3.2 MINIMUM SHIFT KEYING (MSK)

Minimum shift keying (MSK) is a special type of continuous phase. frequency shift keying (CPFSK) where in the peak frequency deviation is equal to
1/4 the bit rate. In other words, MSK is continuous phase FSK with a modulation index of 0.5.

A modulation index of 0.5 corresponds to the minimum frequency spacing that allows two FSK signals to be coherently orthogonal, and the name minimum shift keying implies the minimum frequency separation (i,e. bandwidth) that allows orthogonal detection.

MSK is a spectrally efficient modulation scheme and is particularly attractive for use in mobile radio communication systems. It possesses properties such as constant envelope, spectral efficiency, good bit error rate performance, and self- synchronizing capability.

An MSK signal can be thought of as a special form of OQPSK where the baseband rectangular pulses are replaced with half-sinusoidal pulses.

Consider the OQPSK signal with the bit streams offset .

If half-sinusoidal pulses are used instead of rectangular pulses, the modified signal can be defined as MSK and for an N-bit stream is given by

$$S_{MSK}(t) = \sum_{i=0}^{N-1} m_I(t)\,p(t-2iT_b)\cos 2\pi f_c t + \sum_{i=0}^{N-1} m_Q(t)\,p(t-2iT_b-T_b)\sin 2\pi f_c t$$

$$\text{where } p(t) = \begin{cases} \sin\left(\frac{\pi t}{2T_b}\right) & 0 \le t \le 2T_b \\ 0 & elsewhere \end{cases}$$

and where mi(t) and mQ(t) are the "odd" and "even" bits of the bipolar data stream which have values of ± 1 and which feed the in-phase and quadrature arms of the modulator at a rate of Rb/2.

One version of MSK uses only positive half-sinusoids as the basic pulse shape, another version uses alternating positive and negative half-sinusoids as the basic pulse shape.

MSK can be modified in trigonometric identities as,

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

where φk is 0 or it depends on whether M1(t) is 1 or -1.

From the above equation it can be deduced that MSK has a constant amplitude. Phase continuity at the bit transition periods is ensured by choosing the carrier frequency to be an integral multiple of one fourth the bit rate, 1 /4T.

MSK Power Spectrum

For MSK, the baseband pulse shaping function is given by

$$p(t) = \begin{cases} \cos\left(\frac{\pi t}{2T}\right) & |t| < T \\ 0 & \text{elsewhere} \end{cases}$$

The normalized power spectral density for MSK is given by

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

The MSK spectrum has lower side lobes than QPSK and OQPSK.

Ninety-nine percent of the MSK power is contained within a bandwidth B = 1.2/T, while for QPSK and OQPSK, the 99 percent bandwidth B is equal to 8/T.

