(DEEMED TO BE UNIVERSITY)

Digital Communication 22EC2208A

Digital Carrier Modulation

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Binary Frequency Shift Keying (BFSK)

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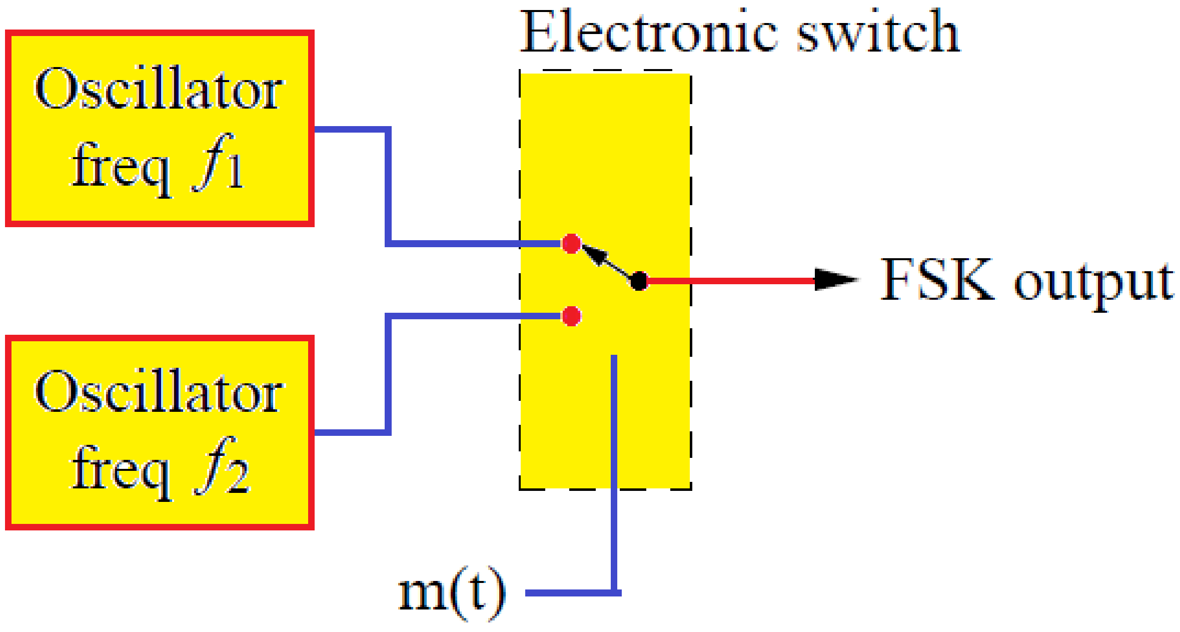
Binary Frequency Shift Keying (**BFSK)**

- Frequency Shift Keying is analogous to Frequency Modulation (FM) in analog domain, where the slope of the time varying angle of the signal, i.e., instantaneous frequency of the carrier signal varies with respect to the baseband signal.
- In the digital symbol, there exist two amplitude levels defined for two logic values one and zero.
- Therefore, two sinusoidal carrier waves of the same amplitude A_c but different frequencies f_1 and f_2 are used to represent the two symbol



Mathematical Model

$$s_i(t) = \begin{cases} \sqrt{\dfrac{2E_b}{T_b}} \cos 2\pi f_1 t, \text{ for symbol 1, corresponds to } i = 1 \\ \sqrt{\dfrac{2E_b}{T_b}} \cos 2\pi f_2 t, \text{ for symbol 0, corresponds to } i = 2 \end{cases} \Rightarrow 0 \le t \le T_b$$

mark

space

f_m Mark frequency

f_s Space frequency

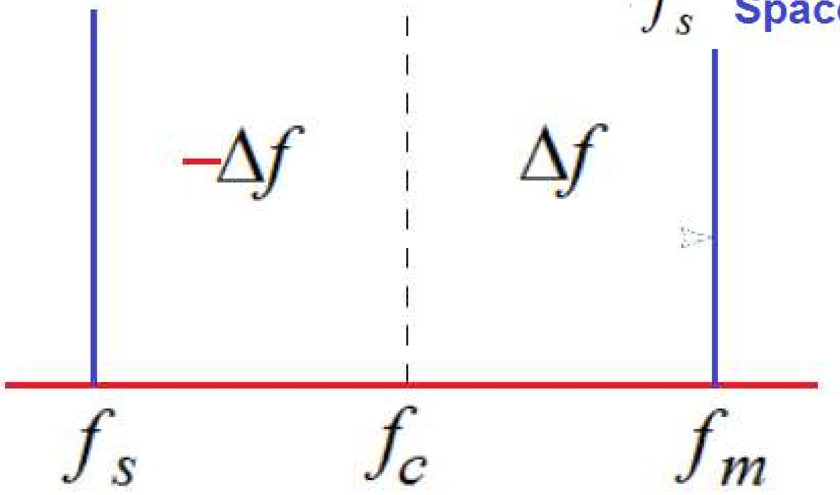
where E_b transmitted signal energy per bit

