ECE2305 Lecture Slides

William StallingsData and Computer Communications Eighth Edition
Section 5.2 – "Digital Data, Analog Signals"

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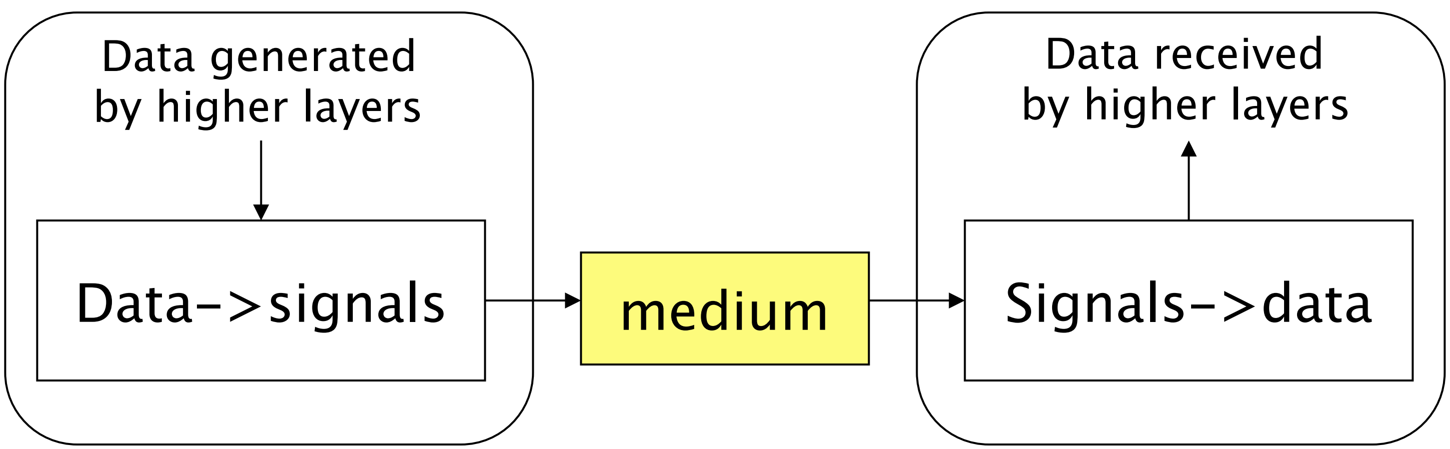
Adapted from Prentice Hall instructor resources

Basics of Signal Encoding

- Important function of the physical layer: Convert data (e.g. bits) to signals (e.g. voltages).
- The signal must be designed to **efficiently propagate through the medium**.
- The signal must also be designed so that the receiver can **correctly interpret** it.

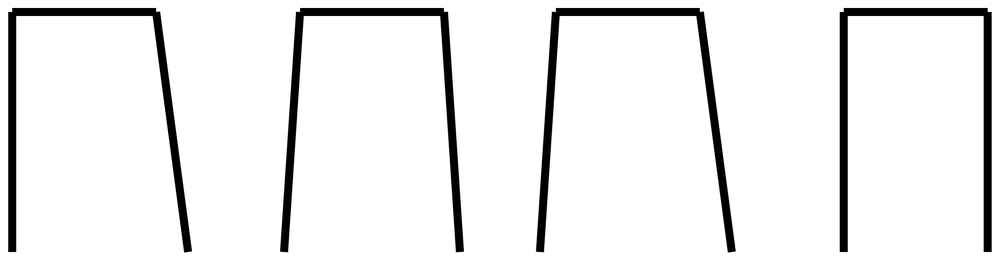


How to convey digital information with signals

- Need two things:
  - A set of $M=2^L$ distinct signals
    - Each signal is called a “symbol”
    - The set is called an “alphabet”
  - A unique mapping between blocks of N bits and each signal
- Example (N=2)
  - Signal set = {  } (2^2 = 4 signals)
  - Unique mapping
    - Logical 00 <-> 
    - Logical 01 <-> 
    - Logical 10 <-> 
    - Logical 11 <-> 

What does this signal mean? 

