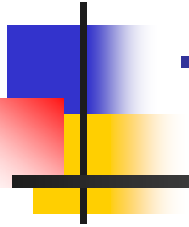
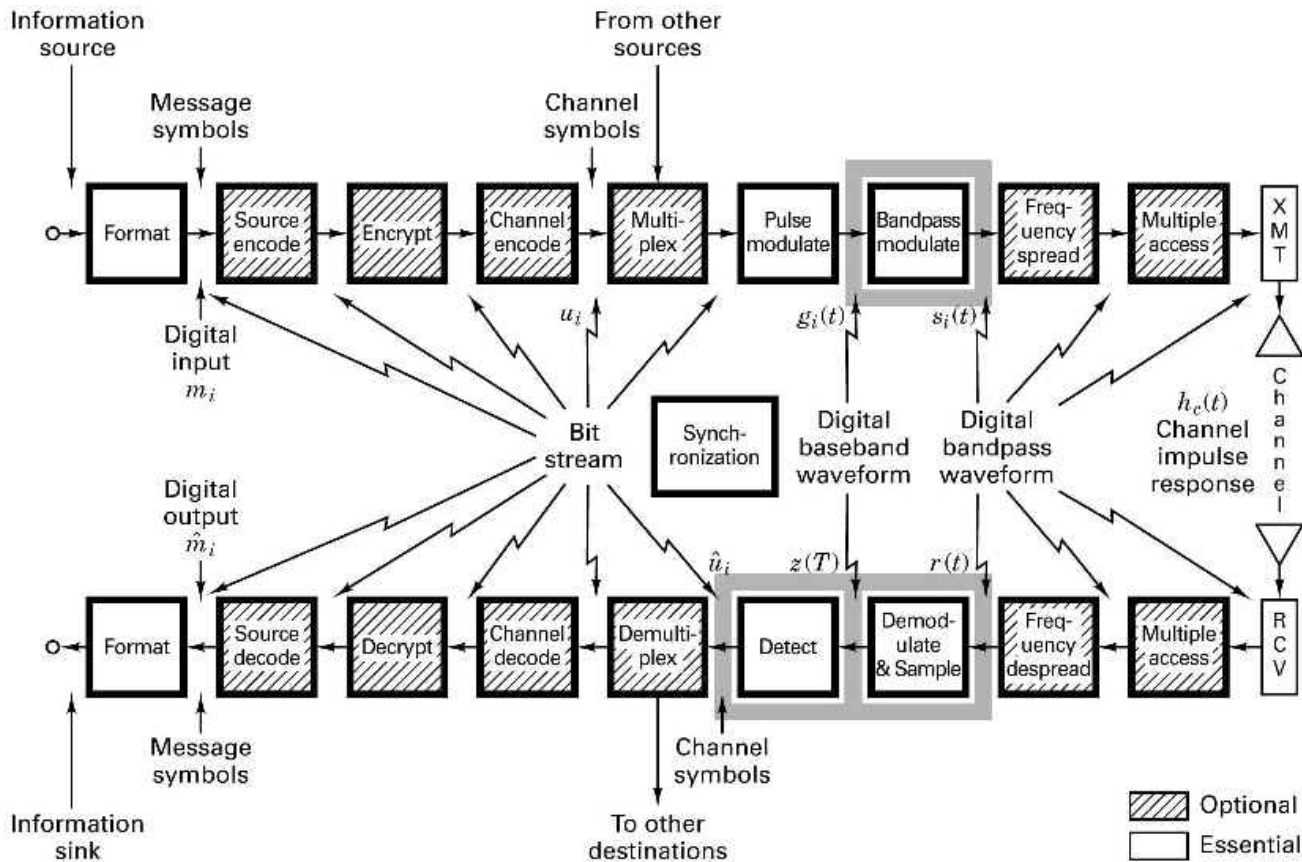


Digital Communications

-Lecture 11



Block Diagram of a Typical Digital Communication System





Contents

- Why Modulate?
- Digital Bandpass Modulation Techniques
- Detection of Signals in Gaussian Noise
- Coherent Detection
- Noncoherent Detection
- Error Performance of Binary Systems
- M-ary Signaling and Performance



Why Modulate?

- Digital modulation

The process by which digital symbols are transformed into waveforms that are compatible with the characteristics of the channel.

- Baseband modulation

The waveforms usually take the form of shaped pulses.



Why Modulate? (Cont.)