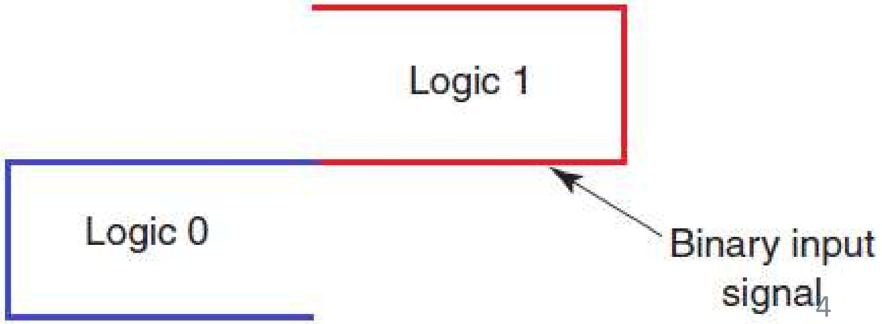
The transmitted frequency with separation

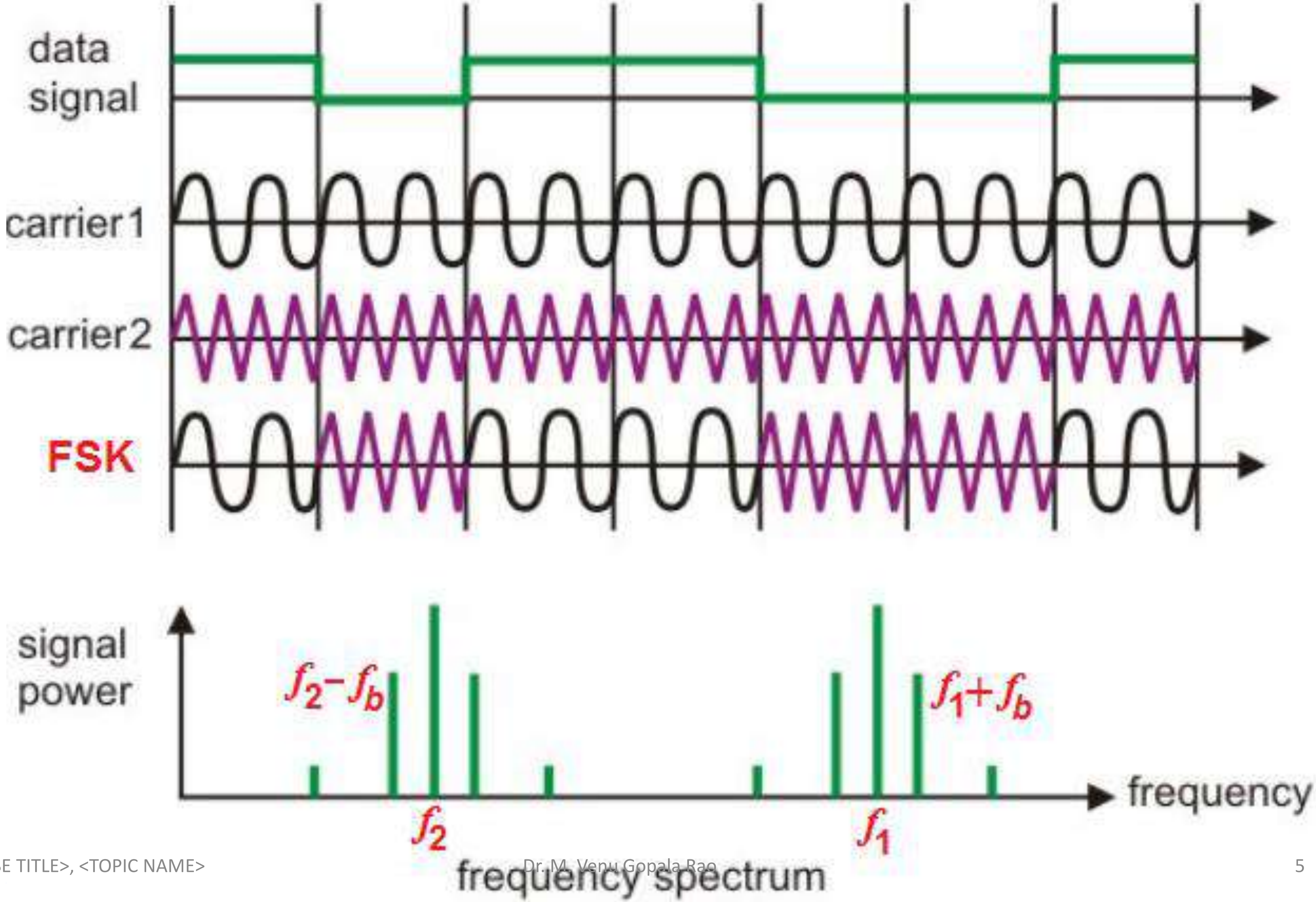
$$\Delta f = \frac{|f_m - f_s|}{2}$$

The Δf is selected such that $s_1(t)$ and $s_2(t)$ are orthogonal

