Department of Electronics & Communication Engg.

Course : Digital Communication -15EC61. **Sem.: 6th (2017-18)**

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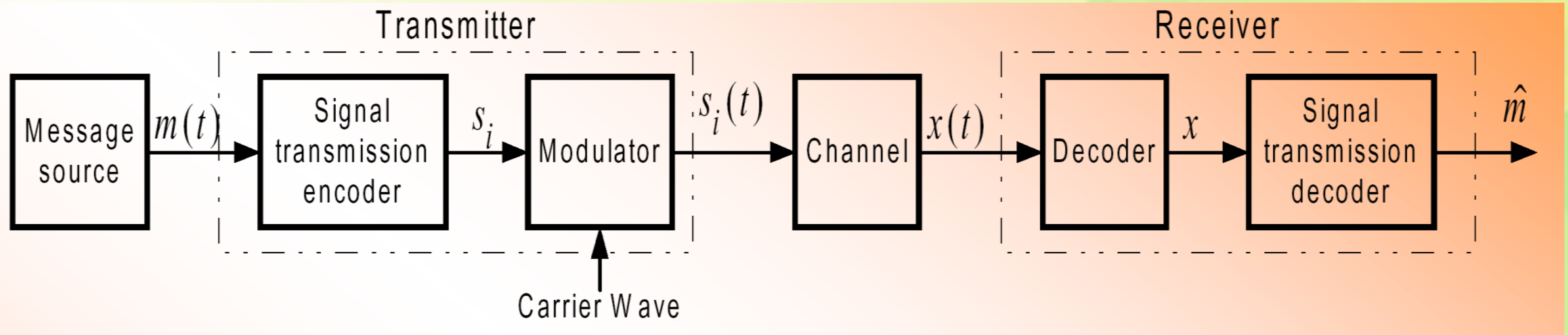
Band pass Modulation and Demodulation



- Bandpass Modulation is the process by which some characteristics of a sinusoidal waveform is varied according to the message signal.
- ***Modulation*** shifts the spectrum of a baseband signal to some high frequency.
- Demodulator/Decoder baseband waveform recovery

Why Modulate?

- Most channels require that the baseband signal be shifted to a higher frequency
- For example in case of a wireless channel antenna size is inversely proportional to the center frequency, this is difficult to realize for baseband signals.
  - For speech signal $f = 3$ kHz $\Rightarrow \lambda = c/f = (3 \times 10^8)/(3 \times 10^3)$
  - Antenna size without modulation $\lambda/4 = 10^5/4$ meters = 15 miles - practically unrealizable
  - Same speech signal if amplitude modulated using f_c=900MHz will require an antenna size of about 8cm.
  - This is evident that efficient antenna of realistic physical size is needed for radio communication system

- Modulation also required if channel has to be shared by several transmitters (Frequency division multiplexing).

Digital Band pass Modulation Techniques

Three ways of representing bandpass signal:

- **(1) Magnitude and Phase (M & P)**
  - Any bandpass signal can be represented as:

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

    - *A(t) ≥ 0* is real valued signal representing the magnitude
    - Θ(t) is the genarlized angle
    - φ*(t)* is the phase
  - The representation is easy to interpret physically, but often is not mathematically convenient
  - In this form, the modulated signal can represent information through changing three parameters of the signal namely:
    - Amplitude *A(t)* : *as in* Amplitude Shift Keying (**ASK**)
    - Phase φ*(t)* : *as in* Phase Shift Keying (**PSK**)
    - Frequency *d*Θ*(t)/ dt* : *as in* Frequency Shift Keying (**FSK**)

Angle Modulation

- Consider a signal with constant frequency:

$$s(t) = A(t)\cos(\theta(t)) = A(t)\cos(\omega_0 t + \varphi)$$

- Its instantaneous frequency can be written as:

$$\omega_i(t) = \frac{d\theta(t)}{dt} = \omega_0$$

or

$$\theta(t) = \int_{-\infty}^{t} \omega_i(\alpha)\, d\alpha$$

Phase Shift Keying (PSK) or PM

- Consider a message signal m(t), we can write the phase modulated signal as

$$\theta(t) = \omega_c t + K_p m(t)$$

$$s_{PM}(t) = A\cos[\omega_c t + K_p m(t)]$$

$$\omega_i(t) = \frac{d\theta}{dt} = \omega_c + K_p m'(t)$$

Frequency Shift Keying (FSK) or FM

- In case of Frequency Modulation

$$\omega_i(t) = \omega_0 + K_f m(t)$$

$$\theta(t) = \int_{-\infty}^{t} [\omega_0 + K_f m(t)] d\alpha$$

$$= \omega_0 t + K_f \int_{-\infty}^{t} m(\alpha) d\alpha$$

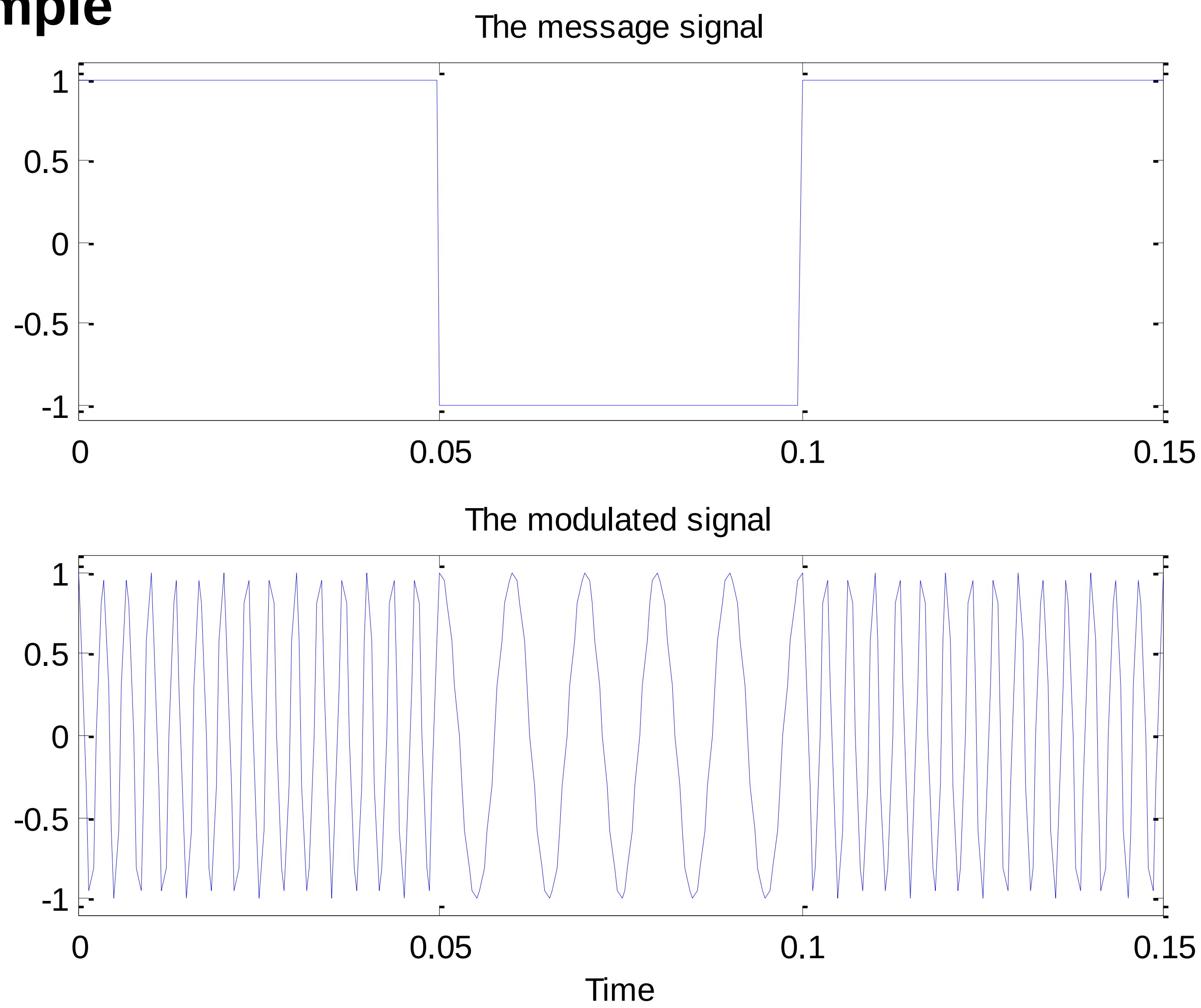
$$s_{FM}(t) = A\cos[\omega_0 t + K_f \int_{-\infty}^{t} m(\alpha) d\alpha]$$

$$= A\cos[\omega_0 t + K_f a(t)]$$

where:

$$a(t) = \int_{-\infty}^{t} m(\alpha) d\alpha$$

Example



The message signal
1
0.5
0
-0.5
-1
0
0.05
0.1
0.15
The modulated signal
1
0.5
0
-0.5
-1
0
0.05
0.1
0.15
Time

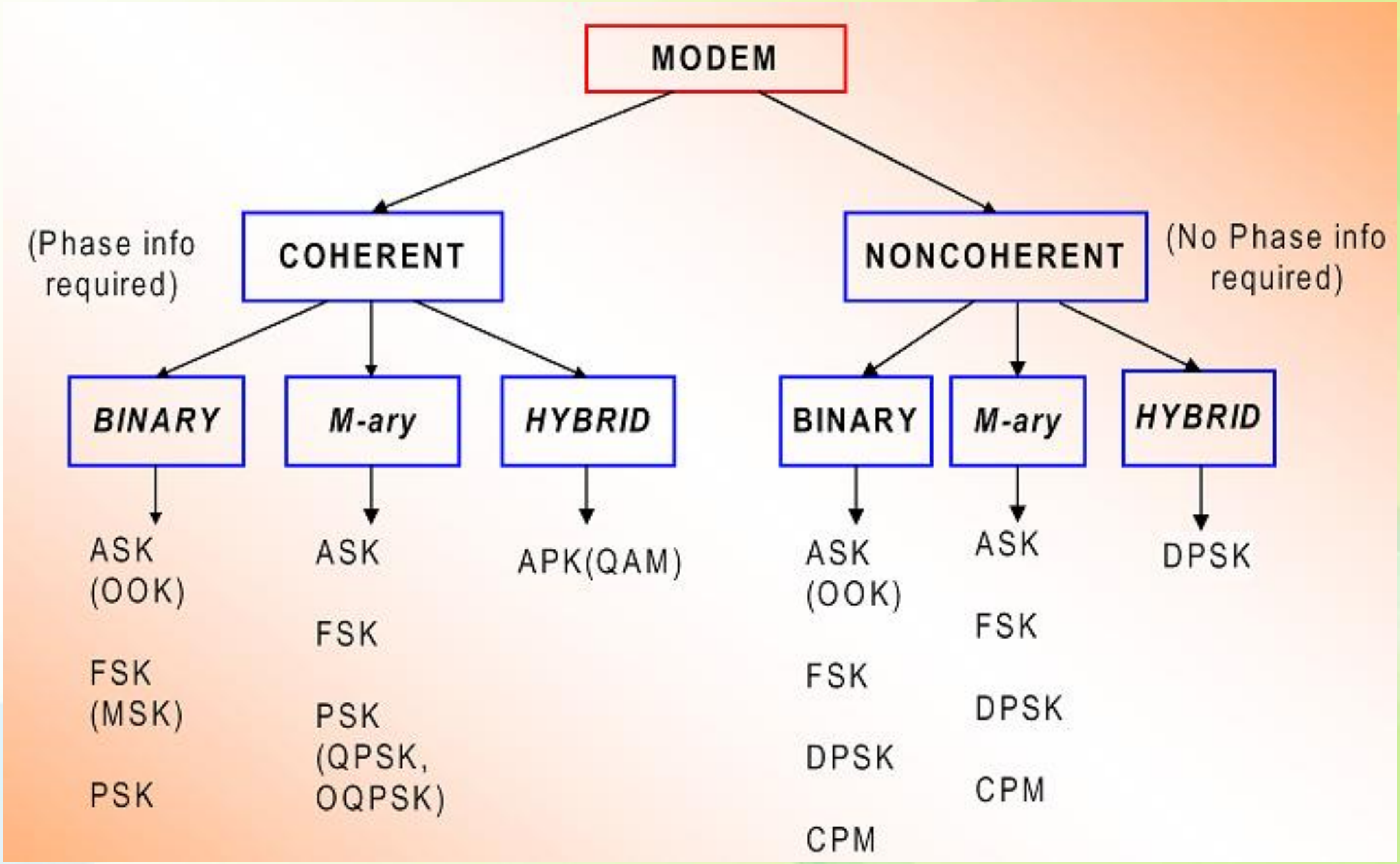
Digital Modulation Schemes

- Basic Digital Modulation Schemes:
  - Amplitude Shift Keying (ASK)
  - Frequency Shift Keying (FSK)
  - Phase Shift Keying (PSK)
  - Amplitude Phase Keying (APK)

- For Binary signals *($M = 2$)*, we have
  - Binary Amplitude Shift Keying (BASK)
  - Binary Phase Shift Keying (BPSK)
  - Binary Frequency Shift Keying (BFSK)

- For $M > 2$, many variations of the above techniques exit usually classified as M-ary Modulation/detection