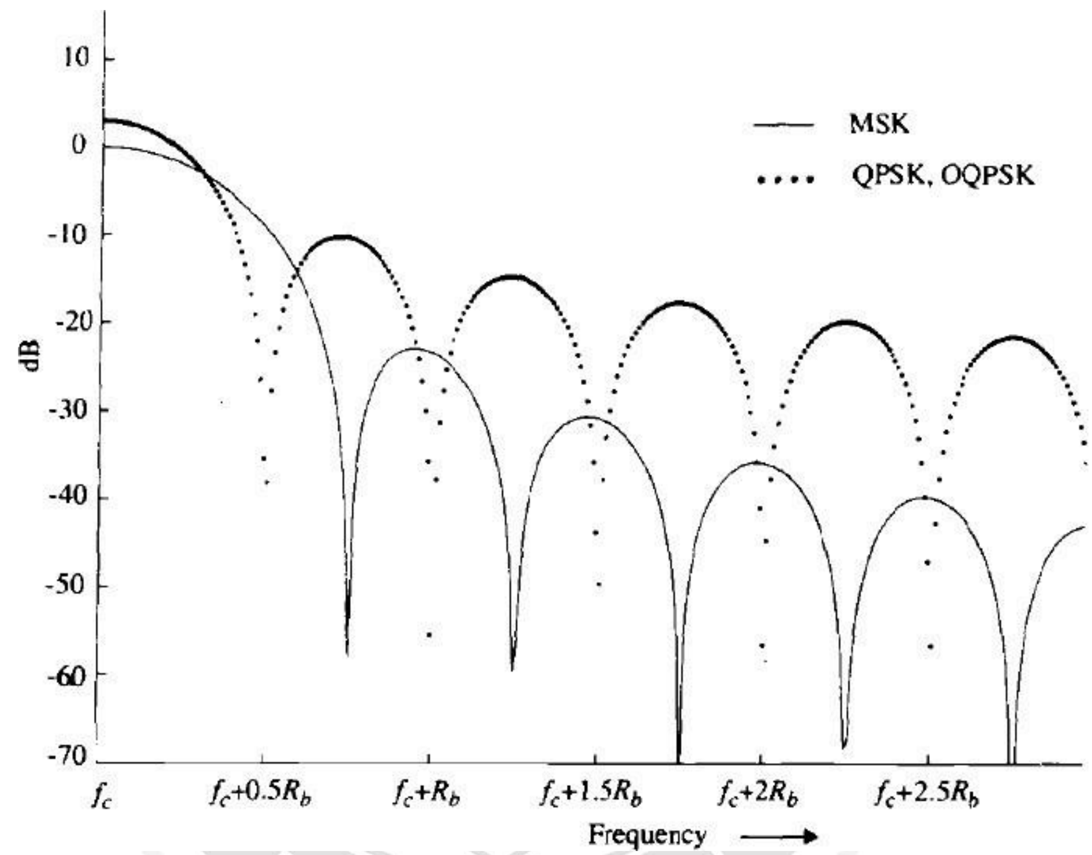

Fig 3.3.1: MSK spectrum with side lobes

[Source : "Wireless communications" by Theodore S. Rappaport,Page-261]

The faster roll off of the MSK spectrum is due to the fact that smoother pulse functions are used. Figure 3.3.1, shows that the main lobe of MSK is wider than that of QPSK and OQPSK, and hence when compared in terms of first null bandwidth, MSK is less spectrally efficient than the phase-shift keying techniques .

MSK Transmitter and Receiver

MSK transmitter is called MSK modulator as shown in figure 3.3.2. Multiplying a carrier signal with cos [πt/2T] produces two phase-coherent signals at fc+ 1 /4T and fc- I /4T.

These two FSK signals are separated using two narrow band pass filters and combined to form the in-phase and quadrature carrier components x(t) and y(t), respectively. These carriers are multiplied with the odd and even bit streams, rn1(t) and mQ(t), to produce the MSK modulated signal SMSK(t).

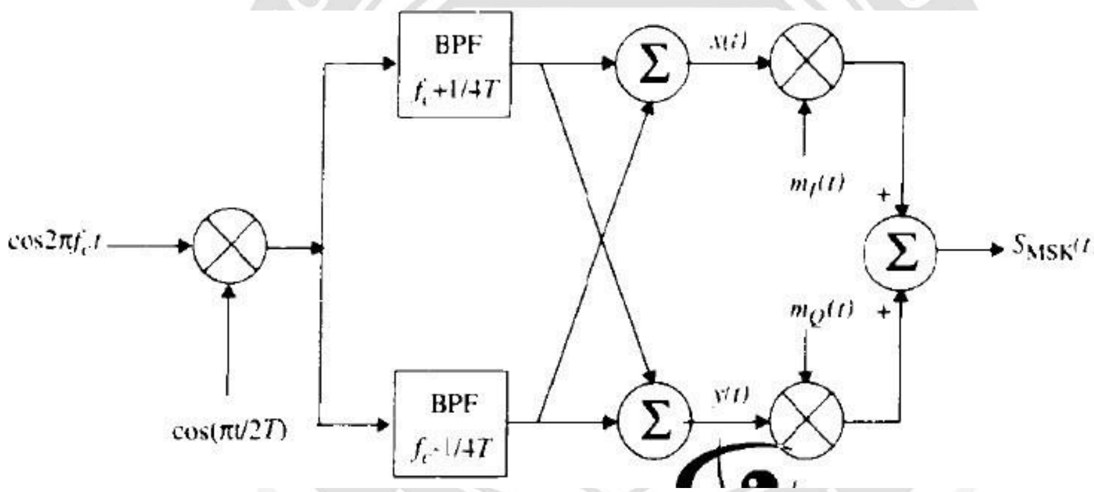

Fig 3.3.2: MSK transmitter

[Source : "Wireless communications" by Theodore S. Rappaport,Page-262]

The block diagram of an MSK receiver is shown in Figure 3.3.3.

