Week 3: Data Communications Fundamentals (Cont'd)

EE3017/IM2003 Computer Communications

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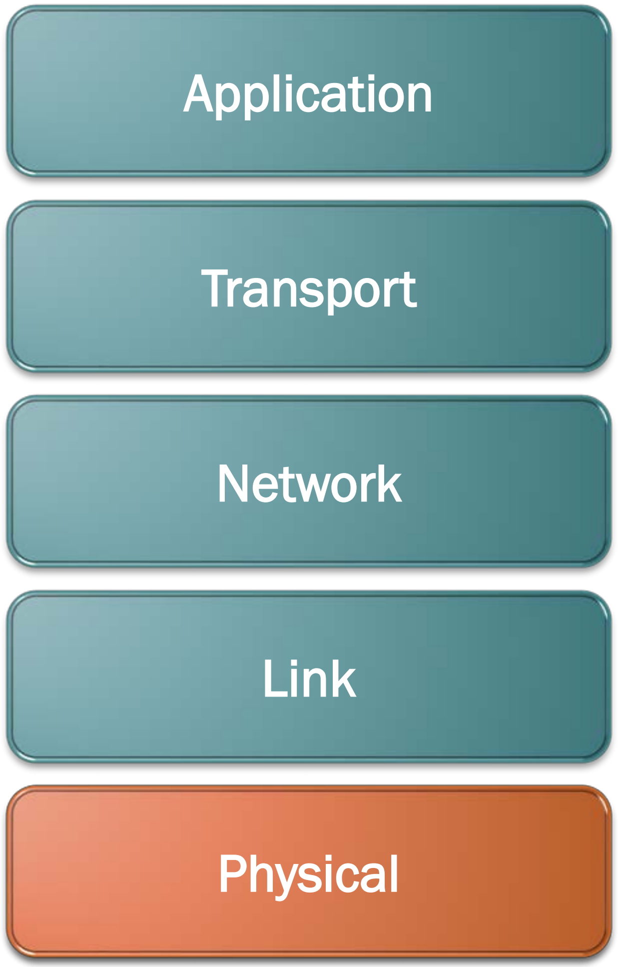
Topic Outline

Introduction to Computer Communications 01

Data Communications Fundamentals 02

Data Transmission and channel capacity,
Line coding and scramble code

Data Link Layer 03



Learning Objectives

By the end of this topic, you should be able to:

- Explain how the digital signals are represented in the six common line coding schemes:
  - Unipolar Non-Return-to-Zero (NRZ)
  - Polar Non-Return-to-Zero (NRZ-Level)
  - Differential Encoding (NRZ-Inverted)
  - Bipolar Encoding (Alternate Mark Inversion)
  - Manchester Encoding
  - Differential Manchester Encoding
- Evaluate the various line coding/modulation and scramble code techniques
- Explain the following scramble code schemes:
  - Bipolar with 8-Zero Substitution (B8ZS)
  - High Density Bipolar Order 3 (HDB3)

Line Coding and Modulation

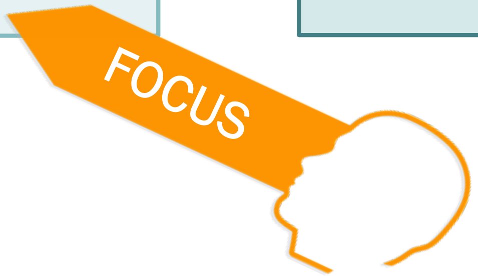
Line Coding and Modulation

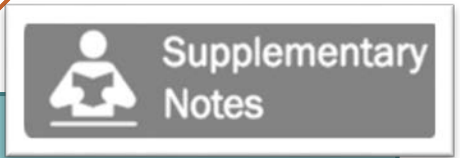
Need to find a proper digital signal to represent the data bits (0 and 1) in **baseband transmission.**

Need to find a proper analog representation (i.e. modulated carrier) of data bits for **bandpass transmission.**

Line Coding

Digital signals carry digital data.