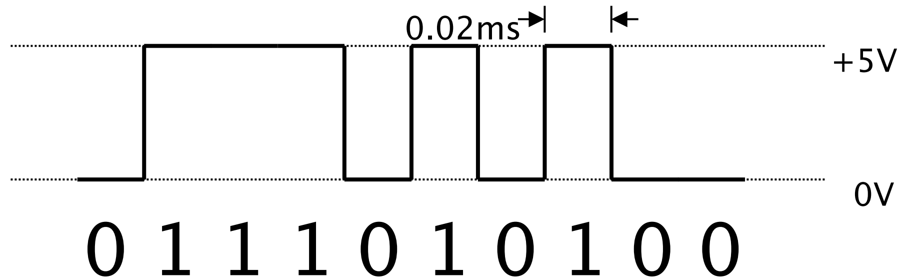
An Example of a Bad Alphabet



Why is this alphabet bad?

“Analog” Signaling Basics

- Recall “digital” signaling, e.g.



- Digital signaling is inappropriate in many scenarios (interference with other signals or inefficient propagation):
  - Wireless communication
  - Optical communication
  - Cable modems
  - Digital subscriber loops (DSL)
  - Even basic voiceband modems (300Hz-3400Hz channel)
- Need “analog” signals in these cases

Common “Analog” Signals for Communication

- Main idea: Alphabet composed of **sinusoidal** signals with distinct amplitude, frequency, and/or phase shifts
- Sinusoidal signals allow control of signal spectrum
  - Efficient propagation in desired medium
  - Avoid interference with other signals
- Pure methods:
  - Amplitude shift keying (ASK)
  - Frequency shift keying (FSK)
  - Phase shift keying (PSK)
- Hybrid methods:
  - Quadrature amplitude modulation (QAM) (signals distinguished by both amplitude and phase shifts)

