Modulation Techniques

MSK, GMSK and Spread Spectrum Techniques

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Wireless Communications

Principles and Practice

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Digital Modulation Techniques for Mobile Radio

Digital Modulation:

1. Provides low bit errors at low received SNRs.
2. Performs well in multipath and fading.
3. Occupies a minimum of bandwidth.
4. Is easy and cost-effective to implement.

The Performance of Digital Modulation Schemes is often measured in terms:

- *Power efficiency* and
- *Bandwidth efficiency*.

Digital Modulation Techniques for Mobile Radio

Power efficiency is expressed as the ratio of the signal energy per bit and to noise power spectral density required at the receiver input for a certain probability of error.

$$\eta_p = \frac{E_b}{N_0}$$

Bandwidth efficiency is the ability of modulation technique to accommodate data within a limited bandwidth.

$$\eta_B = \frac{R}{B} bps / Hz$$

Digital Modulation Techniques for Mobile Radio

The Shannon's *Channel Capacity (C) for AWGN non-Fading*

$$\eta_B = \frac{C}{B} = \log_2\left(1 + \frac{S}{N}\right)$$

Example 5.7

What is the theoretical maximum data rate that can be supported in a 200 kHz channel for SNR = 10 dB, 30 dB. How does this compare to the GSM standard described in Chapter 1?

Solution to Example 5.7

For SNR = 10 dB = 10, B = 200 kHz.

Using Shannon's channel capacity formula (5.37), the maximum possible data rate

$$C = B\log_2\left(1 + \frac{S}{N}\right) = 200000\log_2(1 + 10) = 691.886 \text{ kbps}$$

The GSM data rate is 270.833 kbps, which is only about 40% of the theoretical limit for 10 dB SNR conditions.

For SNR = 30 dB = 1000, B = 200 kHz.

The maximum possible data rate

$$C = B\log_2\left(1 + \frac{S}{N}\right) = 200000\log_2(1 + 1000) = 1.99 \text{ Mbps}.$$

Minimum Shift Keying (MSK)

•Is a special type of continuous phase-frequency shift keying. The peak frequency modulation is equal to ¼ the bit rate.

•The modulation index k_{FSK} equals to ½.

Peak Deviation

$$k_{FSK} = \frac{2\Delta f}{R_b}$$

A modulation index of ½ corresponds to the minimum frequency spacing that allows to FSK signals to be coherently orthogonal, and the name minimum shift keying implies the minimum frequency separation that allows orthogonal detection

Minimum Shift Keying (MSK)

•MSK is a spectrally efficient modulation scheme and is particularly attractive for use in Mobile radio communications systems.

•MSK has a constant envelope, spectral efficiency, good BER performance, and self-synchronizing capability.

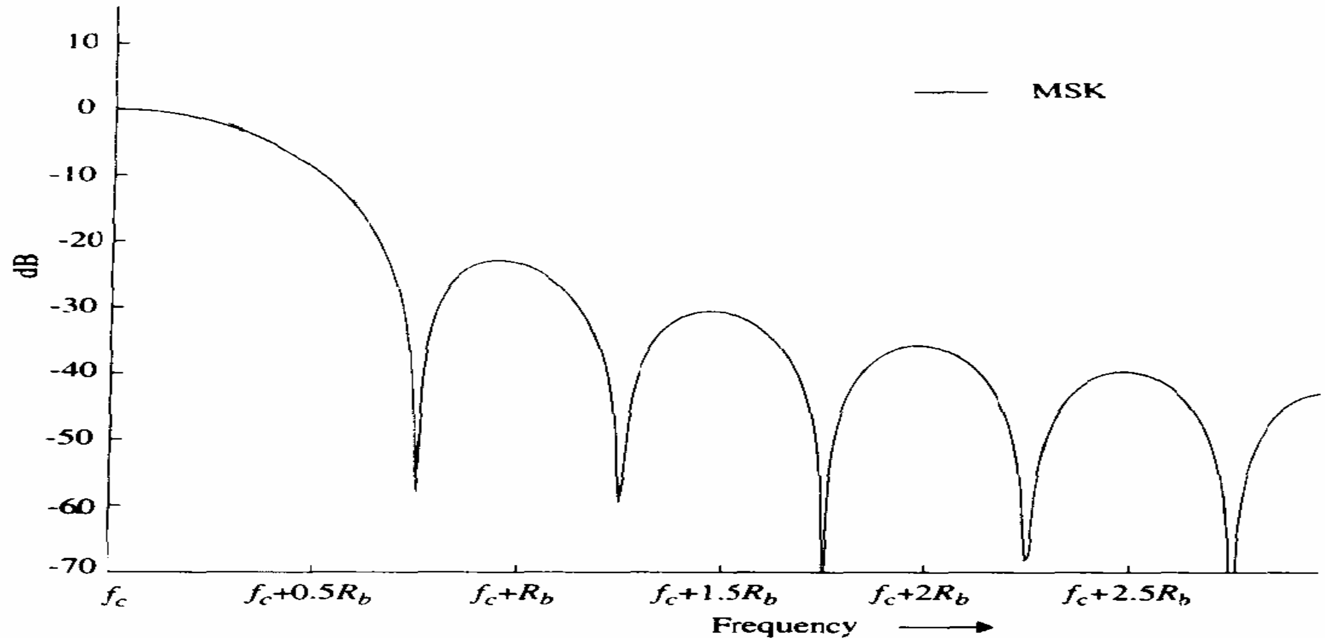
$$S_{\mathrm{MSK}}(t) = \sqrt{\frac{2E_b}{T_b}} \cos\left[2\pi f_c t - m_I(t) m_Q(t) \frac{\pi t}{2T_b} + \phi_k\right]$$