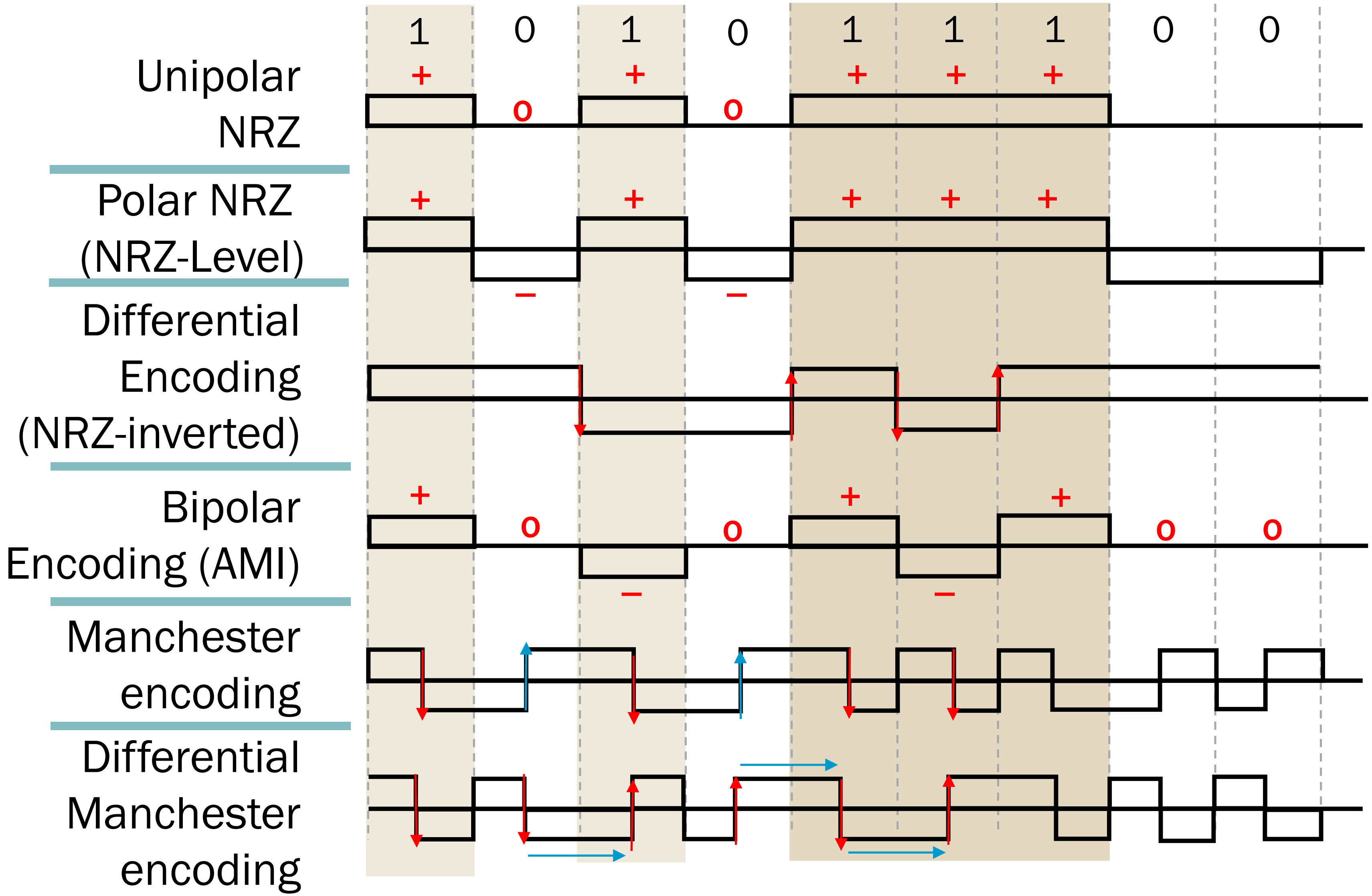




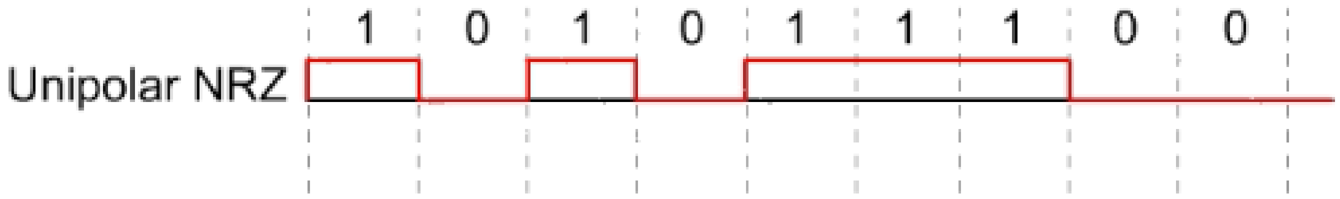
Modulation

Analog signals carry digital data.

Line Coding Schemes



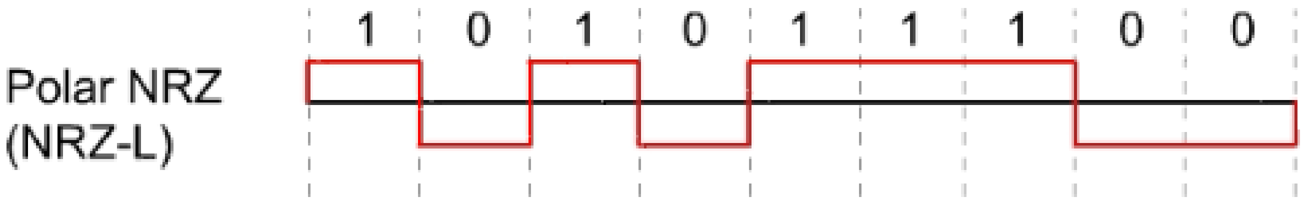
Unipolar Non-Return-to-Zero (NRZ)



Unipolar NRZ

- “1” maps to +A pulse
- “0” maps to no pulse
- Long strings of A or 0
  - Poor timing
  - Low-frequency content
- Simple

Polar Non-Return-to-Zero (NRZ-Level)



Polar NRZ

- “1” maps to +A/2 pulse
- “0” maps to –A/2 pulse
- Long strings of +A/2 or –A/2
  - o Poor timing
  - o Low-frequency content
- Simple

Evaluation of NRZ Codes

Pros

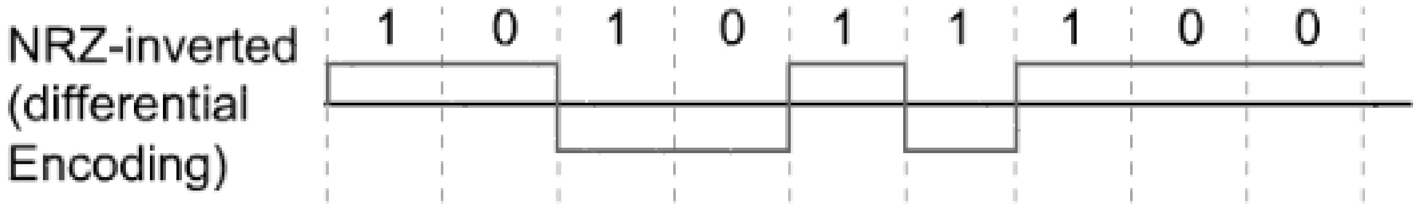
- Easy to engineer
- Make good use of bandwidth
  - less transition less bandwidth

Cons

- Sequence of 0’s or 1’s produces DC components
- Lack of synchronisation capability
  - lacks transitions for long strings of 0’s or 1’s

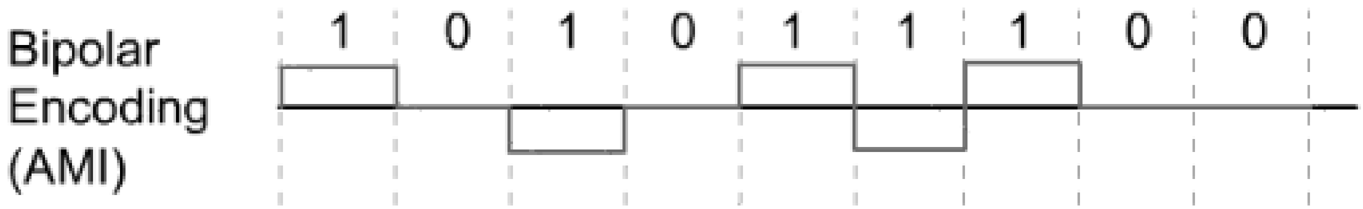
Used for some applications like magnetic recording but seldom used for signal transmission.

Differential Encoding (NRZ-Inverted)



- “1” maps into **transition** in signal level at start of the bit.
- “0” maps into **no transition** in signal level at start of the bit.

Bipolar Encoding (Alternate Mark Inversion)



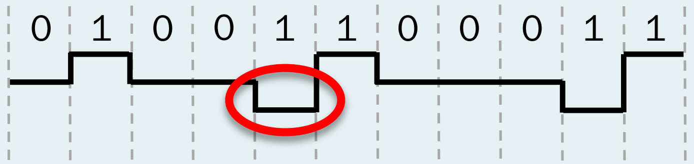
- Three signal levels: {-A, 0, +A}
- “1” maps to +A or –A in alternation
- “0” maps to no pulse
- Every +pulse is matched by –pulse, so little content at low frequencies
- String of 1’s produces a square wave
- Long string of 0’s causes receiver to lose timing synchronisation
  - Use Zero-substitution codes to break long 0’s sequence

Evaluation of AMI Codes

Pros

- Easy error detection
  - o deleting or adding a pulse violates the code property
  - o code violation can be used to detect code substitution

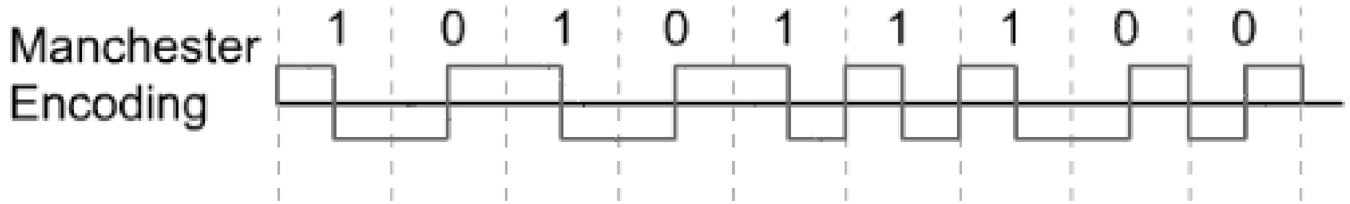
Bipolar Encoding (AMI)