- Bandpass modulation
 - The shaped pulses modulate a sinusoid called a carrier.
 - For radio transmission the carrier is converted to an EM field for propagation. The transmission of EM fields through space is accomplished with the use of antenna. The size of the antenna depends on the wavelength and the application. (For cellular telephones, antennas are typically $\lambda/4$ in size. For the 3,000 Hz baseband signal, 15 miles. However, for example a 900 MHz carrier, 8 cm.)



Why Modulate? (Cont.)

- If more than one signal utilizes a single channel, modulation may be used to separate the different signals. (For example, frequency division multiplexing)
- Modulation can also be used to place a signal in a frequency band where design requirements, such as filtering and amplification, can be easily met. (For example, the case when RF signals are converted to IF in a receiver)



Bandpass Modulation Techniques

- Bandpass modulation is the process by which an information signal is converted to a sinusoidal waveform.
- For digital modulation, such a sinusoid of duration T is referred to a digital symbol.
- The bandpass modulation can be defined as the process whereby the amplitude, frequency, or phase of an RF carrier, or a combination of them, is varied in accordance with the information to be transmitted.



Bandpass Modulation Techniques (Cont.)

- The sinusoid has just 3 features that can be used to distinguish it from other sinusoids: amplitude, frequency, and a phase.

$$s(t) = A(t) \cos[\omega_0 t + \phi(t)]$$

$A(t)$: amplitude

$\omega_0 = 2\pi f$: radian frequency

$\phi(t)$: phase



Bandpass Modulation Techniques (Cont.)

- ASK (Amplitude Shift Keying)
- PSK (Phase Shift Keying)
- FSK (Frequency Shift Keying)
- APK (Amplitude Phase Keying)
 - QAM (Quadrature Amplitude Modulation)

Bandpass Modulation Techniques (Cont.)

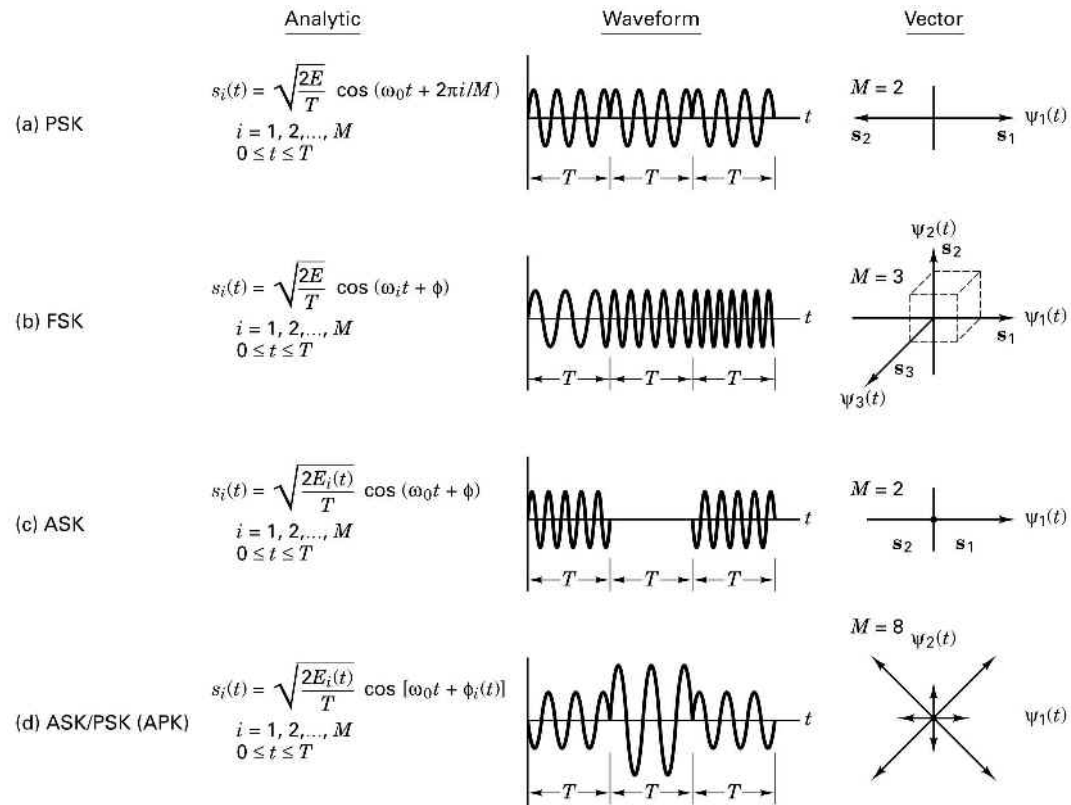


Figure 4.5 Digital modulations. (a) PSK. (b) FSK. (c) ASK. (d) ASK/PSK (APK).