where ϕ_k is 0 or π depending on whether $m_I(t)$ is 1 or -1

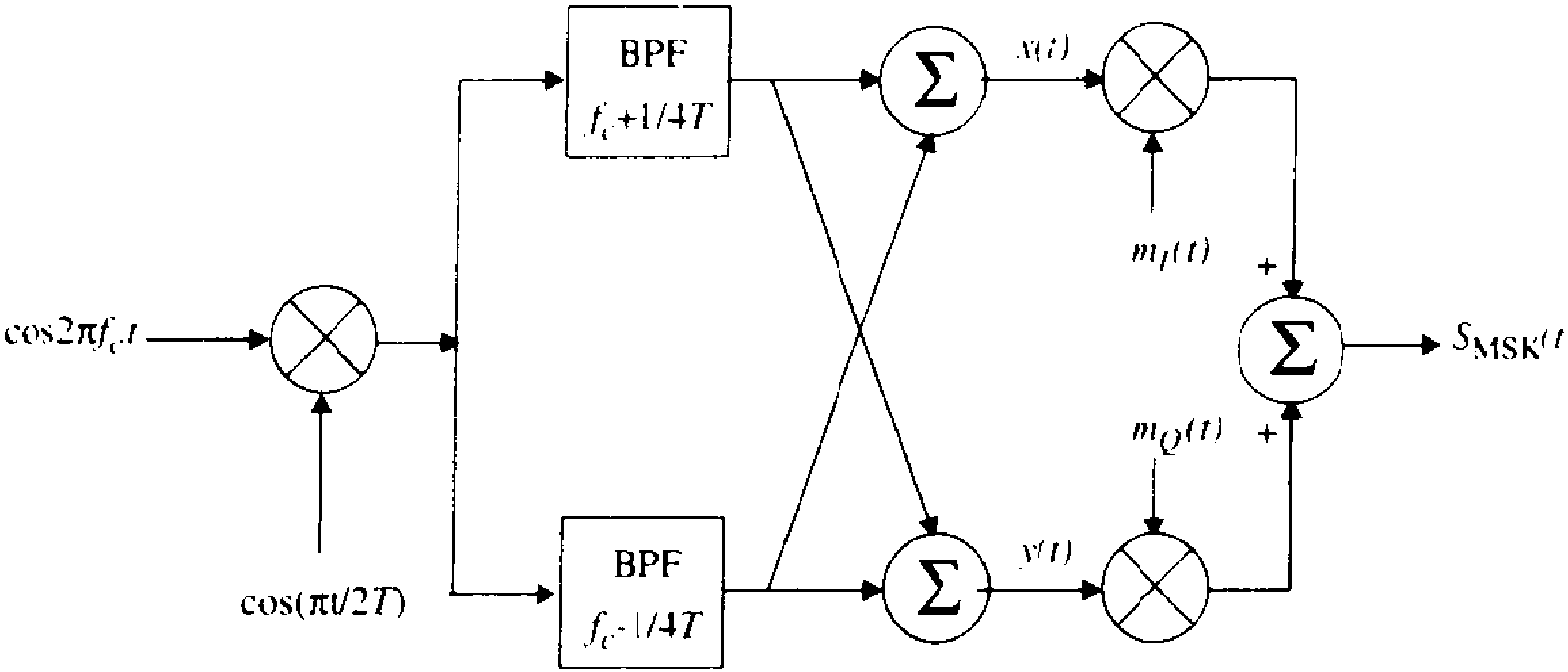
MSK Power Spectrum

The normalized power spectral density for MSK

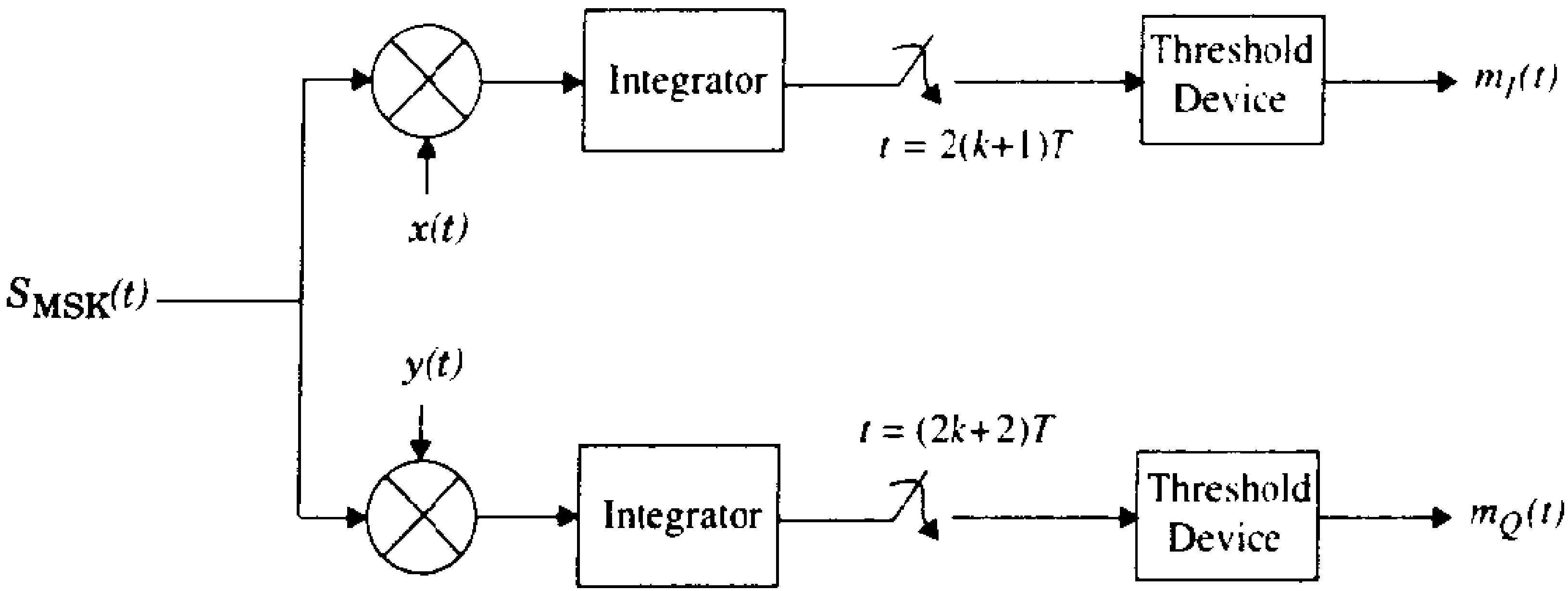
$$P_{MSK} = \frac{16}{\pi^2}\left(\frac{\cos 2\pi(f+f_c)T}{1.16f^2T^2}\right)^2 + \frac{16}{\pi^2}\left(\frac{\cos 2\pi(f-f_c)T}{1.16f^2T^2}\right)^2$$



