PERFORMANCE EVALUATION OF DIFFERENT LINE CODES

V.Sneha Latha *
Assistant Professor, K L University
Andhra Pradesh
Sneha_2k@yahoo.com

Abstract

The ability to communicate has differentiated mankind from other species. 20^{lh} century has seen considerable emphasis on development of efficient communication techniques because how well one is able to communicate has become the yardstick of the socioeconomic status of a nation. The spectrum of techniques used today provides more capacity than ever envisaged, provide global coverage including remote area access, provides simultaneous communication links between fixed points as well as between mobile points or hybrid of these all, at cost effective rates and with higher accuracy than ever achieved.

In this paper different types of encoding techniques with AWGN channel along with their performance characteristics are evaluated.

***Keywords*:**. BPSK; AWGN Channel ;ISI; NRZ-L;.Manchester; UPNRZ;BPNRZ; UPRZ;BPRZ

1. Introduction

A space communication network outperforms the terrestrial communication network carrying international traffic and compares favorably even for the domestic traffic over large distances. In a space communication network there are essentially three segments:

Transmitting
Receiving station and
Channel for propagation

Various subsystems constitute each segment and problems related to them would cover practically the entire spectrum of engineering. Generally the signal at the transmitting station is encoded and modulated properly for transmission to the channel. The signal is modified by the channel and some noise component is introduced. Reverse operations are carried out at the receiving station.

Communication using the High frequency (HF) band between 2 and 30MHz has been a primary means of beyond line of sight communication. Despite the advent of several other kinds of transmitting media such as satellite, optical fiber, coaxial cables etc. HF channel continues to be used extensively owing to the fact that it is economical and flexible. An accurate assessment of the performance of a newly developed HF radio system can be done through repeated tests of the system over an actual channel. When comparison is to be made between two or more encoding techniques over a real channel, they must all be tested simultaneously. Unlike cables, whose properties can be accurately defined and reproduced, ionosphere channel properties can't be reproduced easily.

The channel characteristics and transmission conditions vary uncontrollably. Here tests can't be repeated many times. Moreover, it is not possible to test a system repeatedly for the same channel conditions

2. Data Transmission Rate Considerations

The adequacy of a given data transmission rate for Internet access is influenced by a number of factors .The response time is influenced by link transmission rate (the actual data transfer capability of the connection),the processing over head ,and ,and the typical size of the data transfer (one large file versus many small ones).Processing overhead is a result of the number of operations required at either end to prepare data and process protocol overheads, and the speed with which this can be done by the terminal equipment hardware.

3. Problem Definition

The most significant challenge in this paper is to assess the line coding techniques with probability of error as the parameter.

3.1. Noise Environment

External noise interferes with the transmission of data by combining with the original data bearing signal .This results in distortion which can lead to erroneous decisions at the receiver about the true value of the transmitted data. For this thesis the external interference is assumed to be additive white

Gaussian noise .This means that the noise signal is random and uniformly distributed across the frequency spectrum. While it is expected that the practical noise environment may not be white (i.e. uniformly distributed in frequency), it is assumed that white noise will provide a suitable basis for comparison of alternatives.

It is expected that compromises will be available between improved data -rate and other desirable transmission characteristics.

3.2. Symbol Rate

The spectrum of the data signal is directly influenced by the symbol rate. In general a code that has minimal dependence on low frequency transmission has spectral nulls at the symbol rate, R_s. Thus, symbol rate must be chosen that will result in a spectrum that is reasonably matched to the available pass band. We define a base band symbol as a voltage change on the transmission line. For each biphase bit, two voltage levels are transmitted. The Symbol rate for Rs b/s biphase encoding is thus 2 R_s symbols per second (.5 bits per symbol).This will be the assumed symbol rate for alternative comparisons.

3.3. Channel Bandwidth:

The physical medium used for transmission will typically be unshielded twisted pair. In general the gain of this cable decreases monotonically with frequency and length. This type of impairment also contributes to inter-symbol interference (ISI).It is assumed that equalization can be employed such that the transmission loss is approximately 0dB, from 0 through 300 KHz. The voice and data signals are prevented from interfering with each other by placing a low pass filter in line with any telephone devices and a high pass filter in line with the data transceiver.

4. Need for Modulation

- It is extremely difficult to radiate low frequency signals from an antenna in the form of electromagnetic energy.
- To reduce height of antenna.