Cons

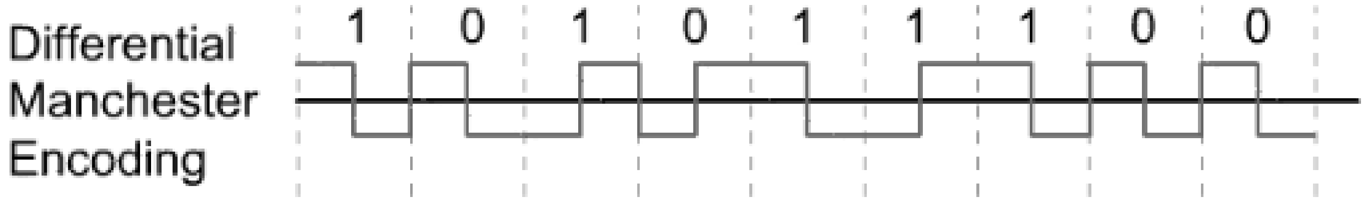
- Not as efficient as NRZ
  - o Each signal element only represents one bit
  - o But a 3-level system should have been able to represent $\log_2 3$ = 1.58 bits
  - o Receiver must distinguish between three levels instead of two
- Absence of transitions in a long sequence of 0's can result in loss in synchronisation

Manchester Encoding



- “1” maps into high-to-low transition (A/2 first T/2, -A/2 last T/2)
- “0” maps into low-to-high transition (-A/2 first T/2, A/2 last T/2)
- Every interval has a transition in the middle
  - Self-clocking feature
  - Timing recovery is easy
  - Uses double the minimum bandwidth
- Simple to implement
- Used in Ethernet (modified version)

Differential Manchester Encoding

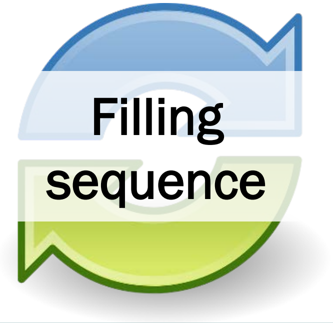


- Mid-bit transition is clocking only
- Transition at start of a bit period represents zero
- No transition at start of a bit period represents one
- Used by IEEE 802.5 (Token ring)
- Performance similar to Manchester Encoding

Scramble Codes

Scramble Codes

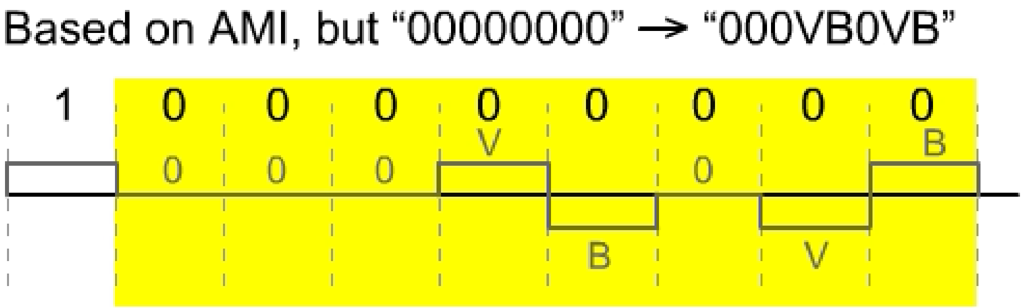
- AMI would be suitable for long distance transmission if long 0's can be avoided.
- Use scramble code to replace sequences that will produce constant voltage. AMI coding combined with different scrambling schemes have been used for long distance transmissions. Such as:
  - B8ZS (Bipolar with 8-Zeros Substitution, North America)
  - HDB3 (High Density Bipolar Order 3, Europe, Japan)



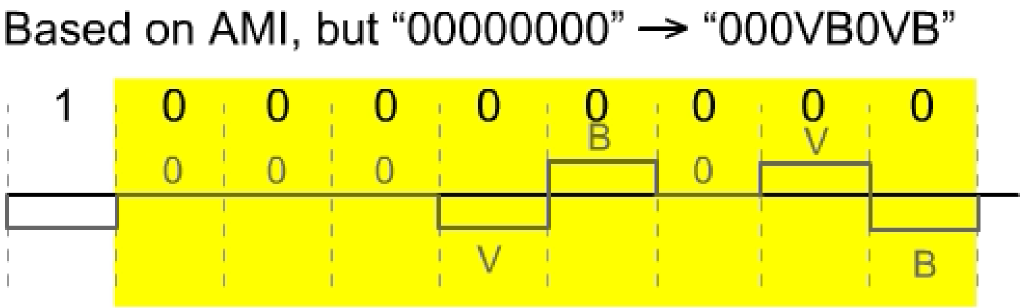
- Must produce enough transitions to synchonise
- Must be recognised by receiver and replaced with original
- Same length as original sequence

- No DC component
- No long sequences of zero level line signal
- No reduction in data rate
- Error detection capability

Bipolar with 8 Zeros Substitution (B8ZS)



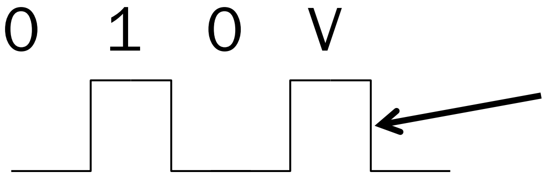
a. Previous level is positive.



b. Previous level is negative.

"V"
- stands for "violation bit"
- follows the polarity of previous non-zero bit

"B"
- stands for "bipolar bit" or "balance bit"
- Inverses the polarity of previous non-zero bit



Violates the AMI rules.

(AMI: V+, V- appears alternatively)

Causes two violations of AMI code:

- Unlikely to occur as a result of noise.
- Receiver detects and interprets as octet of all zeros.

