CHAPTER 03

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DATA TRANSMISSION

SIGNAL IMPAIRMENTS

With any communication system, the signal that is received may differ from the signal that is transmitted due to various impairments. The imperfection causes signal impairment that can degrade the signal quality.

The most significant impairments are:

- Attenuation
- Delay distortion
- Noise

ATTENUATION

The simple meaning of attenuation is loss of energy. The strength of a signal falls off with distance over any transmission medium. If the attenuation is too much, the signal strength may fall into noise level, which can lead to a complete loss of data. To compensate attenuation loss, amplifiers are used to amplify the signal. Attenuation

is proportional to the length of the transmission channel and the frequency of the signal.
Attenuation of a signal is expressed by the following formula:

$$\boxed{A = 10\log_{10} \frac{\text{Output signal level}}{\text{Input signal level}}}$$

where A is attenuation measured in dB (Decibel).

EXAMPLE 1

Suppose a signal travels through a transmission medium and it's power is reduced to one-half. ($P_2 = \frac{1}{2}P_1$). Calculate the attenuation i.e. the loss of power.

Solution:

According to the formula,

$$A = 10\log_{10} \frac{P_2}{P_1}$$

$$= 10\log_{10} \frac{0.5P_1}{P_1}$$

$$= 10\log_{10} 0.5$$

$$= 10 \times (-0.3)$$

$$A = -3dB$$ $\therefore$ A loss of 3dB

Here,
$P_2 = 0.5P_1$
$P_2 = $ Output
$P_1 = $ Input
$A = ?$

EXAMPLE 2

Suppose a signal travels through an amplifier and its power is increased 10 times ($P_2 = 10P_1$), calculate the amplification.

Solution:

According to the formula,

Here

$P_2 = 10P_1$

$P_2 = \text{Output}$

$P_1 = \text{Input}$

$A = ?$

$$A = 10 \log_{10} \frac{P_2}{P_1}$$

$$= 10 \log_{10} \frac{10P_1}{P_1}$$

$$= 10 \log_{10} 10$$

$$= 10 \times 1$$

$$A = 10 \text{dB}$$

Ans.

DELAY DISTORTION

Delay distortion occurs because the velocity of propagation of a signal through a guided medium varies with frequency. For a bandlimited signal, the velocity tends to be highest near the center frequency and fall towards the two edge of the band.

Because of delay distortion, some of the signal components of one bit position will spill over into another bit positions, causing inter symbol interferance.

NOISE

For any data transmission event, the received signal will consist of the transmitted signal, modified by the various distortions imposed by the transmission system, plus additional unwanted signals that are inserted somewhere between transmission and reception. The latter, undesired signals are reffered to as noise. Noise is a major limiting factor in communications system performance.

Noise may be divided into four categories:

- Thermal Noise
- Intermodulation Noise
- Crosstalk
- Impulse Noise

Thermal Noise is due to thermal agitation of electrons. It is present in all electronic devices and transmission media and is a function of temperature. Thermal noise is uniformly distributed across the bandwidth typically used in communications systems and hence it is often referred as white noise.

The amount of thermal noise to be found in a bandwidth of 1 Hz in any device or conductor is:

$$\boxed{N_0 = kT \ (W/Hz)}$$

where,

N_0 = noise power density in watts per 1Hz of bandwidth

K = Boltzman's constant $= 1.38 \times 10^{-23}$ J/K

T = Temperature, in kelvins

EXAMPLE 3.1

Room temperature is usually specified as $T = 17^{\circ}C$ or 290 K. At this temperature find the thermal noise density.

Solution:

$$N_0 = KT \ (W/Hz)$$
$$= 1.38 \times 10^{-23} \times 290 \quad W/Hz$$

$$= 4 \times 10^{-21} \ W/Hz$$

$$= 10\log_{10}(4 \times 10^{-21}) \ dBW/Hz$$

$$\boxed{= -204 \ dBW/Hz}$$

Where, dBW is decibal-watt.

