SYLLABUS

DIGITAL COMMUNICATION

Tutorial	Practical	Theory	Sessional	Total	Time
1	0	75	25	100	3 Hrs.

UNIT I :

Information Theory: Introduction, Entropy, Huffman Coding, Channel Capacity, Channel Coding, Linear Block Codes, Matrix Description, Syndrome Decoding, Hamming Code, Cyclic Code, Convolution Code generation and Viterbi decoding.

UNIT II :

Pulse Modulation System: Model of digital communication systems, Sampling theorem for baseband and bandpass signals: natural sampling, Flat top sampling, Signal recovery & holding, Quantization of signal, Quantization error, Source coding & companding, Pulse code modulation (PCM), Noise in PCM system, Differential pulse code modulation (DPCM), Adaptive pulse code modulation (ADPCM), Delta modulation (DM), Comparison of PCM, DPCM and DM, Adaptive delta modulation, Quantization noise, Time division multiplexed system (T & E type systems), Calculation of O/P signal power, The effect of thermal noise, O/P signal to noise ratio in delta modulation.

UNIT III :

Base Band Pulse Transmission: Matched filter and its properties average probability of symbol error in binary enclosed PCM receiver, Intersymbol interference, Nyquist criterion for distortionless base band binary transmission, ideal Nyquist channel raised cosine spectrum, correlative level coding Duo binary signalling, tapped delay line equalization, adaptive equalization, LMS algorithm, Eye pattern.

UNIT IV :

Digital Pass Band Transmmision: Pass band transmission model; gram Schmidt orthogonalization procedure, geometric Interpretation of signals, Response of bank of correlaters to noise input, detection of known signal in noise, Hierarchy of digital modulation techniques, BPSK, DPSK, DEPSK, QPSK, systems; ASK, FSK, QASK, Many FSK, MSK, Many QAM, Signal space digram and spectra of the above system, effect of intersymbol interference, bit symbol error probabilities, synchronization.

Topics Covered/Syllabus

- Passband transmission model
- Gram Schmidt orthogonalization procedure
- Geometric interpretation of Signals
- Response of bank of correlators to noise input
- Detection of known signal in noise
- Hierarchy of digital modulation techniques
- BPSK
- DEPSK
- ASK
- QASK
- MSK
- DPSK
- QPSK
- FSK
- M-ary FSK
- Effects of intersymbol interference
- Bit versus error probabilities
- Synchronization

DIGITAL PASS BAND TRANSMISSION

4.1. PASSBAND TRANSMISSION MODEL

Q.1: Explain Passband transmission model with the help of block diagram.

Ans. Bandpass modulation is the process by which an information signal is converted into a sinusoidal waveform.

For digital modulation, such a sinusoidal waveform of duration T is referred to as a digital symbol.

Bandpass modulation can be defined as the process in which the amplitude, frequency, or phase of an RF carrier, or a combination of them, is varied in accordance with the information to be transmitted.

A model of passband transmission system is depicted in Fig. 4.1.

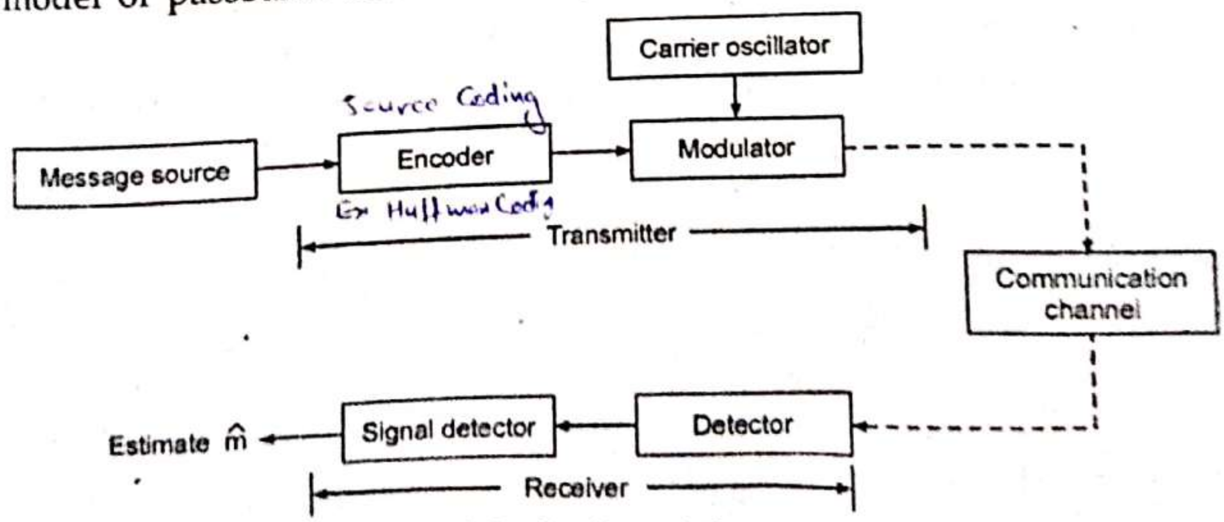


Fig. 4.1: Passband transmission model.

The model has three parts. They are:

(i) Transmitter

(ii) Communication channel

(iii) Receiver.

The message source emits one symbol per T_b seconds. Let these symbols be denoted by $m_1, m_2, ..., m_M$. The probabilities of these symbols are $P(m_1), P(m_2), ..., P(m_M)$.

If all the M symbols from the message source are equally likely, then

$$P(m_1) = P(m_2) = ... = P(m_M) = \frac{1}{M}$$

The message source output is then given to the encoder. The encoder produces a corresponding vector S_i made up of N real elements.

The modulator produces a distinct signal $S_i(t)$ of duration T_b seconds. This signal represents the symbol m_i produced by the message source.

The signal $S_i(t)$ is then transmitted through the communication channel. The communication channel is a bandpass channel.

The communication channel is a linear channel which have a sufficient bandwidth.

The receiver end consists of a detector and a signal detector.