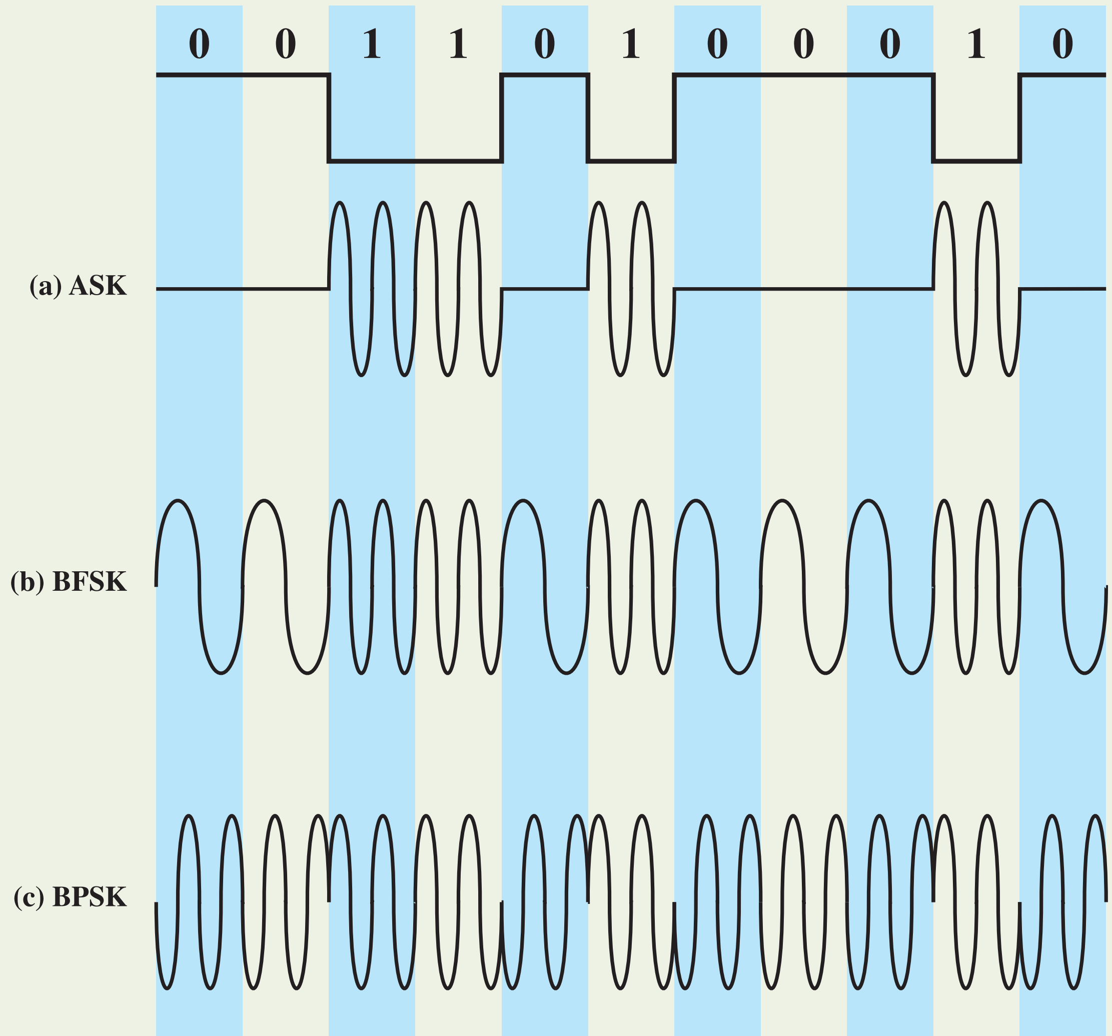
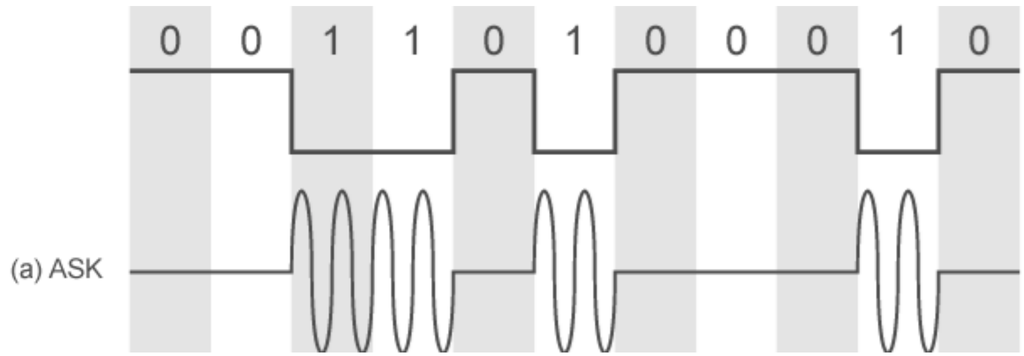
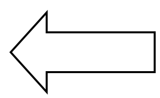


Figure 5.7 Modulation of Analog Signals for Digital Data

Amplitude Shift Keying

- encode data in signal **amplitude**, e.g.
  - Logical 0 -> 0sin(wt)
  - Logical 1 -> Asin(wt)
- Can have more than two amplitudes, e.g.
  - Logical 00 -> 0sin(wt)
  - Logical 01 -> Asin(wt)
  - Logical 10 -> 2Asin(wt)
  - Logical 11 -> 3Asin(wt)
- Used for
  - up to 1200bps telephone modems
  - optical fiber (light on/off)

