A Multilevel NRZ Line Coding Technique

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ABSTRACT
This paper proposes a multilevel Non-Return-to-Zero (NRZ) coding technique for the transmission of digital signals. The Multilevel Technique presented here helps in removing certain problems associated with Bipolar and Manchester coding techniques. This multilevel technique utilizes different D.C. levels for representing a '0' and '1' with a NRZ method. The PSD (power spectral density) of the encoded signal is analyzed and possible generation method is also shown.

General Terms
Digital signal transmission, Line coding, Non-Return-to-Zero (NRZ).

Keywords
Probability of error, Multilevel Signal, Power Spectral Density

1. INTRODUCTION
The advances in communication technology requires upgrading of the transmission of the different types of information such as voice, data, images, multimedia and real-time video. The efficiency can be in terms of protocols, encoding techniques, modulation techniques, system complexity, cost etc. In this paper we analyze one of the important parameter of digital signal transmission i.e. Line Coding. Many line coding techniques have been proposed and they have become standards in telecommunication and computer networks.

Coding can be broadly classified into three types namely source, error control and line coding. The first i.e. source coding is used to remove the redundancy in the information source or the signal to be transmitted. The second type i.e. error control coding is used to correct the impairment caused by the channel/transmission media during transmission. The third type i.e. line coding was introduced for the transmission of baseband signals over a communication channel.

Signals generated from the information source can either be analog or digital in nature. The analog signals are first digitized. These signals are known as Baseband Signals. The communication systems where these baseband signals are transmitted without superimposing them or modulating them on a higher frequency signals are known as Baseband Communication System. Pulse code modulation (PCM) can be used to convert the analog signal to its digital form. Figure 1 shows the block diagram of PCM technique. As can be seen from figure 1, the various steps in PCM are sampling, quantization and coding. The PCM signal cannot be directly transmitted because of disadvantages like Inter Symbol Interference (ISI), synchronization between transmitter and receiver and a undesired DC level if a long string of '1' or '0' occurs. To take care of synchronization and DC level, line coding is done before the signal is transmitted. Figure 2 shows the block diagram of line encoder and decoder as used in transmitter and receiver.

The Discrete Pulse Amplitude Modulation (PAM) signal which is used for encoding is given in equation 1. [3]

$$x(t) = \sum_{k=-\infty}^{\infty} a_k p(t - kT_b) \quad (1)$$

Where a_k is a Random Variable which can take a value depending on the information signal and the type of line code which is used. $p(t-kT_b)$ is the pulse which is to be transmitted. T_b is the bit duration.

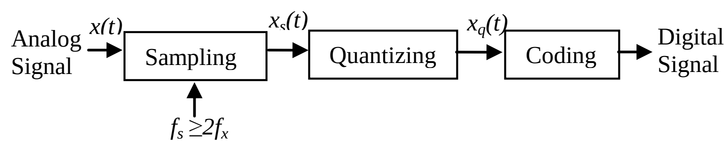

Figure 1. Analog to digital conversion using PCM

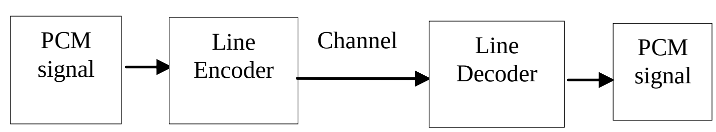

Figure 2. Line Coding

2. LINE CODING
There are many encoding techniques which are used depending on their advantages, disadvantages and their applications. Few commonly used encoding techniques are given below [1 – 3, 10].

- Unipolar Non Return To Zero
- Unipolar Return To Zero
- Polar Non Return To Zero
- Polar Return To Zero
- Bipolar Non Return To Zero
- Bipolar Return To Zero / Alternate Mask Inversion Return To Zero (RZ – AMI)