The receiver operation reverse to the operation performed by the transmitter.

The receiver is designed in such a way that it minimize the effect of channel noise.

The estimate m (of transmitted signal m_i) is recovered from the output of the signal detector.

4.2 GRAM SCHMIDT ORTHOGONALIZATION PROCEDURE

Q.2. What is Gram schmidt procedure? Illustrate how this procedure is used to construct orthogonal waveforms. ***(KU 2017)***

Q.3. Discuss Gram schmidt orthogonalization procedure.

Ans. Suppose there is a set of M energy signals denoted by $S_1(t), S_2(t), ..., S_M(t)$. Let $S_1(t)$ be a set chosen arbitrarily, the first basis function is defined by

$$\phi_1(t) = \frac{S_1(t)}{\sqrt{E_1}}$$

where E_1 is the energy of the signal $S_1(t)$.

then
$$S_1(t) = \sqrt{E_1}\,\phi_1(t)$$
$$= S_{11}\,\phi_1(t)$$

where $S_{11} = \sqrt{E_1}$ and $\phi_1(t)$ has unit energy as required.

Now, using signal $S_2(t)$, coefficient S_{21} is defined as

$$S_{21} = \int_0^T S_2(t)\phi_1(t)\,dt$$

Let $g_2(t)$ be an intermediate function, such that

$$g_2(t) = S_2(t) - S_{21}\phi_1(t) \quad ...(1)$$

which is orthogonal to $\phi_1(t)$ over the interval $0 \le t \le T$ by virtue of the definition of S_{21} and the fact that the basic-function $\phi_1(t)$ has unit energy.

Now, the second basis function is

$$\phi_2(t) = \frac{g_2(t)}{\sqrt{\int_0^T g_2^2(t)\,dt}} \quad ...(2)$$

Substituting eq. (1) in eq. (2), we get

$$\phi_2(t) = \frac{S_2(t) - S_{21}\phi_1(t)}{\sqrt{E_2 - S_{21}^2}} \quad ...(3)$$

where E_2 is the energy of the signal $S_2(t)$.

From eq. (2), it is seen that

$$\int_0^T \phi_2^2(t)\,dt = 1$$

and from eq. (3)

$$\int_0^T \phi_1(t)\phi_2(t)\,dt = 0$$

So, $\phi_1(t)$ and $\phi_2(t)$ form an orthonormal pair as required.

Continuing the procedure in the same manner, a general expression may be written as

$$g_i(t) = S_i(t) - \sum_{j=1}^{i-1} S_{ij}\phi_j(t)$$

where the coefficients s_{ij} are defined by

$$S_{ij} = \int_0^T S_i(t)\phi_j(t)\,dt, \; j = 1, 2, ..., i-1$$

For $i = 1$, the function $g_i(t)$ reduces to $S_i(t)$.

Given the $g_i(t)$, the set of basis functions may be defined as

$$\phi_i(t) = \frac{g_i(t)}{\sqrt{\int_0^T g_i^2(t)\,dt}}, \; j = 1, 2, ..., N$$

which forms an orthogonal set.

The dimensions N is less than or equal to the number of given signals, M, depending on one of the two possibilities.

(i) The signal $S_1(t)$, $S_2(t)$, ..., $S_M(t)$ form a linearly independent set, in which case N = M.

(ii) The signal $S_1(t)$, $S_2(t)$, ..., $S_M(t)$ are not linearly independent, in which case N < M and the intermediate function $g_i(t)$ is zero for $i > N$.

4.3 GEOMETRIC INTERPRETATION OF SIGNALS

Q.4. Illustrate the geometric interpretation of signals.

Ans. Each signal in the set $\{s_i(t)\}$, $i = 1, 2, ..., M$ may be expanded as

$$S_i(t) = \sum_{j=1}^{N} S_{ij}\phi_j(t) \qquad 0 \le t \le T \qquad ...(1)$$

$$i = 1, 2, ..., M$$

The coefficients of the expansion, s_{ij}, are defined as

$$S_{ij} = \int_0^T S_i(t)\,\phi_j(t)\,dt \quad i = 1, 2, ..., M \qquad ...(2)$$

$$j = 1, 2, ..., N$$

Accordingly, each signal in the set $\{S_i(t)\}$ is completely determined by the vector of its coefficients, as shown by

$$S_i = \begin{bmatrix} S_{i1} \\ S_{i2} \\ \vdots \\ S_{iN} \end{bmatrix} \quad i = 1, 2, ..., M \qquad ...(3)$$

The vector S_i is called the signal vector.

If the conventional notion of two and three dimensional Euclidean spaces be extended to an N–dimensional Euclidean space, then the set of signal vectors $\{s_i\}$, $i = 1, 2, ..., M$ may be visualized as the corresponding set of M points in an N-dimensional Euclidean space, with N mutually perpendicular axes labeled $\phi_1, \phi_2, ..., \phi_N$. This N–dimensional Euclidean space is called he signal space.

In an N–dimensional Euclidean space, length of vectors and angles between vectors may be defined.

It is customary to denote the length or norm of a signal vector S_i by the symbol $||S_i||$. The squared length of any signal vector S_i is defined to be the inner product or dot product of S_i with itself.

Fig. 4.2 illustrates the case of a two dimensional signal space with three signals, *i.e.*, N = 2 and M = 3.

In case of N = 2 or 3,

$$||S_i||^2 = (S_i, S_i)$$

$$= \sum_{j=1}^{N} S_{ij}^2 \qquad ...(4)$$

where S_{ij} are the elements of S_i.

For larger values of N, length is defined in the same way.

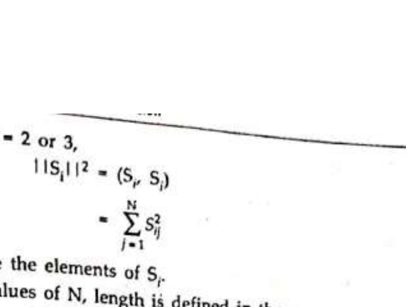


Fig. 4.2: Illustration of geometric interpretation of signals for the case when N = 2 and M = 3.