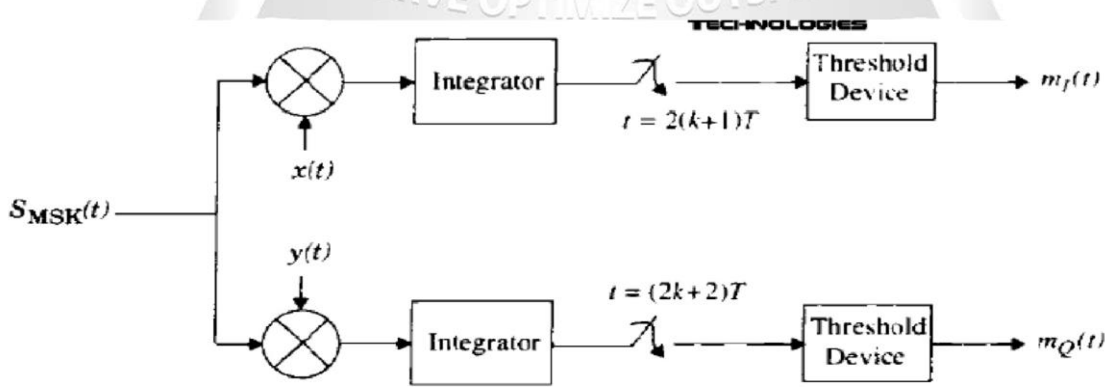

Fig 3.3.3: MSK Receiver

[Source : "Wireless communications" by Theodore S. Rappaport,Page-262]

The received signal SMSK(t) (in the absence of noise and interference) is multiplied by the respective in-phase and quadrature carriers x(t) and y(t).

The output of the multipliers are integrated over two bit periods and dumped to a decision circuit at the end of each two bit periods. Based on the level of the signal at the output of the integrator, the threshold detector decides whether the signal is a 0 or a 1. The output data streams correspond to m1(t) and mQ(t), which are offset combined to obtain the demodulated signal.

GAUSSIAN MINIMUM SHIFT KEYING

GMSK is a simple binary modulation scheme which is the derivative of MSK.

In GMSK, the side lobe levels of the spectrum are further reduced by passing the modulating NRZ data waveform through a pre modulation Gaussian pulse-shaping filter

.

Baseband Gaussian pulse shaping smooths the phase trajectory of the MSK signal and hence stabilizes the instantaneous frequency variations over time. This has the effect of reducing the side lobe levels in the transmitted spectrum.

Pre modulation Gaussian filtering converts the full response message signal (where each baseband symbol occupies a single bit period T) into a partial response scheme where each transmitted symbol spans several bit periods.

GMSK can be coherently detected just as an MSK signal, or non coherently detected as simple FSK. In practice, GMSK is most attractive for its excellent power efficiency (due to the constant envelope) and its excellent spectral efficiency.

The pre modulation Gaussian filtering introduces ISI in the transmitted signal, but it can be shown that the degradation is not severe if the 3 dB-bandwidth-bit duration product (BT) of the filter is greater than 0.5.

GMSK sacrifices the irreducible error rate caused by partial response signaling in exchange for extremely good spectral efficiency and constant envelope properties.

The GMSK pre modulation filter has an impulse response given by

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

and the transfer function given by

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

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

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

The power spectrum of MSK, which is equivalent to GMSK with a BT product of infinity, is also shown for comparison purposes. It is clearly seen from the graph that as the BT product decreases, the side lobe levels fall off very rapid]y.

For example, for a BT=0.5, the peak of the second lobe is more than 30dB below the main lobe, whereas for simple MSK, the second lobe is only 20 dB below main lobe. Reducing BT increases the irreducible error rate produced by the low pass filter due to ISI.
Power spectrum of GMSK is shown in figure 3.3.4.