Demodulation Techniques

- Coherent demodulation (detection)
 - When the receiver exploits knowledge of the carrier's phase to detect the signals
- Noncoherent demodulation (detection)
 - Designed to operate without knowledge of the absolute value of the incoming signal's phase; therefore, phase estimation is not required.
 - Reduced complexity
 - Increased error probability



Demodulation Techniques (Cont.)

- Remark
 - In digital communications, the terms demodulation and detection are often used interchangeably, the terms demodulation emphasizes waveform recovery, and detection entails the process of symbol decision



PSK

- Widely used in both military and commercial communications systems
- General analytic expression

$$s_i(t) = \sqrt{\frac{2E}{T}} \cos[\omega_0 t + \phi_i(t)], \quad 0 \leq t \leq T, \quad i = 1, \dots, M$$

$$\text{where } \phi_i(t) = \frac{2\pi i}{M}$$



PSK (Cont.)

- BPSK (Binary PSK)

$$s_i(t) = \sqrt{\frac{2E}{T}} \cos[\omega_0 t + \phi_i(t)], \quad 0 \leq t \leq T, \quad i = 1, 2$$

where $\phi_1(t) = 0$ and $\phi_2(t) = \pi$

- Modulation data signal shifts the phase of the waveform $s_i(t)$ to one of two states, either zero or π .
- Antipodal signal sets
- Abrupt phase changes at the symbol transitions



FSK

- General analytic expression

$$s_i(t) = \sqrt{\frac{2E}{T}} \cos[\omega_i t + \phi], \quad 0 \leq t \leq T, \quad i = 1, \dots, M$$

where ω_i has M discrete values.

- Signal sets can be characterized with mutually perpendicular vectors (mutually perpendicular axes represents a sinusoid with a different frequency): orthogonal signals



ASK

- General analytic expression

$$s_i(t) = \sqrt{\frac{2E_i(t)}{T}} \cos[\omega_0 t + \phi], \quad 0 \leq t \leq T, \quad i = 1, \dots, M$$

where $\sqrt{\frac{2E_i(t)}{T}}$ has M discrete values.



APK

- General analytic expression

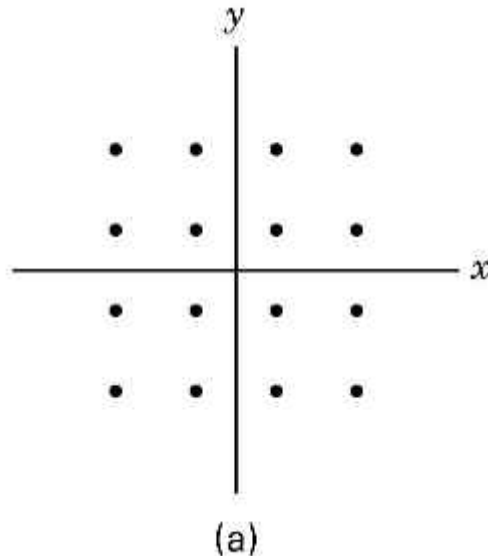
$$s_i(t) = \sqrt{\frac{2E_i(t)}{T}} \cos[\omega_0 t + \phi_i(t)], \quad 0 \leq t \leq T, \quad i = 1, \dots, M$$

- Combination of ASK and PSK
- Simultaneous phase and amplitude changes at the transition times.



QAM

- Consists of two independently amplitude-modulated carriers in quadrature.
- When the set of M symbols in the two-dimensional signal space are arranged in a rectangular constellation.





Comparison of Bit Error Performance for Various Modulation Types

TABLE 4.1 Probability of Error for Selected Binary Modulation Schemes

Modulation	P_B
PSK (coherent)	$Q\left(\sqrt{\frac{2E_b}{N_0}}\right)$
DPSK (differentially coherent)	$\frac{1}{2} \exp\left(-\frac{E_b}{N_0}\right)$
Orthogonal FSK (coherent)	$Q\left(\sqrt{\frac{E_b}{N_0}}\right)$
Orthogonal FSK (noncoherent)	$\frac{1}{2} \exp\left(-\frac{1}{2} \frac{E_b}{N_0}\right)$



Comparison of Bit Error Performance for Various Modulation Types (cont'd)