MSK Transmitter



MSK Receiver



Gaussian Minimum Shift Keying

GMSK is a binary modulation scheme by which the sidelobe levels of the spectrum are further reduced by passing the modulating NRZ data waveform through a premodulation Gaussian pulse-shaping filter.

Baseband Gaussian pulse shaping smoothes the phase trajectory of the MSK signal and hence stabilize the instantaneous frequency variations over time.

The GMSK premodulation filter has an impulse response

$$h_G(t) = \frac{\sqrt{\pi}}{\alpha}\exp\left(-\frac{\pi^2}{\alpha^2}t^2\right)$$

And transfer function

$$H_G(f) = \exp(-\alpha^2 f^2)$$

Gaussian Minimum Shift Keying

The parameter α is related to B

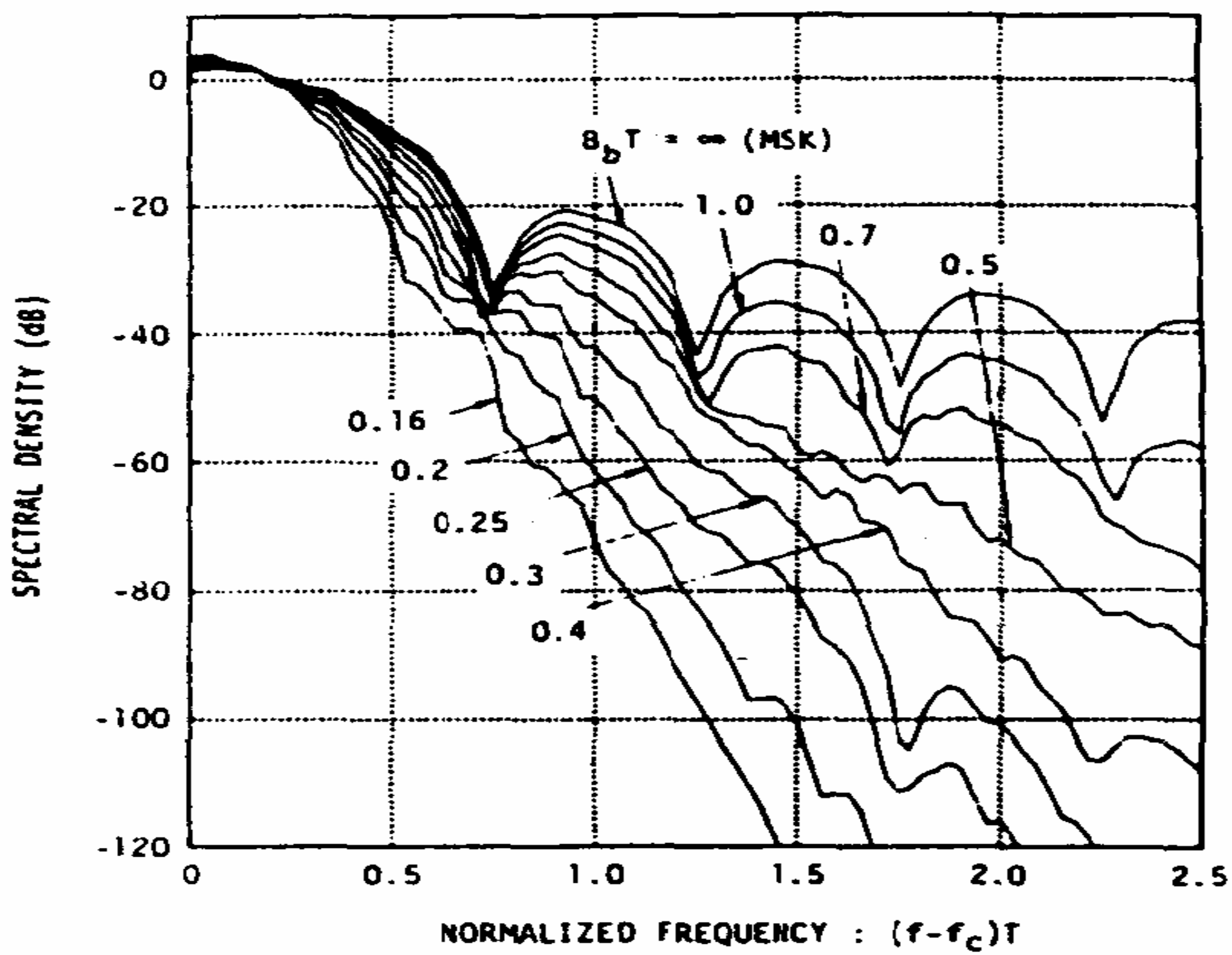
$$\alpha = \frac{\sqrt{ln 2}}{\sqrt{2}B} = \frac{0.5887}{B}$$

The 3-dB bandwidth-bit duration product (BT) of the filter is greater than 0.5.