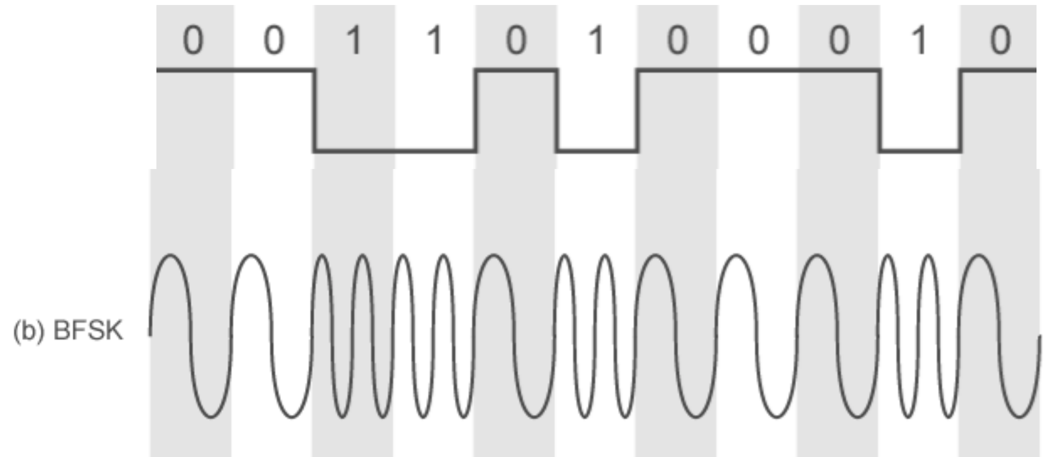




Higher data rate but either increased power or likelihood of error at receiver

Frequency Shift Keying

- encode data in signal **frequency**, e.g.
  - Logical 0 –> sin(wt)
  - Logical 1 –> sin(2wt)
- Can have more than two frequencies, e.g.
  - Logical 00 –> sin(wt)
  - Logical 01 –> sin(2wt)
  - Logical 10 –> sin(3wt)
  - Logical 11 –> sin(4wt)
- Better error resistance than ASK
- Used in old voiceband modems (300 bps)

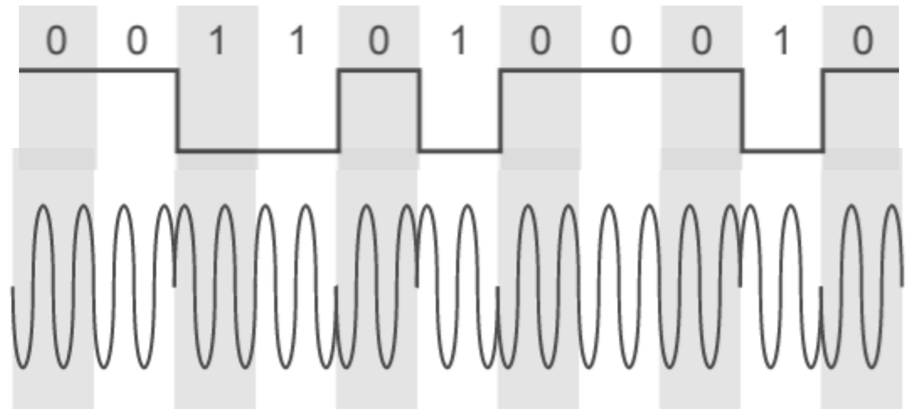


Higher data rate but
either increased bandwidth
or increased likelihood
of error at receiver