Bandpass MOdulation and DEModulation



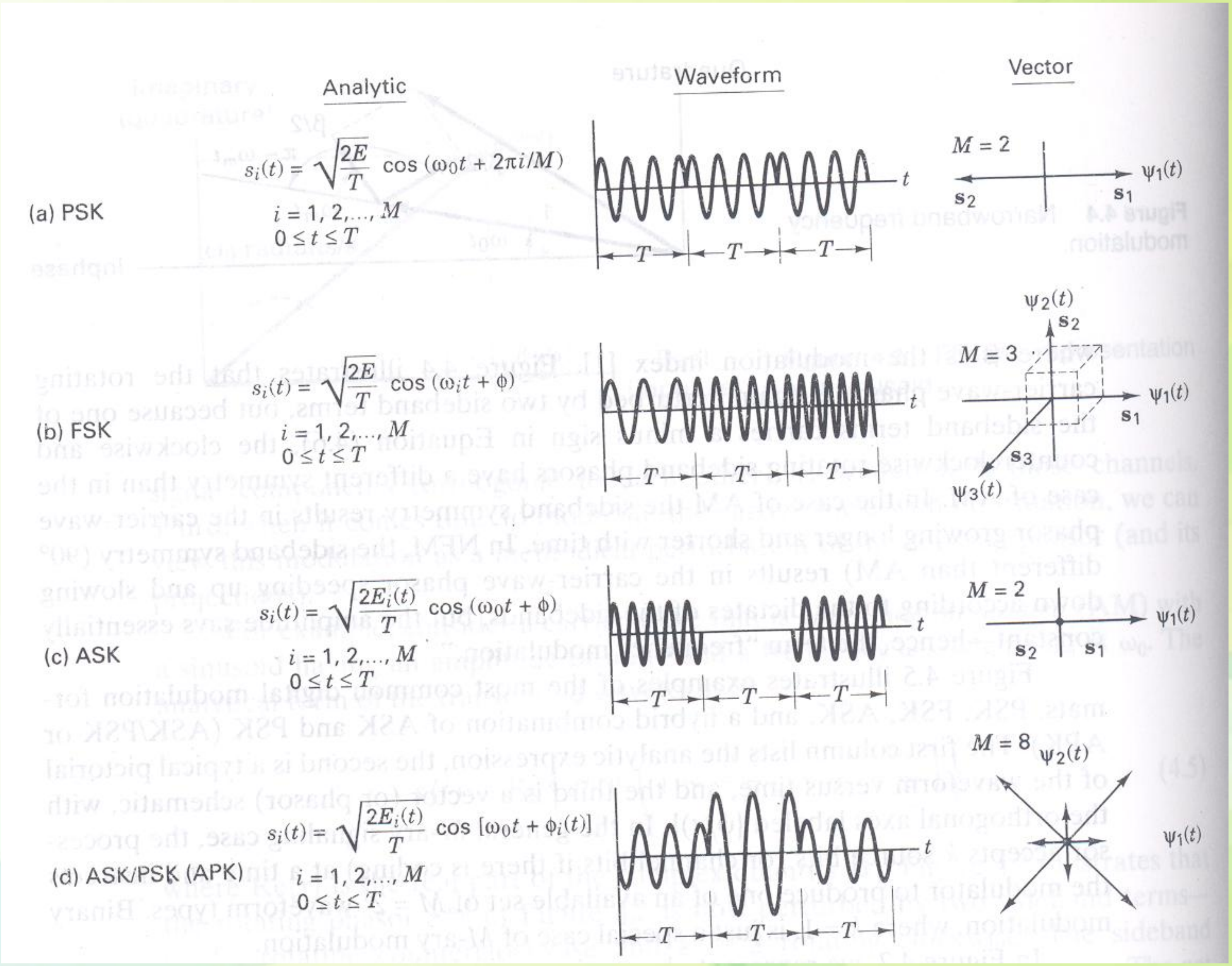
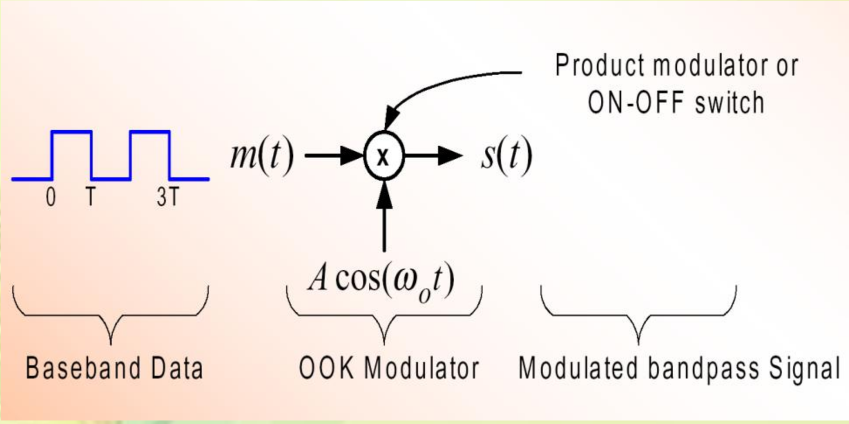
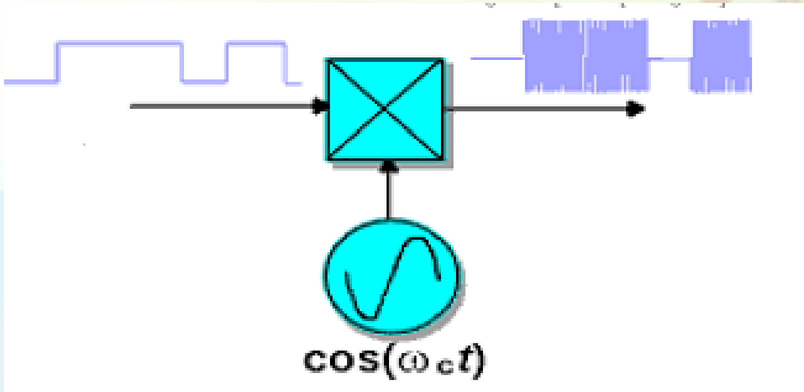


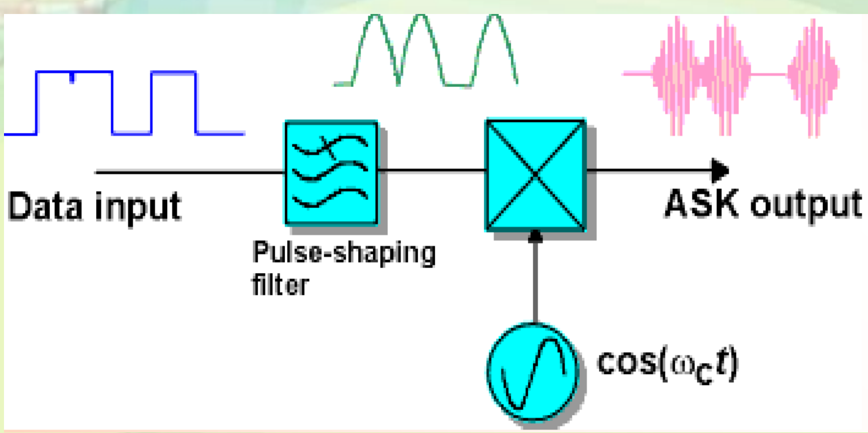
Figure4.5: digital modulations, (a) PSK (b) FSK (c) ASK (d) ASK/PSK (APK)

Amplitude Shift Keying

- **Modulation Process**
  - In Amplitude Shift Keying (***ASK)***, the amplitude of the carrier is switched between two (or more) levels according to the digital data
  - For BASK (also called ***ON-OFF Keying (OOK)***), one and zero are represented by two amplitude levels A_1 and A_0







- ***Analytical Expression:***

$$s(t) = \begin{cases} A_i \cos(\omega_c t), & 0 \le t \le T \ binary\ 1 \\ 0, & 0 \le t \le T \ binary\ 0 \end{cases}$$

where A_i = peak amplitude

$$s(t) = A\cos(\omega_0 t) = \sqrt{2}A_{rms}\cos(\omega_0 t) = \sqrt{2A_{rms}^2}\cos(\omega_0 t)$$

$$= \sqrt{2P}\cos(\omega_0 t) = \sqrt{\frac{2E}{T}}\cos(\omega_0 t) \rightarrow P = \frac{V^2}{R}$$

Hence,

$$s_i(t) = \begin{cases} \sqrt{\dfrac{2E_i(t)}{T}}\cos(\omega_i t), & 0 \le t \le T \ binary\ 1 \\ 0, & 0 \le t \le T \ binary\ 0 \end{cases}, \quad i = 0,2,\ldots\ldots M-1$$

where

$$E = \int_0^T s_i^2(t)dt, \ i = 0,2,\ldots\ldots M-1$$

- Where for binary ASK (also known as ON OFF Keying (OOK))

$$s_1(t) = A_c m(t)\cos(\omega_c t + \phi), \quad 0 \le t \le T \; binary\, 1$$
$$s_0(t) = 0, \quad 0 \le t \le T \; binary\, 0$$

- **Mathematical ASK Signal Representation**
  - The ***complex envelope*** of an ASK signal is:

$$g(t) = A_c m(t)$$

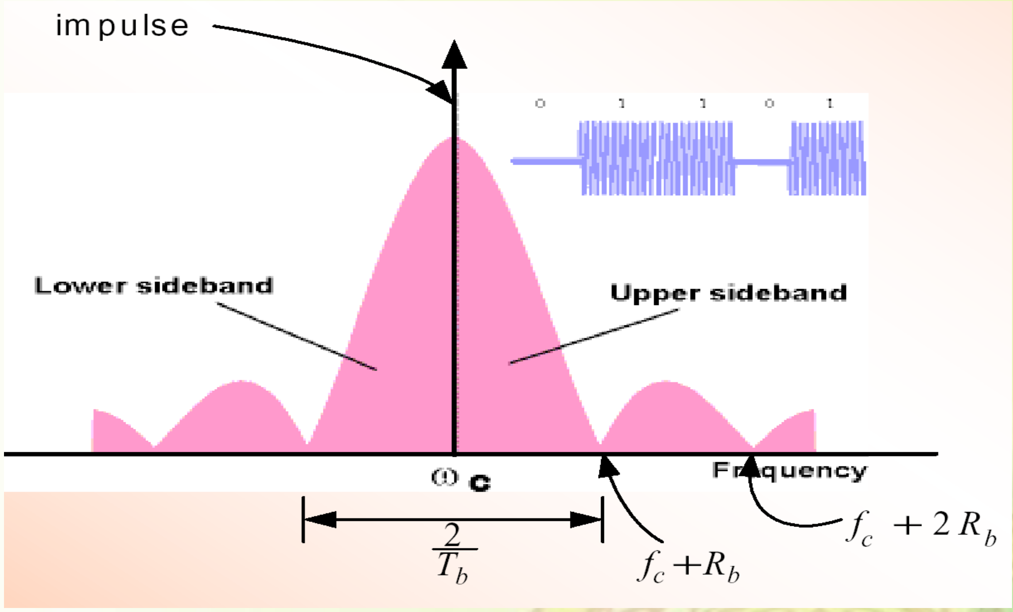
  - The ***magnitude*** and ***phase*** of an ASK signal are:

$$A(t) = A_c m(t), \qquad \phi(t) = 0$$

  - The **in-phase** and **quadrature** components are:

$$x(t) = A_c m(t)$$

$y(t) = 0,$ the quadrature component is wasted.



It can be seen that the bandwidth of ASK modulated is twice that occupied by the source baseband stream

- **Bandwidth of ASK**
  - Bandwidth of ASK can be found from its power spectral density
  - The bandwidth of an ASK signal is twice that of the unipolar NRZ line code used to create it., i.e.,

$$B = 2R_b = \frac{2}{T_b}$$

    - This is the **null-to-null bandwidth** of ASK

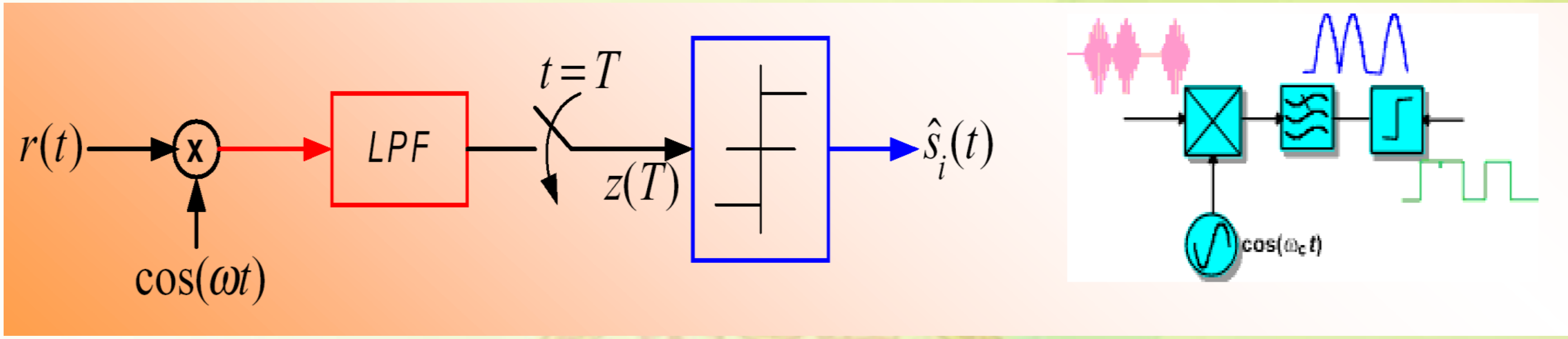
- If raised cosine rolloff pulse shaping is used, then the bandwidth is:

$$B = (1+r)R_b \Rightarrow W = \frac{1}{2}(1+r)R_b$$

- Spectral efficiency of ASK is half that of a baseband unipolar NRZ line code
  - This is because the quadrature component is wasted
- 95% energy bandwidth

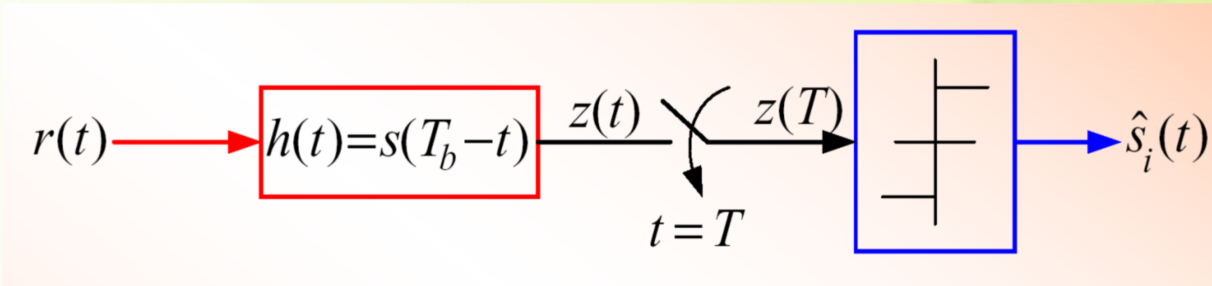
$$B = \frac{3}{T_b} = 3R_b$$

Detectors for ASK
Coherent Receiver

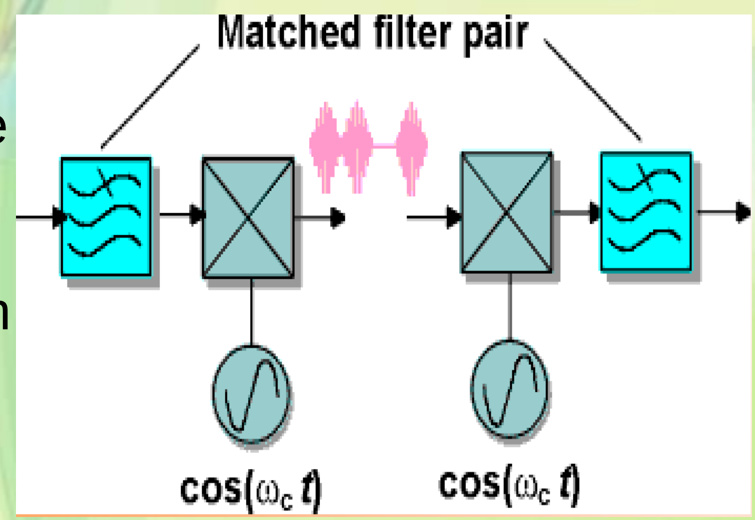


- Coherent detection requires the phase information
- A coherent detector mixes the incoming signal with a locally generated carrier reference
- Multiplying the received signal *r(t)* by the receiver local oscillator (say $A_c cos(w_c t)$) yields a signal with a baseband component plus a component at $2f_c$
- Passing this signal through a low pass filter eliminates the high frequency component
  - In practice an integrator is used as the LPF