The noise is assumed to be independent of frequency. Thus the thermal noise in watts present in a bandwidth of B Hertz can be expressed as,

$$\boxed{N = KTB}$$

or in decibal-watts,

$$\boxed{\begin{aligned} N &= 10\log_{10} k + 10\log_{10} T + 10\log_{10} B \\ &= -228.6 \ dBW + 10\log_{10} T + 10\log_{10} B \end{aligned}}$$

$[K = 1.38 \times 10^{-23}]$

EXAMPLE 3.2

Given a receiver with an effective noise temp of 294K and a 10-MHz bandwidth, calculate the thermal noise at the receiver output.

Solution

$$N = -228.6 \ dBW + 10\log T + 10\log B$$

$$= -228.6\ dBW + 10\log(294) + 10\log(10^7)$$

$$= -228.6 + 24.7 + 70$$

$$\boxed{= -133.9\ dBW}$$ Ans.

Intermodulation noise: when signals at different frequencies share the same transmission medium, the result may be intermodulation noise. The effect of intermodulation noise is to produce signal at a frequency that is the sum or difference of the two original frequency or multiple of those frequencies. For example, the mixing of signals at frequencies f_1 and f_2 might produce energy at the frequency $f_1 + f_2$.

Crosstalk has been experienced by anyone who, while using the telephone, has been able to hear another conversation; it is an unwanted coupling between signal paths. It can occur by electrical coupling between nearby twisted pairs or, rarely coax cable lines carrying multiple signals.

