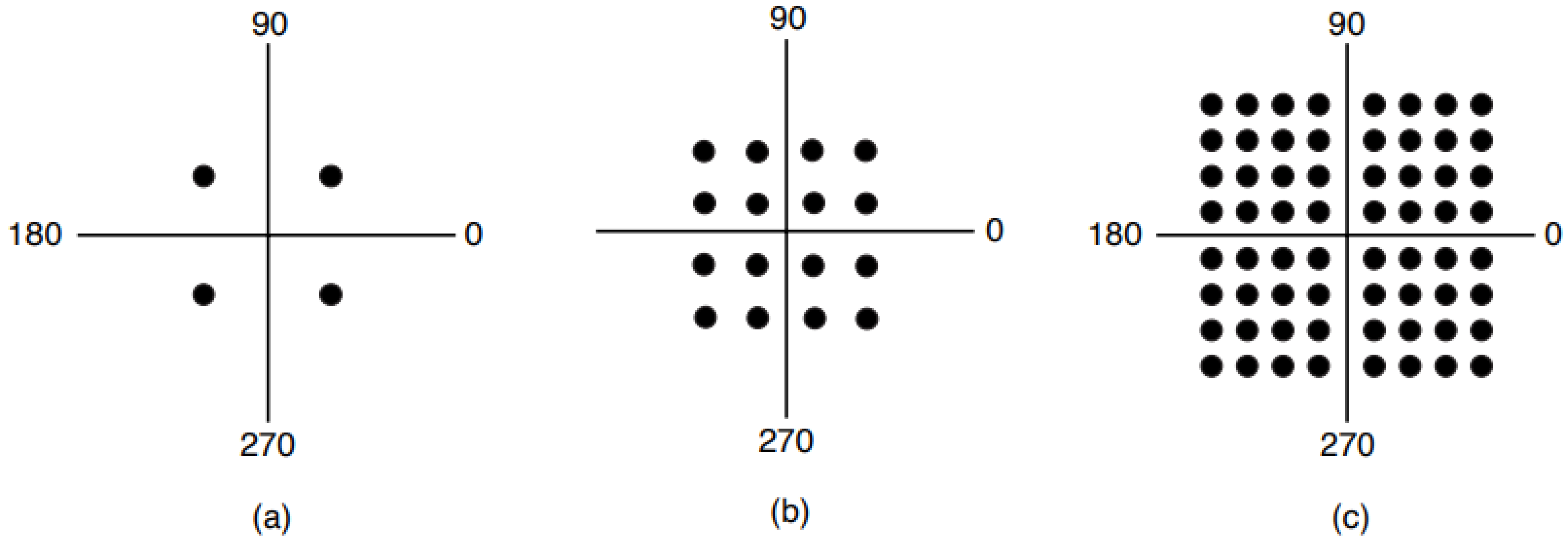
Digital Modulation – Passband Modulation

- Baseband is not convenient for wireless communication
- Wireless transmission often needs to take place in “shifted slices” of the broadband



Digital Modulation – Passband Modulation: Combined Modulations

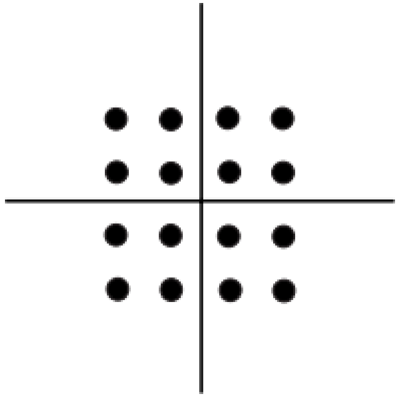
- Quadrature Amplitude Modulation - QAM
  - Amplitude and phase are modulated together
- Constellation Diagram