Some characteristics of sinusoidal carrier varies in accordance with the modulating signal. The general expression of a time varying sine wave of voltage such as a high frequency carrier is given by

$$v(t) = V \sin(2\pi f_c t + ø) \quad (1)$$

Where $v(t)$ = time varying sine wave voltage

V = peak amplitude (volts)

f_c = frequency (hertz)

$ø$ = phase shift (radians)

4.1. BPSK/Phase Reversal Keying (PRK)/ Biphase Modulation:

With Binary phase shift keying , two output phases are possible for a single carrier frequency .One output represents logic 1 and the other logic 0, As the input digital signal changes state, the phase of the output carrier shifts between two angles that are 180^o out of phase.

$$\text{Bandwidth } (B) = 2 f_a = 2 f_b / 2 = f_b \quad (2)$$

Where B = minimum double sided nyquist bandwidth

f_a = fundamental frequency of an alternative 1 or 0 bit sequence.

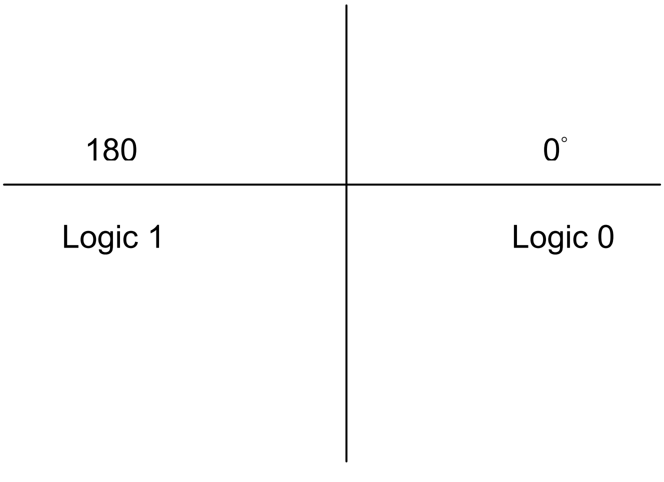

Fig1: Signal constellation of BPSK

Bit error rate or average probability of symbol errors

$$P_e = \tfrac{1}{2} \,\text{erfc}\, \sqrt{E_b/N_o}$$

Where E_b = bit energy

N_o = noise power spectral density

erfc = complementary error function

Transmitted signals:

$S_1(t) = \sqrt{2E_b/T_b}\cos(2\pi f_c)$ and $S_2(t) = 2E_b/t_b \cos(2\pi f_c t + \pi)$ (3)

4.2. Channel

In the analysis of communication system performance the classical AWGN Channel with statistically independent Gaussian noise samples corrupting data samples free of inter symbol interference (ISI) is the usual starting point for developing basic performance results.

In mobile communication systems, the external noise and interference are often more significant than the receiver thermal noise.

Many physical communication channels can be effectively modeled as multipath fading channels. These channels are doubly dispersive channels that exhibit dispersion in both the frequency and time domains. Three phenomenon namely fading, Doppler spread, delay spread has been recognized as the main impairments to reliable communications over these types of channels.

4.2.1 Additive white Gaussian Noise Channel:

Thermal noise is a natural source of noise that cannot be eliminated. Thermal noise is caused by the thermal noise of electrons in all dissipative components – resistors, wires and so on. The same electrons that are responsible for electrical conduction are also responsible for thermal noise.

Thermal noise can be described as a zero mean Gaussian random process. A Gaussian process n (t) is a random function whose value n at any time t is statistically characterized by the Gaussian probability density function.

$$P(n) = 1/\sigma(\sqrt{2\pi})\exp\{-1/2(n/\sigma)^2\} \quad (4)$$

Where σ^2 is variance of n.

The primary spectral characteristics of thermal noise are that is power spectral density is the same for all the frequencies of interest in most communication systems. A simple model for thermal noise assumes that its power spectral density $G_n(f)$ is flat for all frequencies and is denoted as

$$G_n(f) = N_o/2 \text{ watts/Hz} \quad (5)$$

where the factor 2 is included to indicate that $G_n(f)$ is a two sided power spectral density. When the noise power has such a uniform spectral density we refer to it as white noise. The auto correlation function of white noise is given by inverse fourier transform of the noise power spectral density denoted as follows:

$$R(\tau) = F^{-1}\{G_n(f)\} = [N_o/2]\,\delta(\tau) \quad (6)$$

Thus the auto correlation function of white noise is a delta function weighted by a factor of $N_o/2$ and occurring at $\tau = 0$. The delta function in equation means that the noise signal n (t) totally decorrelated from its time shifted version, for $\tau > 0$. Since thermal noise is Gaussian process and the samples are uncorrelated, the noise samples are also independent. Therefore the effect on the detection process of the channel with AWGN is that the noise effects the each transmitted symbol independently. Such a channel is called memory less channel. The term additive means that the noise is simply superimposed or added to the signal.

5. Line Codes

Line coding is a method of encoding each data bit into some signal elements where each signal element is a discrete and discontinuous voltage pulse.