- The output of the LPF is sampled once per bit period
- This sample *z(T)* is applied to a decision rule
  - *z(T)* is called the **decision statistic**
- Matched filter receiver of OOK signal



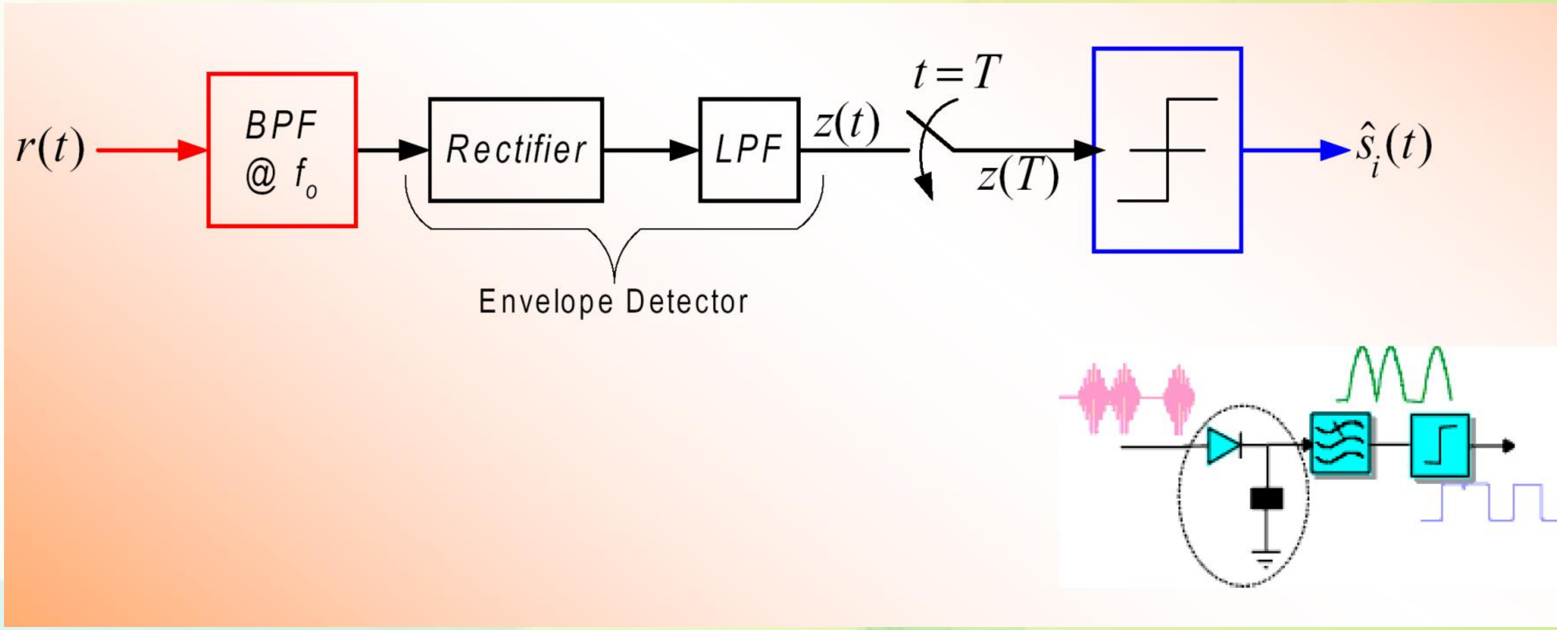
- A MF pair such as the root raised cosine filter can thus be used to shape the source and received baseband symbols
- In fact this is a very common approach in signal detection in most bandpass data modems



Noncoherent Receiver

- Does not require a phase reference at the receiver
- If we do not know the phase and frequency of the carrier, we can use a ***noncoherent receiver* to recover AS**K signal

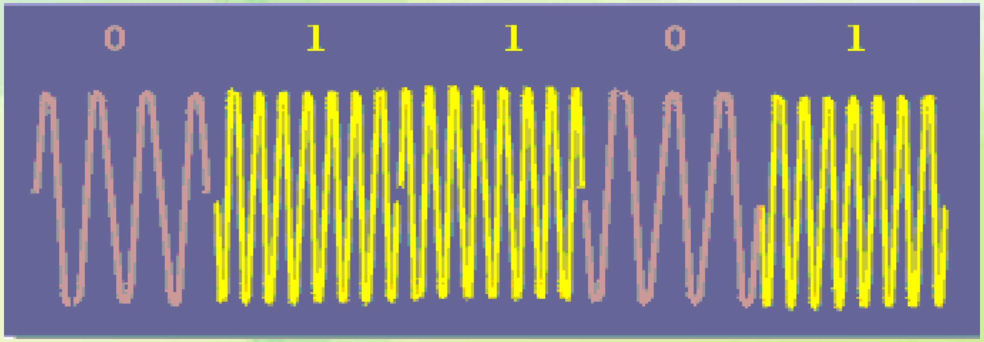
• ***Envelope Detector:***



- The simplest implementation of an envelope detector comprises a diode rectifier and smoothing filter

Frequency Shift Keying (FSK)

- In *FSK*, the instantaneous carrier frequency is switched between 2 or more levels according to the baseband digital data
  - data bits select a carrier at one of two frequencies
  - the data is encoded in the frequency
- Until recently, FSK has been the most widely used form of digital modulation;Why?
  - Simple both to generate and detect
  - Insensitive to amplitude fluctuations in the channel
- FSK conveys the data using distinct carrier frequencies to represent symbol states
- An important property of FSK is that the *amplitude of the modulated wave is constant*
- **Waveform**



- **Analytical Expression**

$$s_i(t) = \sqrt{\frac{2E_s}{T_s}} \cos(\underbrace{\omega_i t + \phi}), \quad i = 0,1,\ldots.M - 1$$

$$\left.\begin{aligned} \theta_i(t) &= [\omega_0 t + \omega_d \int_{-\infty}^{t} m(\tau)d\tau] \\ f_i &= \frac{d}{dt}\theta_i(t) = f_0 + f_d m(t) \end{aligned}\right\} \text{Analog form}$$

- General expression is

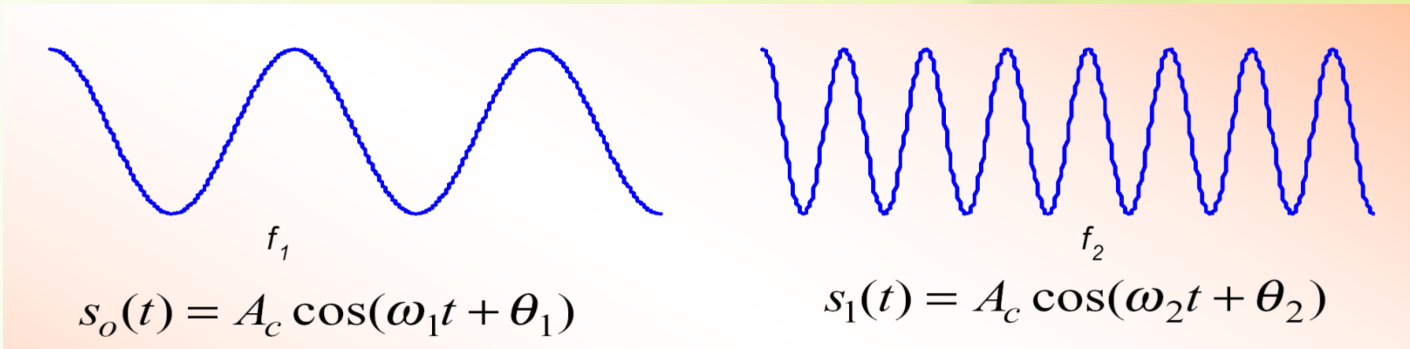
$$s_i(t) = \sqrt{\frac{2E_s}{T_s}} \cos(2\pi f_0 t + 2\pi i \Delta f t), \quad i = 0,1,\ldots.M - 1$$

Where $\Delta f = f_i - f_{i-1}$

$$f_i = f_0 + i\Delta f \quad and \quad E_s = kE_b, \; T_s = kT_b$$

Binary FSK

- In ***BFSK***, 2 different frequencies, *f1* and *f2* = *f1* + Δ *f* are used to transmit binary information



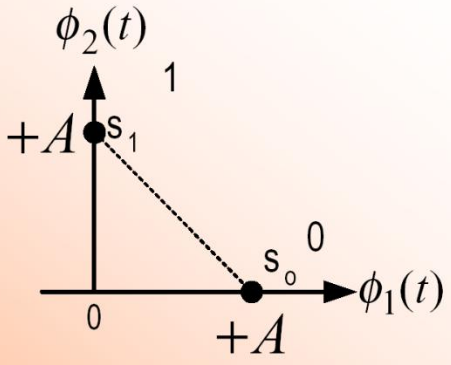
- Data is encoded in the frequencies
- That is, *m(t)* is used to select between 2 frequencies:
- *f1* is the mark frequency, and *f2* is the space frequency

$$s_0(t) = \sqrt{\frac{2E_s}{T_b}} \cos 2\pi(f_1 + \theta_1), \quad 0 \le t \le T_b$$

$$s_1(t) = \sqrt{\frac{2E_s}{T_b}} \cos 2\pi(f_2 + \theta_2), \quad 0 \le t \le T_b$$

$$s(t)=\begin{cases} A_c\cos(\omega_1 t+\theta_1), & when\ m(t)=+1\ or\ X_n=1 \\ A_c\cos(\omega_2 t+\theta_2), & when\ m(t)=-1\ or\ X_n=0 \end{cases}$$

- **Binary Orthogonal Phase FSK**



$$\phi_1(t)=\sqrt{\frac{2E}{T}}\cos(\omega_1 t+\theta_1)$$

$$\phi_2(t)=\sqrt{\frac{2E}{T}}\cos(\omega_2 t+\theta_2)$$

- When w_0 an w_1 are chosen so that $f_1(t)$ and $f_2(t)$ are orthogonal, i.e.,

$$\int_{-\infty}^{\infty}\phi_1(t)\phi_2(t)=0$$

  – form a set of *K = 2* basis orthonormal basis functions

Phase Shift Keying (PSK)

- General expression is

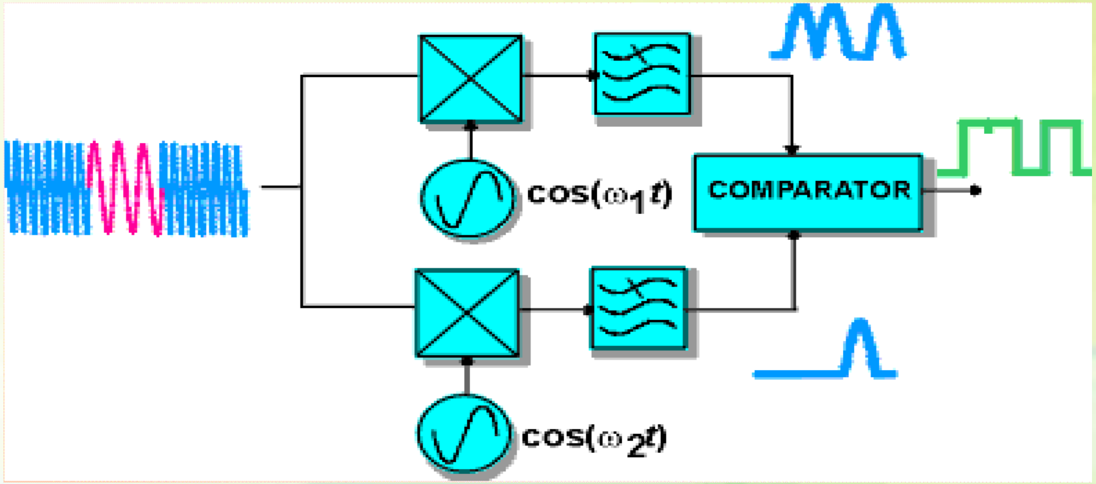
$$s_i(t) = \sqrt{\frac{2E_s}{T_s}} \cos[2\pi f_0 t + \phi_i(t)], \quad i = 0,1,....M-1$$

- Where

$$\phi_i(t) = \frac{2\pi i}{M} \quad i = 0,1,....M-1$$

Coherent Detection of Binary FSK

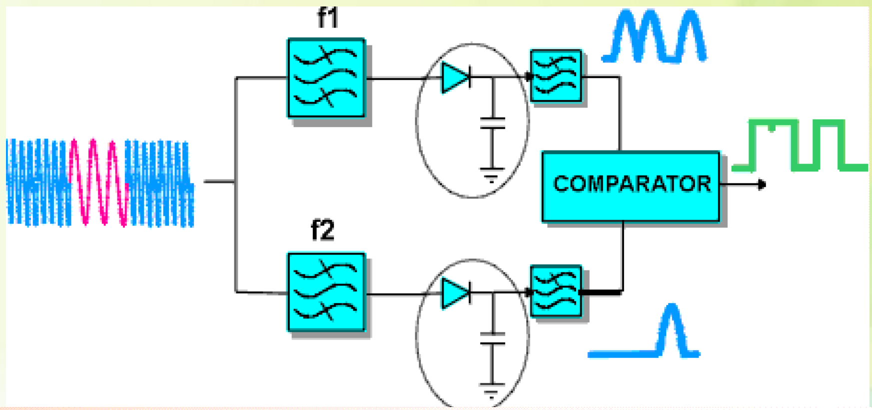
- Coherent detection of Binary FSK is similar to that for ASK but in this case there are 2 detectors tuned to the 2 carrier frequencies

