

## Baseband Transmission

### Introduction

Analogue waveforms can be changed into digital data using PCM or related techniques. For other systems the data is already in a digital form. In the simplest mode of data transmission, one simply transmits this data over a cable. The techniques required for this are also applicable for systems where the resulting baseband data is modulated so that it can be transmitted over the air.

From before, the bandwidth required to transmit a pulse of width  $\tau$  over a cable is:

$$\tau = \frac{1}{2BW_T} \text{ since } \tau = 1/(\text{Data rate}) \text{ the minimum bandwidth required for transmitting}$$

data at a rate R is:

$$R = 2BW_T$$

The efficiency of any communication system is determined by comparing its bandwidth requirements with the above equation.

### Baseband Coding

In many cases the data is coded prior to transmission. The aim of the coding is to:

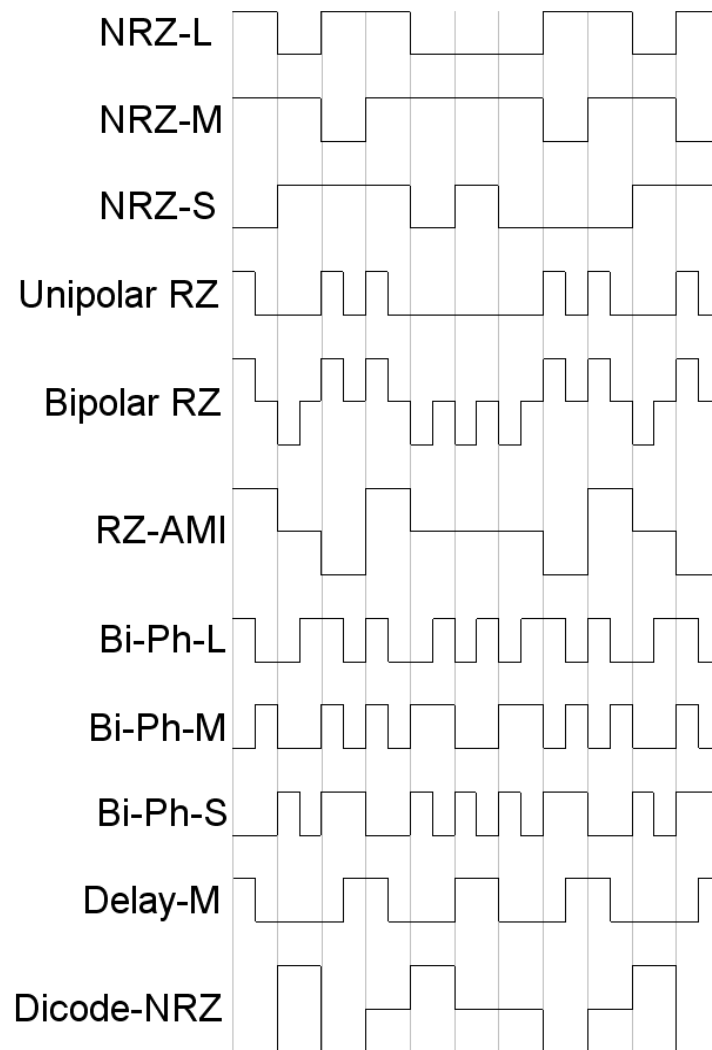
- 1 Change the spectrum, bandwidth or DC components to best match that of the transmission medium. For instance most telephone and Ethernet lines include transformers to provide isolation and prevent dangerous ground potentials. The line will thus not be able to handle a DC component present in the data signal. The data must thus be coded to ensure that there is no DC component in the data.
- 2 To change the data to permit certain common connection ambiguities, like a level inversion. If a transformer is used and the connections are made at random, there is a 50% chance of a data inversion. Some coding schemes are immune to signal inversions.
- 3 To change the transmitted spectrum to facilitate synchronisation.

Common coding schemes are:

NRZ-L Non Return Zero Level: Data is transmitted exactly as received but with a level change, such that 1 corresponds to an output voltage  $+V$  and 0 corresponds to a voltage  $-V$ .

NRZ-M Non Return Zero Mark: This is differential coding and tolerant to an inversion. 1 results in a change in level. 0 results in no change in level.

NRZ-S Non Return Zero Space: This is differential coding and tolerant to an inversion. 0 results in a change in level. 1 results in no change in level. This is the dual of the NRZ-M system and by simply inverting the input data for a NRZ-M system a NRZ-S system results.



Baseband Coding Waveforms

**Unipolar RZ** Unipolar Return to Zero. Data of 1, results in a half width pulse of amplitude  $+V$  and data 0, results in no pulse. Since the  $0 \rightarrow 1$  transition always occurs at  $nT_s$ , (where  $n=0,1,2,3$  etc and  $T_s$  is the sampling period,) the system is easy to synchronise to.

**Bipolar RZ** Bipolar Return to Zero. Data of 1, results in a half width pulse of amplitude  $+V$  and data 0, results in a half width pulse of amplitude  $-V$ . This is thus a three level system and is very easy to synchronise to.

**RZ AMI** Return to Zero Alternate Mark Inversion. Data of 1, results in a half width pulse of amplitude  $+V$  or  $-V$ , with the amplitude alternating for each pulse. Data 0, results in no pulse. This system has a very low DC component, is easy to synchronise to and can be inverted without affecting the data.