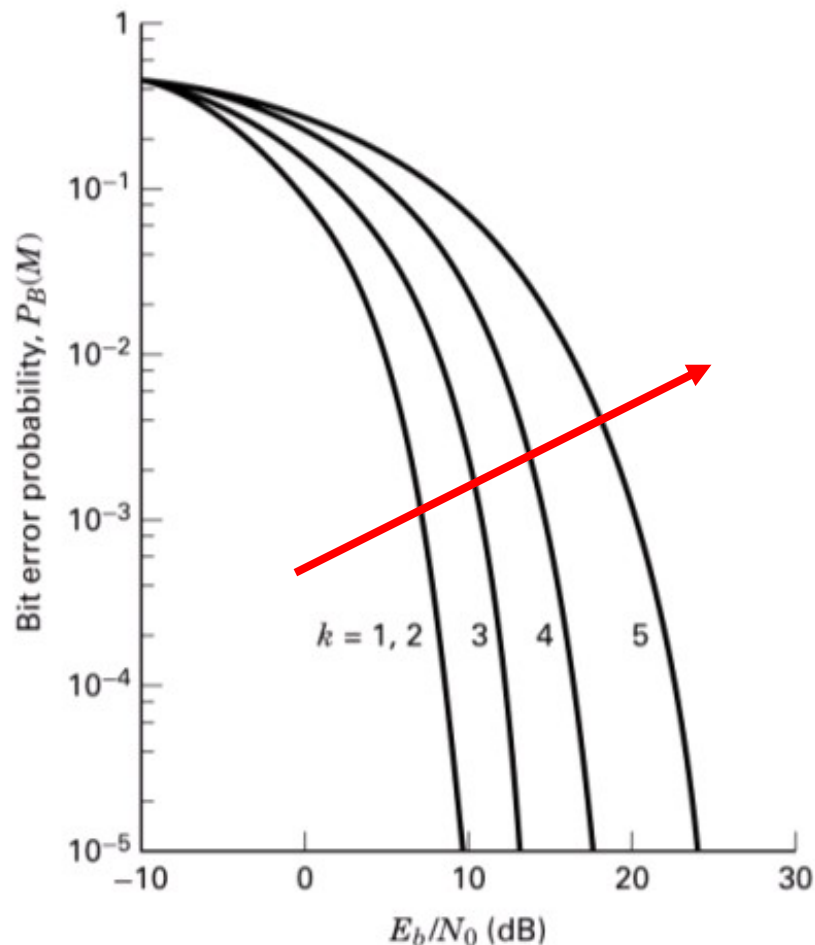
- Coherent Detection

$$Q\left(\frac{d}{2\sigma}\right) = Q\left(\frac{d}{\sqrt{2N_0}}\right), \text{ where } Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^{\infty} \exp\left(-\frac{u^2}{2}\right) du$$