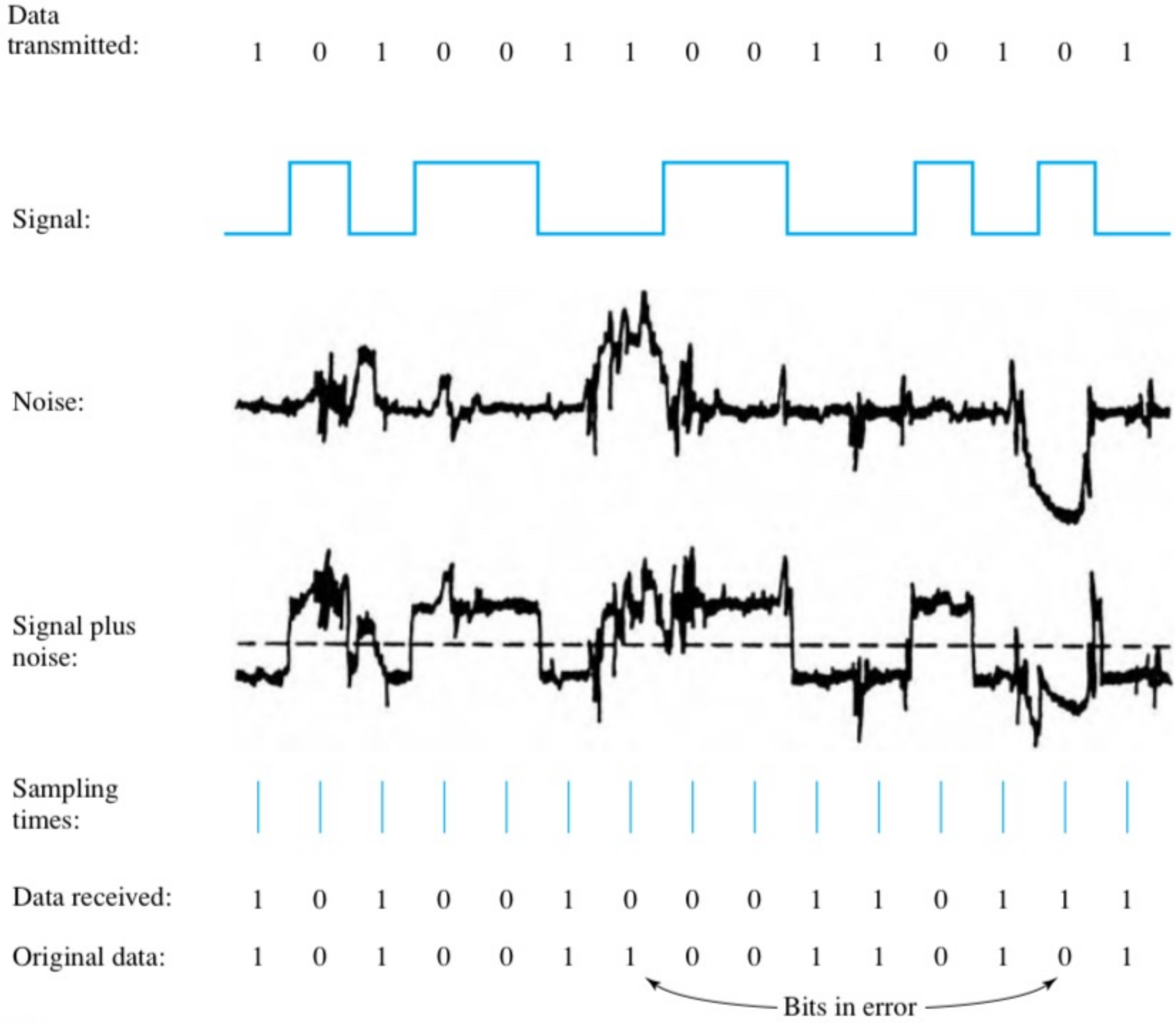


Figure 3.16 Effect of Noise on a Digital Signal

CHANNEL CAPACITY

The maximum rate at which data can be transmitted over a given communication path or channel, under given conditions is reffered to as the channel capacity.

There are four concept here that we are trying to relate to one another:

- Data rate : The rate, in bits per sec (bps), at which data can be communicated.

- Bandwidth: The bandwidth of the transmitted signal as constrained by the transmitter and the nature of the transmission medium, expressed is cycle per second or hertz.

- Noise: The average level of noise over the communication path.

- Error rate: The rate at which error occurs, where an error is the reception of a 1 when 0 was transmitted and vice versa.

NYQUIST BANDWIDTH

Considering the case of a channel that is noise free, where limitation is simply just bandwidth of the signal, Nyquist states that, if the rate of signal transmission is 2B, then a signal with frequencies no greater then B is sufficient to carry the signal. The converse is

Also true: Given a bandwidth of B, the highest signal rate that can be carried is 2B.

With multilevel signaling, the Nyquist formula becomes

$$\boxed{C = 2B \log_2 M}$$

where M is the number of discrete signals or voltage levels.

EXAMPLE 3.3

Consider a voice channel being used, via modem to transmit data. Assume a bandwidth of 3100 Hz. For M=8, a value used is some modems, find the channel capacity (C)

Solution

Channel capacity,

$$C = 2B \log_2 M$$

$$= 2 \times 3100 \times \log_2(8)$$

$$= 18600 \text{ bps}$$ Ans.

$B = 3100$ Hz

$M = 8$

$C = ?$

SHANNON CAPACITY

Nyquist's formula indicates that, all other being equal, doubling the bandwidth doubles the data rate. Now considering the relationship among data rate, noise and error rate, the presence of noise can corrupt one or more data bits.

The key parameter in this reasoning is the signal-to-noise ratio (SNR or S/N). which is the ratio of power in a signal to the power contained in a noise. For convenience the ratio is reported in decibels:

$$\boxed{SNR_{dB} = 10 \log_{10} \frac{\text{signal power}}{\text{noise power}}}$$

Shannon's result is that the maximum channel in Bits per second, obeys the equation,

$$\boxed{C = B \log_2 (1 + SNR)}$$

where, C = capacity of channel in bps

B = Bandwidth of channel in Hz

EXAMPLE 3.4

Let us consider an example that relates the Nyquist and Shannon's formulation. Suppose the Spectrum of the channel is between 3 MHz and 4 MHz and $SNR_{dB} = 24\,dB$. Then

Bandwidth,

$$B = 4\,MHz - 3\,MHz$$
$$= 1\,MHz$$

$$SNR_{dB} = 24\,dB = 10 \log_{10}(SNR)$$

$$2.4 = \log_{10}(SNR)$$

$$SNR = 10^{2.4}$$

$$\simeq 251$$

Now using Shannon's formula,

$$C = B \log_2(1 + SNR)$$
$$= 1 \times 10^6 \times \log_2(1 + 251)$$
$$= 8 \times 10^6 \; \boxed{= 8\,Mbps}$$

* Based on Nyquist formula, how many signal levels are required?