The GMSK filter may be completely defined from B and baseband symbol duration.

Reducing BT increases the error rate produced by the lowpass filter due to ISI.

Gaussian Minimum Shift Keying



GMSK Bit Error Rate

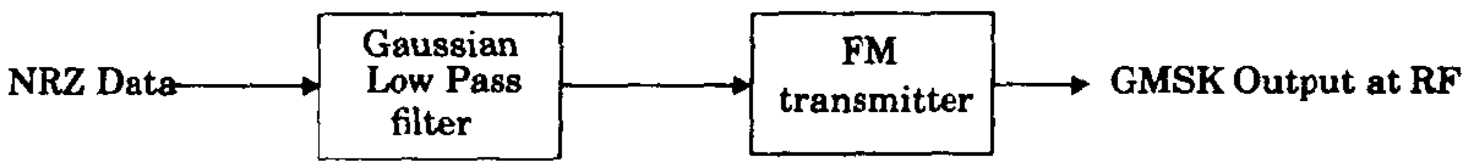
$$P_e = Q\left\{\sqrt{\frac{2\gamma E_b}{N_0}}\right\}$$

$$\gamma \cong \begin{cases} 0.68 & \text{for GMSK with } BT = 0.25 \\ 0.85 & \text{for simple MSK } (BT = \infty) \end{cases}$$

GMSK Transmitter

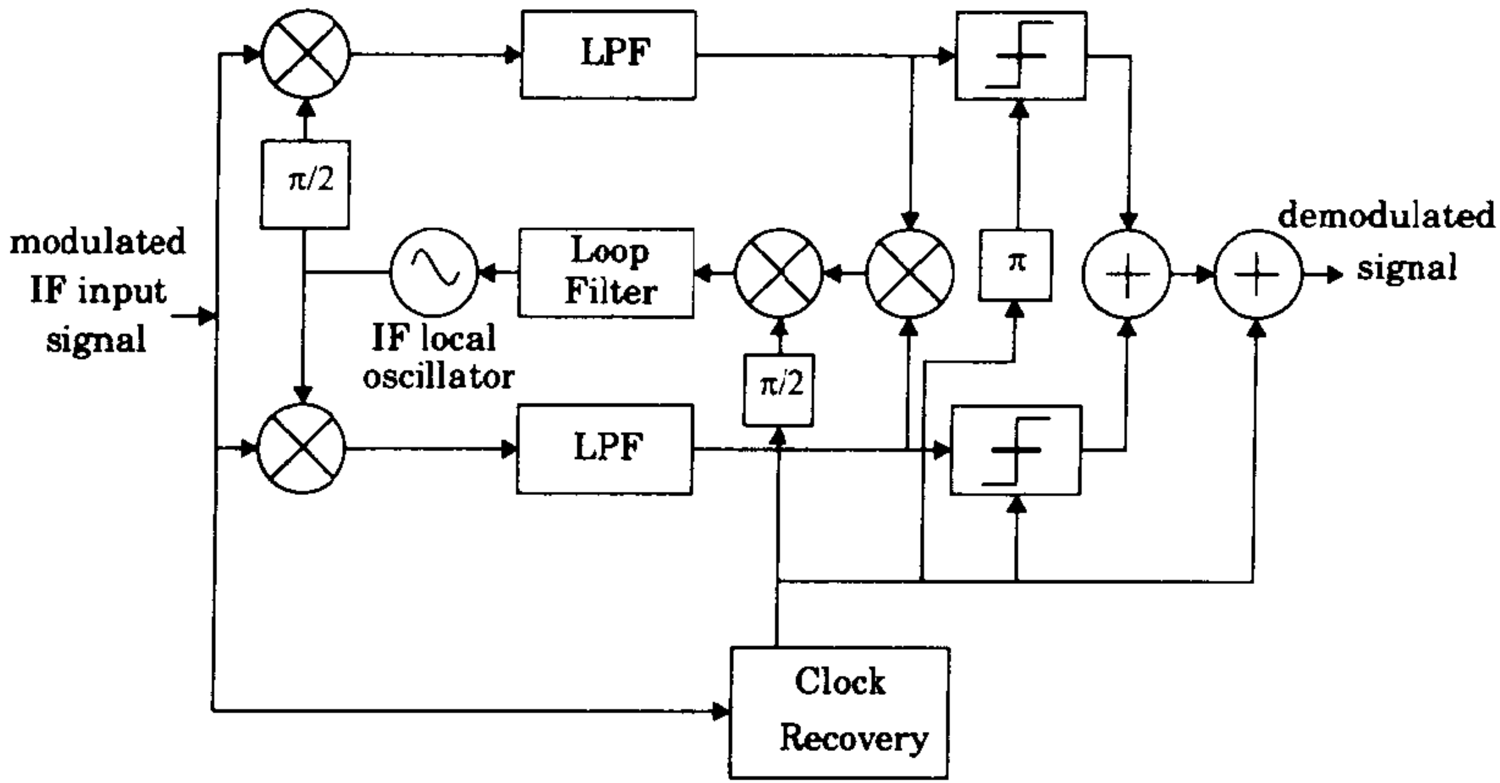
The simplest way to generate a GMSK signal is to pass a NRZ message bit stream through a Gaussian baseband filter having an impulse response

$$h_G(t) = \frac{\sqrt{\pi}}{\alpha} \exp\left(-\frac{\pi^2}{\alpha^2} t^2 \right)$$



This modulation technique is used in GSM systems

GMSK Receiver



Gaussian Minimum Shift Keying

Example 5.11

Find the 3-dB bandwidth for a Gaussian low pass filter used to produce 0.25 GMSK with a channel data rate of R_b = 270 kbps. What is the 90% power bandwidth in the RF channel? Specify the Gaussian filter parameter α.