**Bi-Phase Level (Manchester Coding).** Data of 1 causes a 1→0 transition in the middle of the pulse and a data of 0 causes a 0→1 transition in the middle of the pulse. This system has no DC component and can thus pass through a transformer. Transitions always occur at the middle of the data pulse, resulting in easy synchronisation. A bigger bandwidth is however required.

**Bi-Phase Mark.** Data of 1 causes a transition at the start of the pulse and at the middle of the pulse. Data of 0 causes a transition at the start of the pulse only. This system has No DC component, is easy to synchronise and insensitive to signal inversion during transmission.

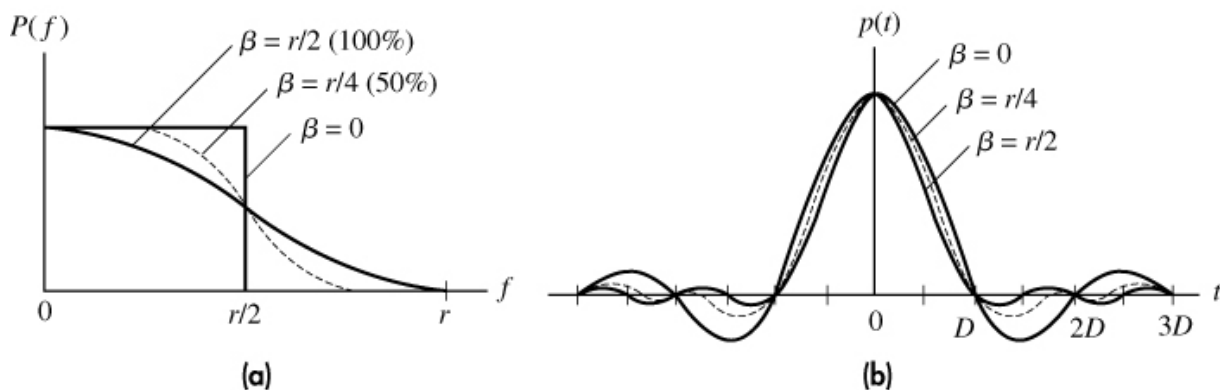
**Bi-Phase Space.** Data of 0 causes a transition at the start of the pulse and at the middle of the pulse. Data of 1 causes a transition at the start of the pulse only. This is the dual of the above system with logic 0 and 1 swapped.

**Delay Modulation.** Data of 1 causes a transition in the middle of the pulse. Data of 0 results in no change all, except that a second or subsequent 0 causes a change in level at the start of the pulse. This system has a low bandwidth, but tends to have a large energy at half the data rate.

**Dicode NRZ.** Dicode Non Return to Zero. A three level system. A change in data level from 0→1 or 1→0 results in a change of signal polarity from +V to -V or -V to +V. No change in Data results in 0V. The value of the data at some time needs to be known to work out the data values at all other times.

### **Nyquist Pulse Shaping**

An ideal filter with a rectangular frequency cut off has a  $\text{Sinx}/x$  time response, resulting in a significant intersymbol interference. To obtain the best data detection with the least amount of errors, the amount of energy into adjacent time slots must be minimised. The intersymbol interference and bandwidth requirements are a compromise. A narrow bandwidth has a high intersymbol interference and a low intersymbol interference requires a larger bandwidth. Nyquist pulse shaping are a good way to effect a compromise.



Nyquist Pulse Shaping waveforms (Carlson Fig 11.3-1)

The frequency response of the Nyquist filter is as follows:

$$P(f) = \begin{cases} \frac{1}{r} & |f| < \frac{r}{2} - \beta \\ \frac{1}{r} \cos^2\left(\frac{\pi}{4\beta}\left(|f| - \frac{r}{2} + \beta\right)\right) & \frac{r}{2} - \beta < |f| < \frac{r}{2} + \beta \\ 0 & |f| > \frac{r}{2} + \beta \end{cases}$$

The corresponding time waveform is:

$$p(t) = \frac{\cos(2\pi\beta t) \sin(\pi r t)}{1 - (4\beta t)^2} = \frac{\cos(2\pi\beta t)}{1 - (4\beta t)^2} \text{sinc}(r t) = \frac{\cos(\pi \alpha r t)}{1 - (2\alpha r t)^2} \text{sinc}(r t)$$

Often the function is normalised with  $\alpha = \frac{2\beta}{r}$  such that  $\beta=r/2$  becomes  $\alpha=1$

When  $\alpha=1$  then there is an extra zero crossing in the time sidelobes at  $1.5T_s$ ,  $2.5T_s$  etc, and the amount of intersymbol interference is very small. The bandwidth required for transmitting the data is however twice as much.

Because of the shape of the transfer function, the Nyquist filter is often called a raised cosine filter. Often in a transmission system one would like the transmitted signal to be filtered in order to minimise the out of band frequency components and one also wants to filter the received signal to minimise the noise and out of band transmissions entering the receiver. To achieve this half the filter is often used in the transmitter and half in the receiver. The frequency transfer function at the transmitter is thus:

$$H(f) = \sqrt{P(f)} \quad \text{where } P(f) \text{ is the Nyquist filter above.}$$

The filter at the transmitter is thus a Root-Raised-Cosine filter. Such filters are used in many mobile phone systems.

### ***Partial Response Signalling***