Phase Shift Keying

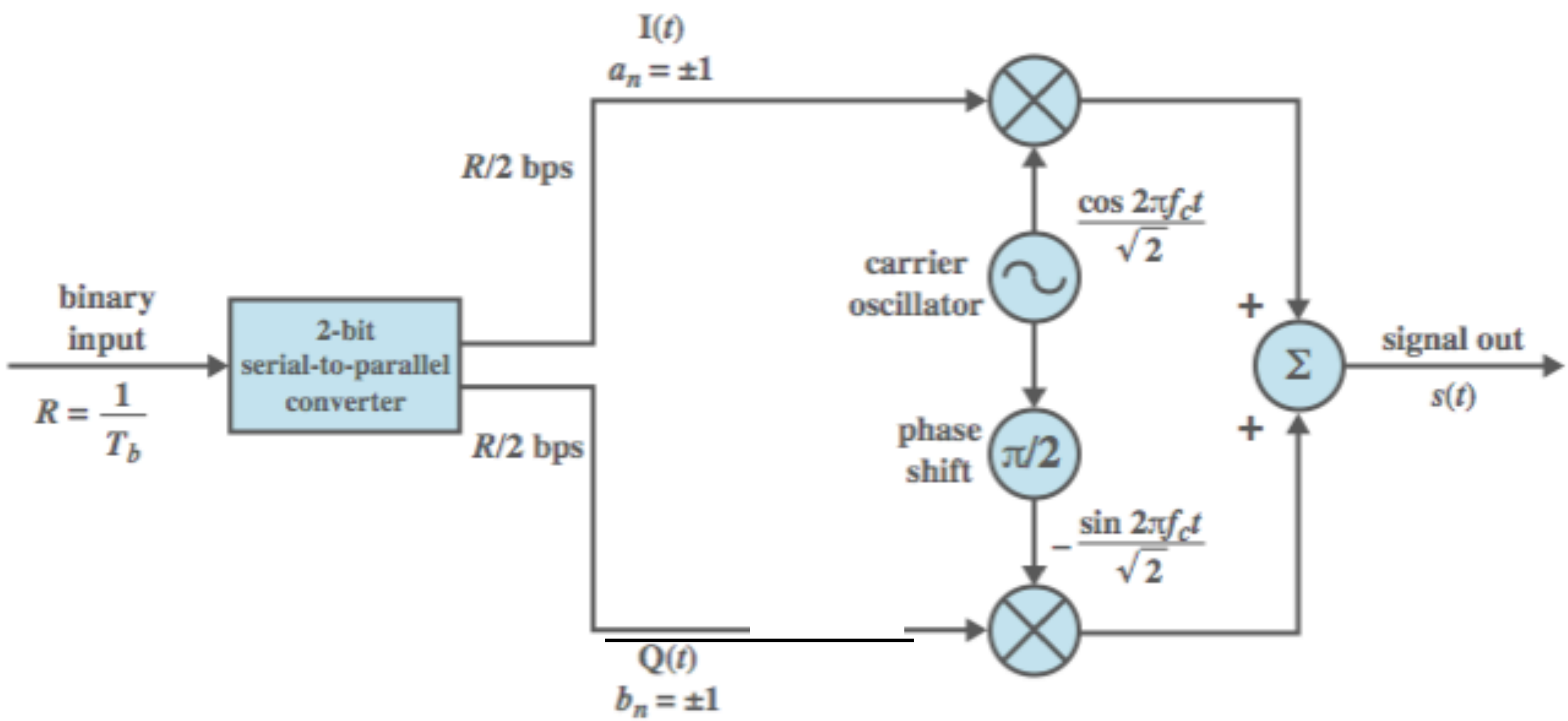
- encode data in signal **phase**, e.g.
  - Logical 0 –> sin(wt+0)
  - Logical 1 –> sin(wt+pi)
- Can have more than two phases, e.g.
  - Logical 00 –> sin(wt+0)
  - Logical 01 –> sin(wt+pi/2)
  - Logical 10 –> sin(wt+pi)
  - Logical 11 –> sin(wt+3pi/2)
- This is called quadrature PSK (QPSK) – very popular for wireless communication

(c) BPSK



Higher data rate but increased likelihood of error at receiver

QPSK Modulator Block Diagram



Spectral Efficiency

$$\eta = \frac{R}{B}$$

	$r = 0$	$r = 0.5$	$r = 1$
ASK	1.0	0.67	0.5
Multilevel FSK			
$M = 4, L = 2$	0.5	0.33	0.25
$M = 8, L = 3$	0.375	0.25	0.1875
$M = 16, L = 4$	0.25	0.167	0.125
$M = 32, L = 5$	0.156	0.104	0.078
PSK	1.0	0.67	0.5
Multilevel PSK			
$M = 4, L = 2$	2.00	1.33	1.00
$M = 8, L = 3$	3.00	2.00	1.50
$M = 16, L = 4$	4.00	2.67	2.00
$M = 32, L = 5$	5.00	3.33	2.50