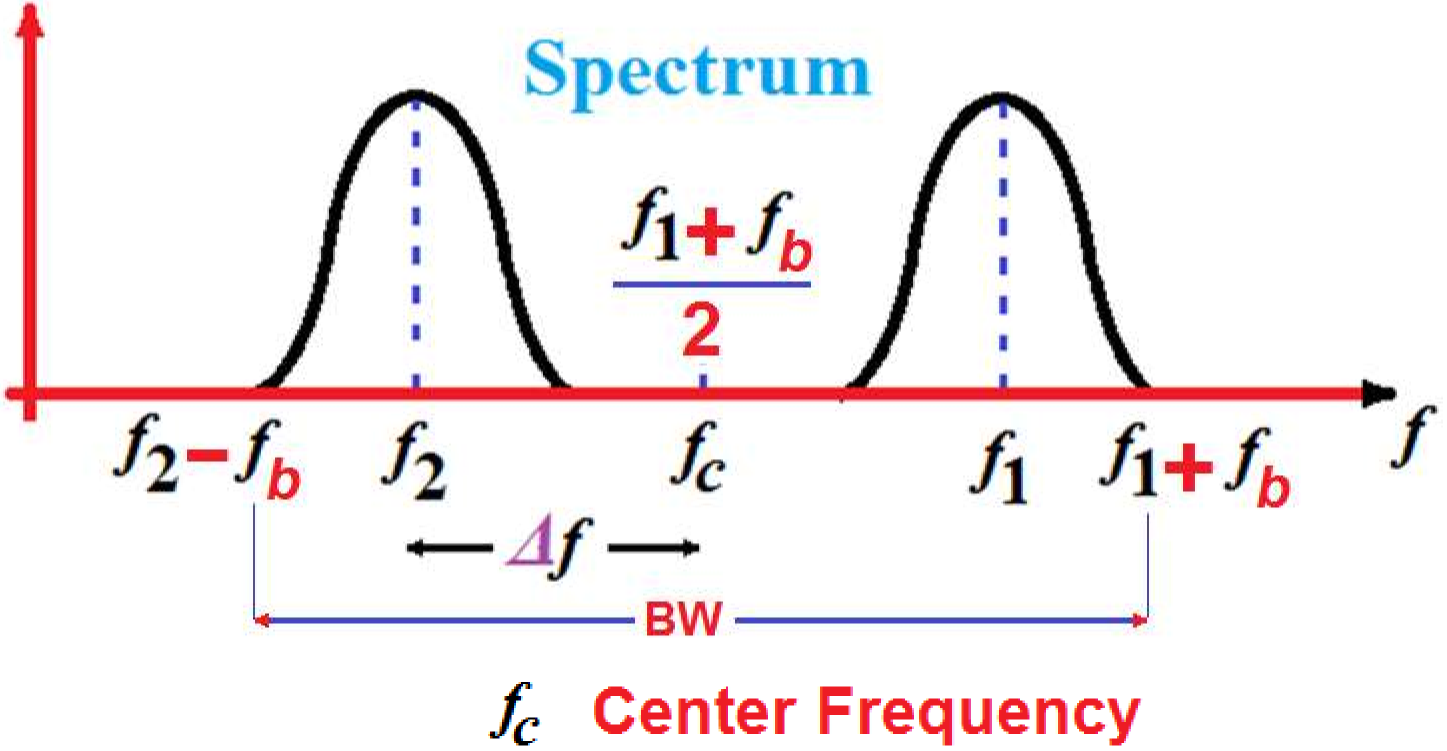
$$\int_o^{T_b} s_1(t)\, s_2(t)\, dt = 0$$






data
signal
carrier 1
carrier2
FSK
signal
power
$f_2 - f_b$
$f_1 + f_b$
frequency
f_2
f_1
frequency spectrum