Figure 3 shows the waveforms for the different line coding techniques. If the bit rate is slow a Non-Return to Zero (NRZ) is enough. But this introduces a DC component in the signal. A typical solution to this impairment is to use a bipolar variation of NRZ-L. Bipolar NRZ-L produces a small DC component if the probability of each polarity is approximately equal to each other; but the real applications have random information sources. Manchester bi-phase codes can eliminate the DC component, because each binary symbol is divided in two parts with an identical duration and different polarities. The main disadvantage of this line code is a large bandwidth as a result of a lot of transitions. Telephone networks have adopted a line code where the polarity of a binary symbol is positive and negative alternatively, Alternate Mark Inversion (AMI) code. AMI is widely used because it has some important advantages: very low DC component and very short bandwidth. But this technique has a problem, because a large number of consecutive 0V levels can produce a synchronization loss. In order to preserve synchronization, there are several kinds of substitution of zeros. In Figure 6 a line code variation designed to substitute eight consecutive zeros (B8ZS). The substitution involves additional transitions, whom can be identified by destination using a non-alternate rule named violation (V). B8ZS is employed in T1 carrier for North- American telephone hierarchy; but in a higher bit rate this technique does not work well. In European standard a four-zero substitution is required for the first telephone hierarchy (HDB3). Figure 5 shows the B8ZS and HDB3 coding techniques [10].

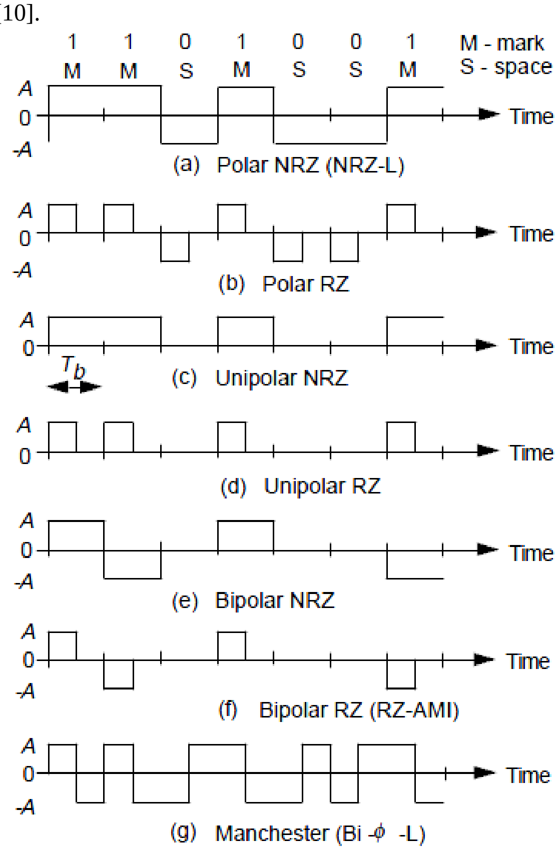

Figure 3. Different line coding waveforms

The effectiveness of the coding technique used depends widely on the Power Spectral Density (PSD) of the waveforms. The PSDs of the above digitally represented coded signal are represented in figure 4. [4, 12]