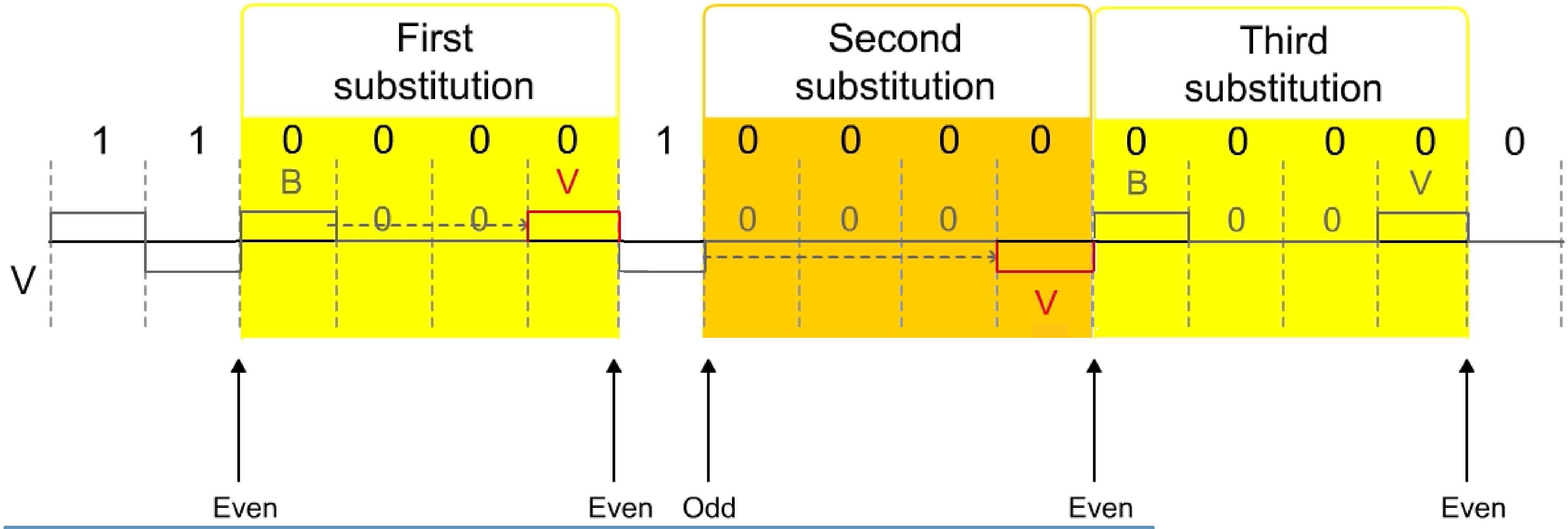
High Density Bipolar 3 Zeros (HDB3)

Count the number of bipolar bits between last “V” and “0000”.

of "1"s

If odd, “0000” → “000V”

If even, “0000” → “B00V”



Two different substitutions are for the balance of polarity.

Summary

Summary

Key points discussed in this topic:

- Six common line coding schemes:
  - Unipolar Non-Return-to-Zero (NRZ)
  - Polar Non-Return-to-Zero (NRZ-Level)
  - Differential Encoding (NRZ-Inverted)
  - Bipolar Encoding (Alternate Mark Inversion)
  - Manchester Encoding
  - Differential Manchester Encoding

- Evaluation of the line coding schemes in terms of synchronisation, low frequency content (DC component), bandwidth efficiency, energy consumption.

Summary

Key points discussed in this topic (cont'd):

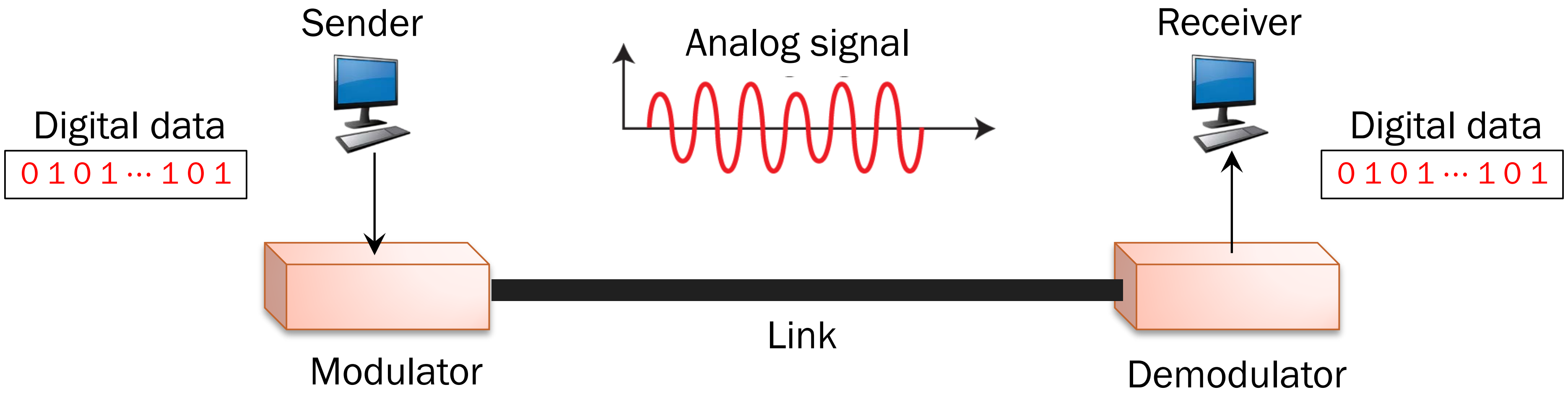
- Scramble codes are used to replace sequences that will produce constant voltage. AMI coding combined with different scramble code schemes have been used for long distance transmissions. Such as:
  - B8ZS (Bipolar with 8-Zeros Substitution, North America)
  - HDB3 (High Density Bipolar Order 3, Europe, Japan)

Modulation

Supplementary Notes

Digital Modulation

- Represent digital data by using modulated carrier waves in a bandpass channel
  - o E.g. Home access via modem
    - ➢Carrier analogue signal from 300 Hz to 3400 Hz (public phone system)
    - ➢Use modem to convert digital signal to analog signals and vice versa
  - o Amplitude shift keying (ASK)
  - o Frequency shift keying (FSK)
  - o Phase shift keying (PSK)



Types of Digital Modulation

Digital data

0 1 0 1 ⋯ 1 0 1

Carrier wave: $A \sin(2\pi f t + \varphi)$

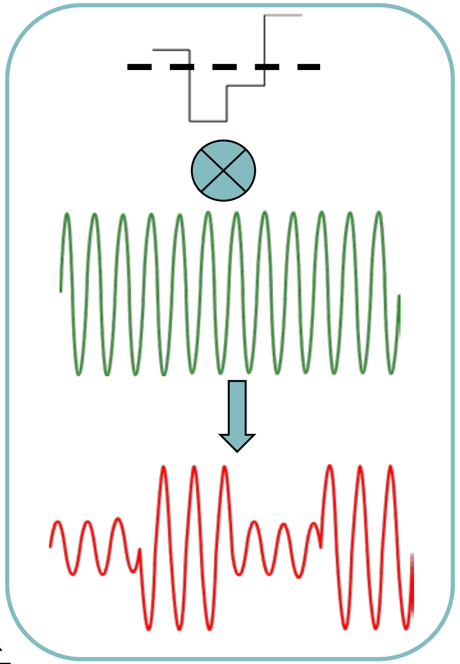
Digital-to-analog conversion

Amplitude shift keying (ASK)