Bandwidth of FSK



Bandwidth =

$$B=(f_1+f_b)-(f_2-f_b)=(f_1-f_2)+2f_b$$

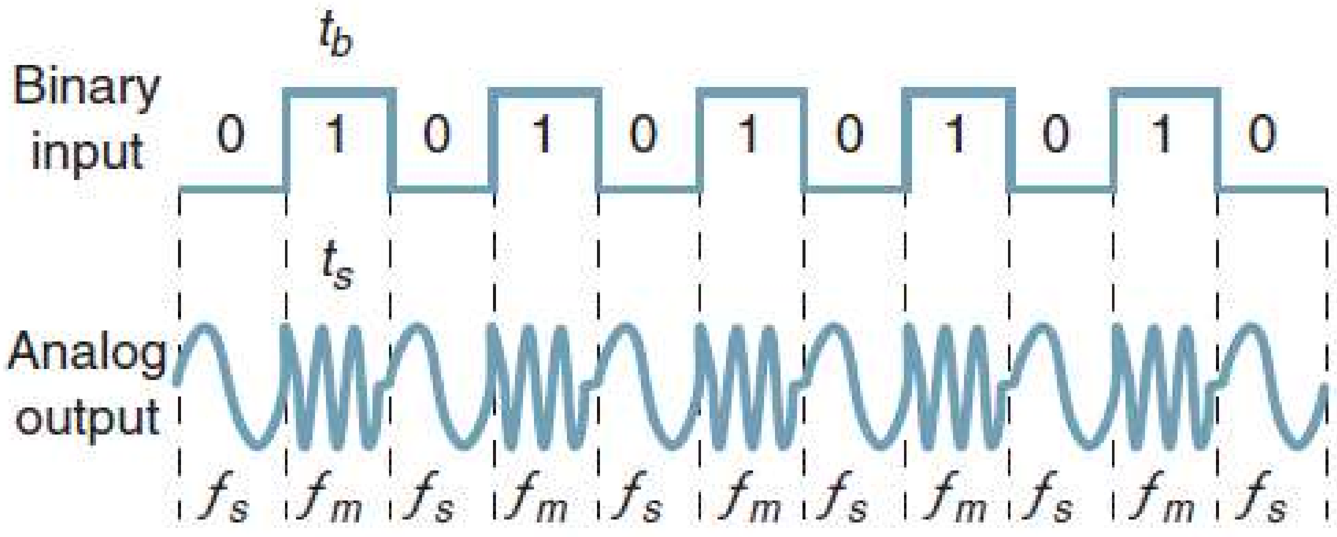
$$=2\Delta f+2f_b=2(\Delta f+f_b)$$ Carson's rule

Baud, Bit rate and Bandwidth of FSK

In Fig (a), it can be seen that the time of one bit (t_b) is the same as the time the FSK output is a mark of space frequency (t_s).

Thus, the bit time equals the time of an FSK signaling element, and the bit rate equals the baud.

$$\boxed{\text{baud} = \frac{f_b}{1} = f_b}$$

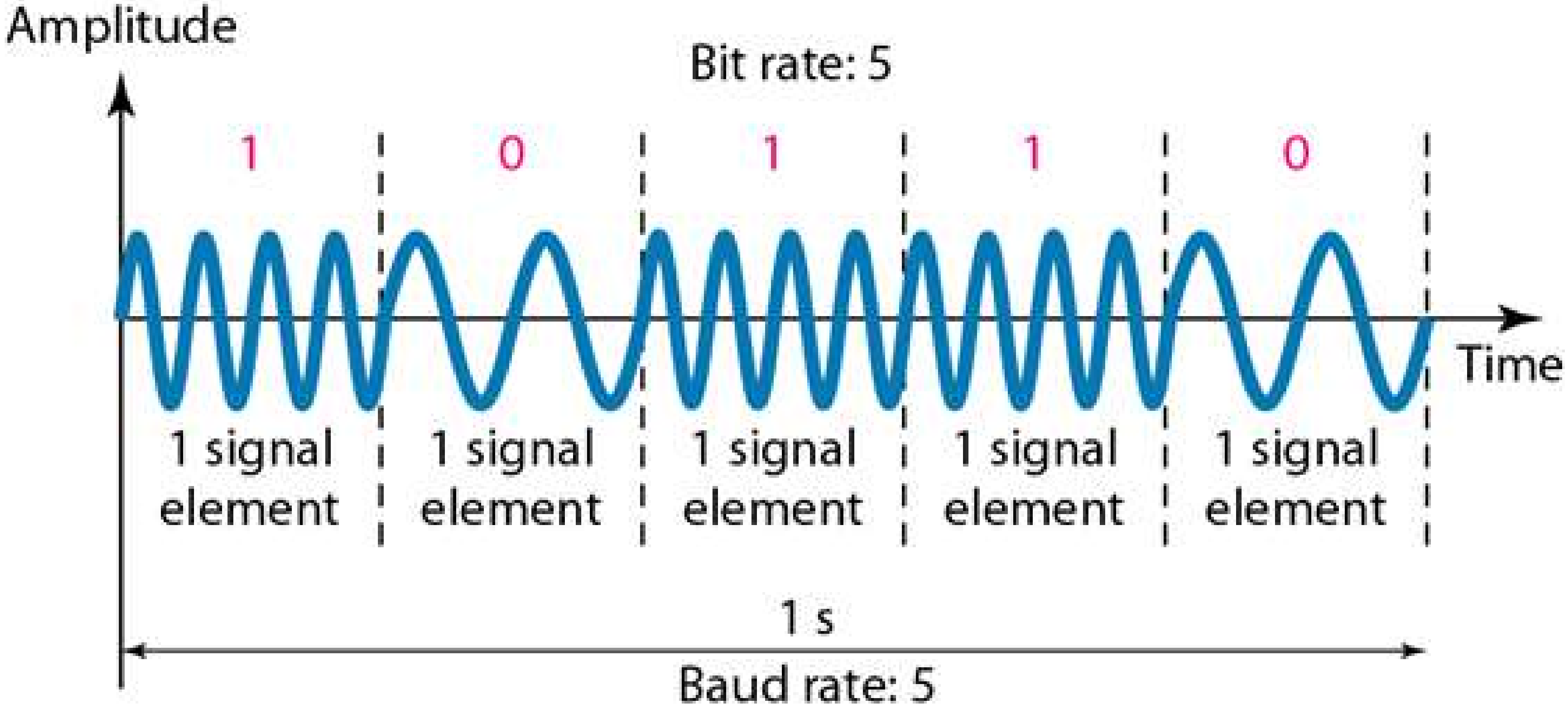


f_m, mark frequency; f_s space frequency

(a)

binary input	frequency output
0	space (f_s)
1	mark (f_m)