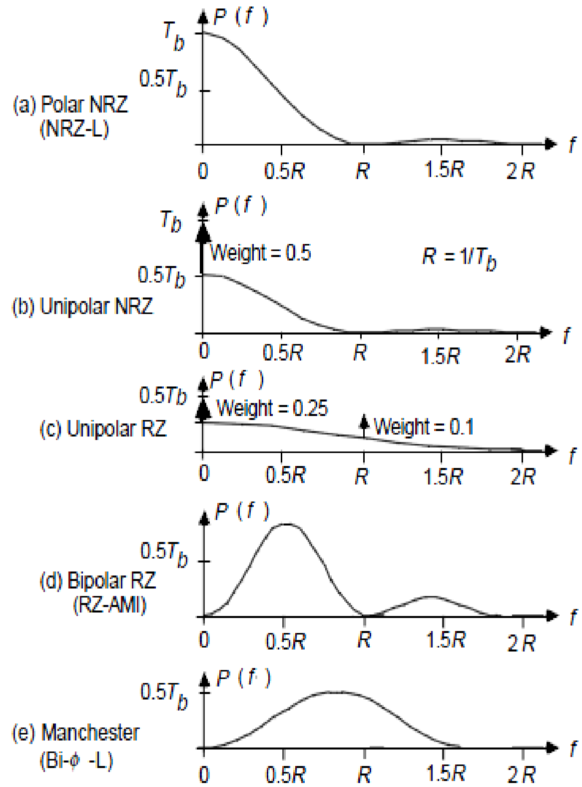

Figure 4. Power Spectral Densities of some line codes

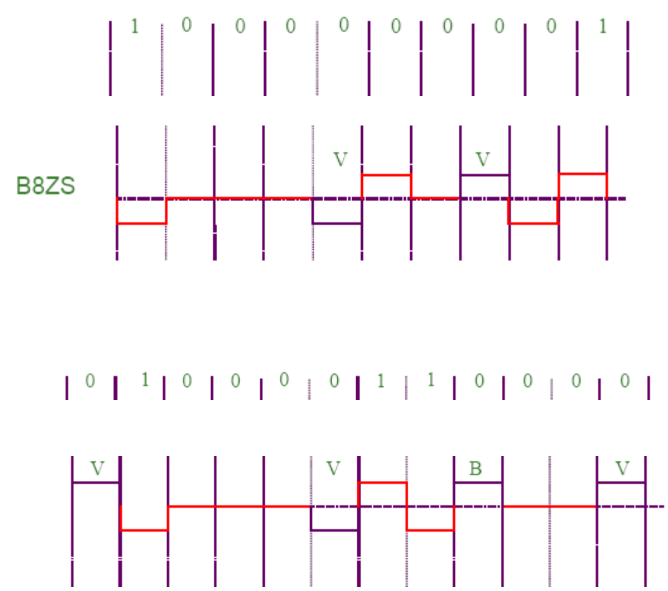

Figure 5. B8ZS line code

3. PROPOSED MULTILEVEL NRZ SIGNAL

The Multilevel Technique presented here helps in removing the problems associated with B8ZS and HDB3. The multilevel technique utilizes different D.C. levels for representing a '0' and '1' with NRZ employment method.

A One '1' is represented as 'A/2' in time interval 0 to Tb/2 and as '-A/2' in the time interval $T_b/2$ to Tb. A Zero '0' is represented as 'A/4' in time interval 0 to $T_b/2$ and as '-A/4' in the time interval $T_b/2$ to T_b. We define our coding equation as:

$$\left.\begin{aligned} x(t) &= \frac{A}{2} & 0 < t < \frac{T_b}{2} \\ x(t) &= -\frac{A}{2} & \frac{T_b}{2} < t < T_b \end{aligned}\right\} \quad a_k = 1$$

$$\left.\begin{aligned} x(t) &= \frac{A}{4} & 0 < t < \frac{T_b}{2} \\ x(t) &= -\frac{A}{4} & \frac{T_b}{2} < t < T_b \end{aligned}\right\} \quad a_k = 0$$

Thus it is a NRZ wave with a discrete D.C. level (A/2 to –A/2) when One '1' is transmitted and another discrete D.C. level (A/4 to –A/4) when Zero '0' is transmitted. Figure 6 shows the Multilevel NRZ waveform generated using equation 2.

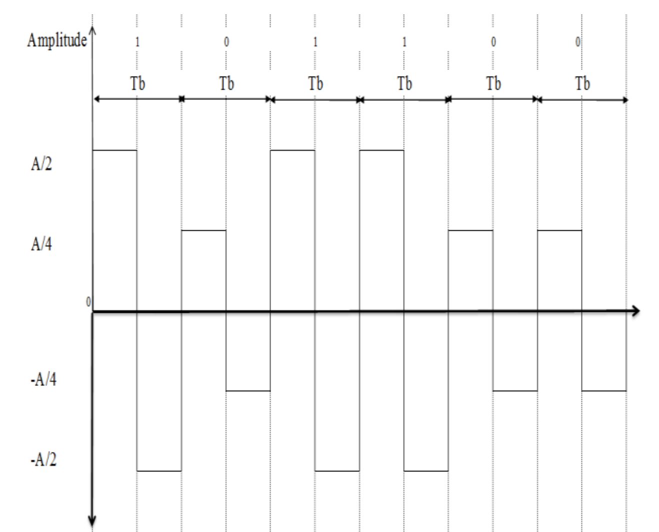

Figure 6. Multilevel NRZ signal waveform

The technique was analyzed and the autocorrelation was determined to be

$$R_\tau = \begin{cases} \frac{5A^2}{8} & n = 0 \\ 0 & n \neq 0 \end{cases} \qquad (3)$$

The Power Spectral Density is the plot of the Amount of *power* per unit (*density*) of frequency (*spectral*) as a function of the frequency. It is represented as:[13]

$$\frac{|P_\delta(f)|^2 \sum_{n=-\infty}^{\infty} R_\tau(n) * e^{-j2\pi f n t}}{T_b} \qquad (4)$$

Where $P_\delta(f)$ is the Fourier Transform of the pulse.