We have,

$C = 8 \times 10^6$

$B = 1 \times 10^6$

$M = ?$

$$C = 2B \log_2 M$$

$$8 \times 10^6 = 2 \times 10^6 \times \log_2 (M)$$

$$4 = \log_2 (M)$$

$$= 2^4$$

$$\boxed{M = 16}$$ Ans.

PRACTICE PROBLEM Class → 09/09/25

* Shannon Nyquist practice problem

B = 20 KHz

SNR = 15 dB

Data rate = 100 KBps

$$C = B \log_2(1 + SNR)$$

$$= 20000 \log_2(1 + 31.62)$$

$$= 100553.6975$$

$$SNR_{dB} = 10 \log_{10}(SNR)$$

$$15 = 10 \log(SNR)$$

$$SNR = 31.62$$

$$B = 20000$$

---

* If we want to achieve 100 KBps data rate, find M.

$$C = 2B \log_2 M$$

$$100000 = 2 \times 20000 \times \log_2(M)$$

$$\log_2(M) = \frac{100000}{2 \times 20000}$$

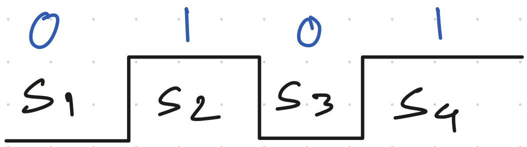
$$\log_2(M) = \frac{5}{2}$$

$$M \approx 2^{2.5} \approx 5.68$$

Bit rate (R) : no. of bits/sec

Baud rate (r) : no. of signal/sec

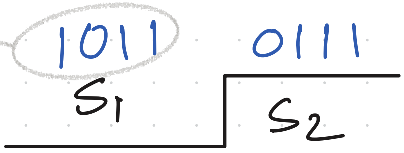
Example :



→ bitrate (R) = 4

→ baud rate $= \frac{4}{1} = 4$

No of bits/sig



→ bitrate (R) = 8

→ baud rate $(r) = \frac{8}{4} = 2$

$$\boxed{\text{Baud rate } (r) = \frac{\text{Bitrate } (R)}{\text{no. of bits/signal } (n)}}$$

$$\text{no of bits/signal } (n) = \frac{R}{r}$$

$$\text{Total no. of signal/element } (L) = 2^n$$

* Also known as (M)

* signal is also known as symbol

* There is a signal, it carries 8 bits per sec.

R=8 [R → Bit rate]

* A signal, it carries 8 bits per signal.

n = 8 [n → no. of signal] {There are 2000 signal / sec}

[r = 2000]

$$n = \frac{R}{r}$$

$$R = n \times r = 8 \times 2000$$

$$= 16000 \text{ bps}$$

$$= 16 \text{kbps}$$

* Assume there is a signal, it has 8000 Bit/s Baud rate 1000. How many signal elements (level) are required?

n =
R = 8000
r = 1000
L =

$$n = \frac{R}{r} = \frac{8000}{1000} = 8$$

$$\boxed{L = 2^n = 2^8 = 256 \text{ levels}}$$

* R = 9600

No of levels = 4 → M L   [M = L]

bits per symbol?