*5.1. **Need for Line Coding***

Line coding is done for achieving many goals such as Introducing spectral nulls at dc frequency when the channel is ac coupled, to attain self-clocking and in-service error monitoring features, to modify the signal spectrum, thereby reducing the cross talk into foreign systems and radio- frequency interferences, y/ to preserve bandwidth, and to reduce the complexity in equalization, detection, echo cancellation & timing recovery circuits e.t.c.

5.1.1.Required characteristics of line code:

Some key characteristics in the line code are its power spectrum, probability of error & a trade-off between symbol rate and no, of transmitting levels. Symbol rate relates directly to the required channel bandwidth, while no of levels relates directly to the noise immunity.

An encoding scheme is chosen basing on the following characteristics of line code:

- *Dc-component***:** Eliminating the dc-component in the signal enables the channel to be ac-coupled. Magnetic recording systems are systems using transformer coupling for electrical isolation and less interference, have less sensitivity to low frequency signal components. Thus the information could be lost.
- *Bandwidth:* Since larger bandwidths result in larger noise contributions, it should be as low as possible. However a large bandwidth may be needed to have timing information available in the bit stream, i.e. a trade-off must be made between timing and noise bandwidth in selecting a line code.
- *Self synchronization***:** With out synchronization, unless the timing clocks in a system are highly stable, a long string of 'n' bits could be misinterpreted as either 'n-1' or 'n+1' bits. However the use of highly stable clocks increases system cost and requires a long system startup time to achieve synchronization.
- *Error detection***:** Though this is the responsibility of a layer of logic above the signaling level, having some error detection capability built into the physical signaling scheme permits the errors to be detected more quickly.
- *Differential encoding***:** In many cases if the leads from a device are accidentally inverted and connected all the ones and zeros may be inverted; for this differential encoding is the best solution. Because, it allows the polarity of a signal to be inverted with out affecting the data detection. Another benefit of this scheme is that it may be more reliable to detect a polarity change than to compare **a** value to a threshold in the presence of noise.

- *Transparency***:** In some protocols certain words are reserved for control sequences. A data protocol is not transparent if-some of the words in a random data file being transferred resemble these control sequences and might be intercepted by the receiver to perform defined actions instead of passing the word to the destination.

The data protocol and line code have to be designed so that *every* possible sequence of data is faithfully and transparently received.

5.2. Principles, merits and demerits

*5.2.1. NRZ-L***:**

In NRZ-L a binary one is represented by one voltage level and a binary zero is represented by another voltage level constant for an entire bit interval. In unipolar signaling both the levels have same algebraic sign usually +5v & 0v respectively (ON-OFF keying). In bipolar NRZ-L both the levels have same magnitude but opposite sign.

- Advantages:

  They are simple to generate.

  Requires minimum bandwidth.

- Disadvantages:

  They possess no inherent error monitoring or correcting capabilities.

  They have no self clocking feature.

  The average power input to the receiver depends on the data pattern. A long string of consecutive ones has a high level of received power but results in a base line wander effect. This results from the low frequency characteristics of ac coupled filter in the receiver.

  Thus we need to avoid a long string of NRZ ones or zeros. Two common techniques used are block codes & scrambling. Scrambling produces a random data pattern by modulo-2 addition with a bit stream & generates the data at the receiver by again performing modulo-2 addition with the same bit pattern. But with these techniques there is an increase in complexity of the circuitry.

- Applications:

  It is extensively used in digital logic circuits.

  It is the most commonly used PCM waveform.