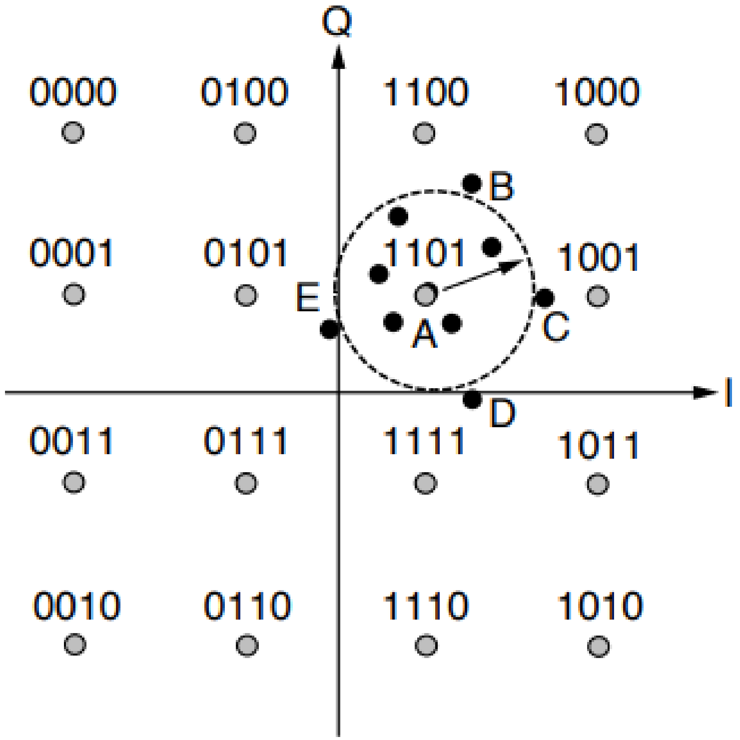


PSK QAM-16 QAM-64

Digital Modulation – Passband Modulation: Avoiding Errors

- How bits are mapped to symbols?