Bit Error Rates

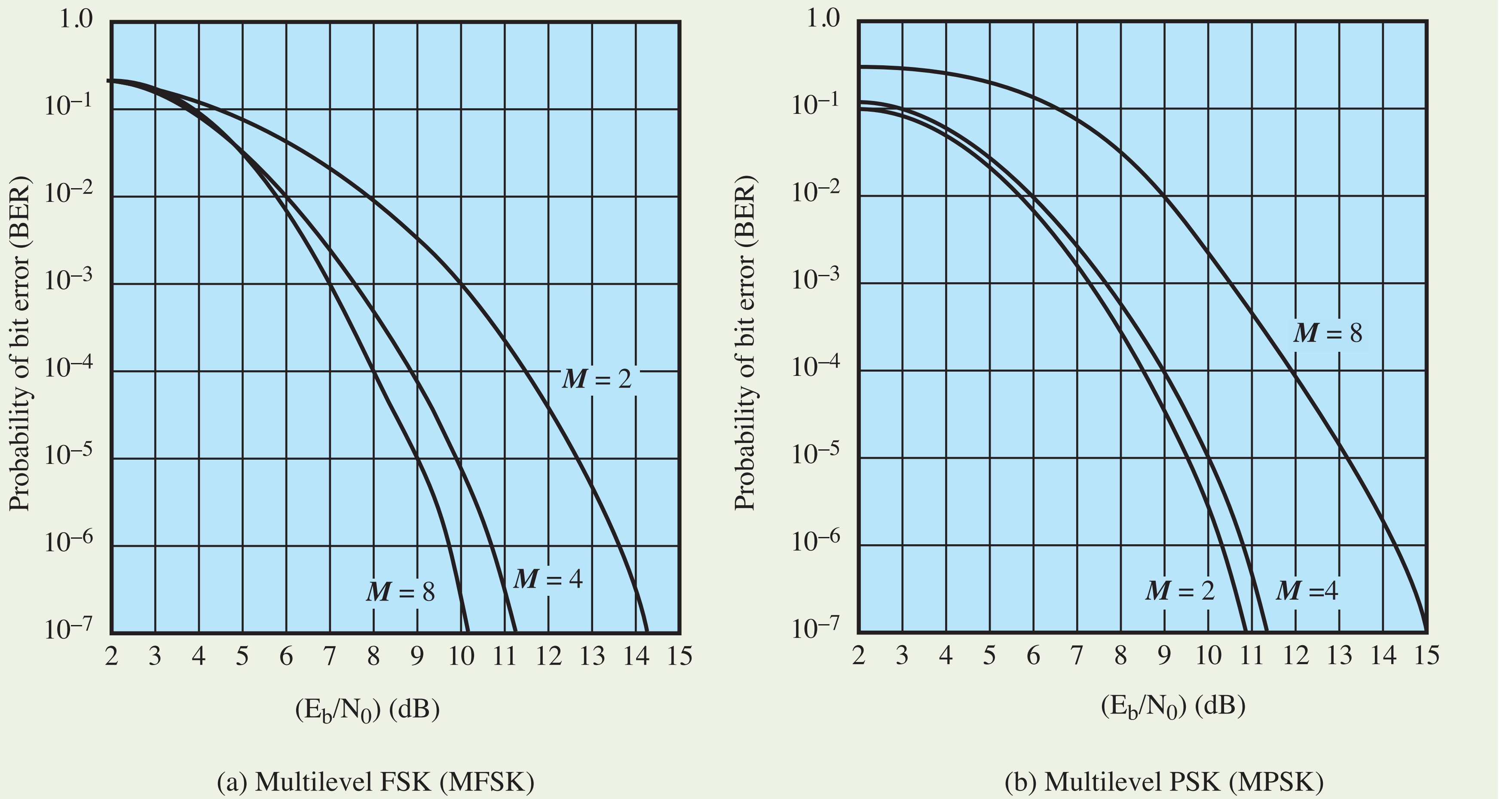