From the above determined Autocorrelation we can easily determine the Power Spectral Density of the Multilevel RZ which is given by:

$$\frac{45A^4 * T_b * \left(sinc\left(\frac{fT_b}{2}\right)\right)^2 * \left(\sin\left(\frac{\pi f T_b}{2}\right)\right)^2}{128} \qquad (5)$$

Normalizing the amplitude D.C. level to 1, the plot of Power v/s fT_b is shown in Figure 7.

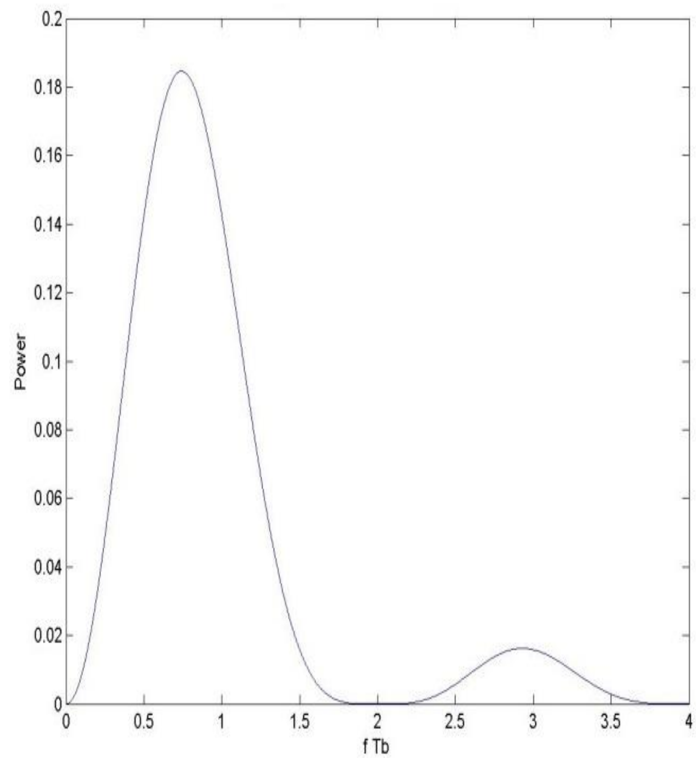

Figure 7. Power Spectral Density of Multilevel NRZ line code

4. PROBABILITY OF ERROR

To examine the error probability performance of the new technology, we begin by stating the problem as a classical binary hypotheses test. Given a sample of the received signal, consisting of an additive mixture of useful signal and noise, we are to determine whether it corresponds to the transmission of a bit "1" or a bit "0". The received signal under each hypothesis can then be modeled as

$H_0 : r(t) = s_0(t) + n(t)$ bit 0

$H_1 : r(t) = s_1(t) + n(t)$ bit 1

where n(t) is a noise waveform possessing a Rayleigh probability density function (pdf) and double-sided power spectral density $N_n/2$, $s_0(t)$ is an unmodified waveform corresponding to the transmission of a bit "0" while $s_1(t)$ is a modified waveform representing the transmission of bit "1". In terms of discrete-time samples, the problem can be restated as follows: on the basis of N amplitude samples of the received waveform consisting of a desired signal additively embedded in Rayleigh noise, we are to determine whether a bit "1" or "0" was transmitted. The duration of the observation interval is T/2, where T is the period of the power signal. With this reformulation the hypotheses test can now be modeled as

y(Ts)= n(Ts) signal absent
y(Ts) = A + n(Ts) signal present

where time instant Ts in the range (0, T), and using the value to make a decision. Since the value n(T) is random, we cannot decide with certainty whether a signal was present or not at the time of the sample. However, a reasonable rule for the decision of whether a 0 or a 1 was received is the following:

$Y(t) \leq V_t$ signal absent — 0 received
$Y(t) \geq V_t$ signal present— 1 received

The variable V_t is the threshold where the two probability density functions intersect. The signal space representation of the line coding technique can be shown to be:

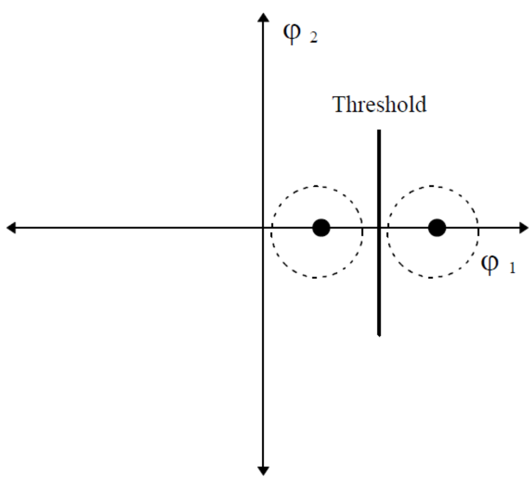

Figure 8. Signal Space Representation.