- Noncoherent Detection

$$\frac{1}{2} \exp\left(-\frac{E_s}{2N_0}\right)$$

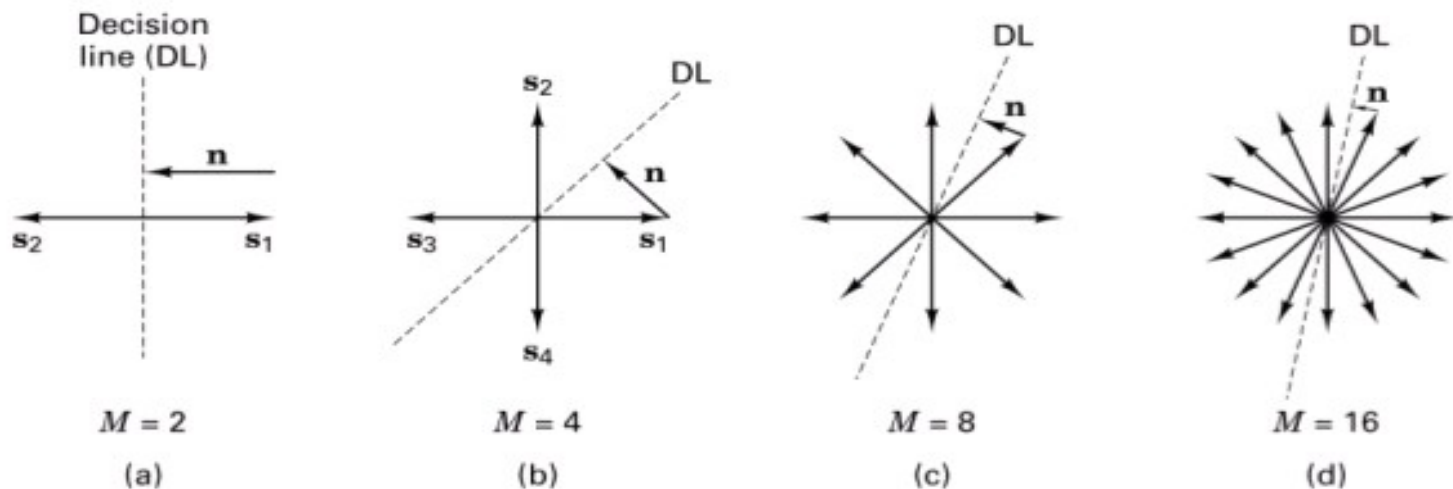
Multiple Phase M-ary Signaling



- ❑ Multiple Phase M-ary signaling over a Gaussian Channel
- ❑ As k increases, the curves move in the direction of degraded error performance
- ❑ Why would any one ever use multiple phase PSK signaling?
- ❑ Bandwidth, throughput, complexity, cost

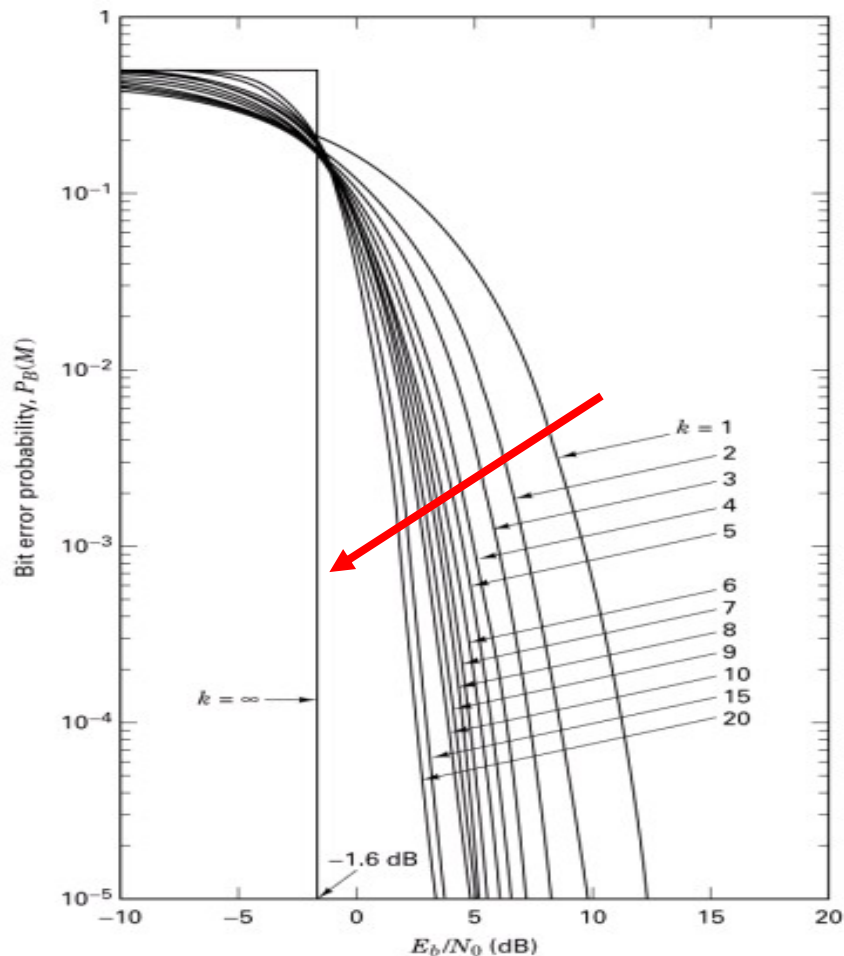
Bit error probability
for coherently detected
multiple phase signaling.

Vectorial View of MPSK Signaling



- $M=2, k=1$, antipodal vectors s_1 and s_2 positioned 180 degree apart. The decision boundary is drawn so as to partition the signal space into two regions. **Noise vector \mathbf{n}** equal in magnitude to s_1 Magnitude and orientation of the minimum energy noise vector that would cause the detector to make a symbol error.
- **$M=4, k=2$** vectors positioned **90 degrees apart**.

M-ary Orthogonal Signaling



- Orthogonal M-ary signaling over a Gaussian Channel
- As k increases, the curves move in the direction of improved error performance

Bit error probability
for coherently detected
M-ary orthogonal signaling.



Vectorial View of MFSK Signaling