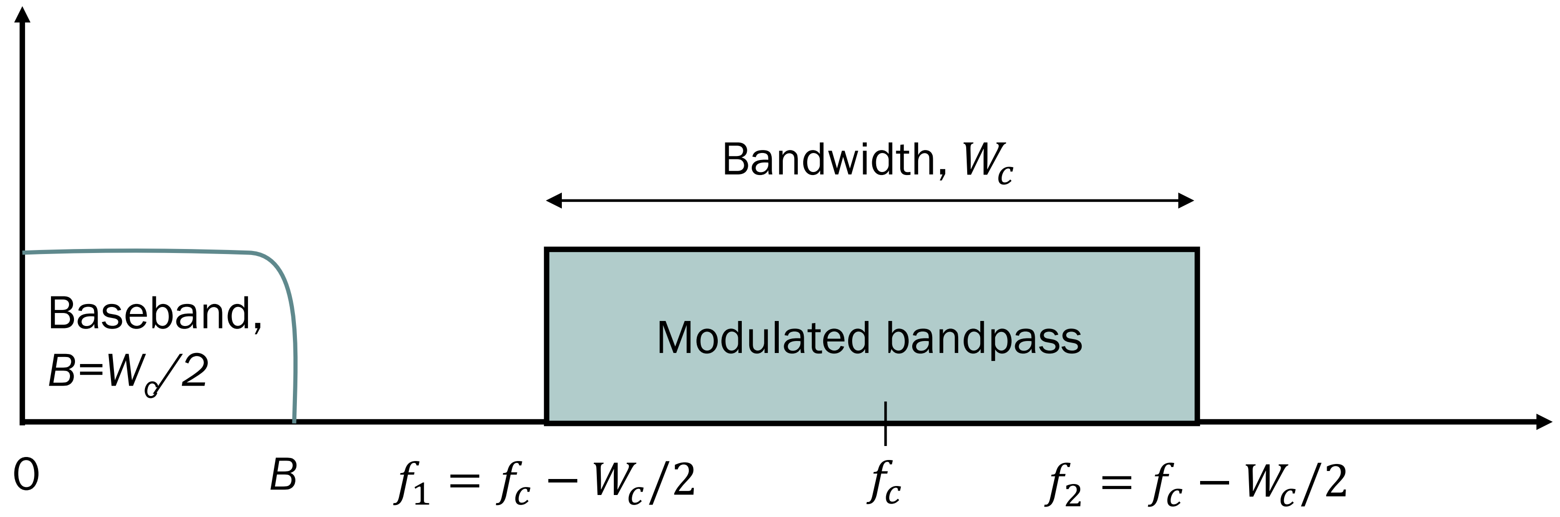
Frequency shift keying (FSK)

Phase shift keying (PSK)

Quadrature amplitude modulation (QAM)

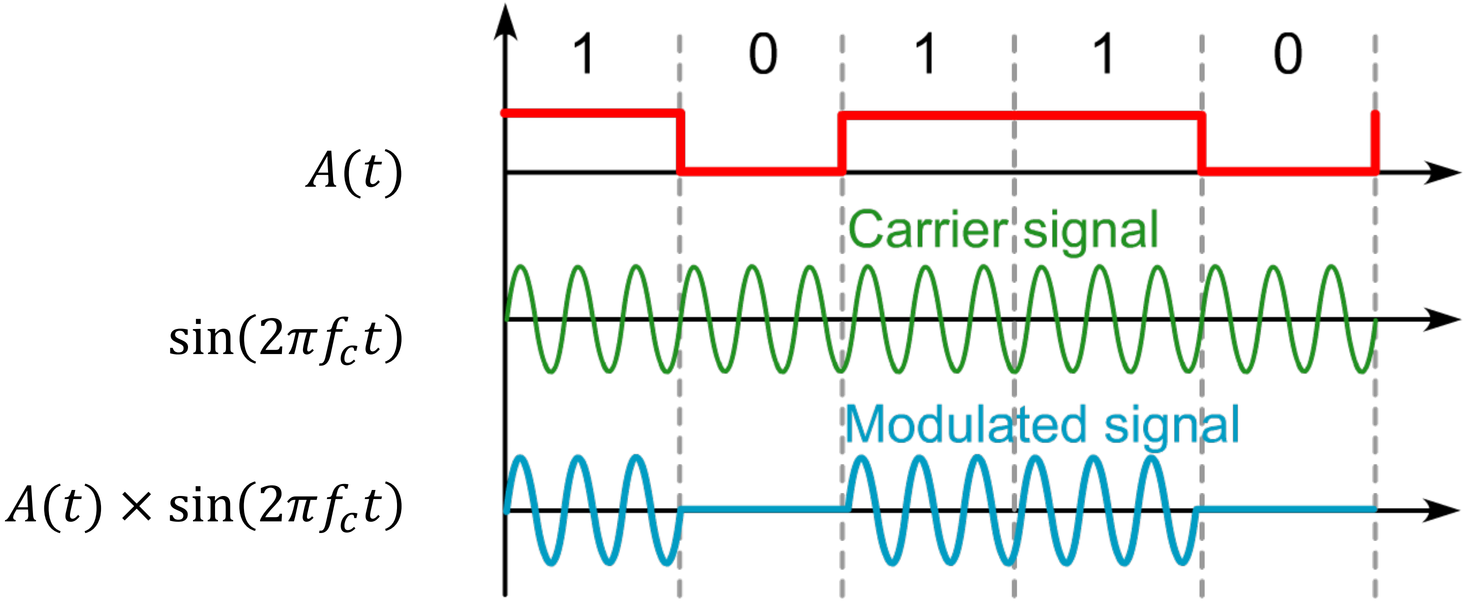


Bandpass Channels



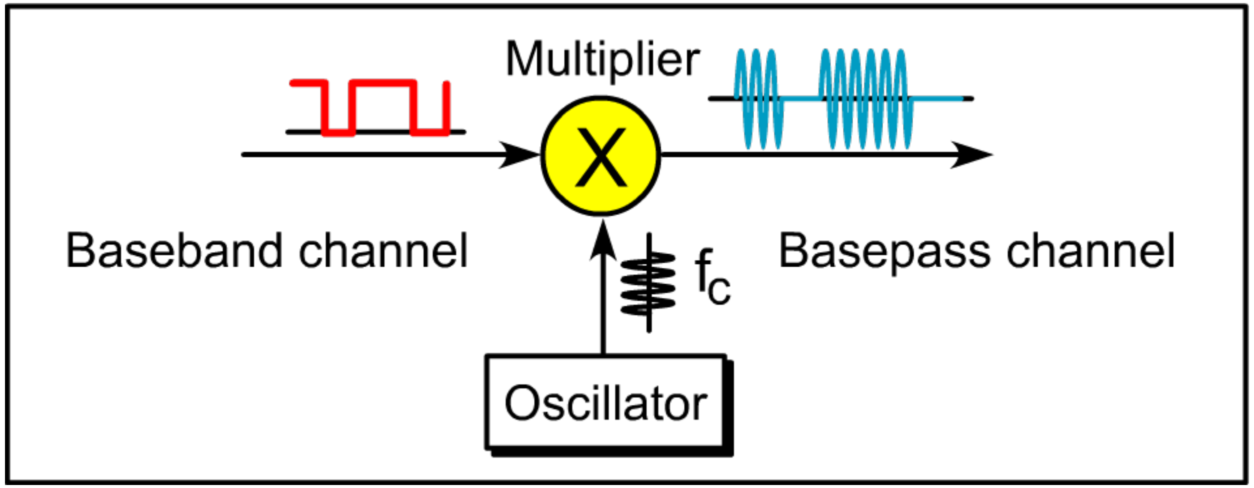
- Bandpass channels pass a range of frequencies around some centre frequency $f_c = (f_1 + f_2)/2$
  - o Radio channels, telephone and DSL modems
- Digital modulators embed information into waveform with frequencies passed by bandpass channel
- Sinusoid of frequency f_c is centred in middle of bandpass channel
- Modulators embed information into a sinusoid

Amplitude Shift Keying (ASK)