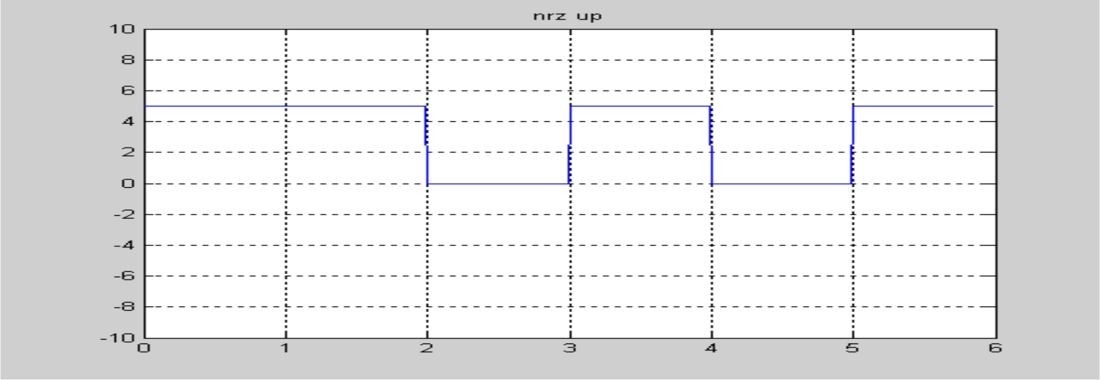

Fig1.NRZ Unipolar

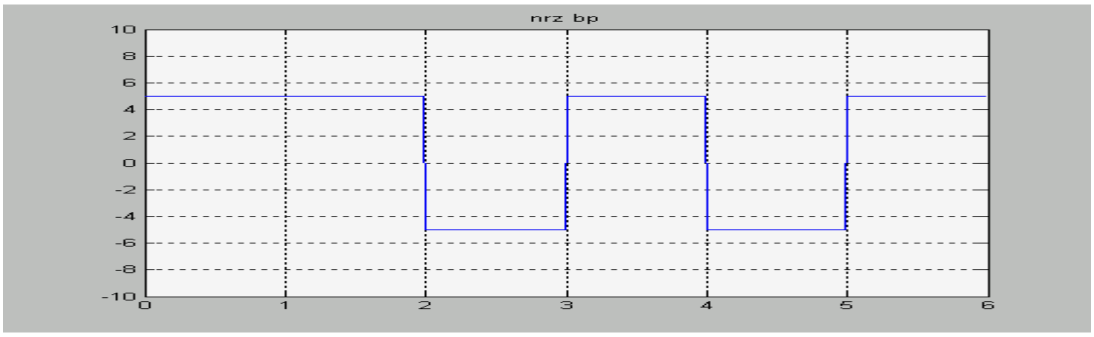

Fig2.NRZ bipolar

5.2.2.RZ:

Return to zero coding consists of unipolar RZ, bipolar RZ and RZ-AMI. With unipolar RZ, a half-bit-wide pulse represents a one, and a zero is represented by the absence of pulse (in bipolar RZ by a half-bit-wide-pulse of opposite polarity).

Both Unipolar RZ and Bipolar RZ are grouped and called as RZ-L. RZ-L has good timing information but requires twice the bandwidth of NRZ code. Also it has no error detecting capability.

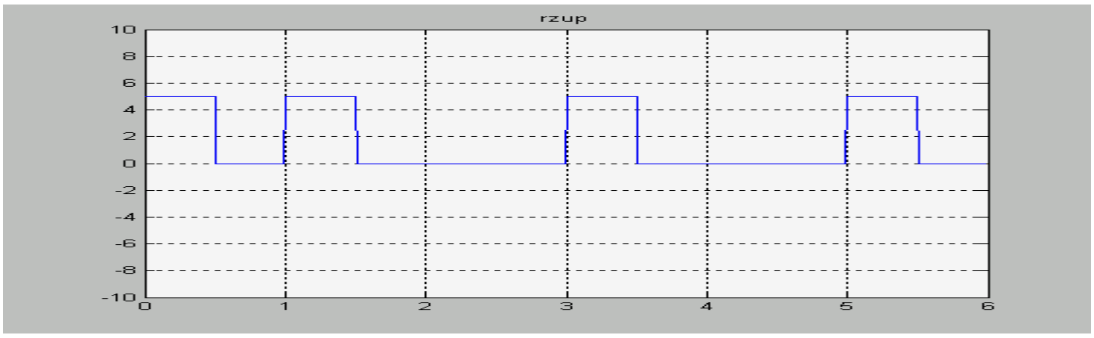

Fig.3.RZ Unipolar

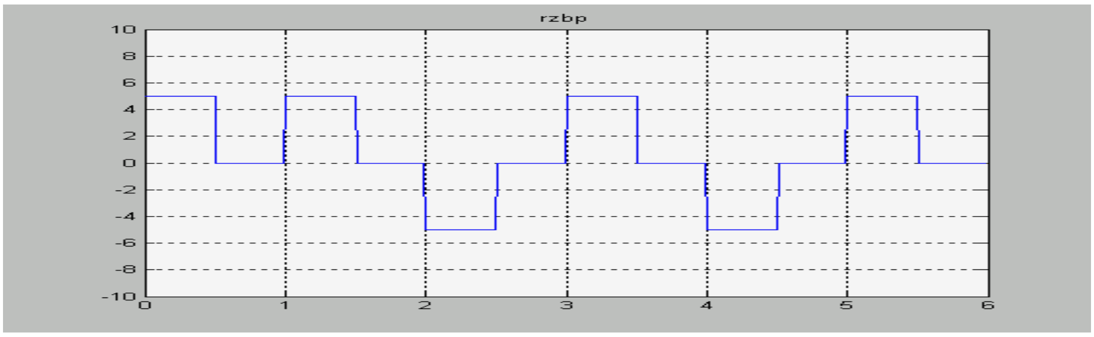

Fig 4.RZ bipolar.