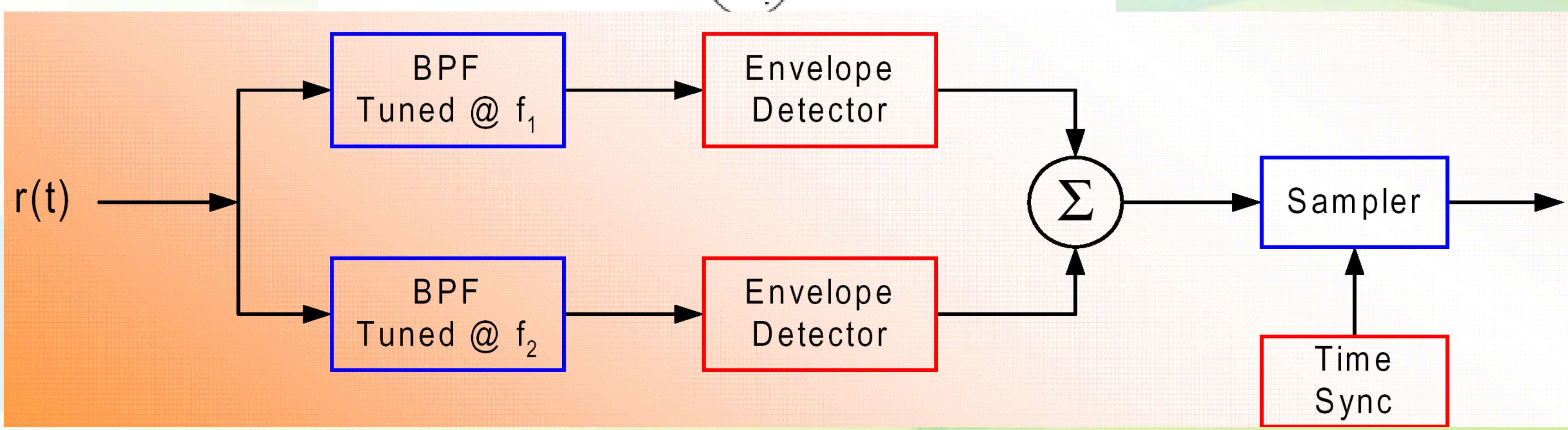


- Recovery of *fc* in receiver is made simple if the frequency spacing between symbols is made equal to the ***symbol rate.***

Non-coherent Detection

- One of the simplest ways of detecting binary FSK is to pass the signal through 2 BPF tuned to the 2 signaling freqs and detect which has the larger output averaged over a symbol period

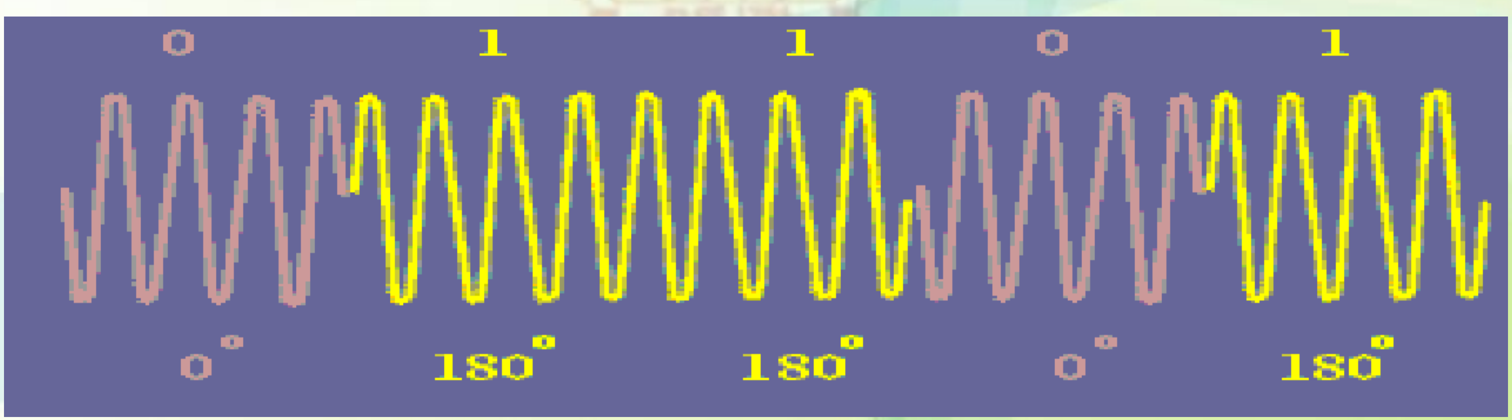




Phase Shift Keying (PSK)

- In PSK, the phase of the carrier signal is switched between 2 (for BPSK) or more (for MPSK) in response to the baseband digital data
- With PSK the information is contained in the instantaneous phase of the modulated carrier
- Usually this phase is imposed and measured with respect to a fixed carrier of known phase – Coherent PSK
- For binary PSK, phase states of 0^o and 180^o are used

- **Waveform:**



- Analytical expression can be written as

$$s_i(t) = A\, g(t) \cos[\omega_c t + \phi_i(t)], \qquad 0 \le t \le T_b,\ \ i = 1, 2, ..., M$$

where

  - g(t) is signal pulse shape
  - A = amplitude of the signal
  - ø = carrier phase

- The range of the carrier phase can be determined using

$$\phi_i(t) = \frac{2\pi(i-1)}{M} \qquad i = 1, ... M$$

- For a rectangular pulse, we obtain

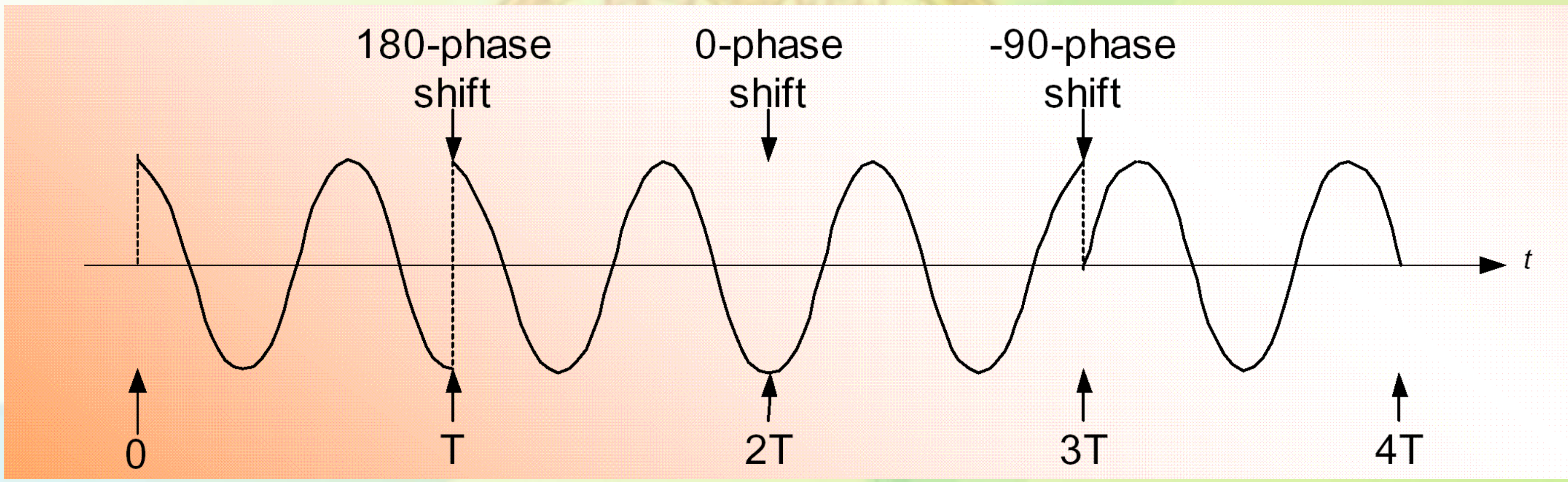
$$g(t) = \sqrt{\frac{2}{T_b}}, \quad 0 \le t \le T_b;\ \ and\ assume\ A = \sqrt{E_b}$$

- We can now write the analytical expression as

$$s_i(t) = \sqrt{\frac{2E_b}{T_b}} \cos\left(\omega_c t + \frac{2\pi(i-1)}{M}\right), \quad 0 \le t \le T_b, \; and \; i = 1,2,....M$$

Constant envelope

carrier phase changes abruptly at the beginning of each signal interval



- In PSK the carrier phase changes abruptly at the beginning of each signal interval while the amplitude remains constant

- We can also write a PSK signal as:

$$s_i(t) = \sqrt{\frac{2E}{T}} \cos\left(\omega_c t + \frac{2\pi(i-1)}{M}\right)$$

$$= \sqrt{\frac{2E}{T}} \left[\cos\frac{2\pi(i-1)}{M} \cos\omega_c t - \sin\frac{2\pi(i-1)}{M} \sin\cos\omega_c t\right]$$

- Furthermore, $s_1(t)$ may be represented as a linear combination of two orthogonal functions $\psi_1(t)$ and $\psi_2(t)$ as follows

$$s_i(t) = \sqrt{E}\cos\frac{2\pi(i-1)}{M}\psi_1(t) - \sqrt{E}\sin\frac{2\pi(i-1)}{M}\psi_2(t)$$

Where

$$\psi_1(t) = \sqrt{\frac{2}{T}}\cos[\omega_c t] \quad and\ \psi_2(t) = \sqrt{\frac{2}{T}}\sin[\omega_c t]$$

- Using the concept of the orthogonal basis function, we can represent PSK signals as a two dimensional vector

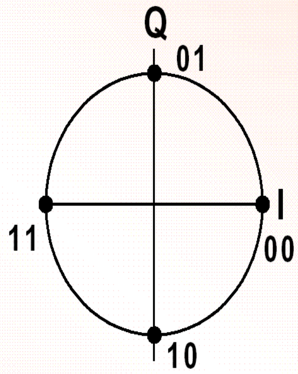
$$s_i(t) = \left(\sqrt{E_b} \cos \frac{2\pi(i-1)}{M} \psi_1, \sqrt{E_b} \sin \frac{2\pi(i-1)}{M} \psi_2 \right)$$

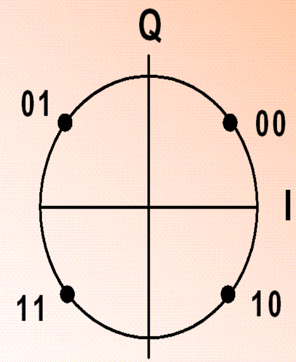
- For M-ary phase modulation $\boldsymbol{M = 2^k}$, where ***k*** is the number of information bits per transmitted symbol

- In an M-ary system, one of $\boldsymbol{M \geq 2}$ possible symbols, $s_1(t), \ldots, s_m(t)$, is transmitted during each $\boldsymbol{T_s}$-second signaling interval

- The mapping or assignment of ***k*** information bits into $\boldsymbol{M = 2^k}$ possible phases may be performed in many ways, e.g. for $\boldsymbol{M = 4}$

$$\theta = 0, \frac{\pi}{2}, \pi, \frac{3\pi}{2}$$





$$\theta = \frac{\pi}{4}, \frac{3\pi}{4}, \frac{5\pi}{4}, \frac{7\pi}{2}$$

- A preferred assignment is to use "Gray code" in which adjacent phases differ by only one binary digit such that only a single bit error occurs in a ***k***-bit sequence. Will talk about this in detail in the next few slides.

- It is also possible to transmit data encoded as the phase change (phase difference) between consecutive symbols
  - This technique is known as Differential PSK (DPSK)

- There is no non-coherent detection equivalent for PSK except for DPSK

M-ary PSK

- In MPSK, the phase of the carrier takes on one of *M* possible values

$$\phi_i(t) = \frac{2\pi(i-1)}{M}, \quad i = 1,2,\ldots\ldots, M$$

- Thus, MPSK waveform is expressed as

$$s_i(t) = \sqrt{\frac{2E}{T}} \cos\left[\omega_0 t + \frac{2\pi(i-1)}{M}\right]$$

$$s_i(t) = g(t) \cos\left[\omega_0 t + \frac{2\pi(i-1)}{M}\right]$$

$M = 2^k$	$MPSK$
2	$BPSK$
4	$QPSK$
8	$8-PSK$
16	$16-PSK$
………..	

- Each $s_i(t)$ may be expanded in terms of two basis function $\Psi_1(t)$ and $\Psi_2(t)$ defined as

$$\psi_1(t) = \sqrt{\frac{2}{T_s}} \cos \omega_c t, \qquad \psi_2(t) = \sqrt{\frac{2}{T_s}} \sin \omega_c t,$$

Quadrature PSK (QPSK)

- Two BPSK in phase quadrature
- QPSK (or 4PSK) is a modulation technique that transmits 2-bit of information using 4 states of phases
- For example

2-bit Information	ø
00	0
01	π/2
10	π
11	3π/2

Each symbol corresponds to two bits

- General expression:

$$s_{QPSK}(t) = \sqrt{\frac{2E_s}{T_s}} \cos\left[2\pi f_c t + \frac{2\pi(i-1)}{M}\right], \quad i = 1,2,3,4 \quad 0 \le t \le T_s$$

- The signals are:

$$s_0 = \sqrt{\frac{2E_s}{T_s}}\cos(\omega_c t) \qquad s_1 = \sqrt{\frac{2E_s}{T_s}}\cos(\omega_c t + \frac{\pi}{2}) = -\sqrt{\frac{2E_s}{T_s}}\sin(\omega_c t)$$

$$s_2 = \sqrt{\frac{2E_s}{T_s}}\cos(\omega_c t + \pi) = -\sqrt{\frac{2E_s}{T_s}}\cos(\omega_c t)$$