(b)


Amplitude
Bit rate: 5
1
0
1
1
0
Time
1 signal element
1 signal element
1 signal element
1 signal element
1 signal element
1 s
Baud rate: 5

Ex1: Determine (a) the peak frequency deviation, (b) minimum bandwidth, and (c) baud for a binary FSK signal with a mark frequency of 49 kHz, a space frequency of 51 kHz, and an input bit rate of 2 kbps.

Solution a. The peak frequency deviation is determined from Equation

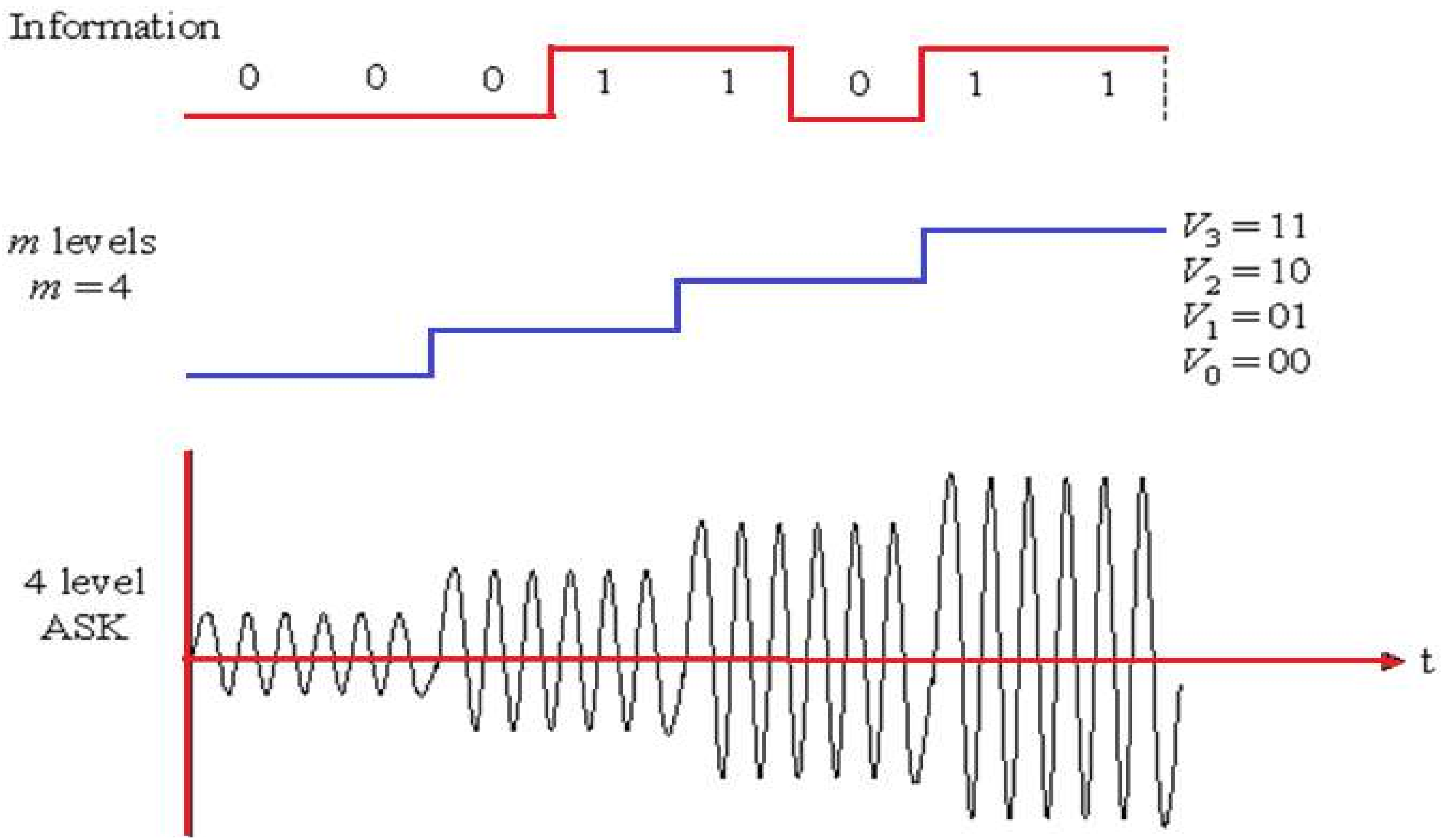
$$\Delta f = \frac{|49\text{kHz} - 51\text{kHz}|}{2} = 1\text{ kHz}$$