$$\log_2(M) = \log_2(4)$$

$$n = 2$$

baud rate $r = \frac{9600}{2}$ $\left[r = \frac{R}{n}\right]$

$= 4800$ baud rate

CHAPTER 05

SIGNAL ENCODING TECHNIQUES

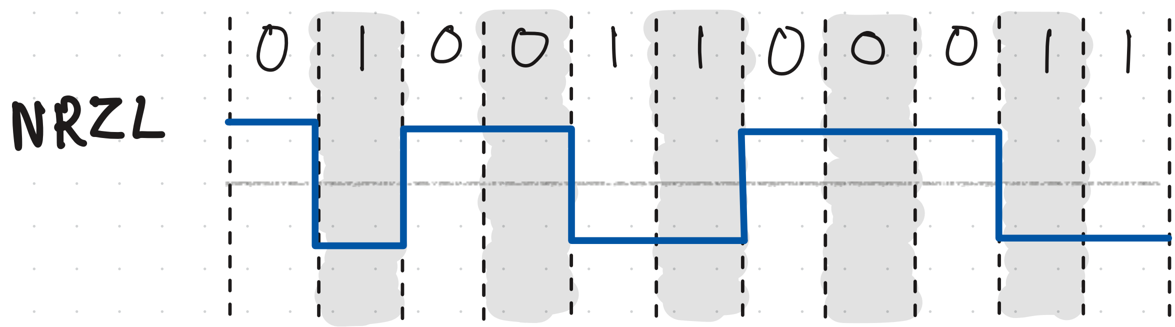
DIGITAL DATA, DIGITAL SIGNAL

NRZL

Non Return to Zero Level (NRZL)

0 = High

1 = Low

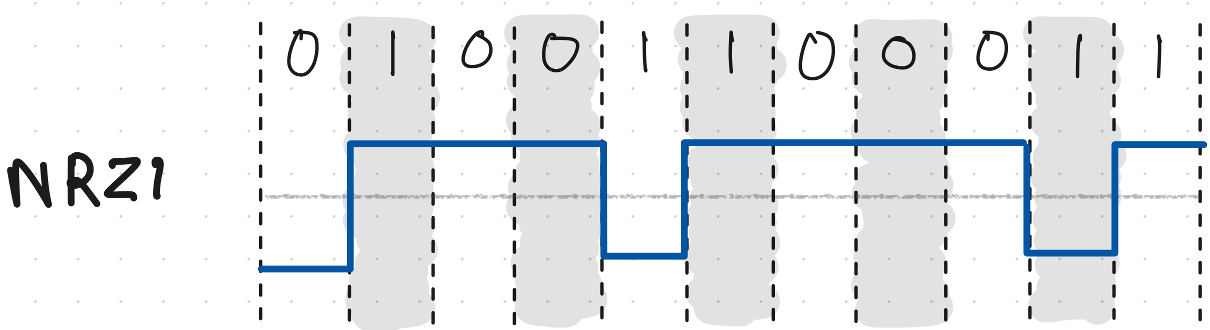


NRZI

Non Return to zero Inverted (NRZI)