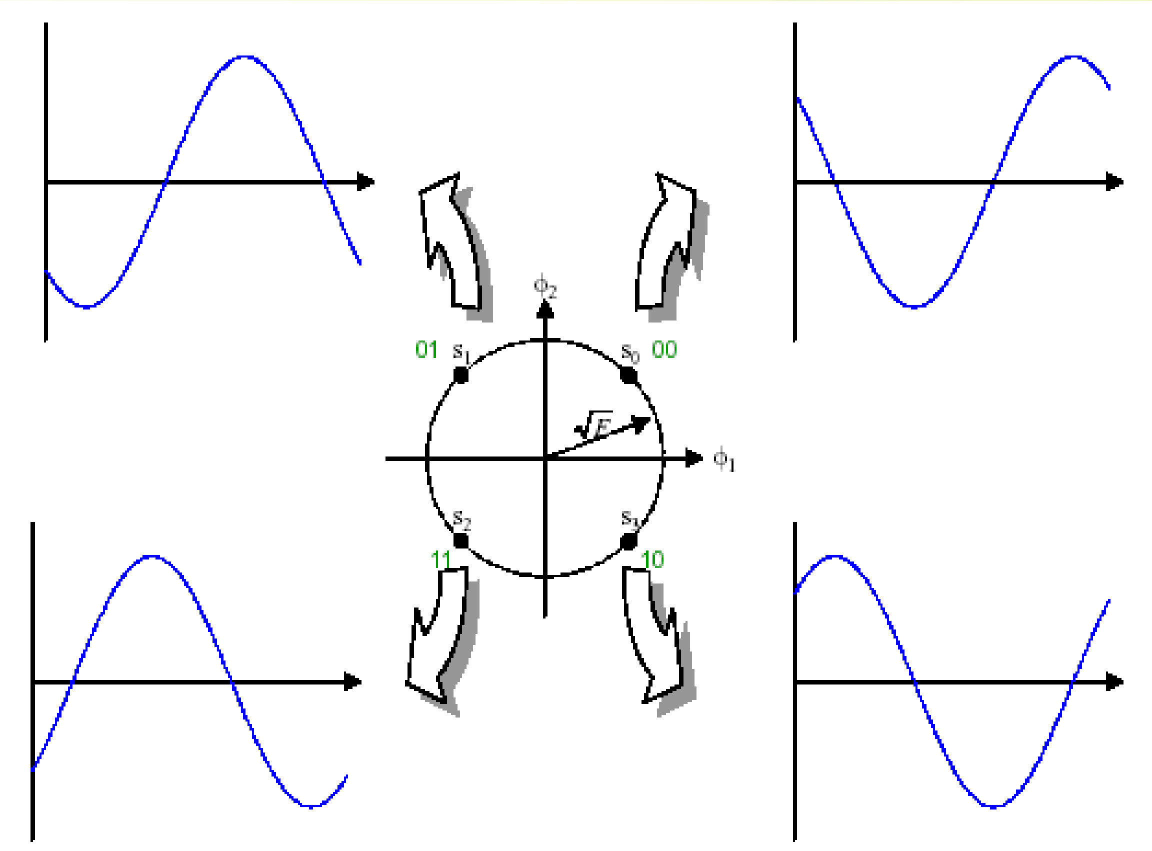
$$s_3 = \sqrt{\frac{2E_s}{T_s}}\cos(\omega_c t + \frac{3\pi}{2}) = \sqrt{\frac{2E_s}{T_s}}\sin(\omega_c t)$$

$$s_{0,2}(t) = \pm\sqrt{\frac{2E_s}{T_s}}\cos\omega_c t, \quad \phi - shift\ of\ 0^0\ and\ 180^0$$

$$s_{1,3}(t) = \pm\sqrt{\frac{2E_s}{T_s}}\sin\omega_c t, \quad \phi - shift\ of\ 90^0\ and\ 270^0$$

- We can also have:

$$s_{QPSK}(t) = \sqrt{\frac{2E_s}{T_s}} \cos\left[\omega_c t + \frac{2\pi(i-1)}{M} - \frac{\pi}{4}\right], \quad i = 1,2,3,4 \quad 0 \le t \le T_s$$



- One of 4 possible waveforms is transmitted during each signaling interval Ts
  - i.e., 2 bits are transmitted per modulation symbol → Ts=***2T_b***)
- In QPSK, both the in-phase and quadrature components are used
- The **I** and **Q** channels are aligned and phase transition occur once every ***T_s* = *2T_b*** seconds with a maximum transition of 180 degrees
- From

$$s_{QPSK}(t) = \sqrt{\frac{2E_s}{T_s}} \cos\left[2\pi f_c t + \frac{2\pi(i-1)}{M}\right]$$

- As shown earlier we can use trigonometric identities to show that

$$s_{QPSK}(t) = \sqrt{\frac{2E_s}{T_s}} \cos\left[\frac{2\pi(i-1)}{M}\right] \cos(\omega_c t) - \sqrt{\frac{2E_s}{T_s}} \sin\left[\frac{2\pi(i-1)}{M}\right] \sin(\omega_c t)$$

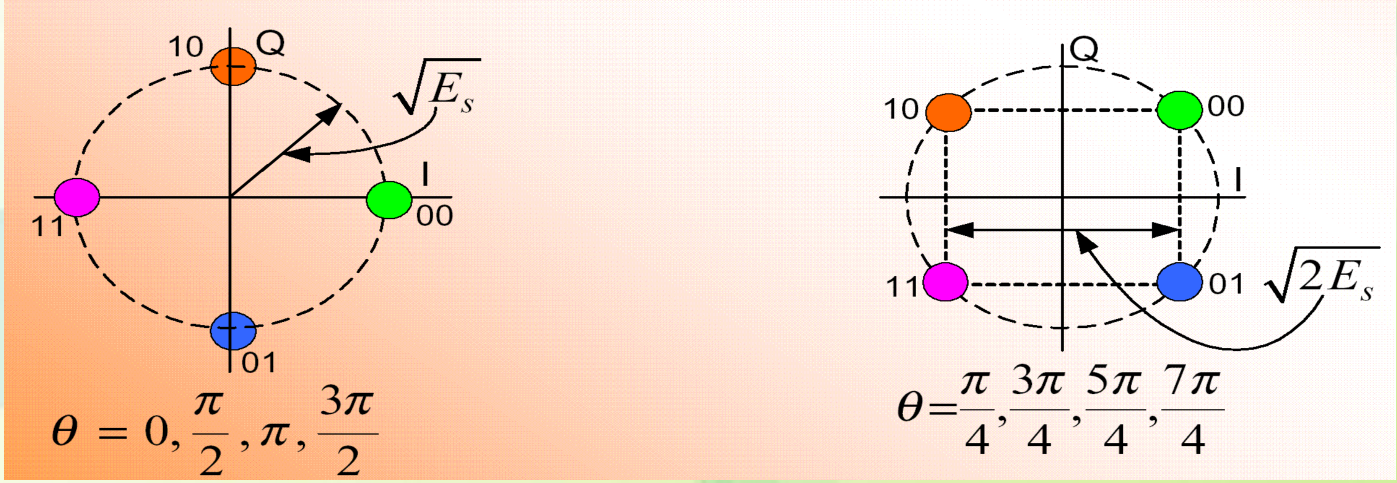
- In terms of basis functions

$$\psi_1(t) = \sqrt{\frac{2}{T_s}} \cos 2\pi f_c t \quad and \quad \psi_2(t) = \sqrt{\frac{2}{T_s}} \sin 2\pi f_c t$$

we can write $s_{QPSK}(t)$ as

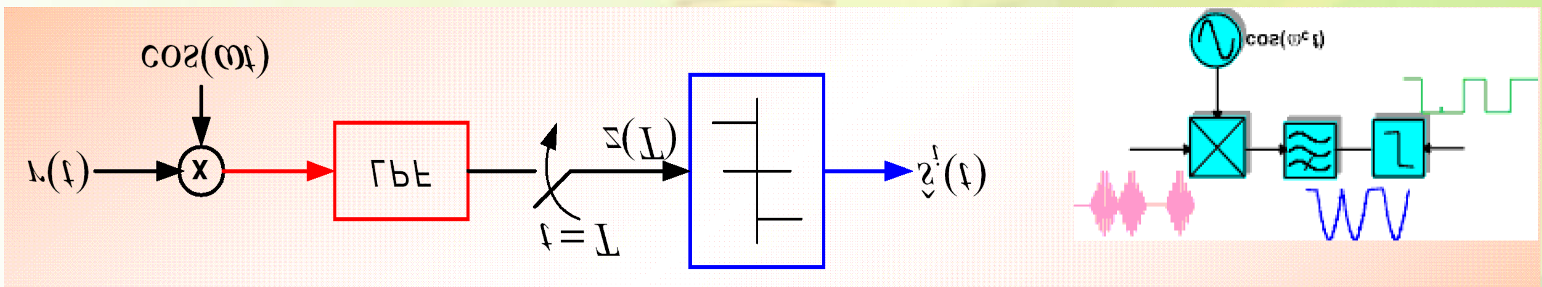
$$s_{QPSK}(t) = \left\{ \sqrt{E_s} \cos\left[\frac{2\pi(i-1)}{M}\right]\psi_1(t) - \sqrt{E_s} \sin\left[\frac{2\pi(i-1)}{M}\right]\psi_2(t) \right\}$$

- With this expression, the constellation diagram can easily be drawn
- For example:



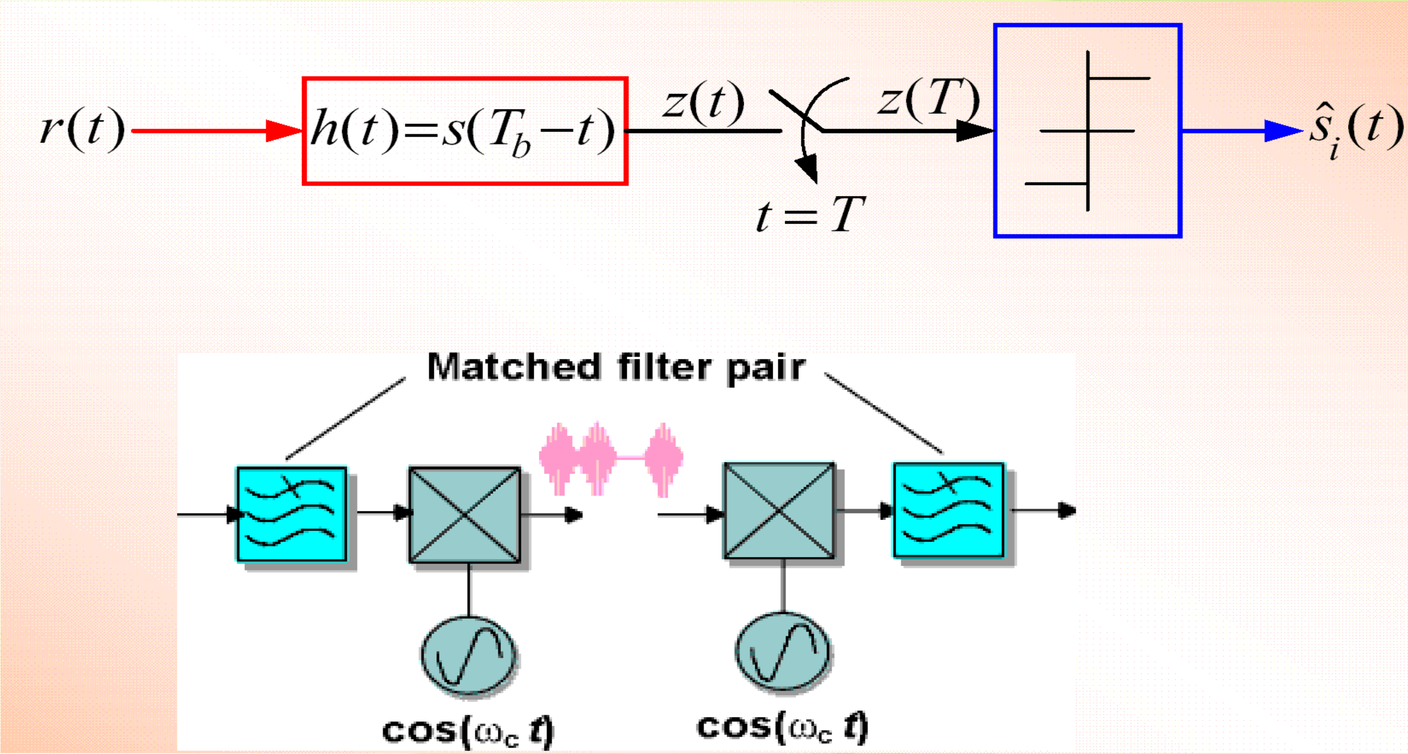
Coherent Detection
1. Coherent Detection of PSK

- Coherent detection requires the phase information
- A coherent detector operates by mixing the incoming data signal with a locally generated carrier reference and selecting the difference component from the mixer output



  - Multiplying *r(t)* by the receiver LO (say *A* $\cos(\omega_c t)$) yields a signal with a baseband component plus a component at $2f_c$
  - The LPF eliminates the high frequency component
  - The output of the LPF is sampled once per bit period
  - The sampled value *z(T)* is applied to a decision rule
    - *z(T)* is called the **decision statistic**

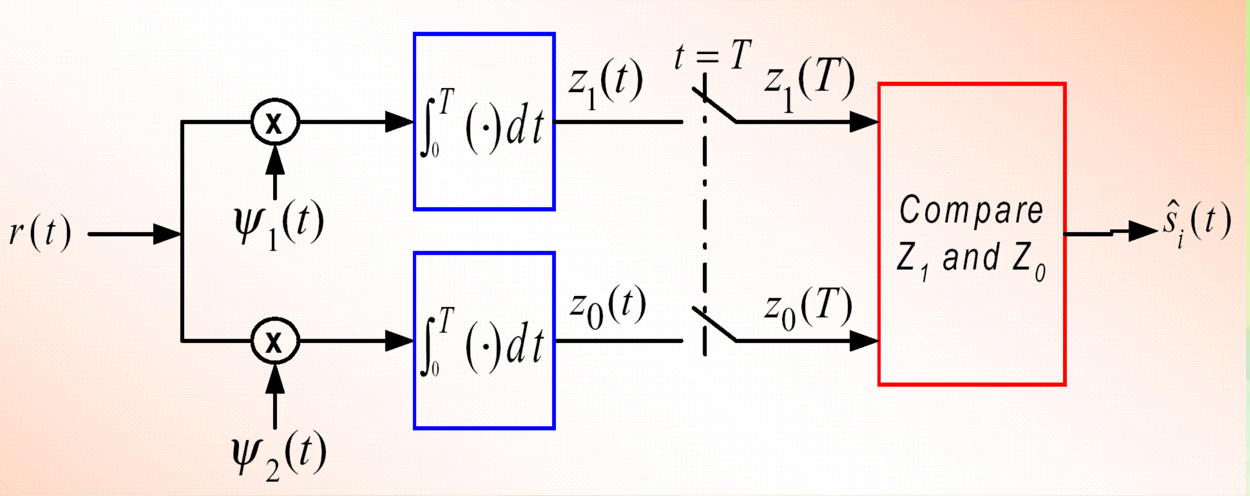
- Matched filter receiver



  – A MF pair such as the root raised cosine filter can thus be used to shape the source and received baseband symbols
  – In fact this is a very common approach in signal detection in most bandpass data modems

2. Coherent Detection of MPSK

- QPSK receiver is composed of 2 BPSK receivers
  - one that locks on to the sine carrier and
  - the other that locks onto the cosine carrier



$$\psi_1(t) = A\cos\omega_0 t$$

$$\psi_2(t) = A\sin\omega_0 t$$

$$z_0(t) = \int_0^{T_s} s_0(t)\psi_1(t)dt = \int_0^{T_s} (A\cos\omega_0 t)\,(A\cos\omega_0 t)dt = \frac{A^2T_s}{2} \triangleq L_0$$

$$z_1(t) = \int_0^{T_s} s_0(t)\psi_2(t)dt = \int_0^{T_s} (A\cos\omega_0 t)\,(A\sin\omega_0 t)dt = 0$$