Solution to Example 5.11

From the problem statement

$$T = \frac{1}{R_b} = \frac{1}{270 \times 10^3} = 3.7\ \mu s$$

Solving for B, where $BT = 0.25$,

$$B = \frac{0.25}{T} = \frac{0.25}{3.7 \times 10^{-6}} = 67.567\ \text{kHz}$$

Thus the 3-dB bandwidth is 67.567 kHz. To determine the 90% power bandwidth, use Table 5.3 to find that $0.57R_b$ is the desired value. Thus, the occupied RF spectrum for a 90% power bandwidth is given by

$$\text{RF } BW = 0.57R_b = 0.57 \times 270 \times 10^3 = 153.9\ \text{kHz}$$

Table 5.3 Occupied RF Bandwidth (for GMSK and MSK as a fraction of R_b) Containing a Given Percentage of Power [Mur81]. Notice that GMSK is spectrally tighter than MSK.

BT	90%	99%	99.9%	99.99%
0.2 GMSK	0.52	0.79	0.99	1.22
0.25 GMSK	0.57	0.86	1.09	1.37
0.5 GMSK	0.69	1.04	1.33	2.08
MSK	0.78	1.20	2.76	6.00

Spread Spectrum Modulation Techniques

•This system is bandwidth inefficient system for a single user but using this technique, many users can use the same bandwidth at the same time without interference in multiple access environment.

• The spreading wave form is controlled by a pseudo-noise (PN) code, which is a binary sequence that appears random but can be reproduced in a deterministic manner by intended receivers.

•Spread spectrum signals are demodulated at the receiver through cross-correlation with a locally-generated version of the pseudorandom carrier to restore the modulated narrowband signal.

Spread Spectrum Modulation Techniques

Spread spectrum well-suited for use in the mobile environment because:

1. Its inherent interference rejection in the mobile environment.
2. Resistance to multipath fading.

Pseudo-Noise (PN) Sequences

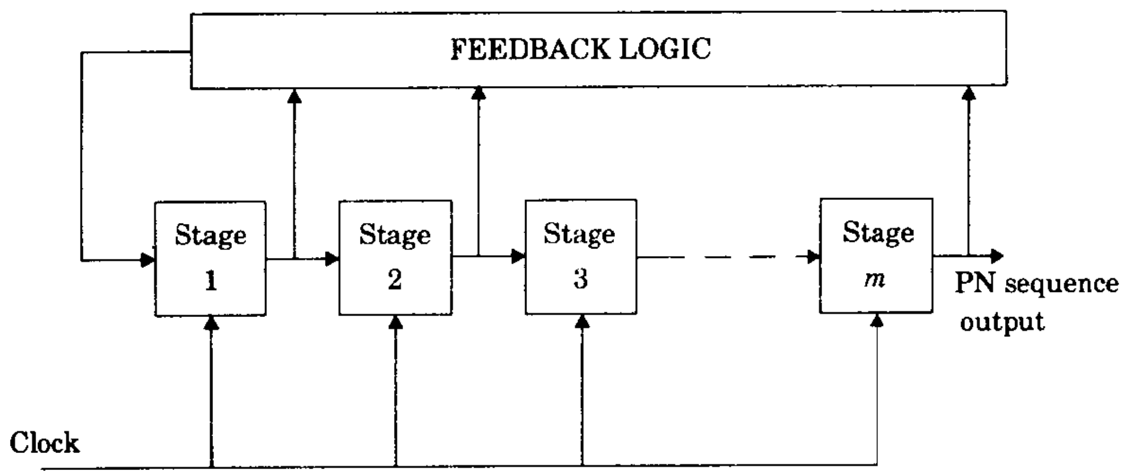
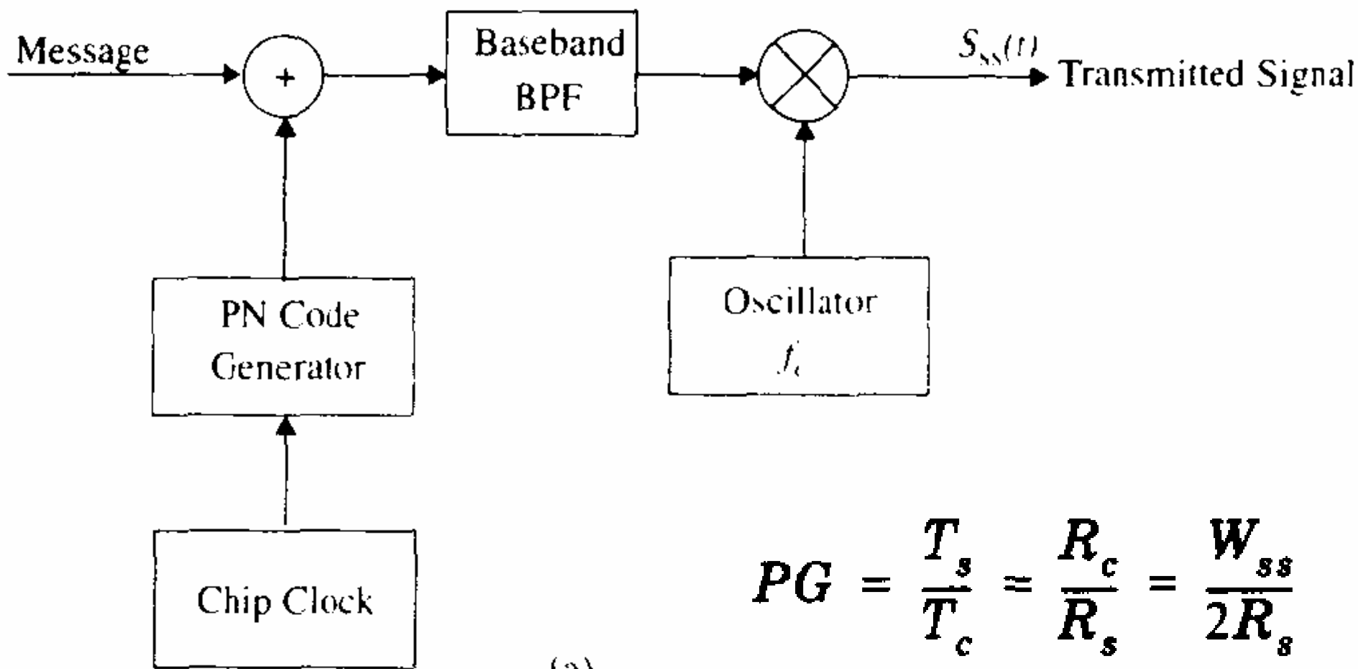