b. The minimum bandwidth is determined from Equation

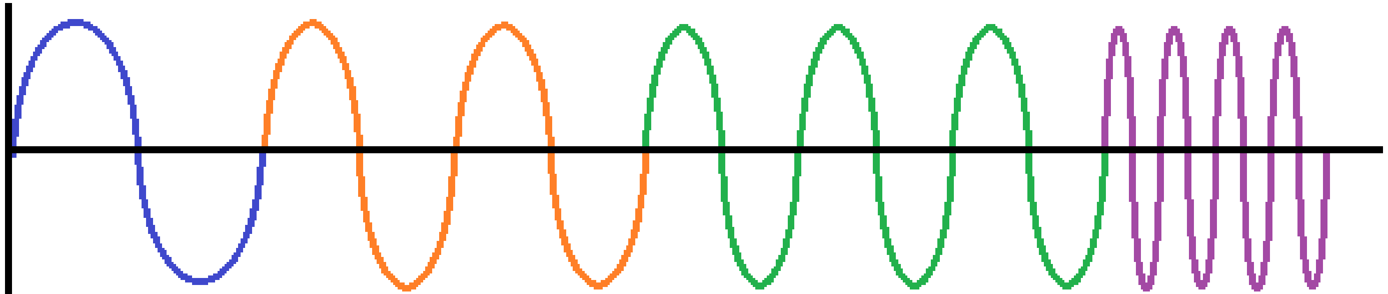
$$B = 2(1000 + 2000) = 6\text{ kHz}$$

c. For FSK, $n = 1$, and the baud is determined from Equation

$$\text{baud} = \frac{2000}{1} = 2000$$


Information
0 0 0 1 1 0 1 1
m levels
m = 4
$V_3 = 11$
$V_2 = 10$
$V_1 = 01$
$V_0 = 00$
4 level
ASK
t

4 level FSK



Bandwidth for M-ary FSK

$$\text{Bandwidth} = 2\frac{f_b}{N} + (M-1)2\Delta f, \quad N = \log_2 M$$

For Coherent M-ary FSK; $2\Delta f = \frac{f_b}{2N}$

Thus $BW = (M+3)\frac{f_b}{2N}$

Signal Space Representation

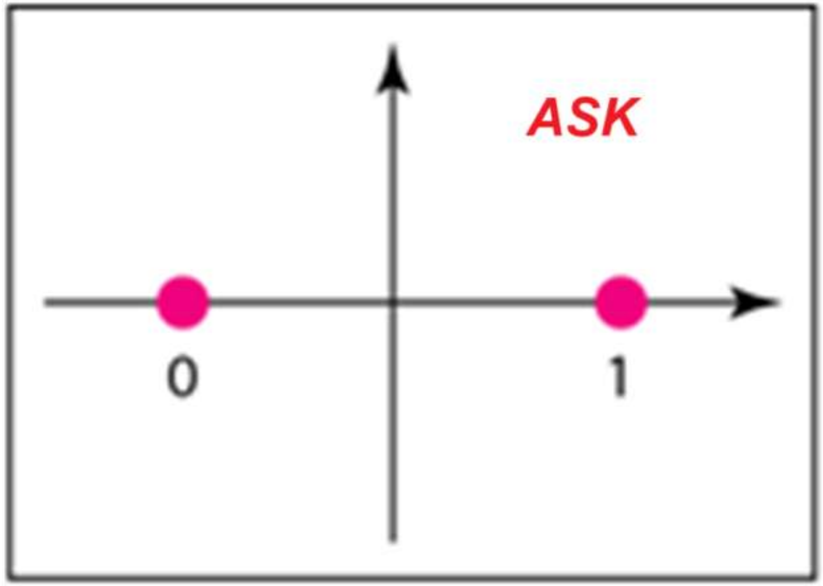
$$s_1(t) = \begin{bmatrix} \sqrt{E_b} & 0 \end{bmatrix}$$