The cosine of the angle between two vectors is defined as the inner product of the two vectors divided by the product of their individual norms. That is, the cosine of the angle between the vectors S_i and S_j equals the ratio $(S_i, S_j)/||S_i||\,||S_j||$.

The two vectors S_i and S_j are thus orthogonal or perpendicular if their inner product (S_i, S_j) is zero.

The energy of a signal $S_i(t)$ of duration T seconds is

$$E_i = \int_0^T S_i^2(t)\,dt \qquad ...(5)$$

Therefore, substituting (1) in (5), we get

$$E_i = \int_0^T \left[\sum_{j=1}^{N} S_{ij}\cdot\phi_j(t)\right]\left[\sum_{k=1}^{N} S_{ik}\cdot\phi_k(t)\right]dt \qquad ...(6)$$

Interchanging the order of Summation and integration

$$E_i = \sum_{j=1}^{N}\sum_{k=1}^{N} S_{ij}S_{ik}\int_0^T \phi_j(t)\,\phi_k(t)\,dt \qquad ...(7)$$

But since the $\phi_j(t)$ form an orthonormal set, then

$$E_i = \sum_{j=1}^{N} S_{ij}^2 \qquad ...(8)$$

Eq. (4) and (8) show that the energy of a signal $S_i(t)$ is equal to the squared length of the signal vector S_i representing it.

In case of a pair of signals $S_i(t)$ and $S_k(t)$, represented by the signal vectors S_i and S_k respectively, then

$$||S_i - S_k||^2 = \sum_{j=1}^{N} (S_{ij} - S_{kj})^2$$

$$= \int_0^T [S_i(t) - S_k(t)]^2 \, dt$$

where $||S_i - S_k||$ is the Euclidean distance between the points represented by signal vector S_i and S_k.

4.4 RESPONSE OF BANK OF CORRELATORS TO NOISY INPUT

Q.5. Explain the response of bank of correlators to noise input. **(*KU 2017*)**

Ans. Suppose that the input to the bank of N product integrators or correlators is not the transmitted signal $S_i(t)$ but rather received signal $x(t)$ is defined in accordance with the AWGN channel as

$$x(t) = S_i(t) + W(t) \begin{cases} 0 \le t \le T \\ i = 1, 2, ..., M \end{cases}$$

where $w(t)$ is a sample function of the white Gaussian noise process $W(t)$ of zero mean and power spectral density $N_0/2$.

The output of correlator j is the sample value of a random variable X_j, where sample value is defined as

$$x_j = \int_0^T x(t)\, \phi_j(t)\, dt$$

$$= S_{ij} + W_j, \; j = 1, 2, ..., N$$

The first component, S_{ij}, is the deterministic component of x_j due to the transmitted signal $S_i(t)$ and is equal to

$$S_{ij} = \int_0^T S_i(t)\, \phi_j(t)\, dt$$

The second component, w_j, is the sample value of a random variable W_j due to the channel noise $w(t)$ and is equal to

$$w_j = \int_0^T W(t)\, \phi_j(t)\, dt$$

Consider a stochastic process whose sample function $x'(t)$ is related to the received signal $x(t)$ as

$$x'(t) = x(t) - \sum_{j=1}^{N} x_j \cdot \phi_j \cdot (t)$$

or

$$x'(t) = S_i(t) + w(t) - \sum_{j=1}^{N} (S_{ij} + w_j)\, \phi_j(t)$$

$$= w(t) - \sum_{j=1}^{N} w_j\, \phi_j(t) = w'(t)$$

The sample function hence depends on the channel noise $w(t)$.

Received signal may be expressed as

$$x(t) = \sum_{j=1}^{N} x_j \cdot \phi_j(t) + x'(t)$$

$$= \sum_{j=1}^{N} x_j \cdot \phi_j(t) + w'(t)$$

$w'(t)$ may be viewed as a remainder that must he included on the right hand side of the equation to preserve equality.

It may be noticed that the expansion of $x(t)$ is random (stochastic) due to the channel noise at the receiver input.

4.5 DETECTION OF KNOWN SIGNAL IN NOISE

Q.6. How can a known signal be detected in noise. Explain in detail.

Ans. Assume that in each time slot of duration T seconds, one of the M possible signals $S_1(t)$, $S_2(t)$ ... $S_M(t)$ is transmitted with equal probability of $\frac{1}{M}$.

Then for AWGN channel, the sample function $x(t)$ is given by

$$x(t) = S_i(t) + w(t) \quad 0 \le t \le T$$

$i = 1, 2, 3, ..., M$

where $w(t)$ is the sample function of the white Gaussian noise process $W(t)$ with zero mean and power spectral density $N_0/2$.

The receiver has to observe the signal $x(t)$ and make the best estimate of the transmitted signal $S_i(t)$.

The transmitted signal $S_i(t)$, $i = 1, 2, ...$ M is applied to a bank of correlators, with a common input and supplied with an appropriate set of N orthonormal basis functions, the resulting correlator outputs define the signal vector S_i.

$S_i(t)$ may be represented by a point in a Euclidean space of dimensions $N \le M$. Such a point is referred as transmitted signal point or message point.

The collection of message point in the Euclidean space is known as signal constellation.

When the receive signal $x(t)$ is applied to the bank of N correlators, the output of the correlator define a new vector x called observation vector.

The observation vector x differs from the signal vector S_i by a random noise vector w.

$$x = S_i + W, \ i = 1, 2, 3, \dots m$$

The vectors x and w are sampled values of the random vectors X and W respectively.

The noise vector w represents the portion of the noise $w(t)$ which will interfere with the detected process.

Based on the observation vector x, the received signal $S(t)$ is represented by a point in the same Euclidean space. This point is referred to as received signal point.

The relation between them is shown in Fig. 4.3.

Fig. 4.3: Effect of noise perturbation on location of the received signal point.