Figure 5.48
Block diagram of a generalized feedback shift register with m stages.

1. PN sequence is a binary sequence that has a very low correlation between shifted versions of the sequence and very low cross-correlation between any two sequences.
2. In a feedback shifted register, binary sequences are shifted through the shift registers in response to clock pulses, and the output of the various stages are logically combined and fed back as the input to the first stage.

Direct Sequence Spread Spectrum (DS-SS)

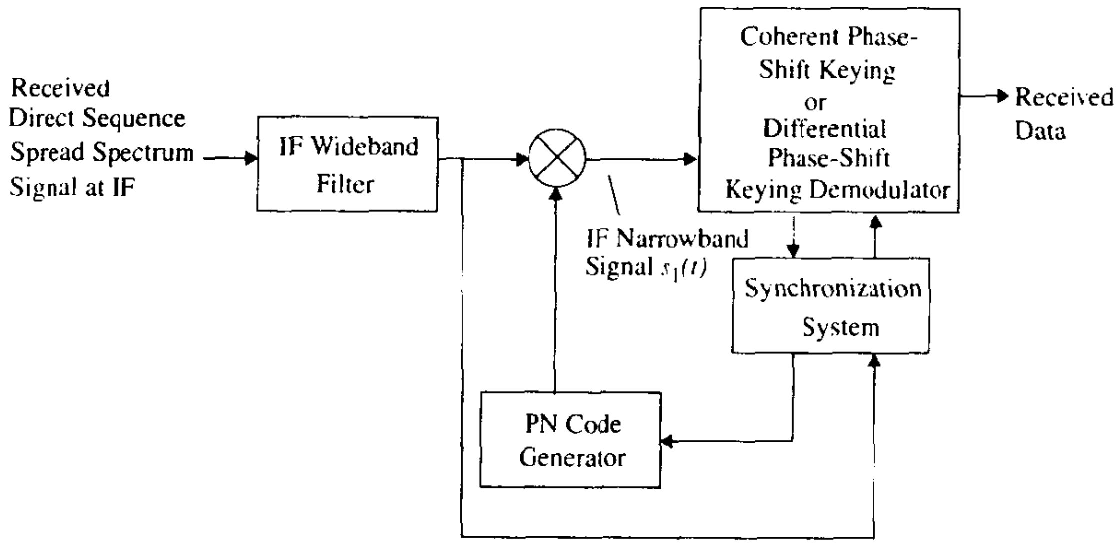
DS-SS system spreads the baseband data by directly multiplying the baseband data pulses with a PN sequence that is produced by PN code generator.



$$PG = \frac{T_s}{T_c} \simeq \frac{R_c}{R_s} = \frac{W_{ss}}{2R_s}$$

(a)

Direct Sequence Spread Spectrum (DS-SS)



(b)