Output	$S_0(t)$	$S_1(t)$	$S_2(t)$	$S_3(t)$
Z_0	Lo	0	-Lo	0
Z_1	0	-Lo	0	Lo

$$L_0 = \frac{A^2 T_s}{2} \cos \frac{\pi}{4}$$

- If $\psi_1(t) = A\cos(\omega_0 t + 45^o)\ and\ \psi_2(t) = A\cos(\omega_0 t - 45^o)$

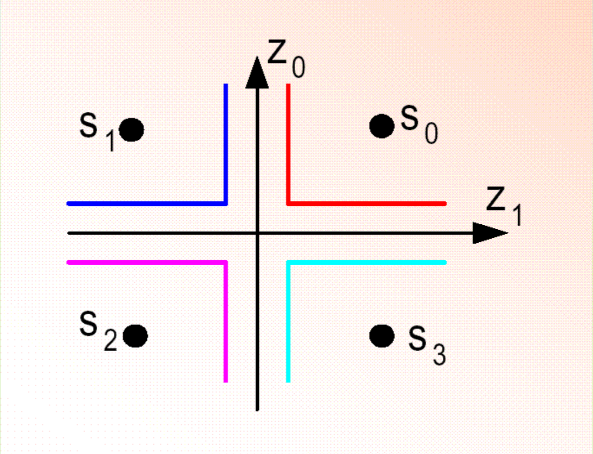
Output	$S_0(t)$	$S_1(t)$	$S_2(t)$	$S_3(t)$
Z_0	Lo	-Lo	-Lo	Lo
Z_1	Lo	Lo	-Lo	-Lo

- Decision:

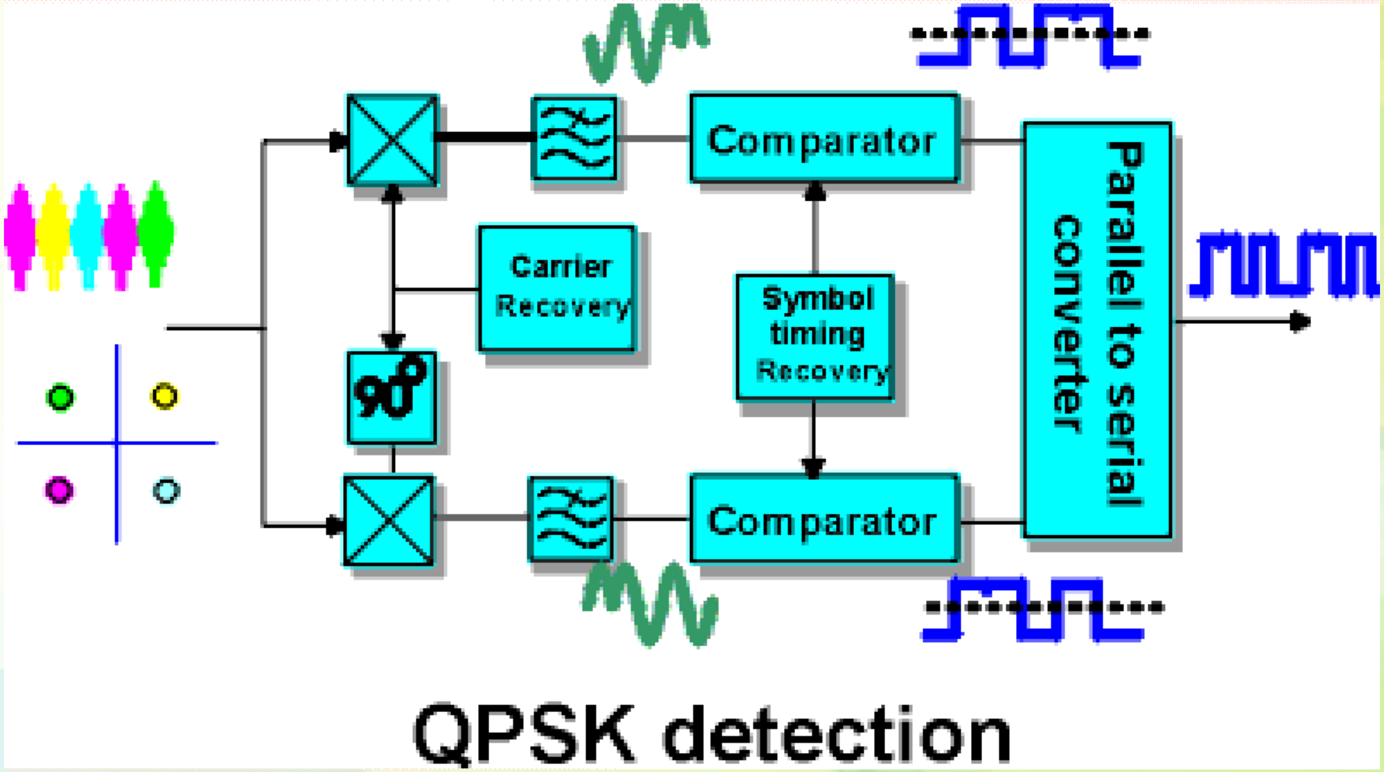
1. Calculate $z_i(t)$ as

$$z_i(t) = \int_0^T r(t)\,\psi_i(t)dt$$

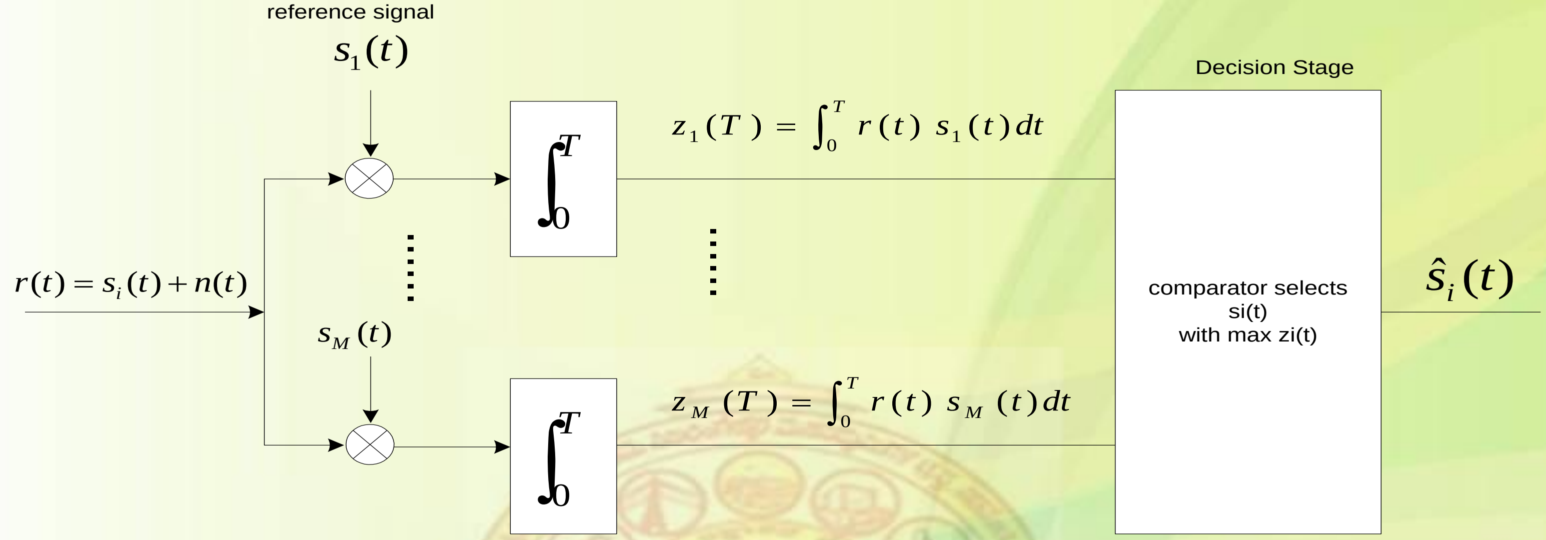
2. Find the quadrant of (Z_0, Z_1)

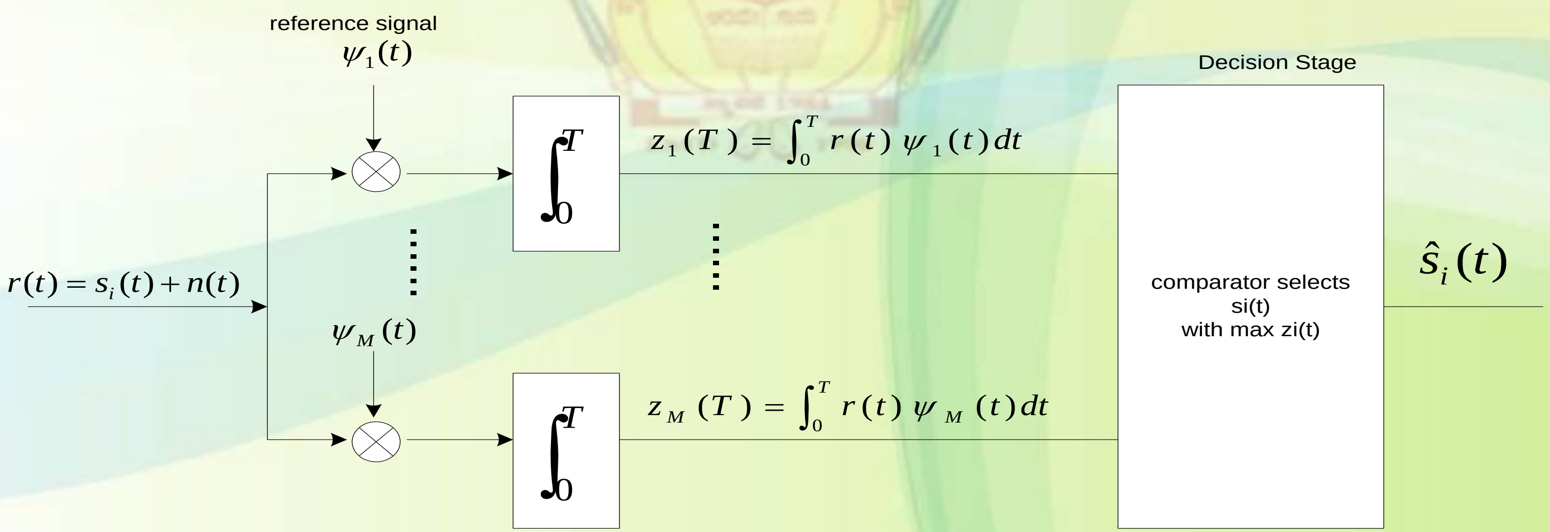


- A coherent QPSK receiver requires accurate carrier recovery using a 4th power process, to restore the 90º phase states to modulo 2π



Correlation Receiver





Differential Modulation

- In the transmitter, each symbol is modulated relative to the previous symbol and modulating signal, for instance in BPSK 0 = no change, 1 = $+180^0$
- In the receiver, the current symbol is demodulated using the previous symbol as a reference. The previous symbol serves as an estimate of the channel. A no-change condition causes the modulated signal to remain at the same 0 or 1 state of the previous symbol.

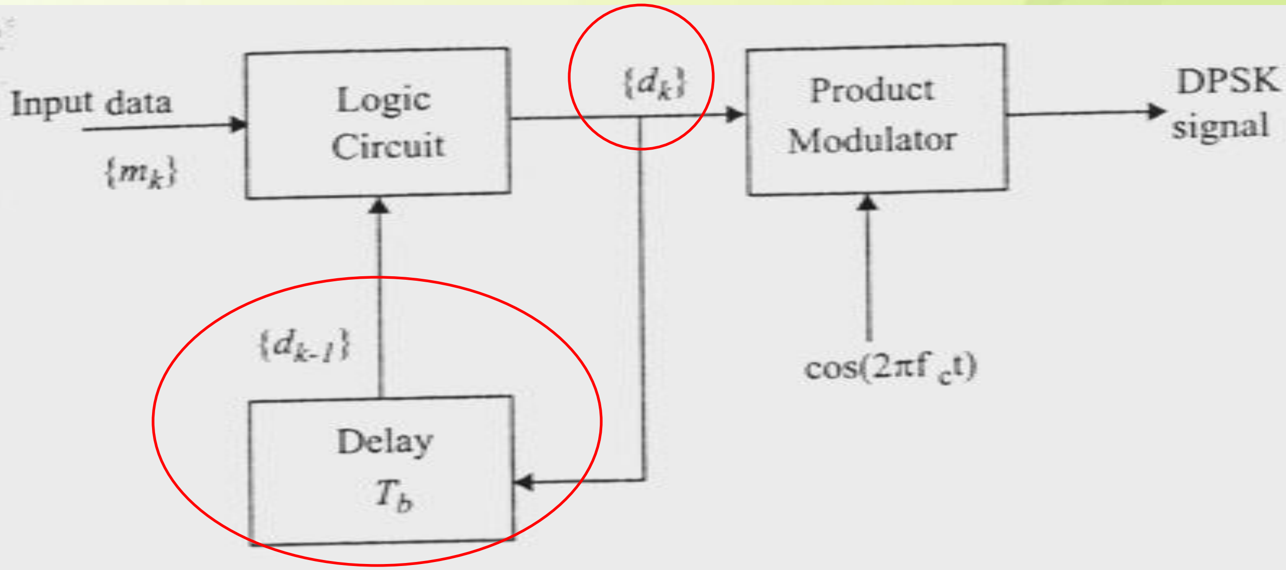


Figure 5.24
Block diagram of a DPSK transmitter.