In the detection problem, the observation vector x given, a mapping is to be performed from x to an estimate of the transmitted symbol, in such a way that would minimize the average probability of symbol error in the decision.

The maximum likelihood detector provides solution to this problem.

4.6 HIERARCHY OF DIGITAL MODULATION TECHNIQUES

Q.7. Explain the different types of digital modulation techniques.

Ans.

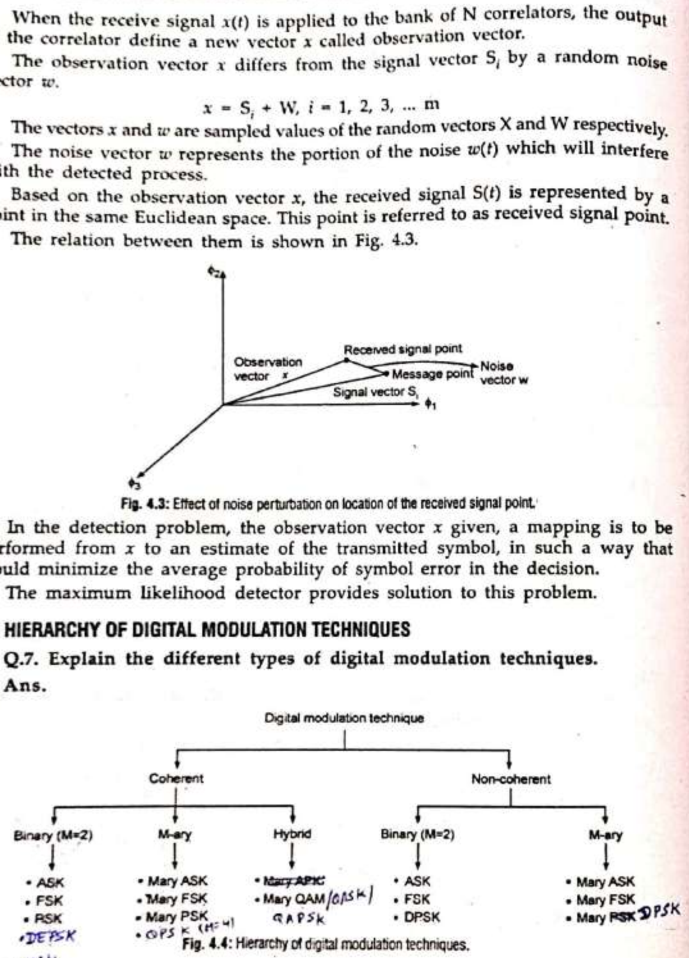


Fig. 4.4: Hierarchy of digital modulation techniques.

The digital modulation techniques can be broadly classified into two categories. They are

(*i*) Coherent techniques

(*ii*) Non-coherent techniques

(i) Coherent Techniques

In the coherent modulation techniques, a phase synchronized carrier is to be generated at the receiver to recover the information signal.

The frequency and phase of this carrier produced at the receiver should be synchronized with that at the transmitter.

Coherent techniques are complex but yield better performance.

(ii) Non-coherent techniques

In the non-coherent techniques, no phase synchronization of local carrier is needed at the receiver end.

These techniques are simpler than coherent techniques.

Their performance is inferior to that of coherent techniques.

There are two types of digital modulation schemes used in these schemes: they are

(*i*) Binary schemes

(*ii*) M-ary schemes

In Binary schemes, we send any one of the two possible signals during each signaling intervals of duration T_b. Example of binary scheme are ASK, FSK and PSK.

In M-ary schemes, we send any one of the M-possible signals during each signaling interval of duration T_b. Examples of M-ary schemes are M-ary PSK, M-ary FSK, QPSK, MSK, QASK or QAM, etc.

M-ary schemes need less bandwidth as compared to the binary schemes.

The error performance of M-ary schemes is poor as compared to the binary schemes.

4.7 BPSK SYSTEMS

Q.8. What do you mean by coherent Binary FSK? Discuss their generation and detection techniques. **(KU 2017)**

Ans. BPSK system is binary phase shift keying.

In BPSK, phase of the sinusoidal carrier is changed according to the data bit to be transmitted.

In BPSK, the binary symbols, '1' and '0' modulate the phase of the carrier. Let us assume that the carrier is

$$S(t) = A \cos 2\pi f_c t$$

where, A = peak value of sinusoidal carrier.

For the standard 1Ω load resistor, the power dissipated would be

4.17 EFFECT OF INTER SYMBOL INTERFERENCE

Q.18. What do you mean by intersymbol interference? What are the effects of intersymbol interference.

Ans. Intersmbol Interference: Refer Unit 3, Section 3.3

Effects of Intersymbol Interference

Intersymbol interference affects the performance of digital systems due to the limited bandwidth occupancy of the systems.

When ISI is present, the correlator receiver or matched filter receiver no more acts as an optimum filter.

This degrades the actual error rate.

The effects of intersymbol interference can be studied with the help of Eye pattern.

Eye pattern: Refer Unit 3, Section 3.12.

4.18 BIT VERSUS SYMBOL ERROR PROBABILITIES

Q.19. Derive an expression for the relation between the average probability of symbol error and the bit error rate.

Ans. The symbol error rate is an appropriate figure of merit when the messages of length $m = \log_2 M$ are transmitted.

But whenever a binary data is to e transmitted, a figure of merit known as the probability of bit error rate (BER) is more meaningful to be used.

The relation between the average probability of symbol error P_e and the bit error rate (BER) can be determined as:

Case 1

In this case, a mapping is performed from binary to M-ary symbols in such a way-that the two binary M-tuples corresponding to any pair of adjacent symbols in an M-ary modulation scheme differ in only one bit position.

This is shown in the signal constellations of M-ary PSK for M = 4 and M = 8 in Fig. 4.41(*a*) and (*b*) respectively.