In the case of Multilevel NRZ line code, the probability density of the envelope, when no signal is present, is the Rayleigh distribution. When a signal is present, the density is Rician. The total probability of error is determined by two possible error conditions. The probability of a "1" being sent and the receiver mistaking it for a "0" and the probability of a "0" being sent and the receiver detecting a "1". The total probability of error is defined in the formula below:

$$P_{err,t} = \frac{1}{2}\int_0^{V_t} p_1(r)dr + \frac{1}{2}\int_{V_t}^{\infty} p_0(r)dr \qquad (6)$$

The functions p_1 and p_0 are the Rician probability density function and the Rayleigh density function respectively. The variable r is the random variable of the envelope detector's output. It is assumed that the likelihood that a "1" or a "0" is transmitted is 1/2. The evaluation of the above formula yields the approximate probability of error for Multilevel NRZ using envelope detection:

$$P_{err,SNR} = \frac{1}{2}\left(1 + \sqrt{\frac{1}{\pi SNR}}\right) * \exp\left(-\frac{SNR}{4}\right) \qquad (7)$$

5. ADVANTAGES

It can be seen that there is no power for the D.C. transmission (D.C. level of the coding is zero) which helps in the power conservation. This is an advantage which Multilevel RZ shares with the Bipolar Coding and Manchester Coding.

There are many other advantages of the Multilevel RZ coding, which are as follows:

- There is a transition of the D.C. amplitude level in the Coded Waveform after every $T_b/2$ time period irrespective of the data transmitted (1 is transmitted or 0 is transmitted or even if two 1s are transmitted or a 1 and a 0, or vice-versa) and never is zero D.C. amplitude level. Thus irrespective of the number of Zeros and Ones transmitted in any possible combination the VCO is able to reproduce the waveform without being in the idle condition (which arises when a continuous stream of 0s is transmitted using Unipolar RZ and Unipolar NRZ, VCO being given Zero i/p goes in idle condition.)
- Since there is a transition of the D.C. amplitude level in the Coded Waveform after every $T_b/2$ time period irrespective of the data transmitted the timing information of a bit can be easily extracted (noting time when D.C. amplitude level remains same and doubling it).

  The signals are prone to noise from various sources resulting in a distorted waveform. For this purpose when Digital Signals are transmitted a Repeater is used to regenerate the signal from its distorted form. This Repeater Circuit requires the Timing Information which is easily acquired if this Coding Technique is implemented.
- The PSD acquires a zero value at all 2nTb, thus by using proper filters like Raised cosine filters the side lobes can be suppressed and the multiplexing of the signals can be easily achieved
- It has already been mentioned that in Telephony Communication when a continuous stream of Zero is transmitted certain techniques viz. HDBN and BZ8s are implemented, but if Multilevel RZ coding technique is implemented we don't need to implement the HDBN and BZ8s since no D.C. amplitude level is transmitted.

6. DISADVANTAGES

The disadvantage of the Multilevel NRZ is that many transitions take place due to four discrete D.C. levels, used to transmit the data.

7. PROPOSED CIRCUIT

The proposed circuit shown in figure 9 uses the output of IC 555, which is a Timer IC. It can be utilized to generate a pulse waveform of a specific frequency (which is set at T_b – the bit rate of the Multilevel Coding) and given as an input to the decision making switch. The encrypted waveform (digital data to be transferred) is used as a decision making signal. The switch works on the input given by the digital input signal, if the digital input signal is 1 the output of the Timer IC is passed through a predesigned amplifier circuit which amplifies the IC 555 output from a D.C. level of [A/4,-A/4] to [A/2,-A/2], else the output of the Timer IC is simply given as an output on the channel. Thus the AES encrypted waveform is then channel coded (Multilevel NRZ) using the above circuit.