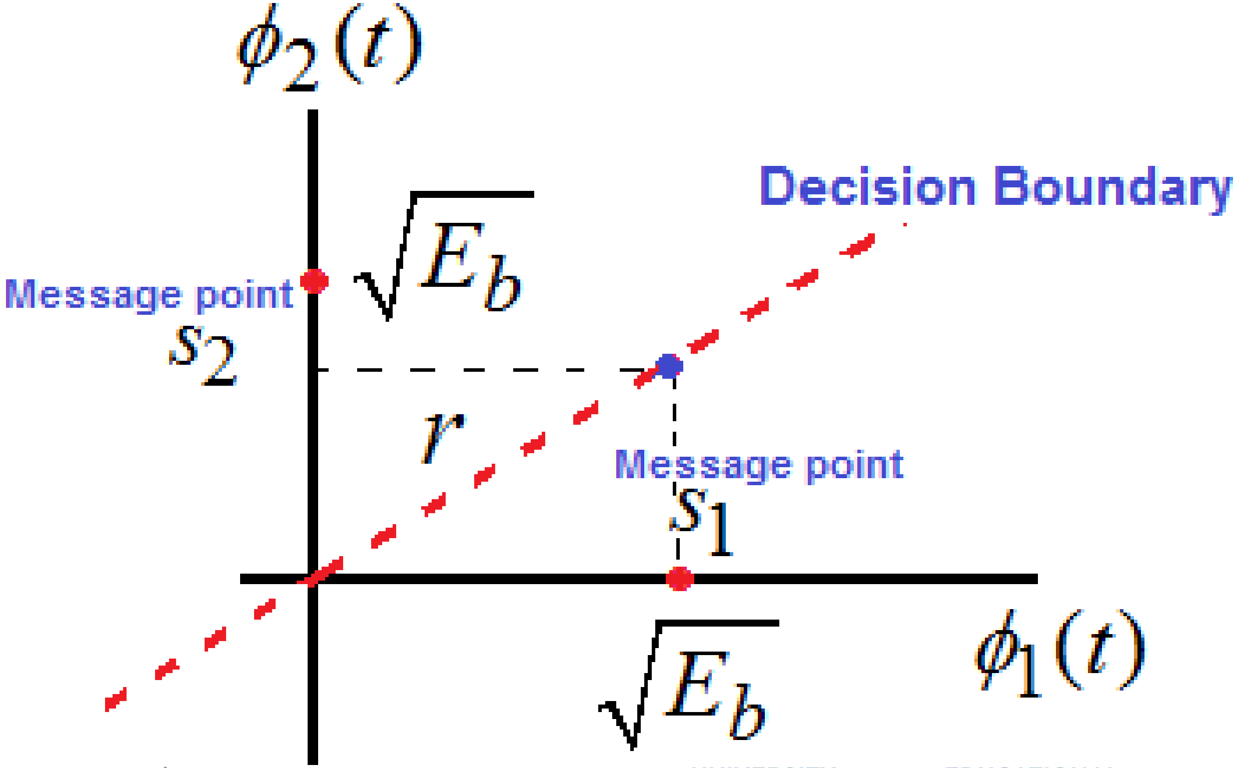
$$s_2(t) = \begin{bmatrix} 0 & \sqrt{E_b} \end{bmatrix}$$

$$r = [r_1 \;\; r_2]$$

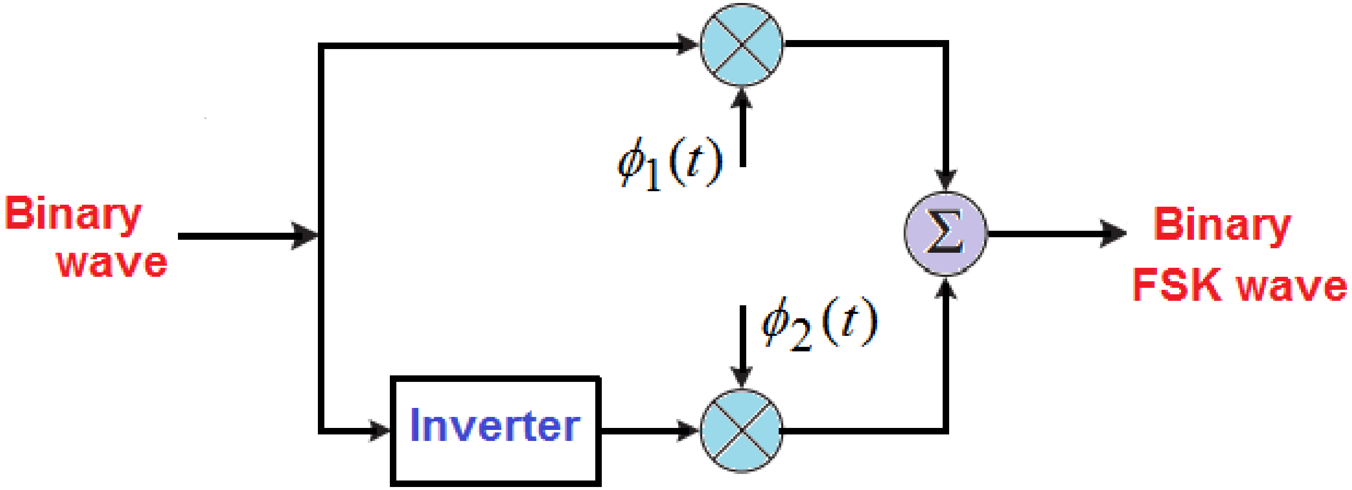
$$r_1 = \int_0^{T_b} r(t)\,\phi_1(t)\,dt$$