0 = No transition at the beginning of the interval

1 = transition at the beginning of the interval

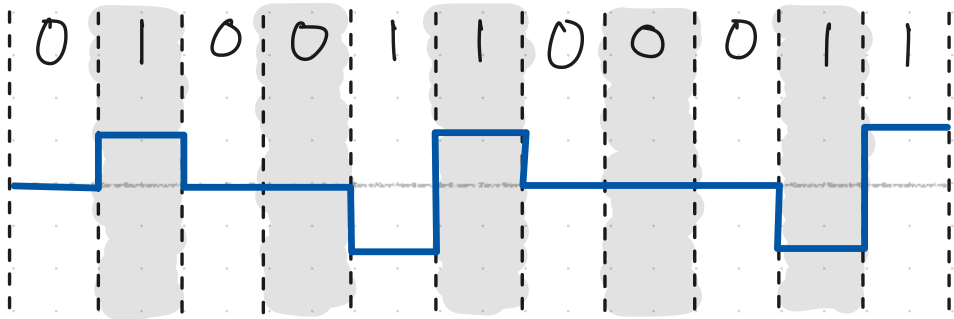


BIPOLAR AMI

0 = no line signal

1 = positive or negative level, alternating for succesive ones

most recent preceding 1 bit has negative voltage

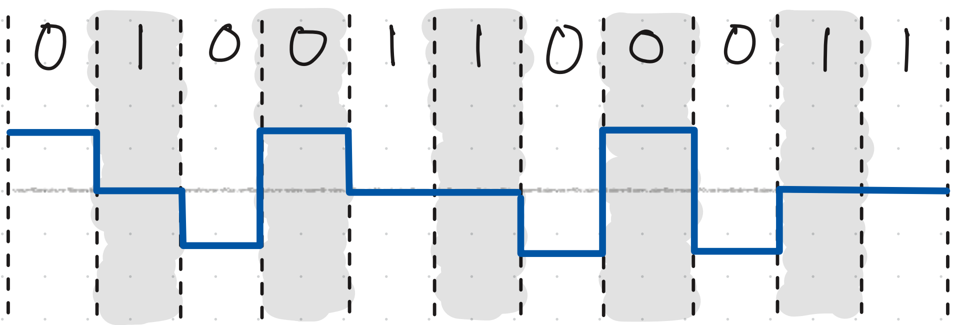


PSEUDO TERNARY

0 = positive or negative level, alternating for succesive ones

1 = no line signal

most recent preceding 0 bit has negative voltage

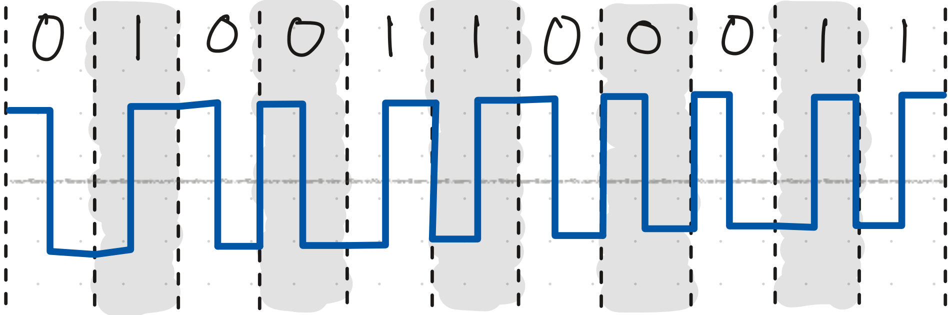


MANCHESTER

Always transition in the middle of interval

0 = high to low

1 = low to high