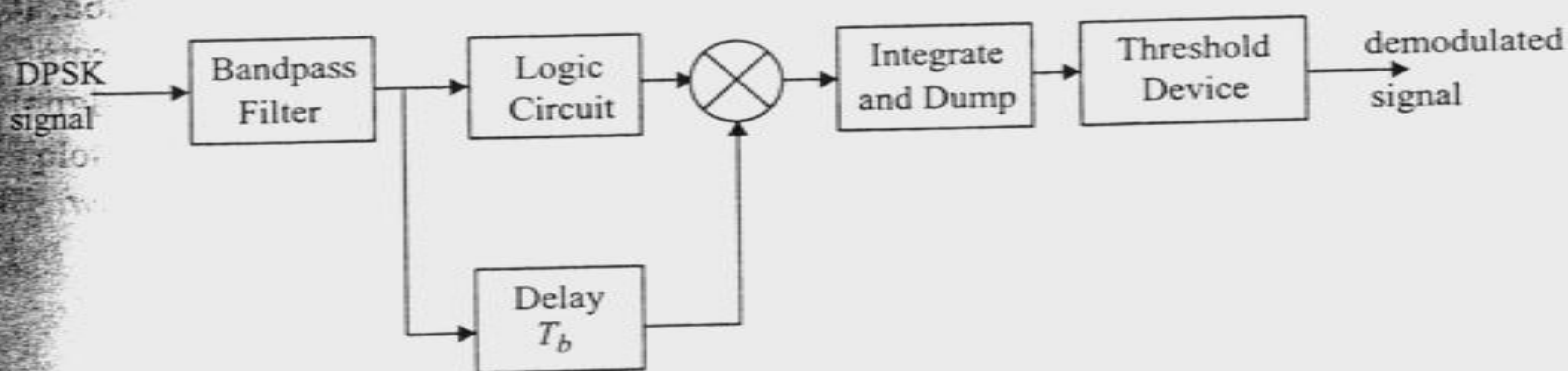


Figure 5.25
Block diagram of DPSK receiver.

Table 5.1 Illustration of the Differential Encoding Process

$\{m_k\}$		1	0	0	1	0	1	1	0
$\{d_{k-1}\}$		1	1	0	1	1	0	0	0
$\{d_k\}$	1	1	0	1	1	0	0	0	1

DPSK

Let $\{d_k\}$ denote the differentially encoded sequence with this added reference bit. We now introduce the following definitions in the generation of this sequence:

• If the incoming binary symbol b_k is 1, leave the symbol d_k unchanged with respect to the previous bit.

• If the incoming binary symbol b_k is 0, change the symbol d_k with respect to the previous bit.

DPSK

- to send symbol 0, we advance the phase of the current signal waveform by 180 degrees,
- to send symbol 1, we leave the phase of the current signal waveform unchanged.

Generation of DPSK:

- The differential encoding process at the transmitter input starts with an arbitrary first bit, serving as reference.

Differential Phase Shift Keying (DPSK):

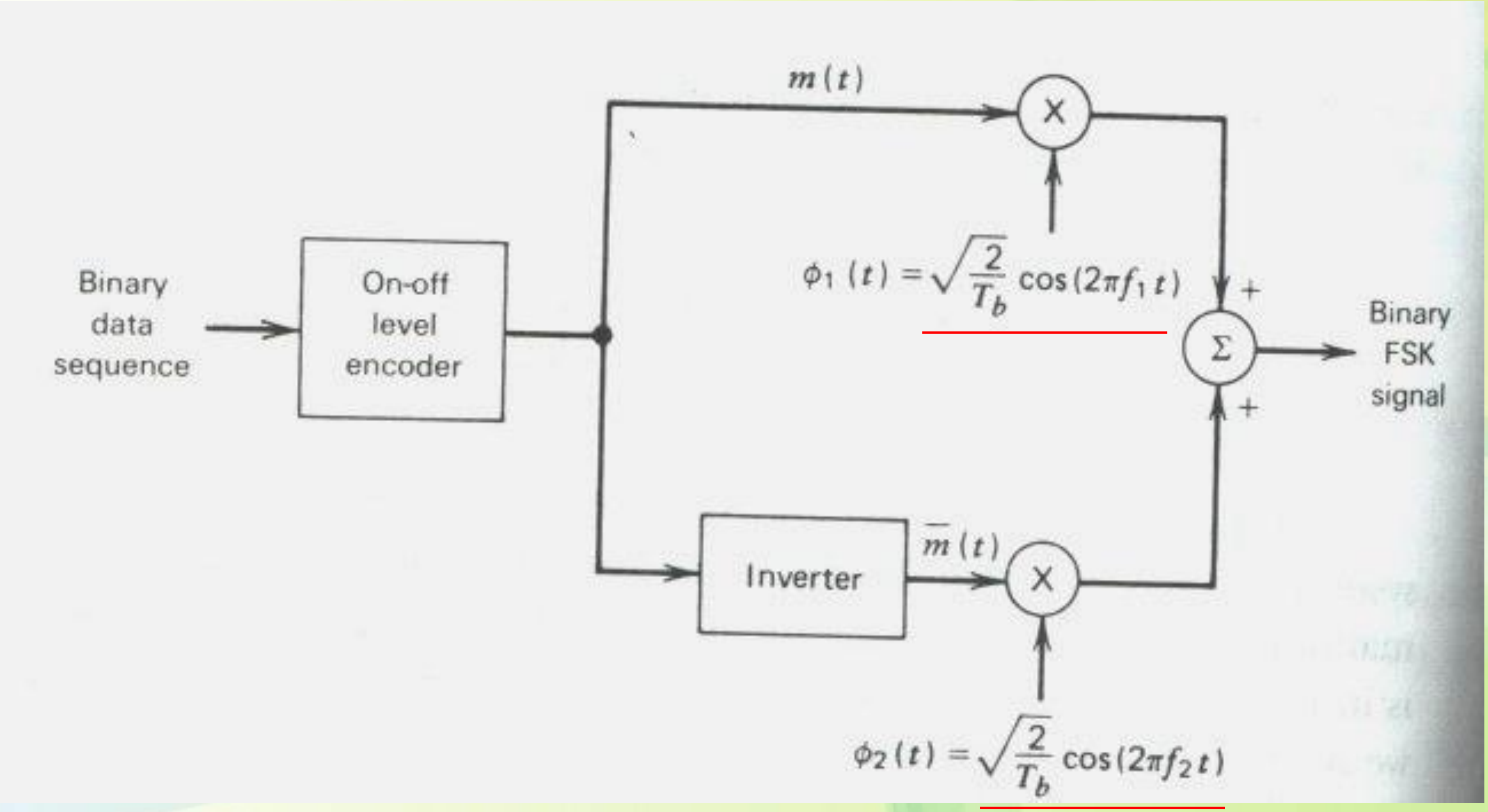
• DPSK is a non coherent form of phase shift keying which avoids the need for a coherent reference signal at the receiver.

Advantage:

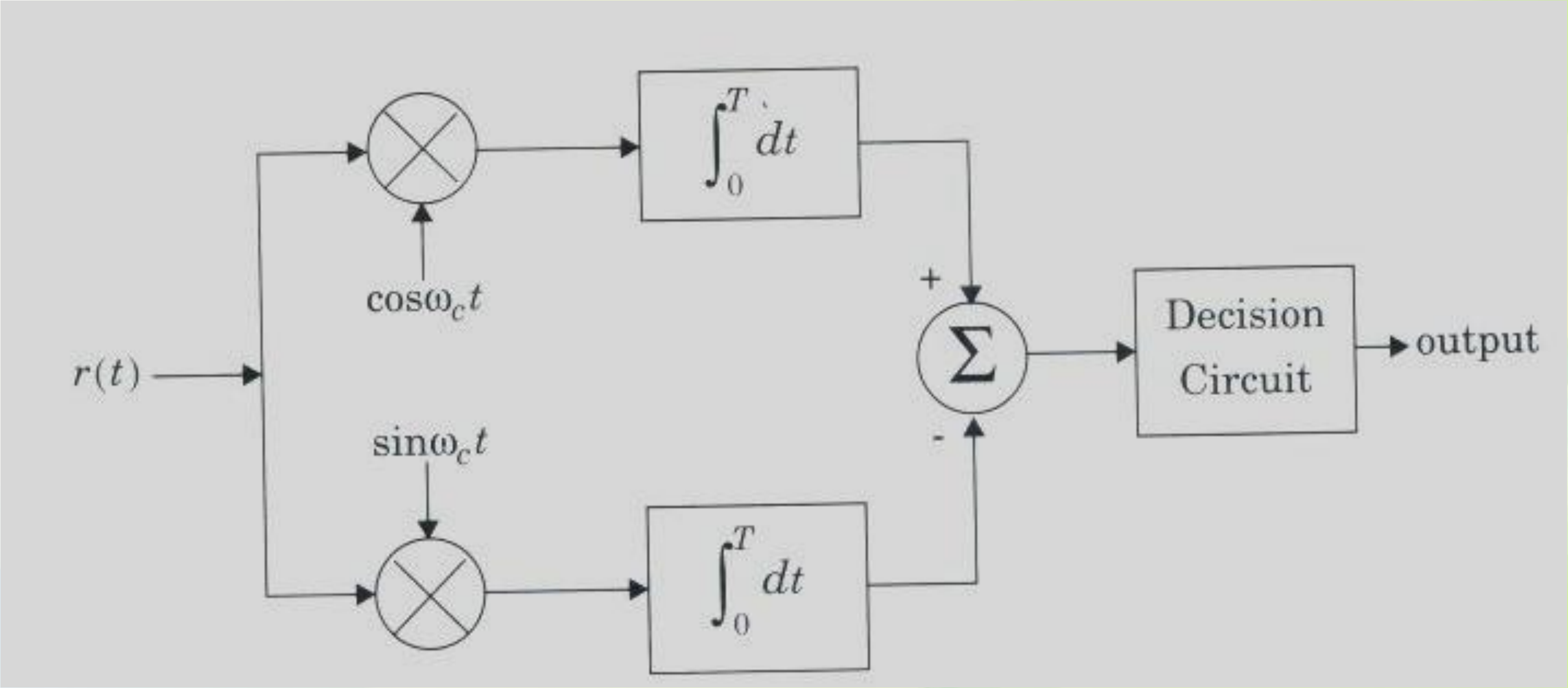
• Non coherent receivers are easy and cheap to build, hence widely used in wireless communications.

•DPSK eliminates the need for a coherent reference signal at the receiver by combining two basic operations at the transmitter:

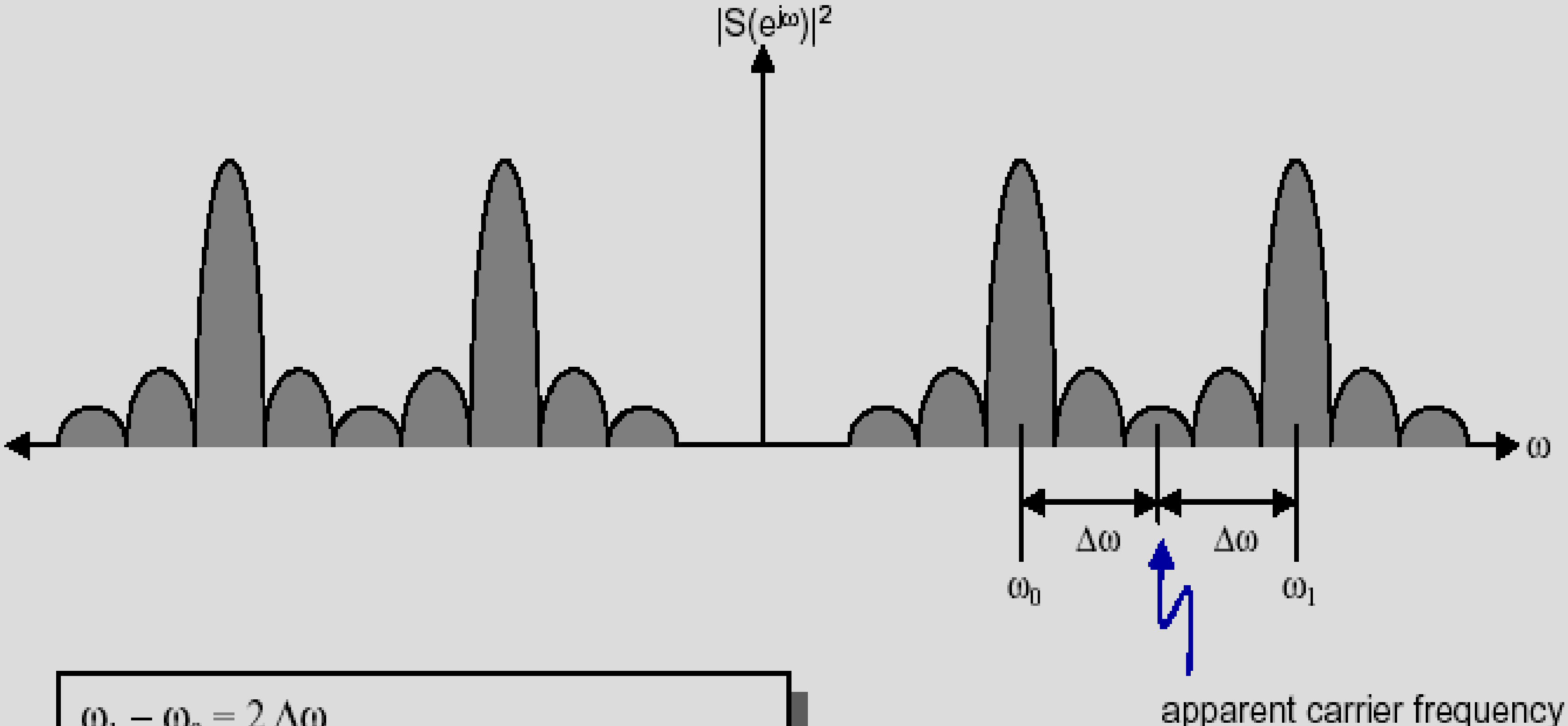
BFSK Transmitter



Coherent Detection Of BFSK



FSK Spectrum



$\omega_1 - \omega_0 = 2\,\Delta\omega$

where

$\Delta\omega$ = frequency shift from apparent carrier

Minimum Shift Keying (MSK)

MSK is a continuous phase-frequency shift keying;

Why MSK?

-- Exploitation of Phase Information besides frequency.