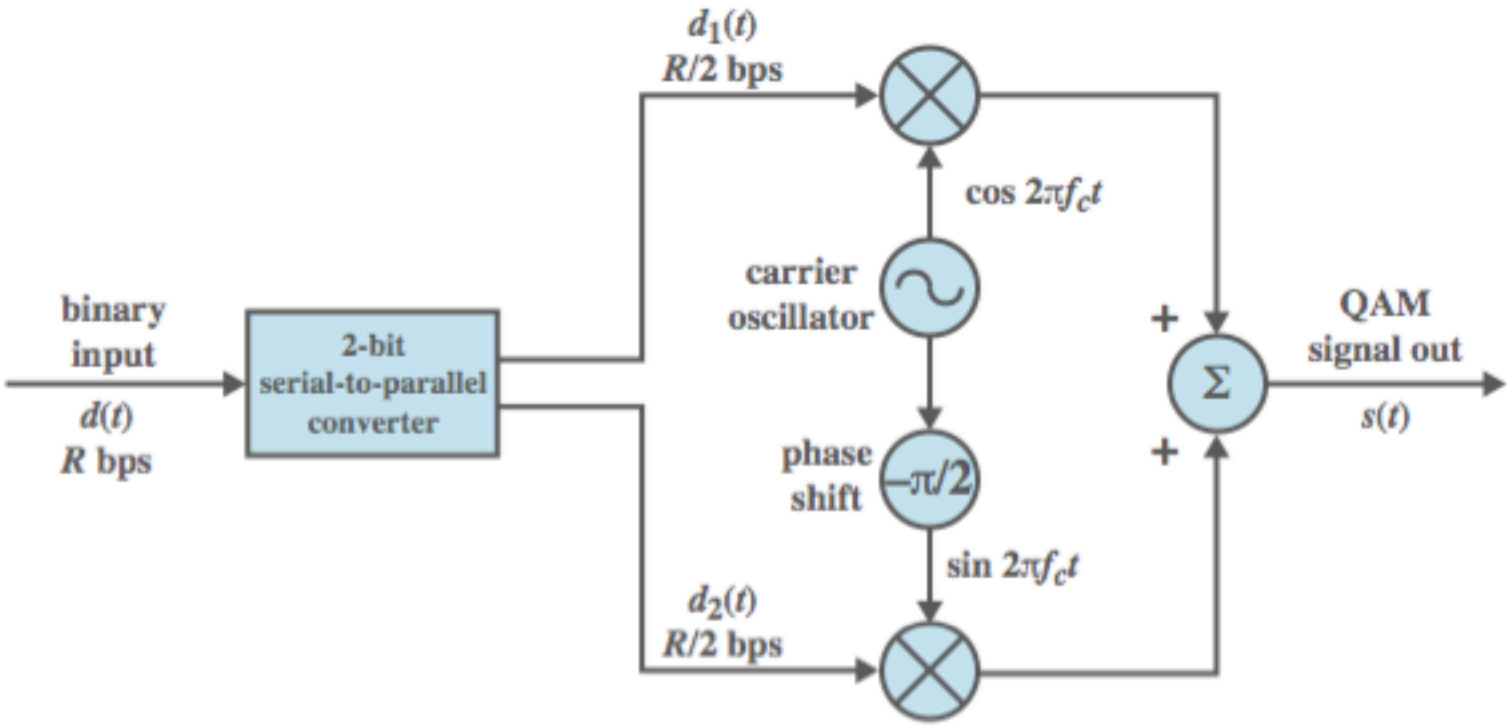