5.2.3.Bl-ø-L:

Also known as Manchester coding is used in optical communications and in some satellite telemetry links. In this a binary one is represented by a negative going transition at the middle of the bit duration and a positive going transition at middle indicates a binary zero.

- Advantages

  It has efficient timing information than any other line code has.

  It is simple to generate and uses only two levels for representing binary data.

- Disadvantages

  It has no inherent error monitoring capability.

  It requires twice the bandwidth of the NRZ signal.

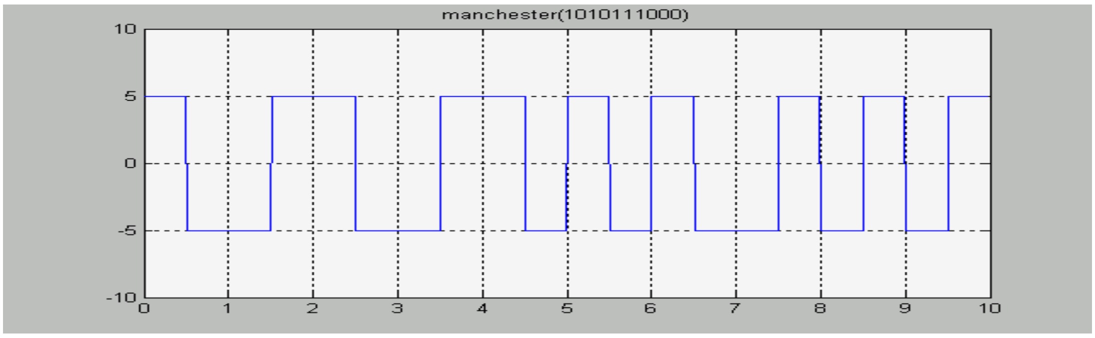

Fig 5.Manchester.

5.3. Comparison of Line Codes

To determine the minimum bandwidth required to propagate a line-encoded signal, we must determine the highest fundamental frequency associated with it. With UPNRZ and BPNRZ, the worst-case condition is an alternating 1/0 sequence, and the highest fundamental frequency is one-half of the bit rate. And with UPRZ and BPRZ, the bandwidth is equal to the bit rate.

With NRZ encoding, a long string of either 1s'or 0s produces a condition in which a receiver may lose its amplitude reference for optimum discrimination between received 1s and 0s. The average DC component of unipolar signaling is +V/2 and bipolar signaling is of 0 V.

With UPRZ a long string of 0s generates a data signal void of transitions. With BPRZ, a transition occurs in each bit position regardless of whether the bit id a 1 or a 0. Therefore, BPRZ encoding is best suited for clock recovery.

With UPNRZ, BPNRZ, UPRZ and BPRZ transmissions there is no way to determine if the received data have errors.

Table 1. Line-Encoding Summary

Encoding Format	**Minimum Bandwidth**	**Average DC**	**Clock Recovery**	**Error Detection**
UPNRZ	fb/2*	+V/2	Poor	No
BPNRZ	fb/2*	0V*	Poor	No
UPRZ	fb	+V/2	Good	No
BPRZ	fb	0 V*	Best*	No

6. Encoding data for improved transmission

Base band line coding and relevant principles and theory and its evolution for use in specified environment are discussed.

6.1. Data Transmission

The electrical characteristics of data signals as found in electronic circuitry are, in general ,poorly matched to the characteristics of most transmission or storage environments .Modulation is a well known process that can be used to transform a signal for transmission in a passband.Alternatively ,the process of baseband coding ,or line coding ,can also be used to alter a signal’s spectrum ,thus matching its frequency characteristics to those of the pass band .This section discuses the advantages of baseband coding in a low frequency pass band environment .It also investigates the main impairments and the characteristics that are of importance when selecting a suitable line coding method.

6.1.1 Characteristics of Base band Line Coding:

Base band coding is also employed to condition the data for transmission, including altering its spectrum. The available bandwidth is changed from a baseband to a pass band because of the elimination of the low frequency end of the spectrum for voice transmission. Baseband coding alone is often used to create a “dc free” signal spectra, thereby decreasing the dependence on the low end of the frequency spectrum. Thus either baseband coding or modulation techniques could be applied to the spectrum of the data signal to match this channel.