The received spread spectrum signal for a single user can be represented as

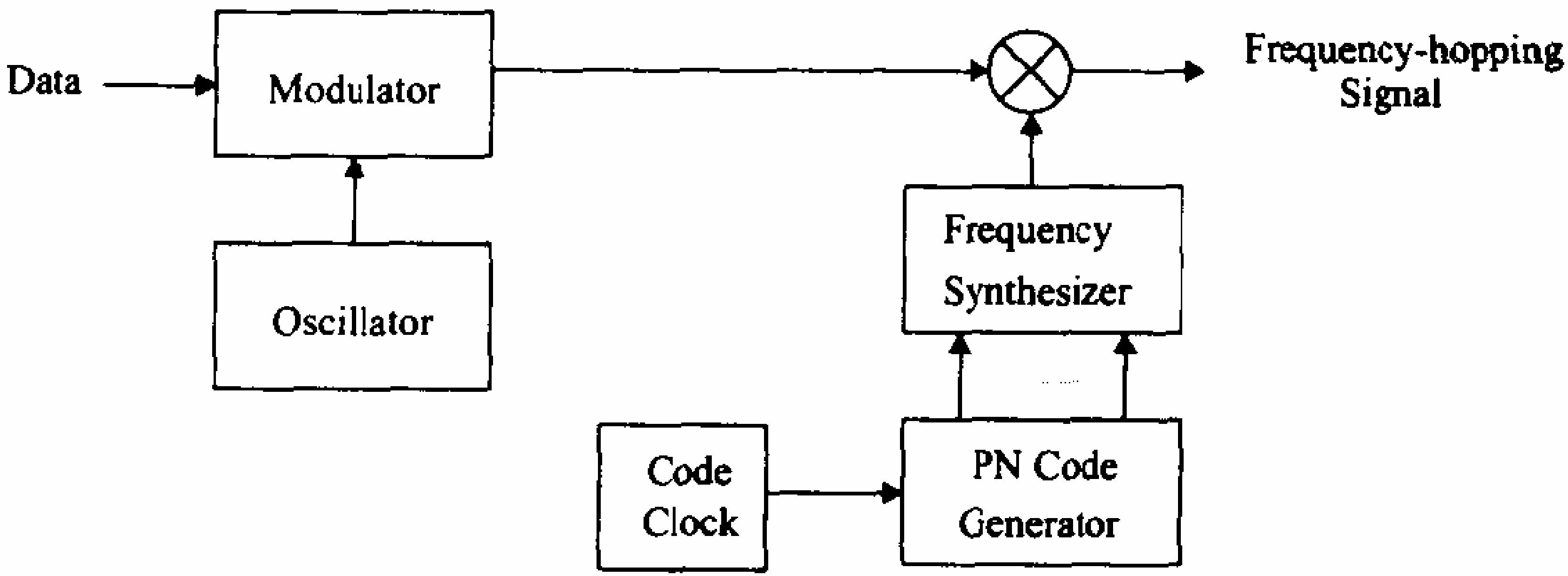
$$S_{ss}(t) = \sqrt{\frac{2E_s}{T_s}}m(t)p(t)\cos(2\pi f_c t + \theta) \tag{5.133}$$

where $m(t)$ is the data sequence, $p(t)$ is the PN spreading sequence, f_c is the carrier frequency, and θ is the carrier phase angle at $t = 0$.

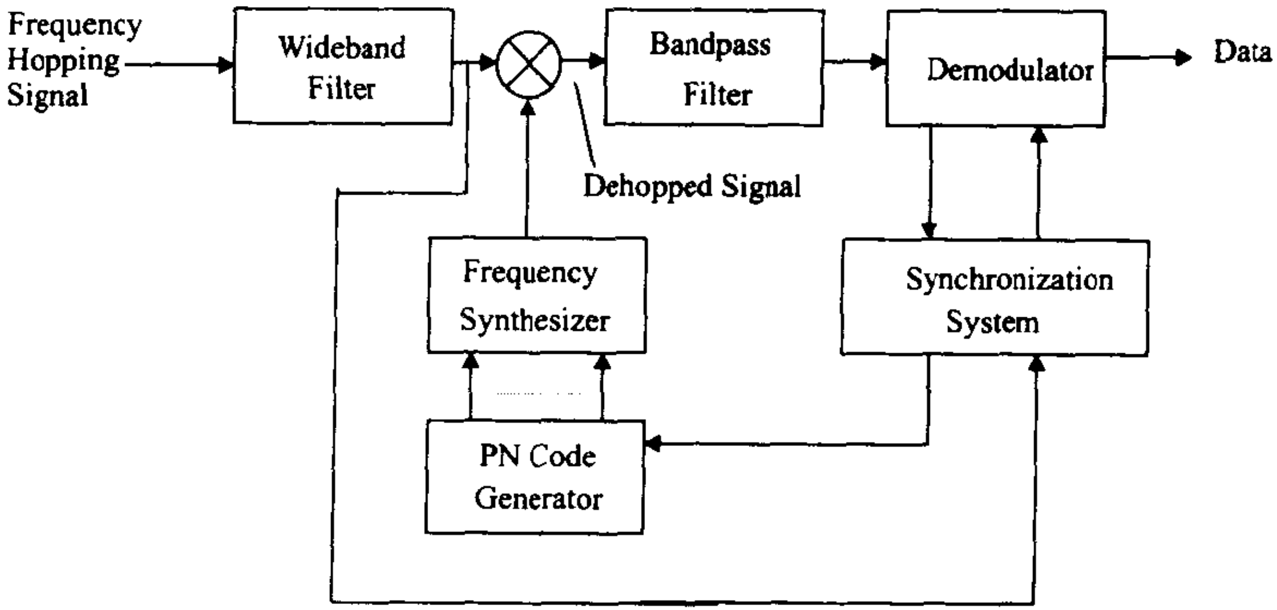
Frequency Hopped Spread Spectrum (FH-SS)

- A **frequency hopping signal** is a sequence of modulated data bursts with time-varying, pseudorandom carrier frequencies.
- **Hopset** is the set of possible carrier frequency.
- The bandwidth of a channel used in a hopset is called **instantaneous bandwidth**.
- The bandwidth of the spectrum over which the hopping occurs is called the **total hopping bandwidth**.
- Data is sent by hopping the transmitter carrier to seemingly random channels which known only to the desired receiver.
- Frequency hopping may be classified as **Fast** or **Slow**.