$A(t)$ is unipolar NRZ coded

$A(t) \times \sin(2\pi f_c t)$

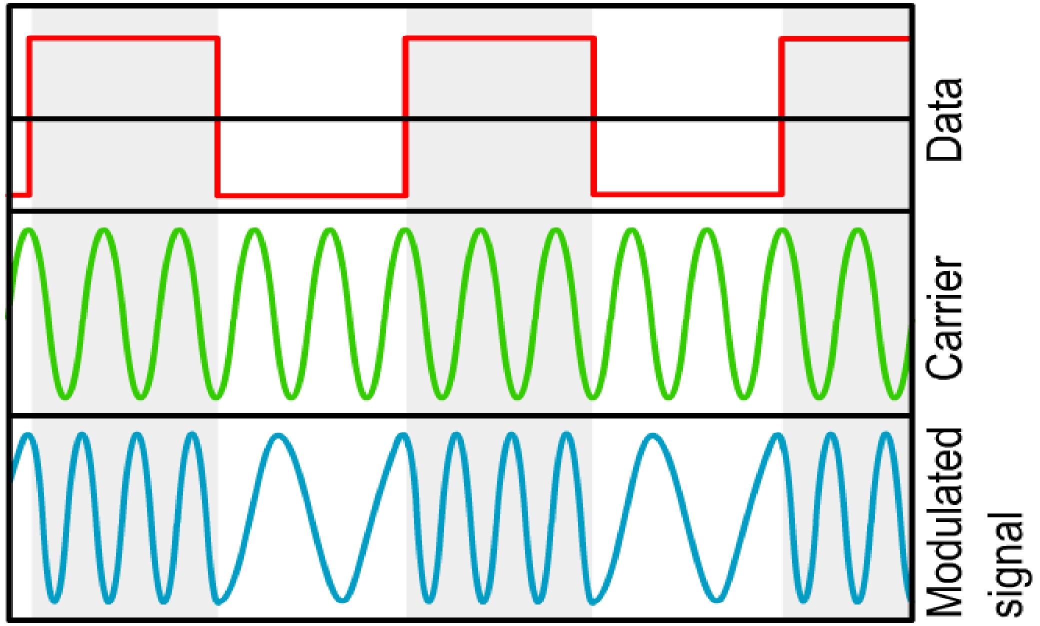


Binary Frequency Shift Keying (BFSK)