Raw binary data can be transformed through line coding to achieve a number of desirable characteristics including:

1. *Spectral shaping*: The available transmission bandwidth may have certain restrictions or bands of interference .The most common of these is the case where there is very little or no transmission capability at and near zero frequency(dc) as encountered in transformer coupled transmission lines or magnetic recording media. For these cases ,codes have been developed that have spectral requirements that approximately match the available bandwidth ,thus reducing the loss of signal energy and improving the accuracy of data recovery .The gains in this respect are often achieved at the expense of characteristics such as data rate or noise margin.
2. *Strong clocking and timing components:* In order to accurately detect and decode a symbol sequence after transmission through an impaired channel, accurate timing information is required. If this timing information must be recovered from the incoming data stream ,an appropriate coding method must be chosen. Usually a code with frequent transitions or a strong component at a certain frequency will allow the easy extraction of timing information .By contrast ,it is difficult to obtain reliable timing information from a code which allows transmission of a long sequence of constant –valued symbols .For example ,AMI transmits a zero –valued symbol for each binary zero. In order to provide the regular zero crossings which allow clock recovery ,further coding can be done to replace a specified number of sequential zero crossings with a special unique sequence containing non-zero symbols. When this special sequence is detected at the receiver ,the original number of zeros is again inserted in the outgoing data.
3. *Bandwidth compression*: In the base band environment, redundancy arises only by design ,when it is used to provide error detection or correction. The bandwidth requirements of data transmission are primarily a function of the symbol rate. Choosing a line coding method that assigns more bits per symbol will result in a decreased symbol rate and thus a reduced bandwidth requirement .
4. *Error detection and correction*: Line coding can also be used to add redundancy or special sequences which can be used at the receiver to detect and correct errors. A simple example is found in AMI line coding, which is in fact a three-level (ternary) code, where the transmission of a non-zero symbol must be of opposite polarity to that of the previous non-zero symbol. Baseband techniques, when they can be successfully applied, avoid the numerous complexities of modulation involved in pass band transmission..

Following determination of an expression for the theoretical PSD for coding method, the following comparative measurements can be made for each alternative:

The transmission bandwidth required to encompass the main lobe of the PSD up to the first null-This observation is made by plotting the PSD over a suitable frequency range.

- Calculate the amount of signal power in the voice band ,300 to 3400 Hz, to determine the relative propensity for interference into the voice communication band.

- Calculate the amount of signal power in the 0 to 10 kHz band ,to determine the approximate amount of signal power that will be lost in the separation filtering process.

The value may be determined by evaluating the integral

$$P = \int_{f1}^{f2} \phi(f)\, df \qquad (7)$$

Over the appropriate limits, where P=power in the interval f1 to f2 and $\phi(f)$ is the expression for the single sided PSD of the code being examined.

7. Model Description

The model takes the written text contained in a source, text file as source information. When the rising edge of the trigger signal is detected the 'trigger read from file ' block reads from a file a record whose length is specified in the output vector length parameter'. The data type parameter ASCII converts the input text to integers at the output, where the scalar signal is converted into frame based column vector.

The integer to bit converter block maps a vector of integers to a vector of bits whose length is equal to 7. The first bit of output vector is most significant bit (MSB). Then these bits are given to unbuffer block which converts a frame to scalar samples output at a higher sample rate. Then these scalar samples are given to user defined block(s-function) which contains the encoding logic for that particular line code (NRZ, RZ, MANCHESTER).The output of s-function is electrical representation of voltage levels corresponding to binary input .

Then these output voltage levels are applied to frame status conversion in which scalar signal is converted into frame based column vector. The encoded output is given to BPSK modulator.

The encoded output is modulated using BPSK modulator and is transmitted through the AWGN channel where the noise introduced. The AWGN channel adds a frame of Gaussian noise to single channel signal. The Eb/No (db) is varied in steps using software to obtain Eb/No Vs BER plot, Here Eb/No is related to Es/No by the formula EbNodB+10log10(log2 (M)).Then these modulated bits are given to demodulator input.

The received signal at the input of demodulator comprises of Tx signal along with the noise. The BPSK demodulator demodulates modulated signal and is converted into scalar samples. Then these samples are decoded using s-function block which contains decoding logic corresponds to that particular encoding technique.

In order to calculate Bit Error Rates for varying Eb/No we need to use a block called Error Rate Calculation Block. The block accepts Tx and Rx signals, which must share the same sampling rate as inputs and produces a vector of length three whose entries correspond to

(1) The Error Rate
(2) Total number of errors, that is, comparisons between unequal elements
(3) The total number of comparisons that the block made.

The block sends this output data to the workspace with some variable name (ex. bernrzbp) in order to tabulate the corresponding Eb/N_0 and BERs. The output port of this block contains the running error statistics that can be displayed.

The modulator input and demodulator output signals are unbuffered so that each matrix row becomes an independent time sample in the output. The relational operator block outputs a zero when the two signals agree, and a one when they differ .The top window on the scope displays the transmitted signal .The middle window displays the received signal. The bottom of the scope displays a zero where the two signals agree and a one where they differ.