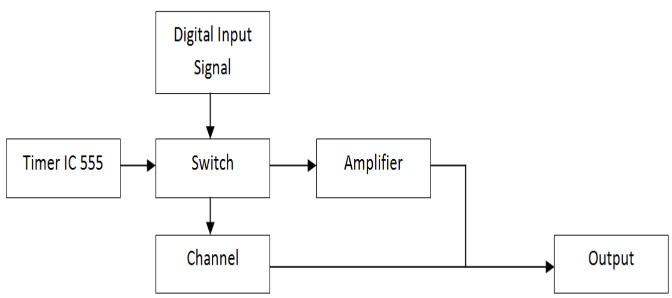

Figure 9. Block diagram for coding signals using Multilevel coding NRZ technique

8. APPLICATION

The channel coding techniques find their applications in many communication systems like Ethernet, Telephony, Photobiology, etc. Figure 10 shows the steps involved in the employment of the Multilevel NRZ Transmission.

The analog signal to be transmitted is digitalized by band limiting it, sampling the band limited signal and the quantizing the sampled signal. The digital signal is then either first encrypted and then passed on to the Multilevel NRZ encoder or directly given to the encoder, which converts the serial bits of the digital Unipolar signal into the Multilevel NRZ signal. This multilevel signal is then passed on to the power amplifiers to increase the signal to noise ratio (to reduce the probability of error) and then passed by the Raised Cosine Filters. This signal is then transmitted along the channel medium and intercepted after a fixed length of the channel to regenerate the signal so that the noise does not become dominant in the signal and the retrieval of the information remains simple.

A reverse process is employed at the receiver terminal of the system to get the analog signal back from the encoded signal.

9. CONCLUSION

In this research paper we have proposed an effective mechanism to transmit the digital data. The multilevel NRZ coding technique helps in removing certain problems which are associated with Bipolar and Manchester coding techniques. A circuit for generating this code also has been suggested.

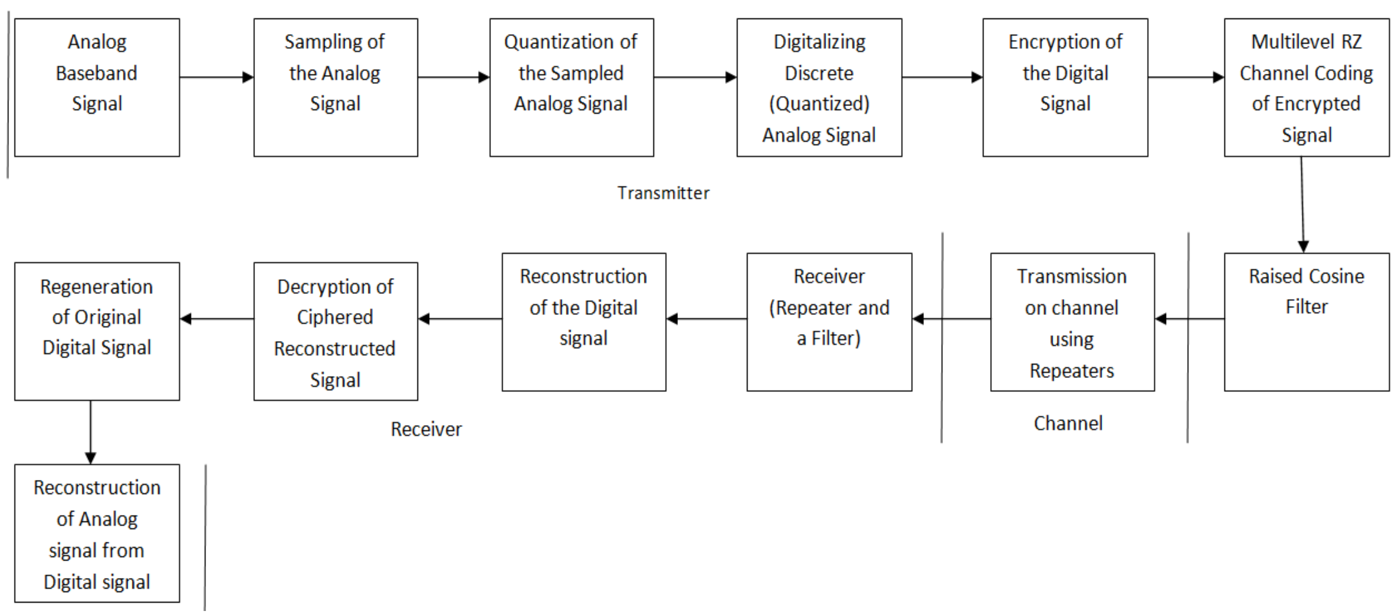

Figure 10: The steps involved in the employment of the Multilevel NRZ Transmission.

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