Frequency Hopped Spread Spectrum Transmitter



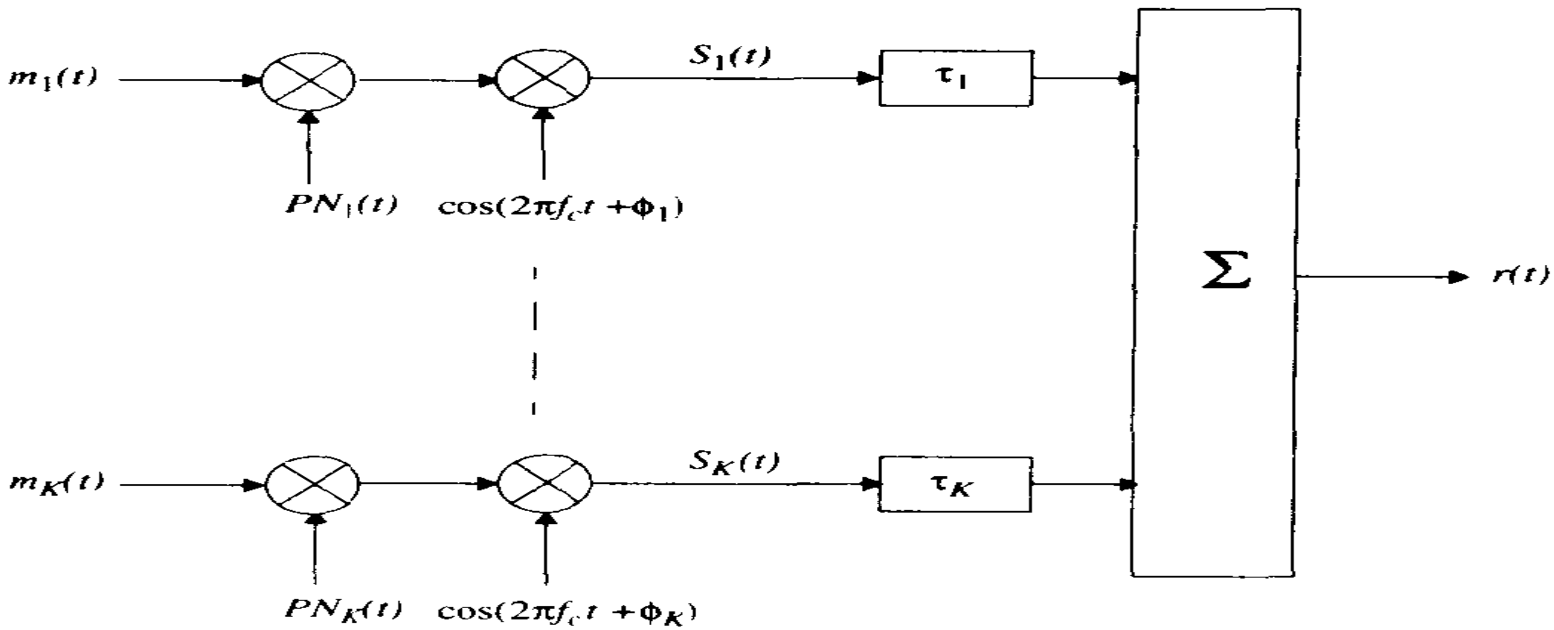
Frequency Hopped Spread Spectrum Receiver



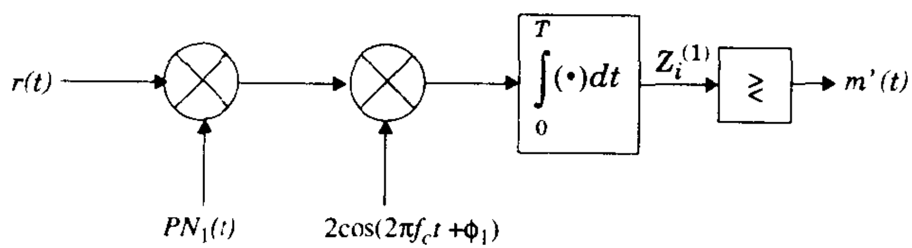
(b) Receiver

If only a single carrier frequency (single channel) is used on each hop, digital data modulation is called *single channel modulation*. Figure 5.51 shows a single channel FH-SS system. The time duration between hops is called the *hop duration* or the *hopping period* and is denoted by T_h. The total hopping bandwidth and the instantaneous bandwidth are denoted by W_{ss} and B, respectively. The processing gain = W_{ss}/B for FH systems.

Performance of DS-SS



(a) Model of K users in a CDMA spread spectrum system



(b) Receiver structure for user 1

Performance of DS-SS

A DS-SS systems with ***k*** multiple access users (as shown in Figures) assuming that each user has a PN sequence with ***N*** chips per message symbol period ***T*** such that $NT_c = T$. Where the transmitted signal of the **kth** user

$$S_k(t) = \sqrt{\frac{2E_s}{T_s}} m_k(t) p_k(t) \cos(2\pi f_c t + \phi_k)$$

The average probability of bit error given by

$$P_e = Q\left(\frac{1}{\sqrt{\frac{K-1}{3N} + \frac{N_0}{2E_b}}}\right)$$

And for single user ***k=1*** is (BPSK)

$$P_e = Q\left(\sqrt{\frac{2E_b}{N_0}}\right)$$

For the interference limited case and thermal noise=0

$$P_e = Q\left(\sqrt{\frac{3N}{K-1}}\right)$$

Performance of FH-SS

For BFSK

$$P_e = \frac{1}{2}\exp\left(-\frac{E_b}{2N_0}\right)$$

For **M** possible hoping channels (slots)

$$P_e = \frac{1}{2}\exp\left(-\frac{E_b}{2N_0}\right)\left(1-\frac{K-1}{M}\right)+\frac{1}{2}\left[\frac{K-1}{M}\right]$$

For thermal noise=0

$$P_e = \frac{1}{2}\exp\left(-\frac{E_b}{N_0}\right)\left\{1-\frac{1}{M}\left(1+\frac{1}{N_b}\right)\right\}^{K-1}+\frac{1}{2}\left[1-\left\{1-\frac{1}{M}\left(1+\frac{1}{N_b}\right)\right\}^{K-1}\right]$$

where N_b is the number of bits per hop.