$\Delta f(t)$

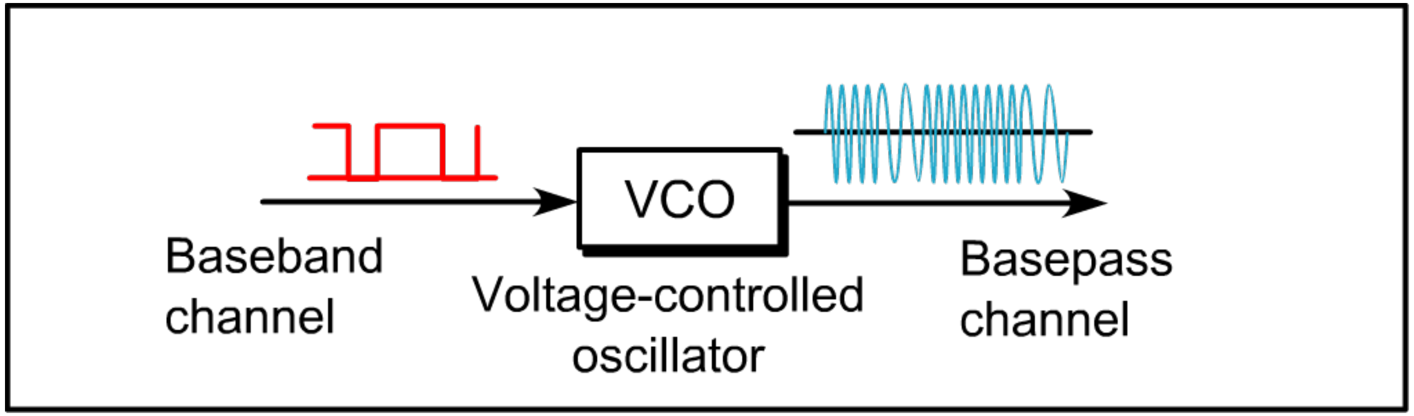
$\sin(2\pi f_c t)$

$\sin(2\pi(f_c + \Delta f(t))t)$



$\Delta f(t)$ is polar NRZ coded

$\sin(2\pi(f_c + \Delta f(t))t)$

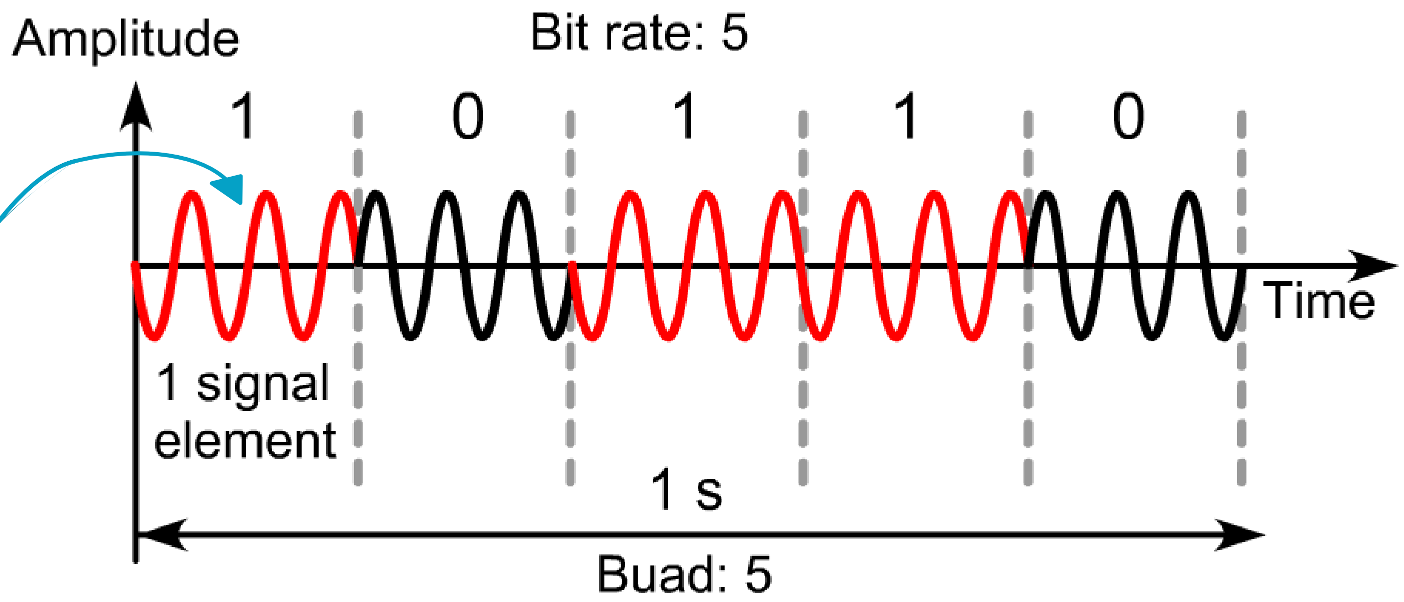


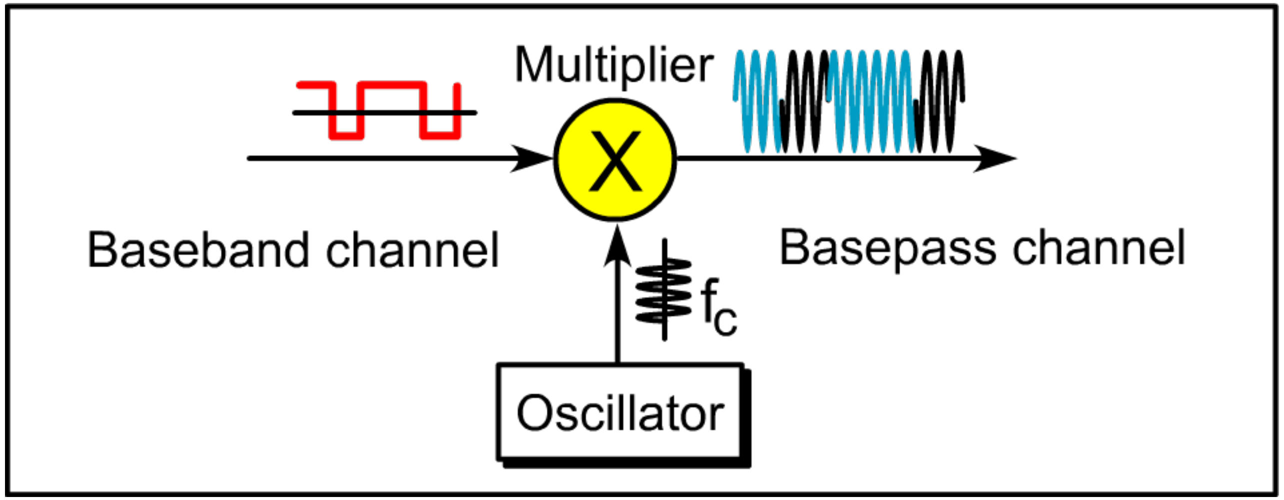
Phase Shift Keying (PSK)

$$\sin(2\pi f_c t + \varphi(t))$$

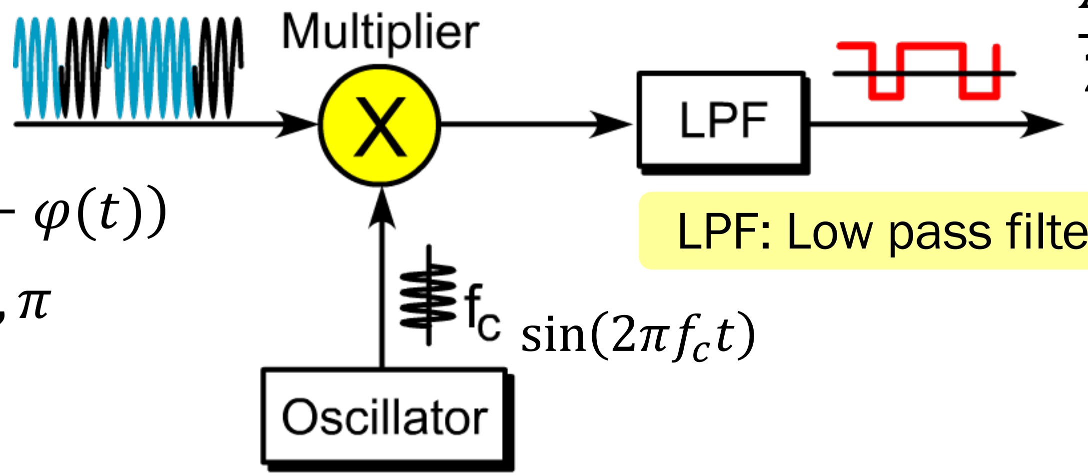
$$\varphi(t) = \begin{cases} 0 & \text{"0"} \\ \pi & \text{"1"} \end{cases}$$

$$\sin(2\pi f_c t + \pi) = -\sin(2\pi f_c t)$$





Demodulation of PSK



$$A\sin(2\pi f_c t + \varphi(t))$$

$$\varphi(t) = 0, \pi$$

$$\sin(2\pi f_c t)$$

LPF: Low pass filter

$$\frac{A}{2}\cos(\varphi(t)) = \begin{cases} \frac{A}{2} & \varphi(t) = 0 \\ -\frac{A}{2} & \varphi(t) = \pi \end{cases}$$

$$A\sin(2\pi f_c t + \varphi(t))\sin(2\pi f_c) = \frac{A}{2}\left[\underbrace{\cos(\varphi(t))}_{\text{Low freq.}} - \underbrace{\cos(4\pi f_c t + \varphi(t))}_{\text{High freq.}}\right]$$

Can we use $\cos(2\pi f_c t)$ to demodulate the same signal?

Quadrature Modulation

- In coherent system, receiver ‘knows’ the phase of the incoming carrier wave.

- Under coherent detection schemes, “sin” and “cos” waves are two distinctive carrier waves which can carry signals independently in the same channel without cross talk.

- Signal carried by “cos” wave is called in-phase component; signal carried by “sin” wave is called quadrature component.

$$\boxed{\sin(2\pi f_c t) = \cos(2\pi f_c t + \pi/2)}$$

- Quadrature modulation refers to modulation schemes that carry signals on both in-phase and quadrature components.

- Quadrature modulation technique is widely used in modern communication systems.

Quadrature Modulation (Cont'd)

Combine ASK and PSK to modulate the amplitude of "sin" and "cos".

$$A(t)\cos(2\pi f_c t + \varphi(t)) \Rightarrow A(t)\cos(2\pi f_c t)$$

ASK: $A(t) = A, 3A$

PSK: $\varphi(t) = 0, \pi$

$$A(t) = \begin{cases} 3A & "11"\ (3A, 0) \\ A & "10"\ (A, 0) \\ -A & "01"\ (A, \pi) \\ -3A & "00"\ (3A, \pi) \end{cases}$$