Figure 5.13 Theoretical Bit Error Rate for Multilevel FSK and PSK

Hybrid method: Quadrature Amplitude Modulation (QAM)

- Basic idea: encode data in both **phase** and **amplitude**, e.g.
  - Logical 00 -> Acos(wt)+Asin(wt)
  - Logical 01 -> Acos(wt)-Asin(wt)
  - Logical 10 -> -Acos(wt)+Asin(wt)
  - Logical 11 -> -Acos(wt)-Asin(wt)
- No binary methods, but lots of higher order QAM:
  - 4QAM (2 bits per signal, like QPSK)
  - 16QAM (4 bits per signal)
  - 64QAM (6 bits per signal)
  - 256QAM (8 bits per signal)
  - …
- Used in applications where spectral efficiency is critical, e.g. DSL and high data rate wireless

QAM Modulator Block Diagram



Which "Analog" Modulation Scheme Should I Use?

- **It depends…**
- **Power efficiency** important?
  - FSK is energy efficient but not bandwidth efficient
- **Spectral efficiency** important?
  - QAM, PSK, ASK are more bandwidth efficient but less energy efficient
- **Optical** systems?
  - ASK (very difficult to control/detect phase in optical transmission)
- Lots of tradeoffs. Best choice depends on the application.

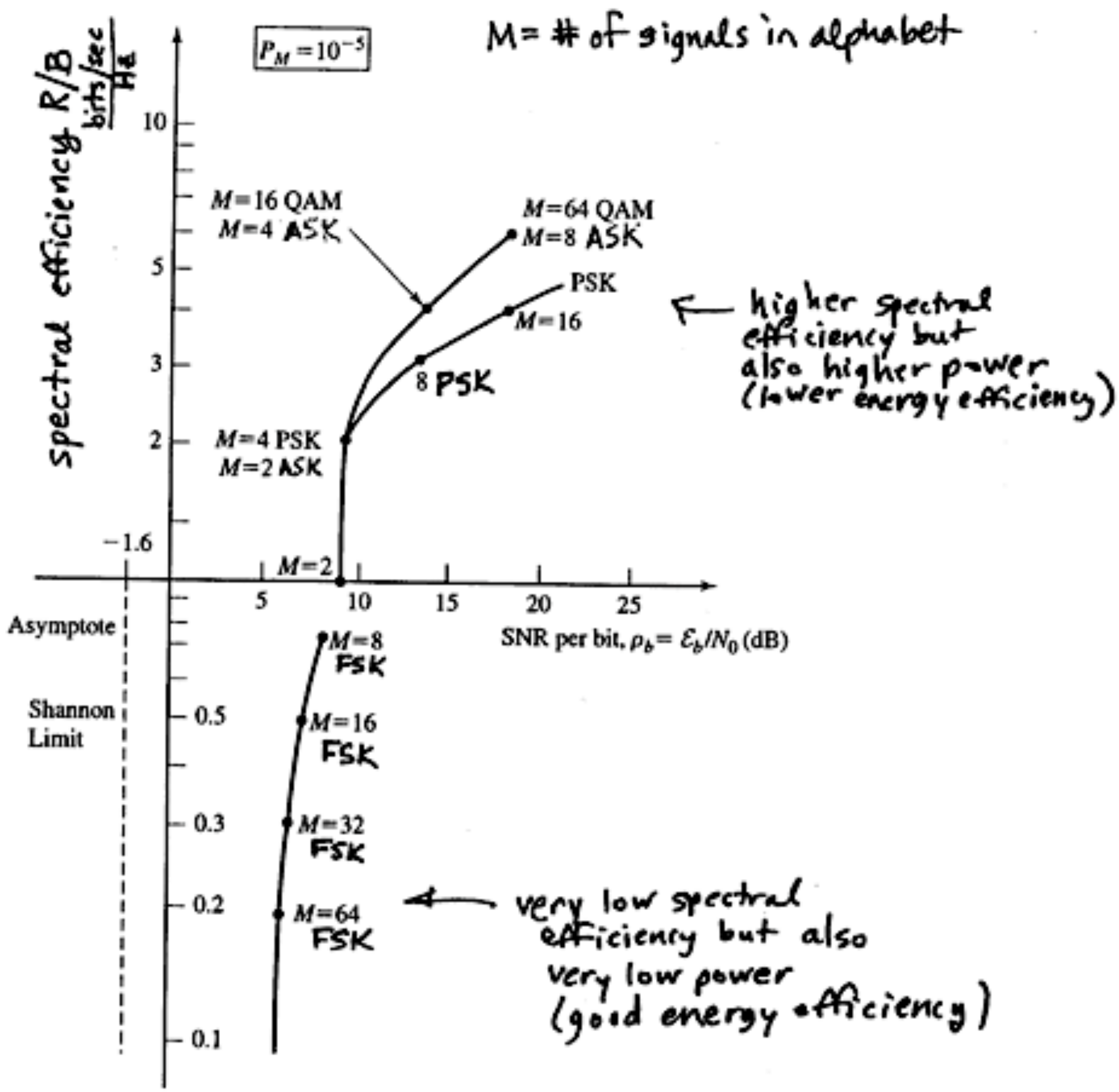


Figure 7.66 Comparison of several modulation methods at 10^{-5} symbol error probability.

From Communication Systems Engineering
Proakis & Salehi