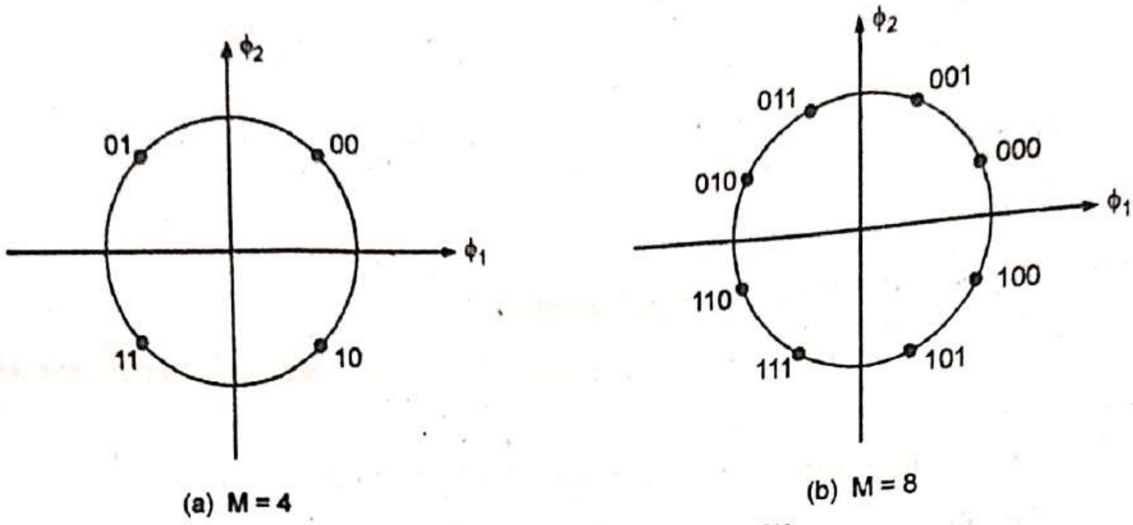


Fig. 4.41: Signal constellation of M-ary PSK.

When the symbol error probability P_e is small then the possibility of mistaking one symbol for its nearest symbols is greater than any other type of symbol error.

Due to the use of gray code, for a given symbol rate, the most probable number of bit errors is only one.

There are $\log_2$ M-bits per symbol.

Therefore, the relation between BER and symbol error probability Pe is as follows:

$$BER = \frac{P_e}{\log_2 m}, M \geq 2$$

Case 2

In this case, let us assume that all the symbol errors are equally likely and they occur with a probability given as:

$$\frac{P_e}{M-1} = \frac{P_e}{2^k - 1}$$

where P_e = the average probability of symbol error

$$\boxed{K = \log_2 m.}$$

For this case, the relation between BER and P_e is given as

$$BER = \left[\frac{2^k}{2^k - 1}\right] P_e$$

where,

$$\boxed{K = \log_2 M}$$

4.19 SYNCHRONIZATION

Q.20. Write a short note on synchronization.

Ans. The coherent reception of a digitally modulated signal requires that the receiver be synchronous with the transmitter.

So synchronization may be defined as:

'Two sequences of related events performed separately, one in the transmitter and the other in the receiver, are said to be synchronous relative to each other when the events in one sequence and the corresponding events in the other occur simultaneously, except for some finite delay.'

There are two basic modes of synchronization:

(i) Carrier Synchronization

(ii) Symbol Snchronization

(i) Carrier Synchronization

When coherent detection is used in signaling over AWGN channels via the modulation of a sinusoidal carrier, knowledge of both the frequency and phase of the carrier is necessary. The process of estimating the carrier phase and frequency is called **carrier recovery or carrier synchronization.**

(ii) Symbol Synchronization

To perform demodulation, the receiver has to know the instants of time at which the modulation in the transmitter changes its state *i.e.*, the receiver has to know the starting and finishing times of the individual symbols, so that it may determine when to sample and when to quench the product-intergrators. The estimation of these times is known as clock recovery or symbol synchronization.

Depending on whether some form of aiding is used or not, synchronization schemes may be classified as:

(i) Data aided synchronization

(ii) Non data aided synchronization

(i) Data aided synchronization

In data-aided synchronization schemes, a preamble is transmitted along with the data bearing signal in a time multiplexed manner on a periodic basis.

The preamble contains information about the symbol timing, which is extracted by appropriate processing of the channel output at the receiver.

Such an approach is commonly used in digital satellite and wireless communications, where the motivation is to minimize the time required to synchronize the receiver to the transmitter.

Limitations of data-aided synchronization are:

(a) Reduced data throughput efficiency, which is incurred by assigning a certain portion of each transmitted frame to the preamble.

(b) Reduced power efficiency, which results from the allocation of a certain fraction of the transmitted power to the transmission of the preamble.

(ii) Non data aided synchronization

In this scheme, the use of preamble is avoided and the receiver has the task of establishing synchronization by extracting the necessary information from the noisy distorted modulated signal at the channel output.

Throughout and power efficiency are improved in this approach but the time taken to establish synchronization is increased.

Algorithmic Approach to Synchronization

Given the received signal, the maximum likelihood method is used to estimate two parameters. Carrier phase and symbol timing.

In the algorithmic approach, the symbol-timing recovery is performed before phase recovery. This is done because once the envelope delay incurred by signal transmission through a dispersive channel is known, then one sample per symbol at the matched filter output may be sufficient for estimating the unknown carrier phase.

Computational complexity of the receiver is minimized by using synchronization algorithms that operate at the symbol rate 1/T.

The algorithmic approach to synchronization is as follows:

(*i*) Through processing the received signal corrupted by channel noise and channel dispersion, the likelihood function is formulated.

(*ii*) The likelihood function is maximized to recover the clock.

(*iii*) With clock recovery achieved, the next step is to maximize the likelihood function to recover the carrier.