$$r_2 = \int_0^{T_b} r(t)\,\phi_2(t)\,dt$$





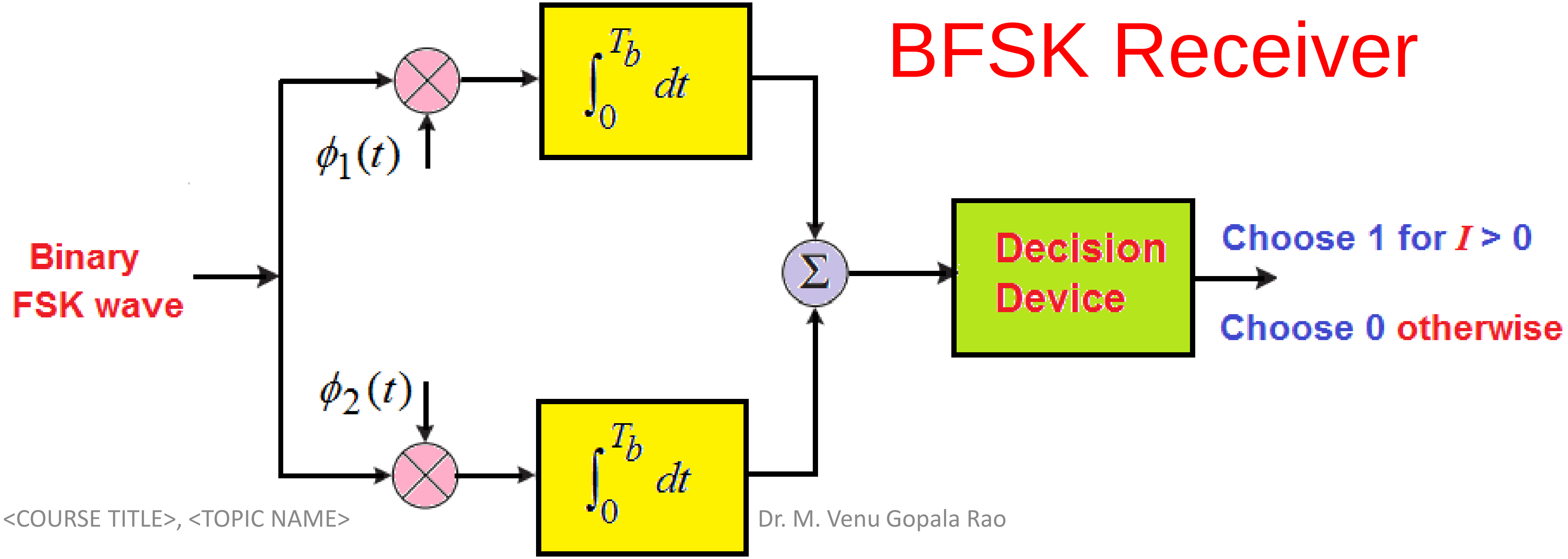
BFSK Transmitter



$$\phi_1(t) = \sqrt{\frac{2}{T_b}} \cos 2\pi f_1 t$$

$$\phi_2(t) = \sqrt{\frac{2}{T_b}} \cos 2\pi f_2 t$$

BFSK Receiver



Bit Error Rate for BFSK

$$\mathrm{BER}_{ASK} = Q\left(\sqrt{\frac{E_b}{N_0}}\right)$$

The average probability of error

$$\mathrm{BER}_{FSK} = Q\left(\sqrt{\frac{E_b}{N_0}}\right) \Rightarrow 3\text{ dB worse than BPSK}$$

Find the SNR / bit and average power required at the demodulator to maintain a BER = 10^{-6} using BFSK for data transmission over a radio channel at 56 kbps. Assume that the channel adds white Gaussian noise with power spectral density $N_0 = 10^{-10}$.

Use $Q(x) = 10^{-6} \Rightarrow x = 4.75$

$$BER_{BFSK} = Q\left(\sqrt{\frac{E_b}{N_0}}\right) \Rightarrow \sqrt{\frac{E_b}{N_0}} = 4.75 \Rightarrow E_b = 2.256\text{x}10^{-9}$$

$$P_{av} = \frac{E_b}{T_b} = E_b R_b = 2.256\text{x}10^{-9}\text{x}56\text{x}10^{3} = 126.34\mu\text{W} = -9\text{ dBm}$$

Digital data **80 kbps** is transmitted over an AWGN channel with PSD

$\frac{N_o}{2} = 10^{-10}$ W/Hz. Calculate the averaged receiver power level to achieve a

BER $= 10^{-6}$ for coherent FSK. Use $Q(x) = 10^{-6} \Rightarrow x = 4.75$

Advantages of FSK:

- FSK is ideally a constant envelope modulation; hence, more power-efficient class-C non-linear Power Amplifiers can be used in the transmitter.
- FSK is more bandwidth efficient than ASK.
- Reasonably simple modulation and demodulation schemes.

Disadvantages of FSK:

- The difference between coherent FSK detection and non-coherent FSK detection is not significant for higher FSK levels.
- The extra hardware required for coherent FSK detection is hence hard to justify.
- Coherent FSK is not often used in practice due to the difficulty (and cost) in generating two reference frequencies close together at the receiver.

End