GMSK Bit Error Rate

The bit error probability is a function of BT, since the pulse shaping impacts ISI. The bit error probability for GMSK is given by

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

where γ is a constant related to BT by

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

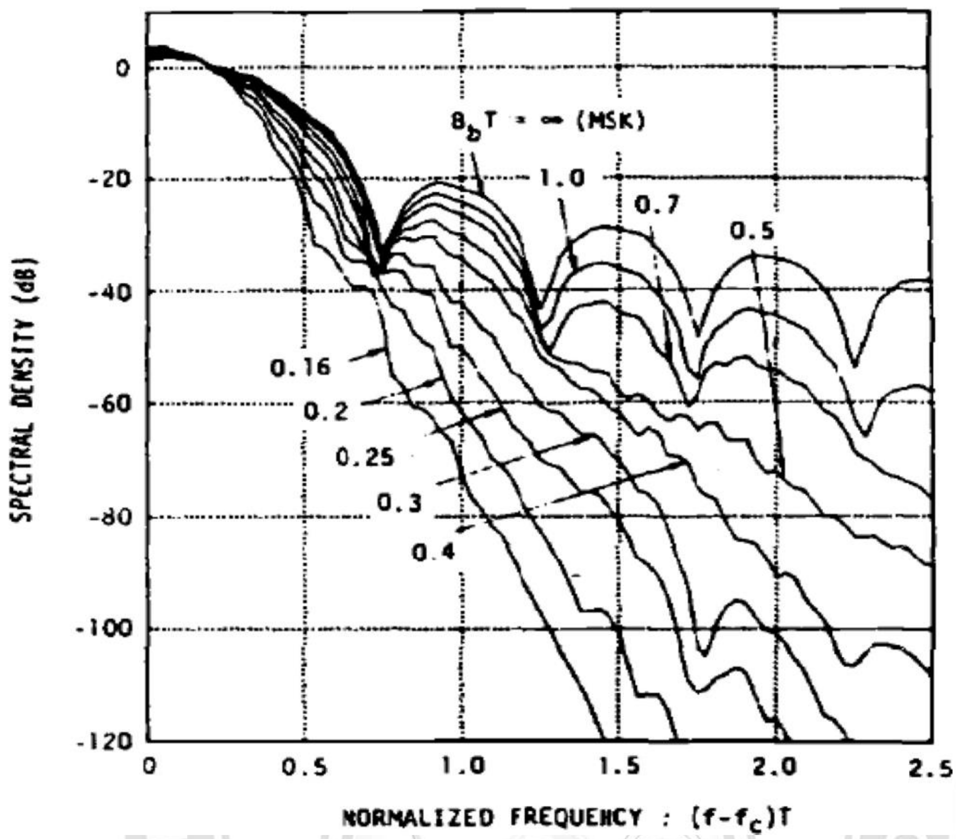

Fig 3.3.4: Power spectrum of GMSK

[Source : "Wireless communications" by Theodore S. Rappaport,Page-264]

GMSK Transmitter and Receiver

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 followed by an FM modulator.

This modulation technique is shown in Figure 3.3.5 and is currently used in a variety of analog and digital implementations for the U.S. Cellular Digital Packet Data (CDPD) system as well as for the Global System for Mobile (GSM) system.

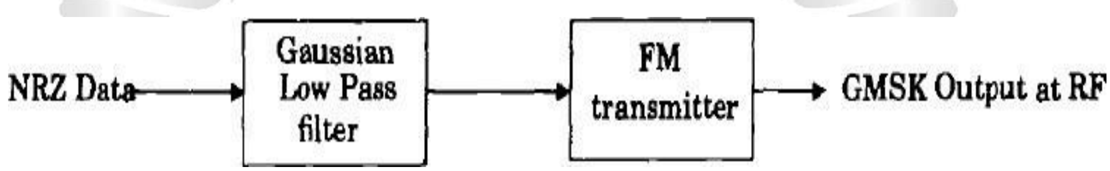

Fig3.3.5: GMSK transmitter using direct FM generation

[Source :" Wireless communications" by Theodore S. Rappaport,Page-265]

GMSK signals can be detected using orthogonal coherent detectors as shown in Figure 3.3.6.