QUICK REVIEW

- Bandpass modulation is the process by which an information signal is converted into a sinusoidal waveform.
- The digital modulation techniques can be classified into 2 categories:
  (*i*) Coherent techniques
  (*ii*) Non coherent techniques
- In coherent modulation techniques, a phase synchronized carrier is to be generated at the receiver to recover the information source.
- In non-coherent modulation techniques, no phase synchronization of local carrier is needed at the receiver end.
- In binary phase shift keying (BPSK), phase of the sinusoidal carrier is changed according to the data bit to be transmitted.
- In amplitude shift keying (ASK), only one unit energy carrier is used which is switched on or off depending upon the input binary sequence.
- In frequency shift keying (FSK), the frequency of a sinusoidal carrier is shifted according to the binary symbol.
- Two sequences of related events performed separately, one in the transmitter and the other in the receiver, are said to be synchronous relative to each other when the events in one sequence and the corresponding events in the other occur simultaneously, except for some finite delay."
- There are two basic modes of synchronization
  (*i*) Carrier synchronization
  (*ii*) Symbol synchronization
- Depending on whether some form of aiding is used on not, synchronization schemes may be classified as
  (*i*) Data aided synchronization
  (*ii*) Non data aided synchronization

□□□

HIERARCHY

Digital Mod

- Digital Mod^n Tech.
  - Coherent
    - Binary (M=2)
      - ASK | BASK
      - FSK | BFSK
      - PSK | BPSK
      - DEPSK
      - MSK (Special case of CPFSK)
    - M-ary
      - M-ary ASK
      - M-ary FSK
      - M-ary PSK
      - QPSK (M=4)
    - Hybrid
      - QAM / QASK / QAPSK
  - Non-Coherent
    - Binary (M=2)
      - ASK
      - FSK
      - DPSK
    - M-ary
      - M-ary ASK
      - M-ary FSK
      - M-ary DPSK

* Do only Coherent Techniques

* FSK & M ary FSK are only Scheme which are mostly used Non-Coherently Practically

Some Points

Some Points.

* erfc is the monotonically decreasing function.

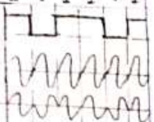
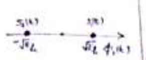
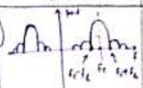
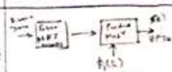
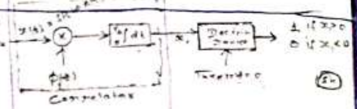
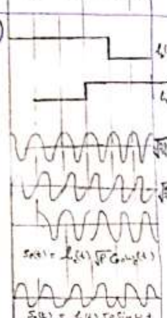
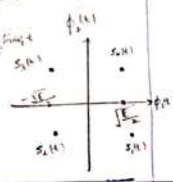
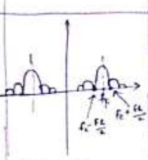
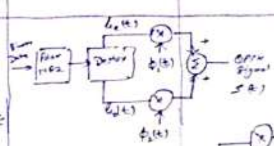
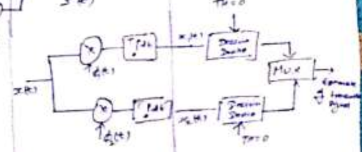
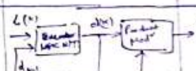
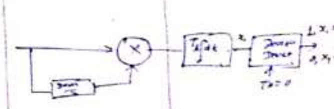
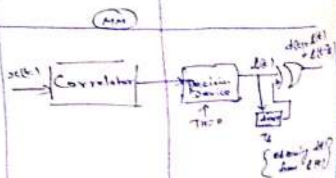
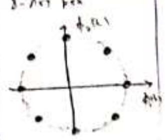
e.g. Let $P_e = \frac{1}{2}\, erfc\left(\frac{d}{2\sqrt{N_0}}\right)$, if $\frac{d}{2\sqrt{N_0}}$ increases, P_e falls rapidly.

The maximum value of $P_e = \frac{1}{2}$ when $\frac{d}{2\sqrt{N_0}}$ is very small. $P_e = \frac{1}{2}$ means receiver will make incorrect decision for half No. of times.

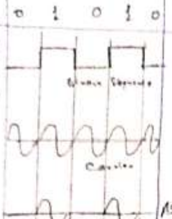
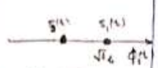
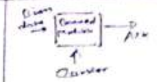
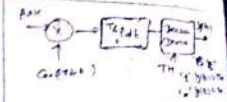
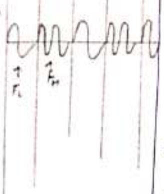
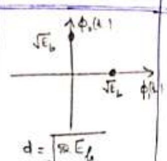
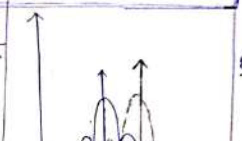
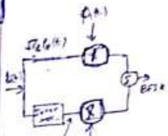
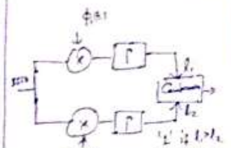
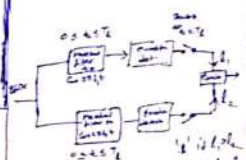
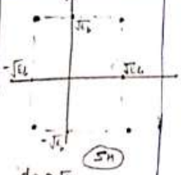
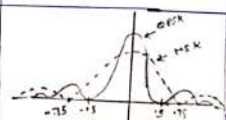
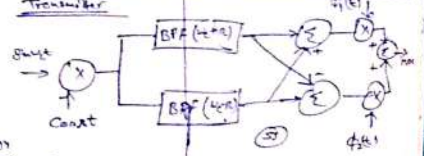
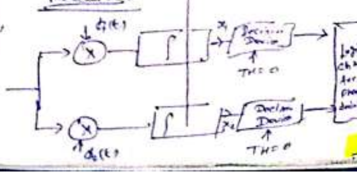
* Coherent Detection exhibits less P_e than Non Coherent. But Coherent detection needs more hardware.