- Bit (Translation) Error

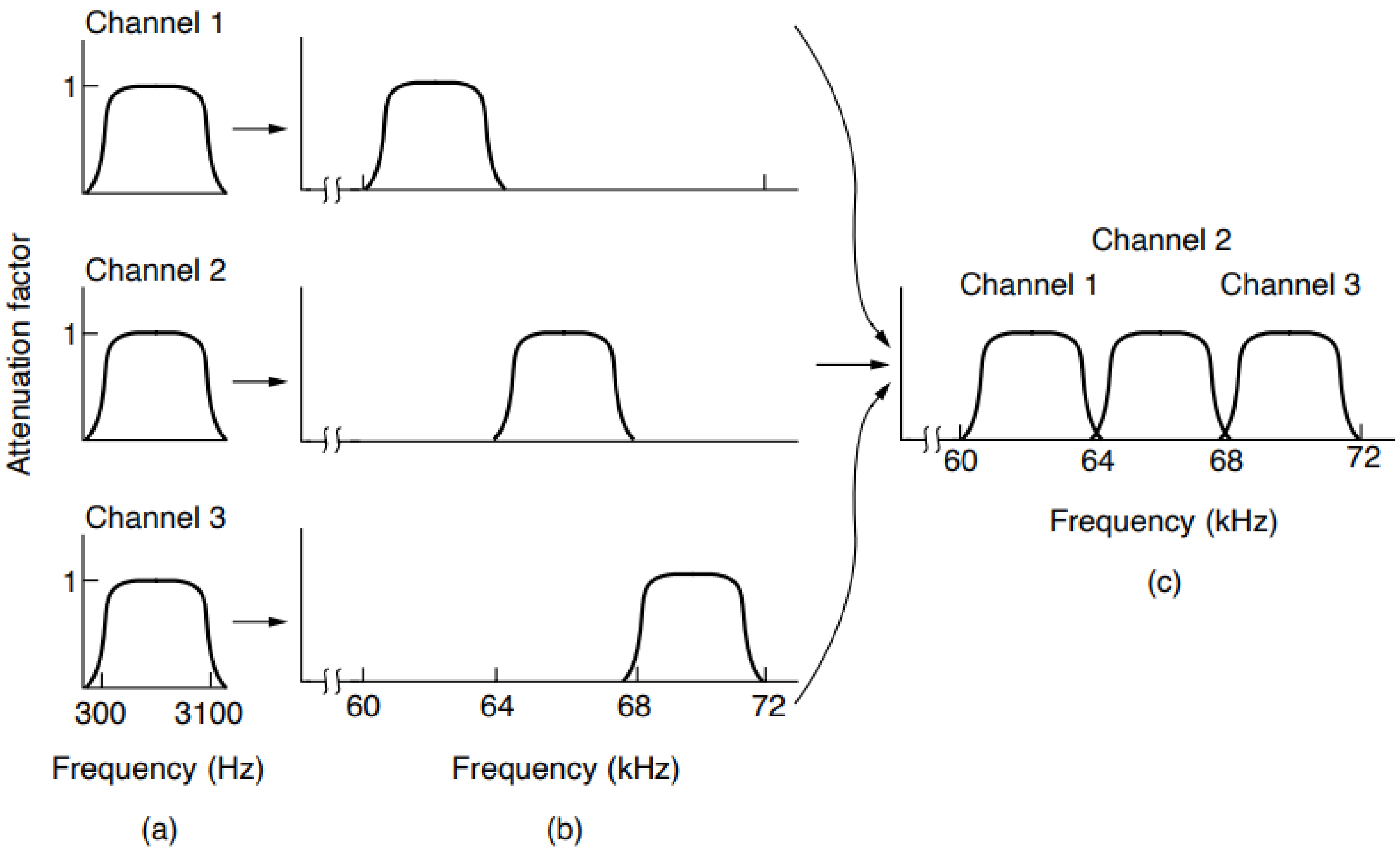




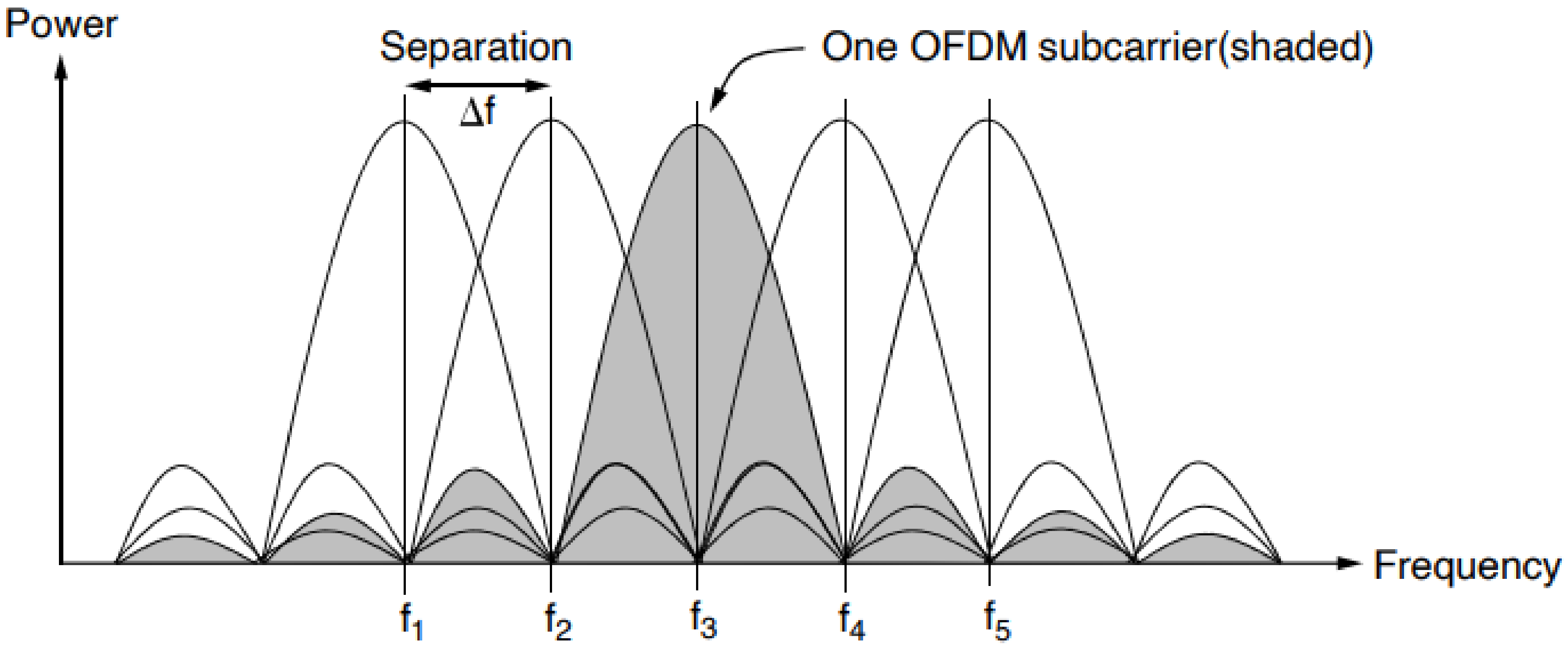
When 1101 is sent:

Point	Decodes as	Bit errors
A	1101	0
B	1100	1
C	1001	1
D	1111	1
E	0101	1

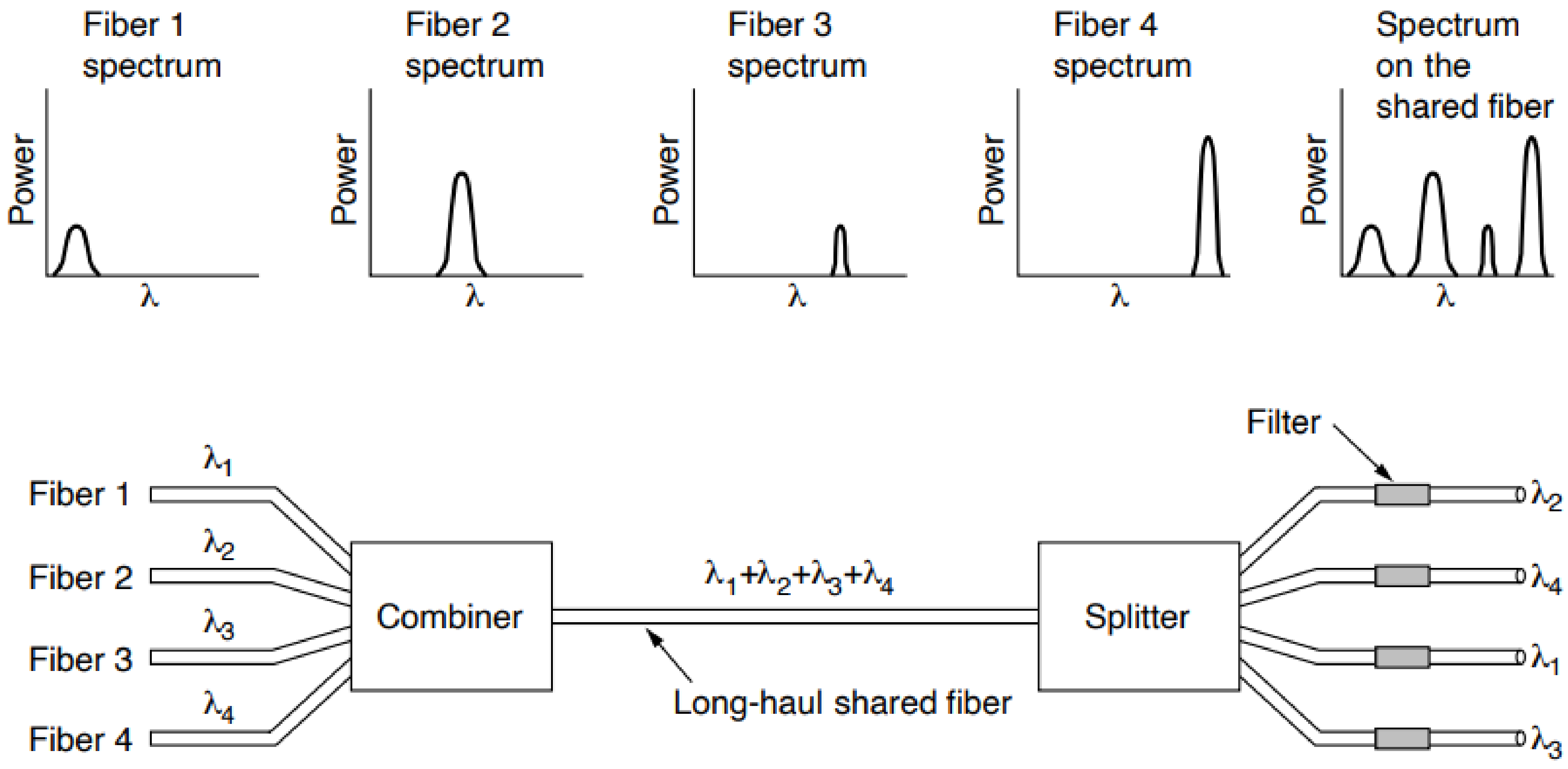
Digital Transmission – Multiplexing: Frequency Division Multiplexing