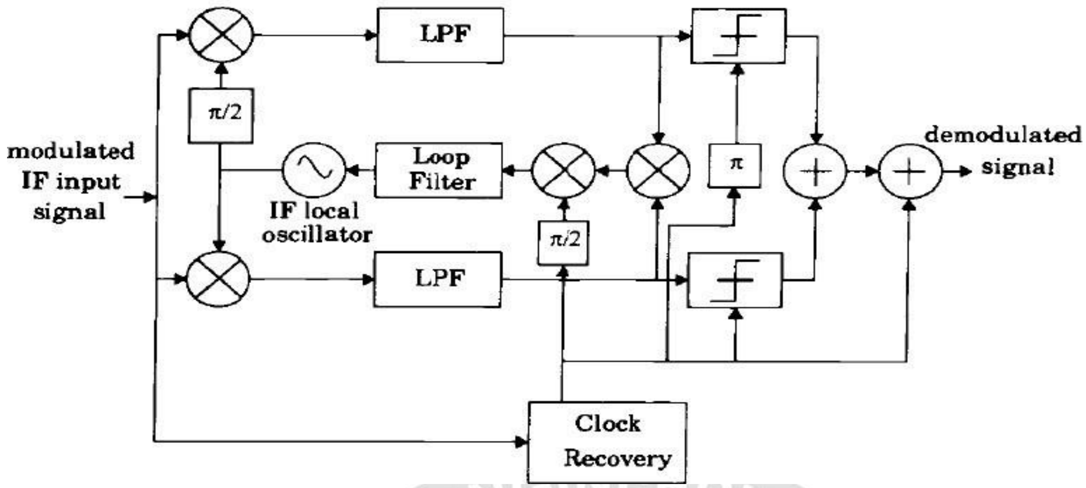

Fig 3.3.6:GMSK using using orthogonal coherent detectors

[Source :"Wireless communications" by Theodore S. Rappaport,Page-266]

This type of receiver can be easily implemented using digital logic as shown in (figure.3.3.7). The two D flip-flops act as a quadrature product demodulator and the XOR gates act as baseband multipliers.The mutually orthogonal reference carriers are generated using two D flip-flops, and the VCO center frequency is set equal to four times the carrier center frequency.

A non optimum, but highly effective method of detecting GMSK signal is to simply sample the output of an FM demodulator.

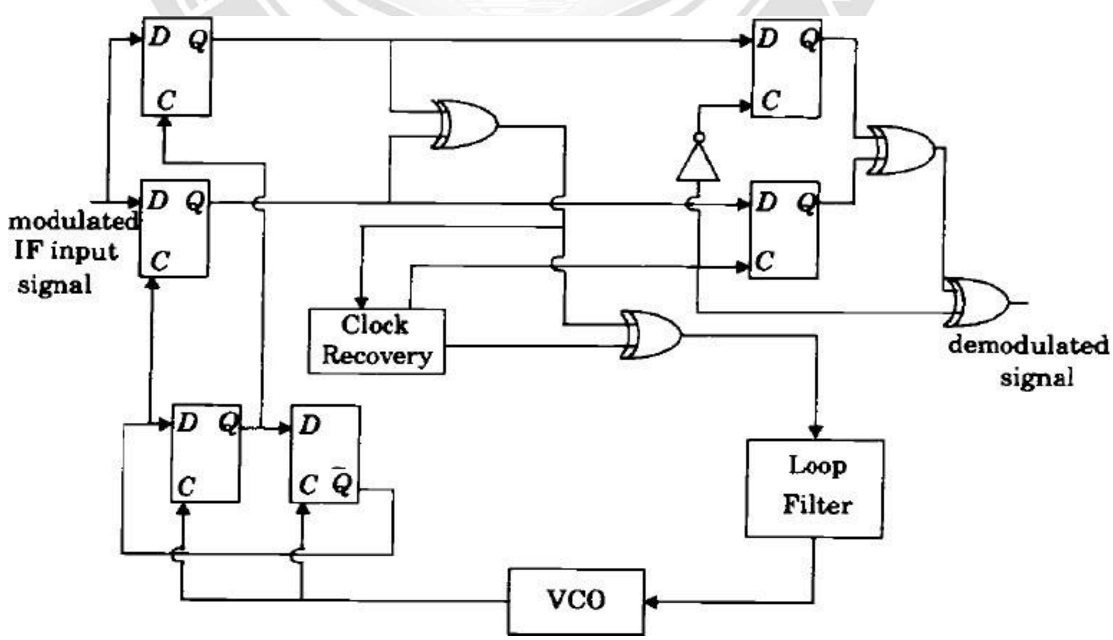

Fig 3.3.7: Digital logic circuit for GMSK demodulation

[Source : "Wireless communications" by Theodore S. Rappaport,Page-266]