P.T.O

SH —
ES —
MM —

	Definition	Equation	Waveforms	Signal-Space Diagram	Bit error Probability	Spectrum & BW	Transmitter	Receiver
BPSK M = 2 Binary Phase Shift Keying (Imp)	Phase of Carrier is Changed by 180°	$s(t) = \pm\sqrt{\frac{2E_b}{T_b}}\cos 2\pi f_c t$ $s_1(t) = +\sqrt{E_b}\,\phi_1(t)$ $s_2(t) = -\sqrt{E_b}\,\phi(t)$ where $\phi_1(t) = \sqrt{\frac{2}{T_b}}\cos 2\pi f_c t$	1 2 3 4 5 6 1 0 1 1 0 1 	 $d = 2\sqrt{E_b}$ (SH)	$P_e = \frac{1}{2}\,erfc\left(\frac{d}{2\sqrt{N_0}}\right)$ $(P_e)_{BPSK} = \frac{1}{2}\,erfc\left(\sqrt{\frac{E_b}{N_0}}\right)$ (SH) $\frac{N_0}{2}$ = Noise psd	 $BW = 2f_b$ (ES)	 (SH)	 Correlator 1 if $x > 0$ 0 if $x < 0$ (SH)
QPSK M = 4 Quadrature Phase Shift Keying (Imp)	Phase of Carrier is Changed by 90° ($0°$, $90°$, $180°$, $270°$) OR ($45°$, $135°$, $225°$, $315°$) $s_{QPSK} = \sqrt{E_s}\,b_o(t)\sin\omega_c t + \sqrt{E_s}\,b_e(t)\cos\omega_c t$ $b_o(t)$ = odd sequence $b_e(t)$ = even sequence	$s_i(t) = \sqrt{\frac{2E}{T}}\cos\left(2\pi f_c t + (2i-1)\frac{\pi}{4}\right)$ $\cos(A+B) = \cos A\cos B - \sin A\sin B$ $s_1(t) = \sqrt{\frac{E}{2}}\phi_1(t) - \sqrt{\frac{E}{2}}\phi_2(t)$ $s_2(t) = -\sqrt{\frac{E}{2}}\phi_1(t) - \sqrt{\frac{E}{2}}\phi_2(t)$ $s_3(t) = -\sqrt{\frac{E}{2}}\phi_1(t) + \sqrt{\frac{E}{2}}\phi_2(t)$ $s_4(t) = +\sqrt{\frac{E}{2}}\phi_1(t) + \sqrt{\frac{E}{2}}\phi_2(t)$ $\phi_1(t) = \sqrt{\frac{2}{T}}\cos 2\pi f_c t$ $\phi_2(t) = \sqrt{\frac{2}{T}}\sin 2\pi f_c t$ $E_b = \frac{E}{2}$ = Signal energy/bit $E = E_s = 2E_b$ $T = T_s = 2T_b$	 $s_e(t) = b_e(t)\sqrt{P}\cos\omega_c t$ $s_o(t) = b_o(t)\sqrt{P}\sin\omega_c t$	$d_{min} = \sqrt{\frac{E}{2}} + \sqrt{\frac{E}{2}} = \sqrt{2E} = 2\sqrt{E_b}$ $[\because E = 2E_b]$ 	$d_{min} = 2\sqrt{E_b}$ $P_e = \frac{1}{2}\,erfc\sqrt{\frac{E_b}{N_0}}$ Same as BPSK	 $BW = f_b$ (Half than BPSK)	 QPSK Signal $s(t)$	 Carrier of transmitted signal
DPSK Differential PSK	Non Coherent version of PSK If sequence $b(t)$ is modified such that next bit depends on previous bit	b_k: 1 0 0 1 0 0 d_{k-1}: 1 1 0 1 1 0 d_k: 1 1 0 1 1 0 1 Transmitted Phase: 0 π 0 0 π 0 • If $b_k = 1$, no change d_k w.r.t. previous bit • If $b_k = 0$, change d_k w.r.t. previous bit * Assume b_k * Assume d_{k-1} (SH)		 DPSK Signal Space diagram (SH)	* Higher bit error rate than BPSK, QPSK as error in 1st bit creates error in second. (SH) or (MM)		 (MM)	 (MM)
DEPSK Differential encoded PSK	* T^r Same as DPSK * R^r — is Uses Coherent detection	Same as DPSK			* Less P_e than DPSK as Coherent detection is used * Complex Receiver		Same as DPSK	
M-ary PSK (M = no. symbols)	M-ary PSK will have • N bit Symbol • $T_s = NT_b$ • $E_s = NE_b$ • $2^N = M$ possible Symbols	$s(t) = \sqrt{\frac{2E_s}{T_s}}\cos(\omega_c t + \phi_m)$ where $\phi_m = (2m+1)\frac{\pi}{M}$ $\phi_1(t)$ & $\phi_2(t)$		8-Ary PSK 	$d = 2\sqrt{E_s}\sin\left(\frac{\pi}{M}\right)$	$BW = \frac{2f_b}{M}$		

P.T.O.