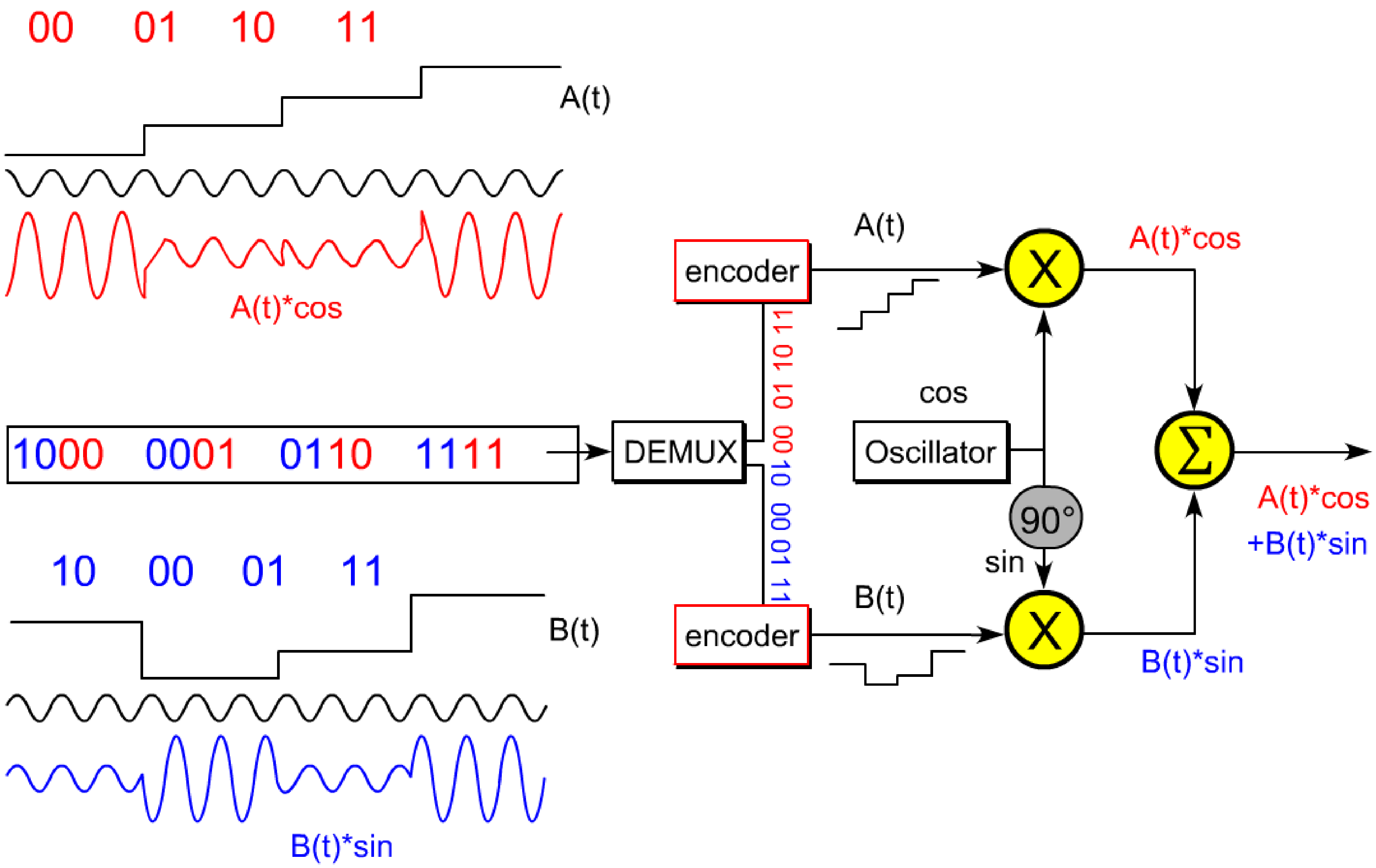
$$B(t)\sin(2\pi f_c t + \theta(t)) \Rightarrow B(t)\sin(2\pi f_c t)$$

ASK: $B(t) = B, 3B$

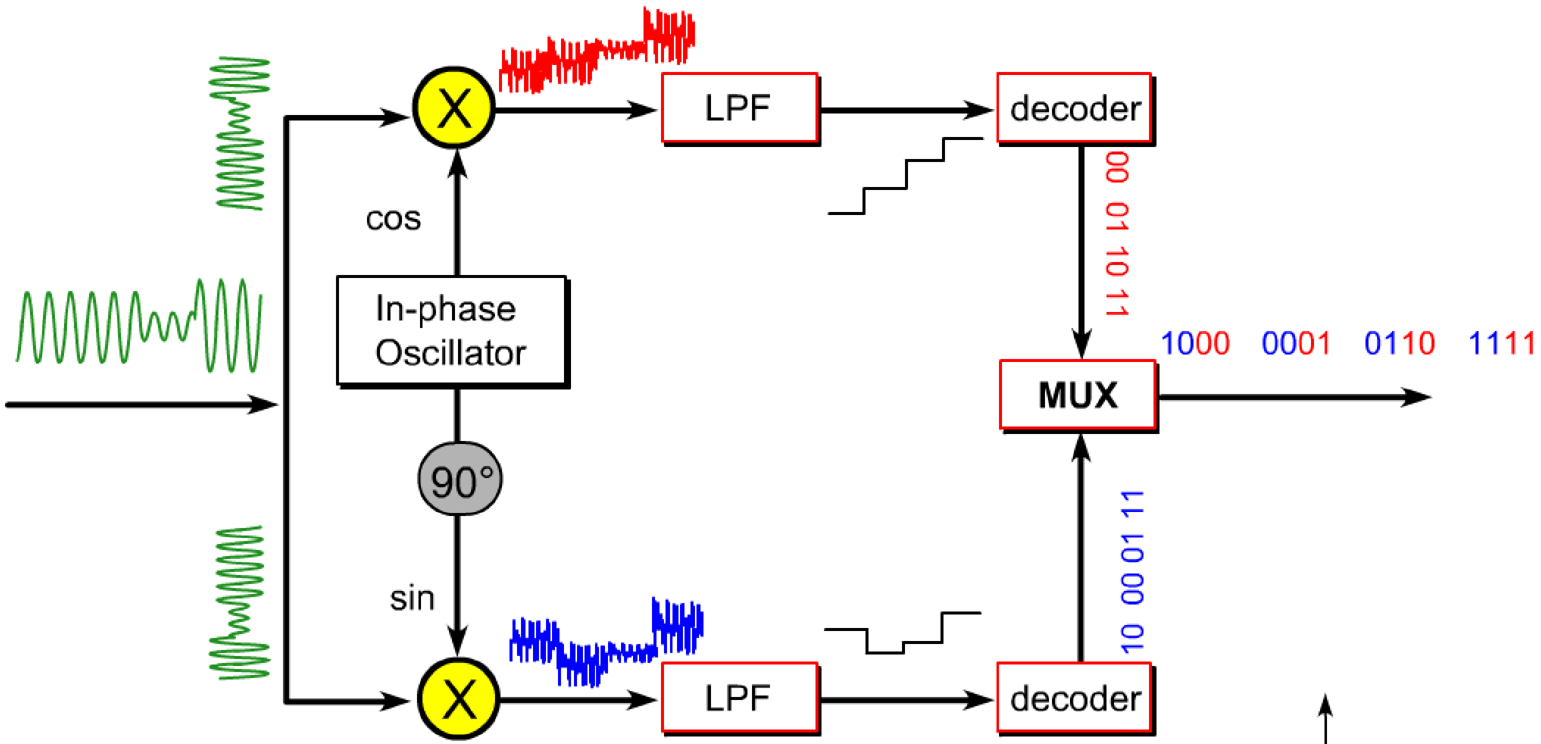
PSK: $\theta(t) = 0, \pi$

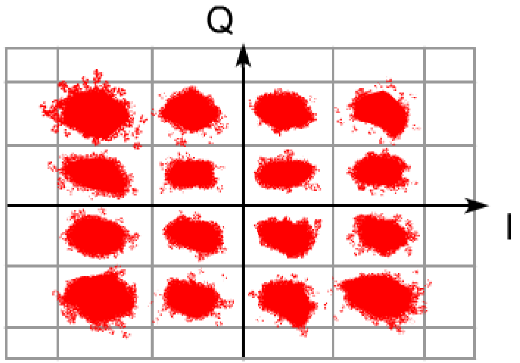
$$B(t) = \begin{cases} 3B & "11"\ (3B, 0) \\ B & "10"\ (B, 0) \\ -B & "01"\ (B, \pi) \\ -3B & "00"\ (3B, \pi) \end{cases}$$

QAM Modulation



QAM Demodulation





16-QAM constellation diagram