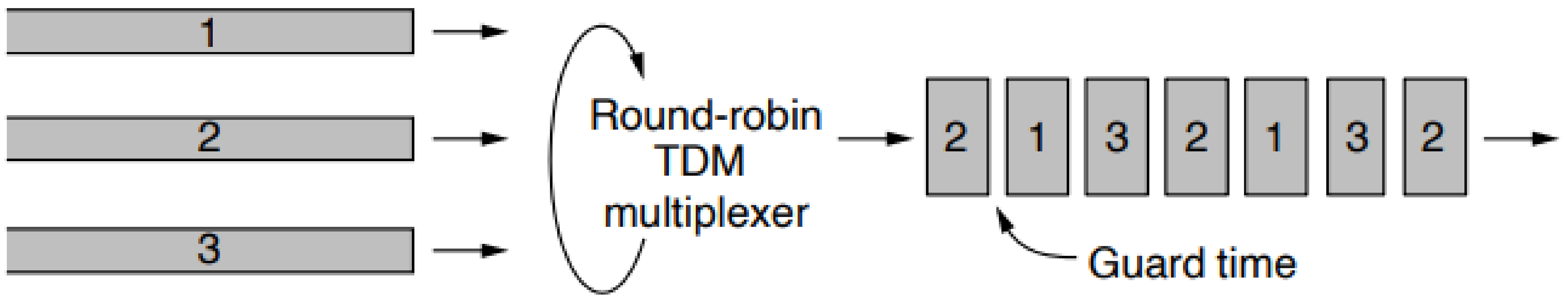
Digital Transmission – Multiplexing: Orthogonal FDM



Digital Transmission – Multiplexing: Wavelength Division Multiplexing



Digital Transmission – Multiplexing: Time Division Multiplexing



Digital Transmission – Multiplexing: Spatial Division Multiplexing

Digital Transmission – Multiplexing: Code Division Multiplexing

Fundamentals

- Each node has a unique "chip"
  - Binary sequence that identifies the node
  - Notation: 5-bit chip for node A

    A = (+1, -1, +1, +1, -1)
- Coding (for node A)
  - Bit 1: A = (+1, -1, +1, +1, -1)
  - Bit 0: ~A = (-1, +1, -1, -1, +1)
- Chips are **pair-wise orthogonal**
  - Technically: the inner product of each pair of chips is 0
  - Intuitively: there is the same number of "equal" pairs and "different" pairs

Properties

- Consider two chips S and T
- Assumption: S . T = 0
- Colloraries:
  - S . ~T = 0
  - S . S = 1
  - S . ~S = -1

Digital Transmission – Multiplexing: Code Division Multiplexing

Decoding

- All potential receiver nodes know chips of all transmitting nodes
  - When and how this information is shared?
- Received signal is S (combination of signals)
- To obtain node A's portion of S
  - Bit from node A = S . A

Example

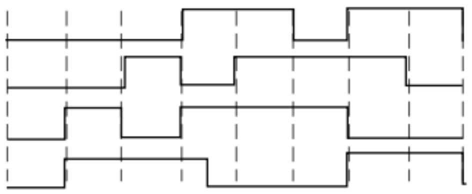
$A = (-1\ -1\ -1\ +1\ +1\ -1\ +1\ +1)$

$B = (-1\ -1\ +1\ -1\ +1\ +1\ +1\ -1)$

$C = (-1\ +1\ -1\ +1\ +1\ +1\ -1\ -1)$

$D = (-1\ +1\ -1\ -1\ -1\ -1\ +1\ -1)$

(a)



(b)

$S_1 = C = (-1\ +1\ -1\ +1\ +1\ +1\ -1\ -1)$

$S_2 = B+C = (-2\ \ 0\ \ 0\ \ 0\ +2\ +2\ \ 0\ -2)$

$S_3 = A+\overline{B} = (\ 0\ \ 0\ -2\ +2\ \ 0\ -2\ \ 0\ +2)$

$S_4 = A+\overline{B}+C = (-1\ +1\ -3\ +3\ +1\ -1\ -1\ +1)$

$S_5 = A+B+C+D = (-4\ \ 0\ -2\ \ 0\ +2\ \ 0\ +2\ -2)$

$S_6 = A+B+\overline{C}+D = (-2\ -2\ \ 0\ -2\ \ 0\ -2\ +4\ \ 0)$

(c)

$S_1 \bullet C = [1+1+1+1+1+1+1+1]/8 = 1$

$S_2 \bullet C = [2+0+0+0+2+2+0+2]/8 = 1$

$S_3 \bullet C = [0+0+2+2+0-2+0-2]/8 = 0$

$S_4 \bullet C = [1+1+3+3+1-1+1-1]/8 = 1$

$S_5 \bullet C = [4+0+2+0+2+0-2+2]/8 = 1$

$S_6 \bullet C = [2-2+0-2+0-2-4+0]/8 = -1$

(d)