In this way 5 such different model diagrams are created for different line codes NRZ-BP, NRZ-UP, RZ-BP, RZ-UP and MANCHESTER. The corresponding file names are nrzbp, nrzup, rzbp, rzup and manch (.mdl) .The corresponding work space variable names are bernrzbp, bernrzup, berrzbp, berrzup and bermanch.

8. Experimental Results

The performance evaluation of different line codes and comparison of different phase modulation techniques are made on the basis of error probability. These are shown in Fig.6, Fig.7 and fig.8

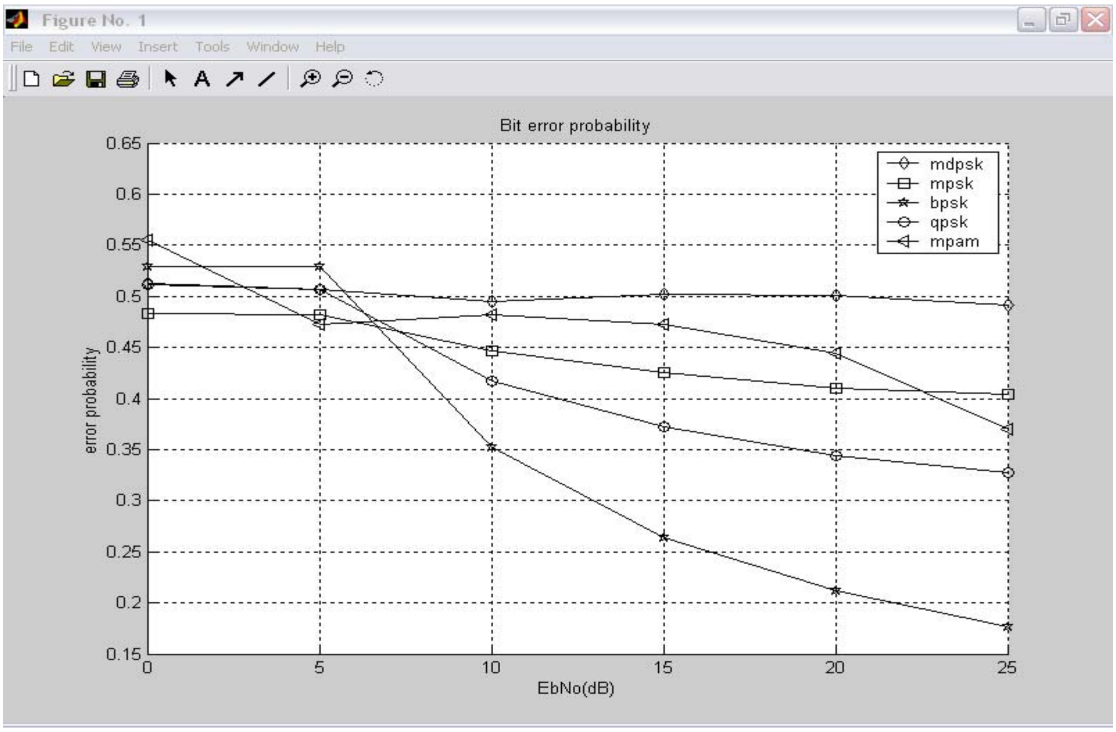

Fig 6. Comparison of different phase modulation techniques

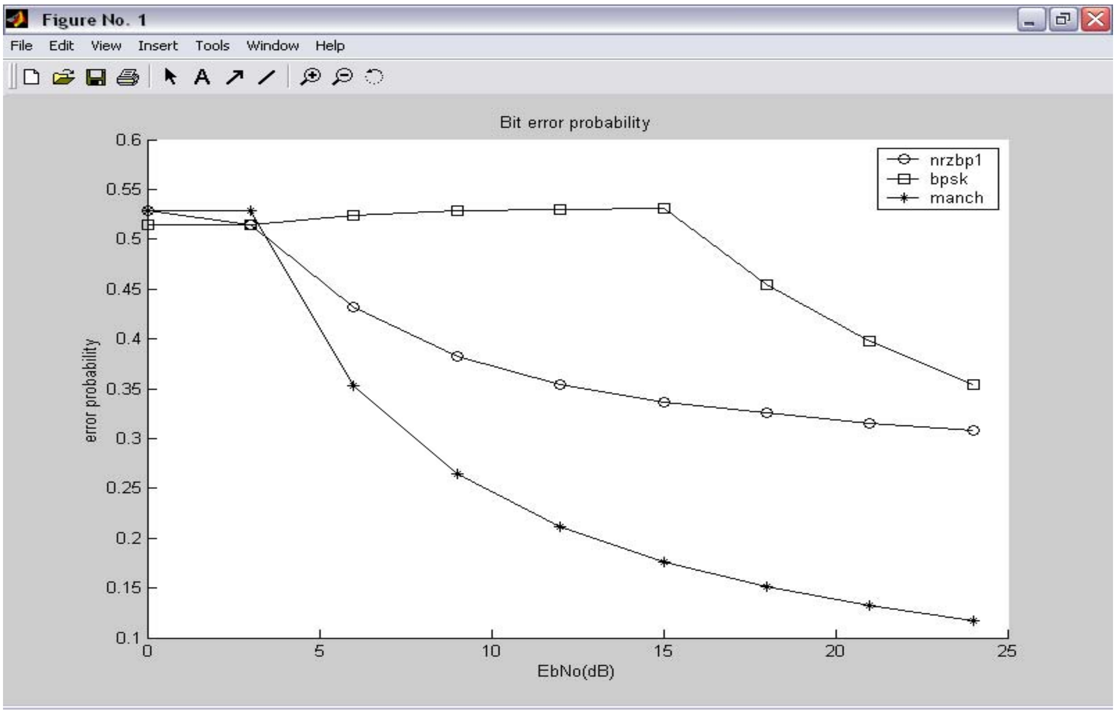

Fig 7. Comparison of BPSK with and without using line code

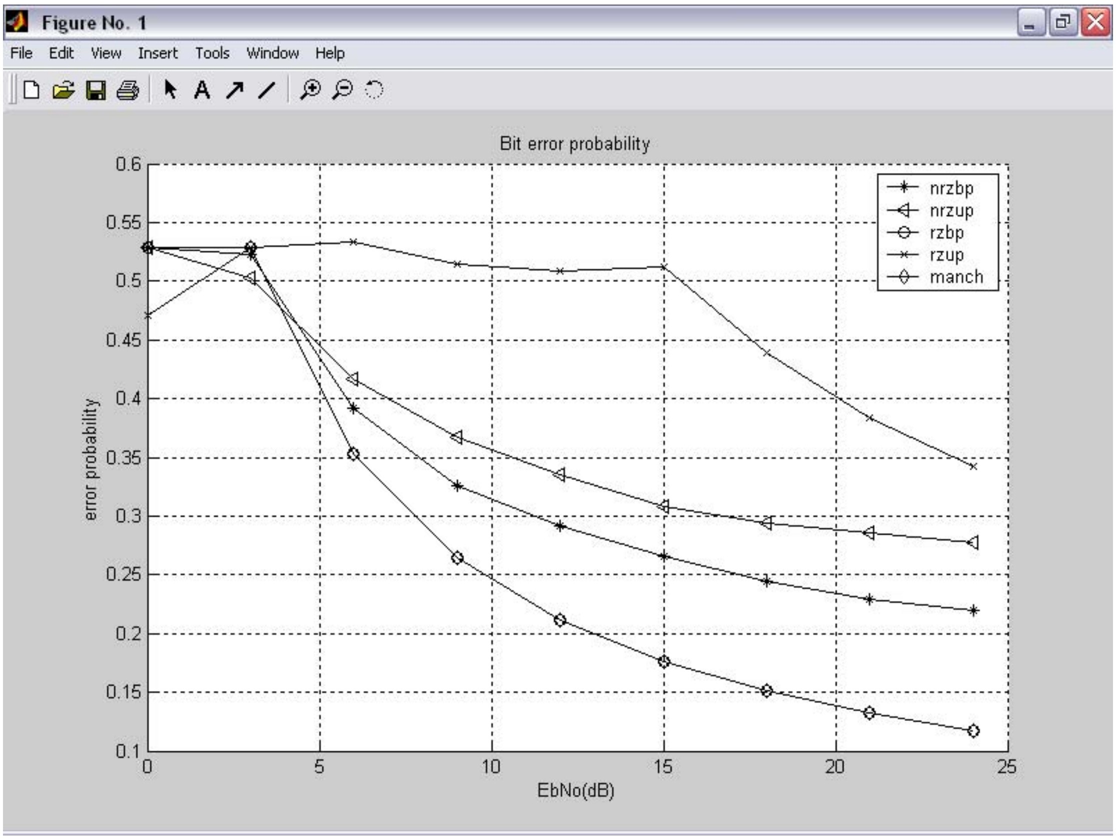

Fig 8. Comparison of different line codes

9. Conclusion

Line coding should make it possible for the receiver to synchronize itself to the phase of the received signal. If the synchronization is not ideal, then the signal to be decoded will not have optimal differences (in amplitude) between the various digits or symbols used in the line code. This will increase the error probability in the received data It is also preferred for the line code to have a structure that will enable error detection

In this paper we have discussed about different types of encoding techniques with AWGN channel along with their performance characteristics. We also made the comparison of different line codes based on their probability of error. With this investigation we can confirm that Bipolar-RZ is recommended for providing an increased data transmission rate in the pass band environment with less probability of error.

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