Representation of a MSK signal

$$s(t) = s_1\phi_1(t) + s_2\phi_2(t) \qquad 0 \leq t \leq T_b$$

the appropriate form for the orthonormal basis functions $\phi_1(t)$ and $\phi_2(t)$ is as follows:

$$\phi_1(t) = \sqrt{\frac{2}{T_b}} \cos\left(\frac{\pi}{2T_b} t\right) \cos(2\pi f_c t) \qquad -T_b \leq t \leq T_b \tag{7.59}$$

and

$$\phi_2(t) = \sqrt{\frac{2}{T_b}} \sin\left(\frac{\pi}{2T_b} t\right) \sin(2\pi f_c t) \qquad 0 \leq t \leq 2T_b \tag{7.60}$$

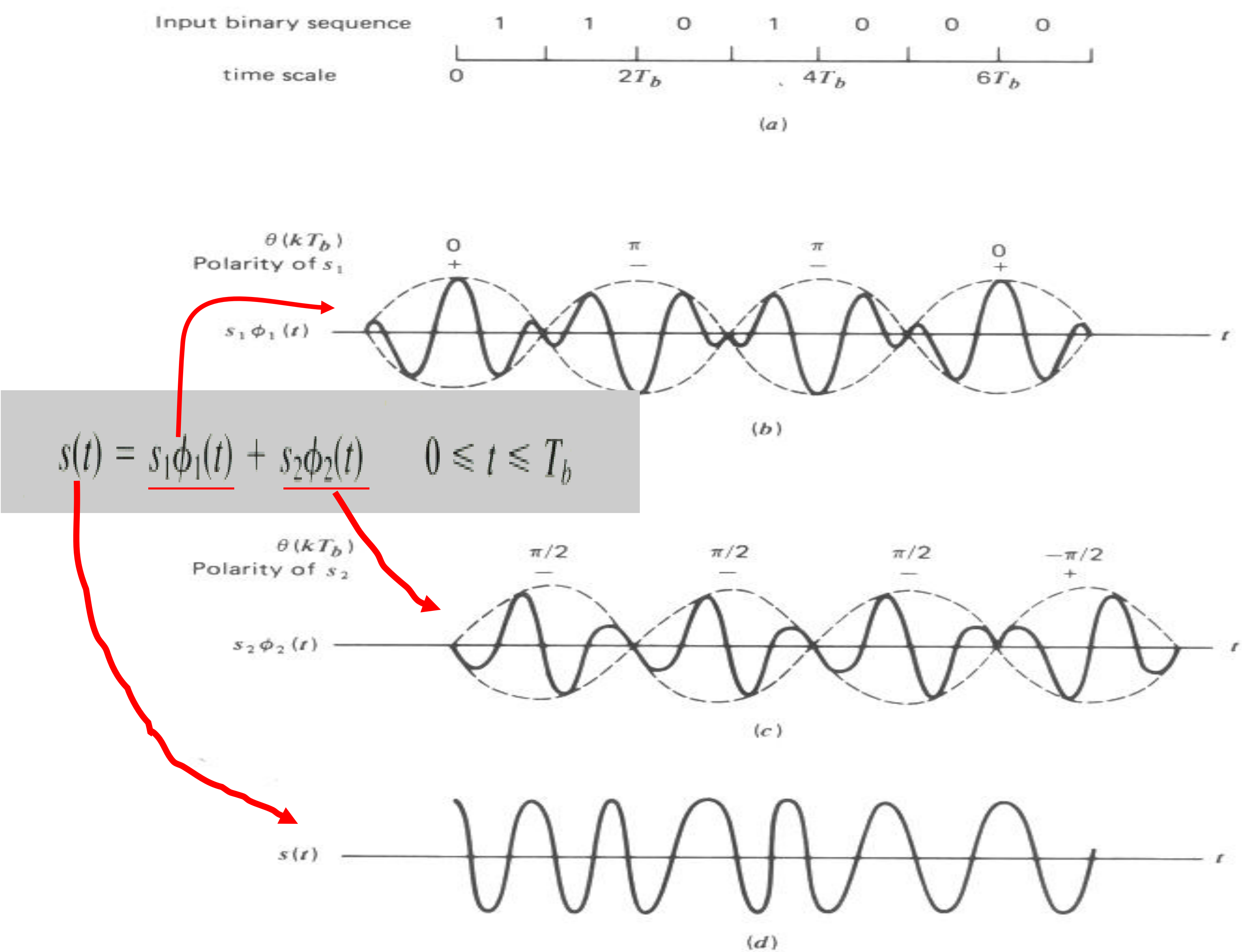
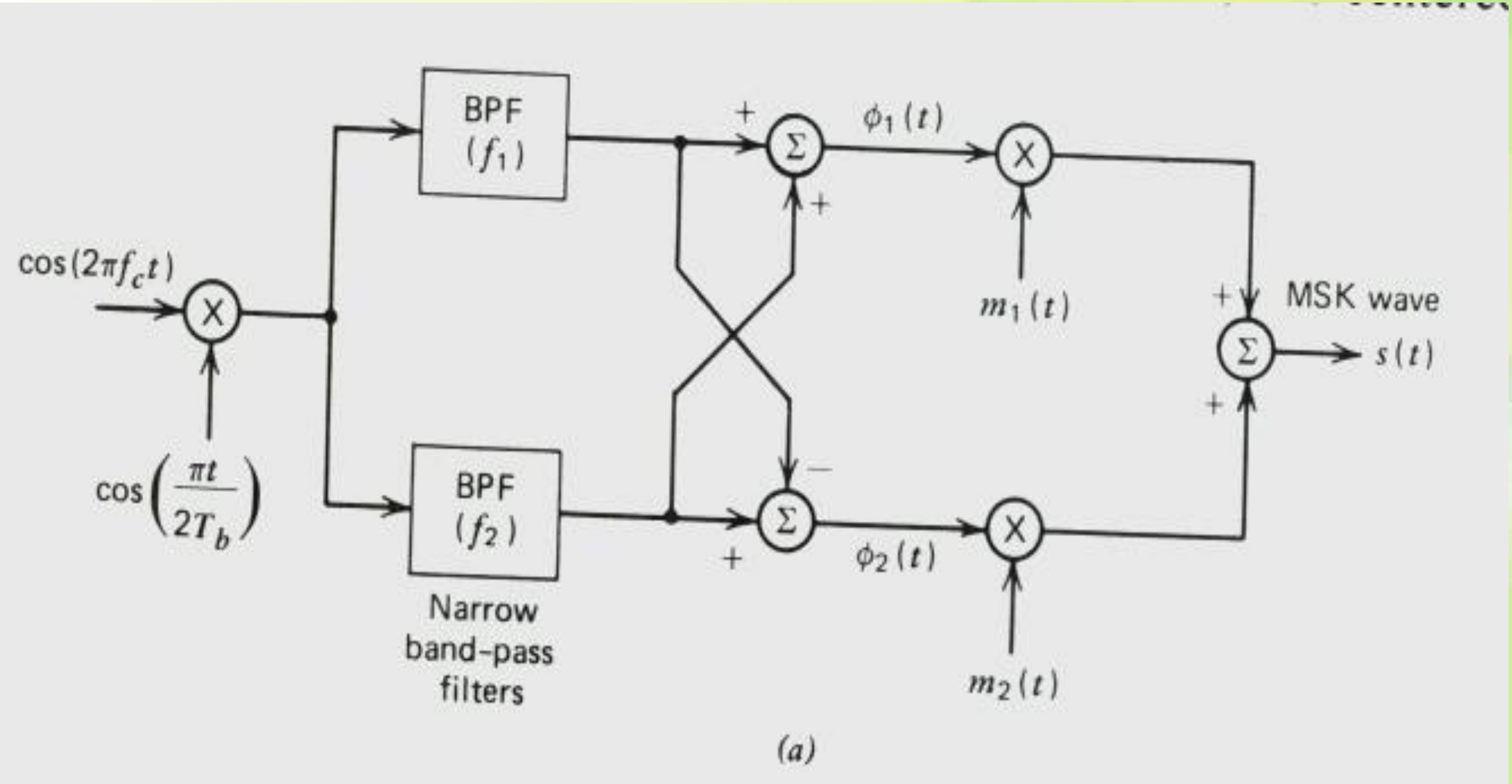
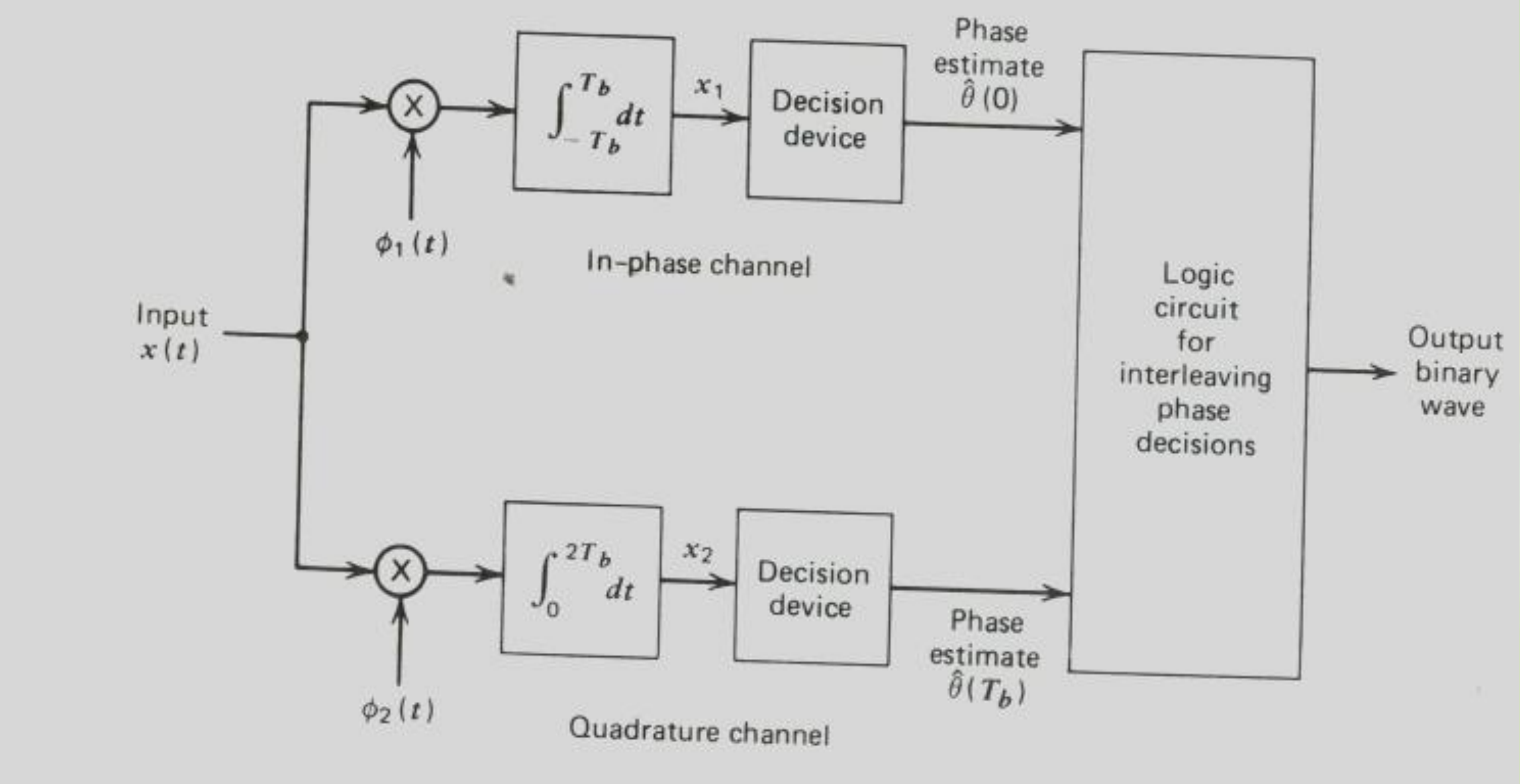


Figure 7.13 Sequence and waveforms for MSK signal. (*a*) Input binary sequence. (*b*) Scaled time function $s_1\phi_1(t)$. (*c*) Scaled time function $s_2\phi_2(t)$. (*d*) MSK signal $s(t)$ obtained by adding $s_1\phi_1(t)$ and $s_2\phi_2(t)$ on a bit-by-bit basis.

MSK Transmitter



MSK Receiver



M-ary Quadrature Amplitude Modulation (QAM)

- It's a Hybrid modulation

- As we allow the amplitude to also vary with the phase, a new modulation scheme called quadrature amplitude modulation (QAM) is obtained.

- The constellation diagram of 16-ary QAM consists of a square lattice of signal points.

Fig: signal Constellation of M-ary QAM for M=16

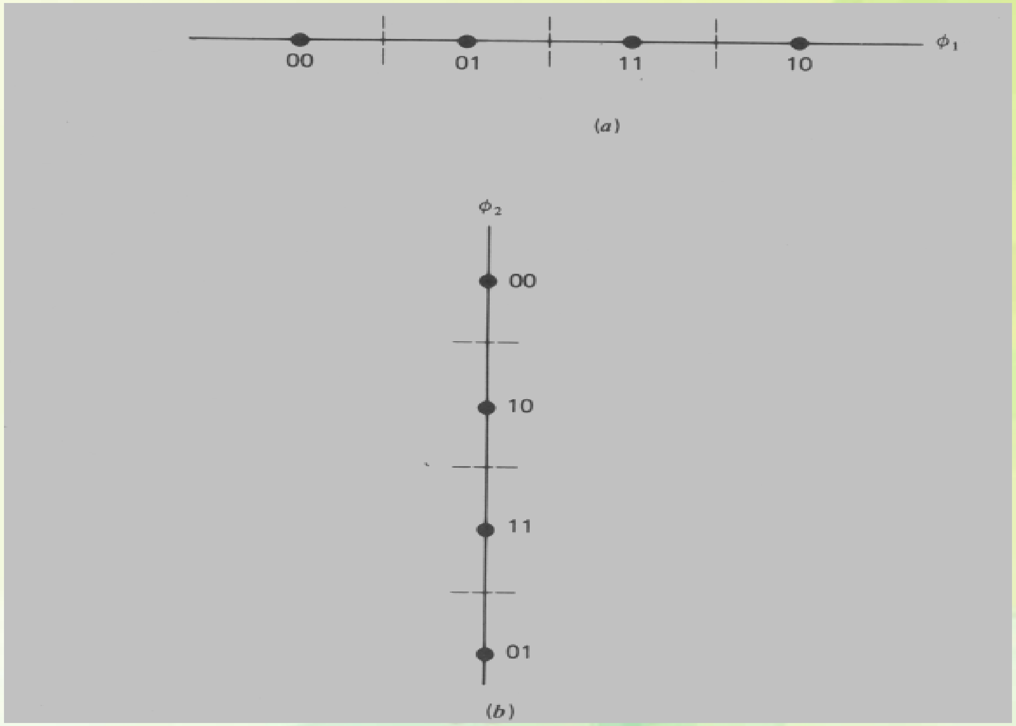


Fig: Decomposition of signal Constellation of M-ary QAM

The general form of an M-ary QAM signal can be defined as

$$S_i(t) = \sqrt{\frac{2E_{min}}{T_s}}\, a_i \cos(2\pi f_c t) + \sqrt{\frac{2E_{min}}{T_s}}\, b_i \sin(2\pi f_c t)$$

$$0 \le t \le T \qquad i = 1, 2, \ldots, M$$

where

E_{min} is the energy of the signal with the lowest amplitude and

a_i and b_i are a pair of independent integers chosen according to the location of the particular signal point.

- In M-ary QAM energy per symbol and also distance between possible symbol states is not a constant.

Queries ….?