Name	Definition	Equation	Waveform	Signal space Diagram & d	Bit error Probability	Spectrum & BW	Tx	Rx
ASK/BASK or Amp ASK or ON-Off Keying	* Carrier is switched on & off depending upon digital sequence	$s(t) = \sqrt{\frac{2E_b}{T_b}} \cos(2\pi f_c t)$ for binary '1' $s(t) = 0$ for binary '0' $s_1(t) = \sqrt{E_b}\,\phi_1(t)$ $s_2(t) = 0$ where $\phi_1(t) = \sqrt{\frac{2}{T_b}} \cos 2\pi f_c t$		 $d = \sqrt{E_b}$	$P_e = \frac{1}{2} \operatorname{erfc} \frac{1}{2}\sqrt{\frac{E_b}{N_0}}$	Same as BPSK $BW = 2f_b$		
BFSK $b(t)$ / $P_H(t)$ / $P_L(t)$: 1 / +1V / 0V; 0 / 0V / +1V Coherent	$s(t) = \sqrt{E_b}\, P_H(t) \cos 2\pi f_H t + \sqrt{E_b}\, P_L(t) \cos 2\pi f_L t$ where f_H & f_L are selected such that $f_H - f_L = 2f_b$ $f_H = m f_b$, $f_L = n f_b$ Integer multiple of f_b so that f_H & f_L are orthogonal.	Two carriers of different frequencies are transmitted depending upon binary sequence		 $d = \sqrt{2E_b}$ This d is less than $(d)_{BPSK}$ This is orthogonal BFSK Two symbols are orthogonal	$(P_e) = \frac{1}{2} \operatorname{erfc} \sqrt{\frac{E_b}{2N_0}}$ Coherent * It is more than BPSK	 $BW = 4f_b$		
BFSK Non-Coherent	"	"	"	"	$P_e = \frac{1}{2} \exp\left(-\frac{E_b}{2N_0}\right)$ Non Coherent orthogonal BFSK	"	"	
MSK Minimum shift keying or CPFSK with deviation ratio equal to half or Shaped QPSK (No. of bits per symbol is two as in QPSK)	* f_H & f_L are as close as possible for their orthogonality to prevail $f_H - f_L = \frac{f_b}{2}$ $\frac{f_b}{2}$ is minimum value of orthogonality. * Baseband signal is multiplied with quadrature carriers to get smooth signal rather than rectangular pulse (53)	$s(t) = \sqrt{\frac{2E_b}{T_b}} \left(b_e(t) \sin \frac{2\pi t}{4T_b}\right) \cos \omega_c t + \sqrt{\frac{2E_b}{T_b}} \left(b_o(t) \cos \frac{2\pi t}{4T_b}\right) \sin \omega_c t$ * No abrupt changes in phase of MSK like QPSK. * MSK exhibits phase continuity (53)	Draw * $b(t)$ * $b_e(t)$ * $b_o(t)$ * $\sin \frac{2\pi t}{4T_b}$ * $\cos \frac{2\pi t}{4T_b}$ * $b_e(t) \sin \frac{2\pi t}{4T_b}$ * $b_o(t) \cos \frac{2\pi t}{4T_b}$ Pg 3(3), (53)	 (54) $d = 2\sqrt{E_b}$	$P_e = \frac{1}{2} \operatorname{erfc} \sqrt{\frac{E_b}{N_0}}$ Same as BPSK, QPSK (54)	 $(BW)_{MSK} = (1.5)(BW)_{QPSK}$ * The main lobe of QPSK have 90% energy * The main lobe of MSK have 99% energy * Side lobe of MSK are smaller * To have 99% energy in QPSK, side bands are needed to be include, which increases the $(BW)_{QPSK}$ than $(BW)_{MSK}$ (53)	Transmitter  (53)	
							Receiver 	

* It is more relevant to consider MSK as shaped QPSK.
* It makes MSK more complex when it is considered as CPFSK.

P.T.O

- Explain Passband Transmission model.
- Imp. Explain Gram Schmidt Procedure
- Imp. Illustrate Geometric Interpretation of Signals
- Imp. Explain Schema of Bank of Correlators to ...
- Explain detection of ... of Known Signals.
- Explain M-ary Modulation Tech.
- Imp. Explain ISI & its effect.
- Imp. Write a note on Synchronization
- * (Prof. Mastermind)

Previous year (Q7) (Q3)

M-ary PSK vs M-ary FSK

- M-ary FSK need more BW
- P_e of MFSK is less than MPSK

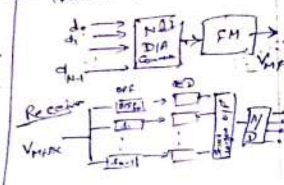
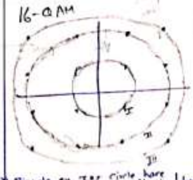
M-ary PSK vs MQAM (M=16)

- Both need same BW
- MPSK have more P_e as point are closer

$$d \propto \frac{1}{P_e}$$

$$E_s = NE_b$$

	M-ary FSK	M-ary PSK	M-ary QAM
d	$d=\sqrt{2NE_b}$ or $d=\sqrt{2E_s}$	$d = 2\sqrt{E_s}\sin\frac{\pi}{M}$	$d = 2\sqrt{0.1E_s}$ (for M=16)
BW	$\frac{2^{N+1}\times f_b}{N}$	$\frac{2f_b}{N}$	$\frac{2f_b}{N}$

Name	Definition	Equation	Waveform	Signal-space diagram & d	Bit error probability	Spectrum BW	Transmitter
M-ary FSK	In M-ary FSK, there are total of M signals each having N bit. $2^N = M$. These M signals have $f_0, f_1, \ldots f_{M-1}$ frequencies	$s(t) = \sqrt{\frac{2E}{T}}\cos\ldots t$; $c = 0, 1, 2, \ldots M-1$; $T = NT_b$; $2^N = M$; $E = NE_b$; N bits per symbol	—	$d = \sqrt{2NE_b}$	Less than M-ary PSK	$BW = \frac{2^{N+1}f_b}{N}$ (It is more than M-ary PSK)	
QAM or QASK or QAPSK	Phase & amplitude both are changed. $s_k(t) = \sqrt{\frac{2E}{T}}a_k\cos 2\pi f_c t - \sqrt{\frac{2E}{T}}b_k\sin 2\pi f_c t$; $k = 0, \pm1, \pm2, \pm3 \ldots$; for M-ary QAM, $L = \sqrt{M}$ then $[a_i, b_i] = \begin{bmatrix}(-L+1, L-1) & (-L+3, L-1) & \cdots & (L-1, L-1) \\ \vdots & \vdots & & \vdots \\ (-L+1, -L+1) & (-L+3, -L+3) & \cdots & (L-1, -L+1)\end{bmatrix}$	M-ary QAM will have M signal, which changes either in phase or amplitude.	—	16-QAM  * Signals on Ist circle have same amplitude, but differ in phase. * Respective signals on IInd, IIIrd circle have same phase, but diff. amplitude	$d = 2\sqrt{0.1E_s}$ (This is for M=16); $P_e = 2\left(1-\frac{1}{\sqrt{M}}\right)\text{erfc}\sqrt{\frac{E}{N_0}}$; $E = NE_b$	$BW = \frac{2f_b}{N}$	No need