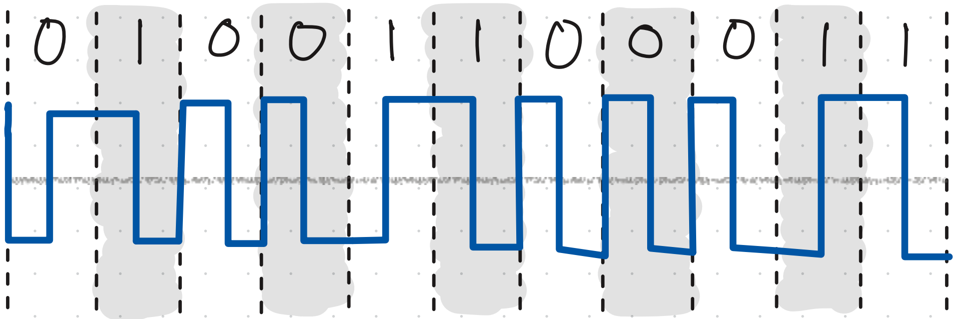


DIFFERENTIAL MANCHESTER

Always transition in the middle of interval

0 = transition at the beginning of interval

1 = no transition at the beginning of interval

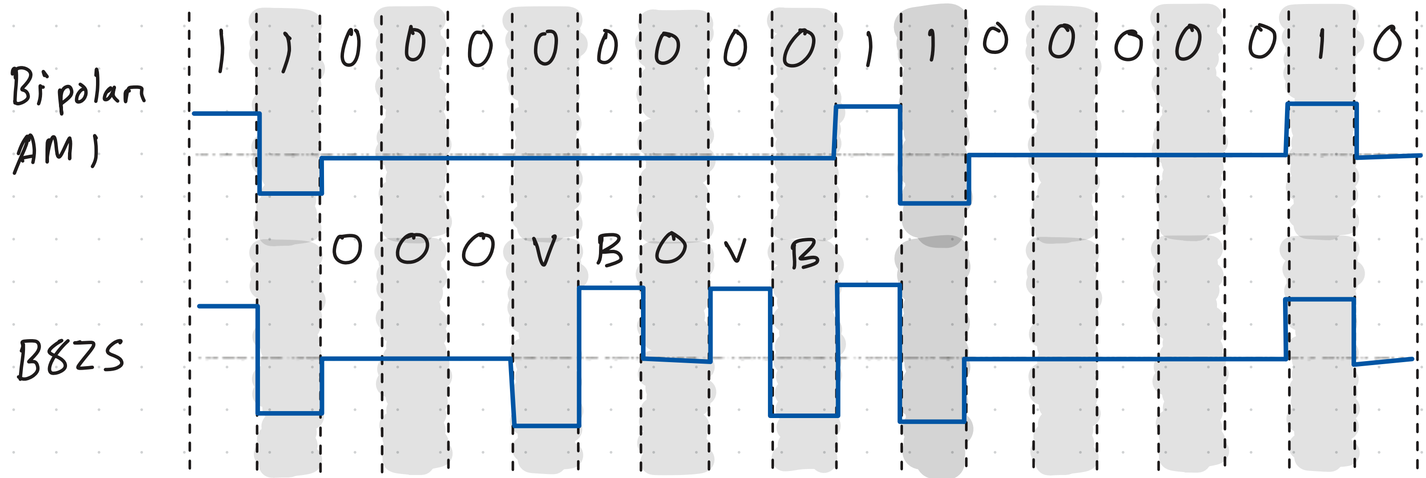


B8ZS (Bipolar with 8 Zeros Substitution)

Same as Bipolar AMI, except that any string of 8 zeros is replaced by a string with two code violations. Commonly used in North America.

If octet of zero occurs -

- For preceding positive voltage → 000+-0-+
- For preceding negative voltage → 000-+0+-



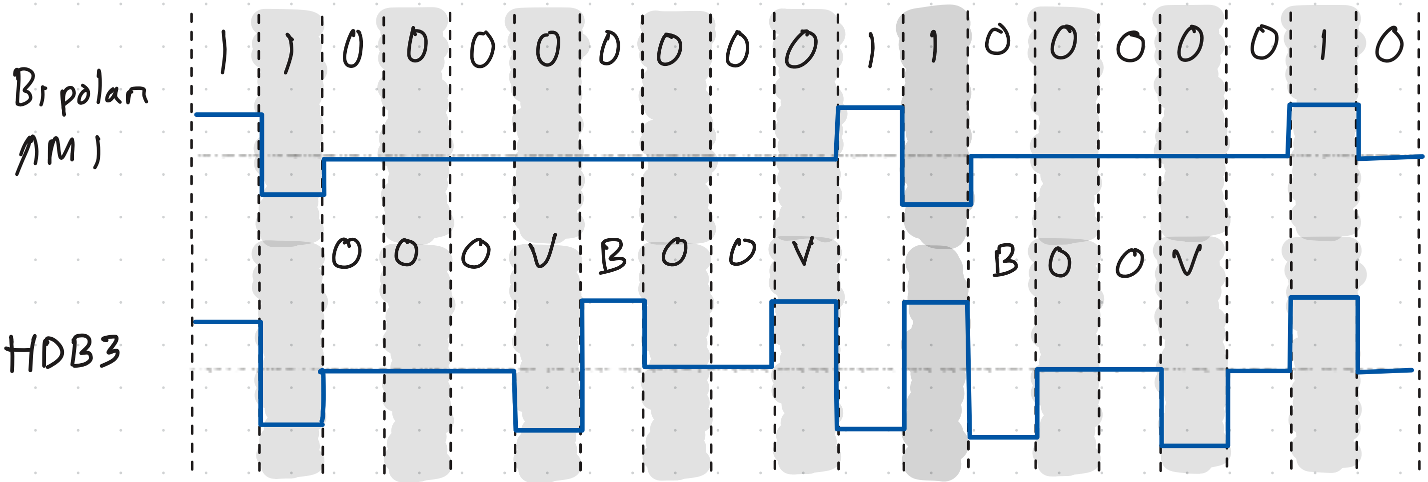
V = Violation

B = Valid Bipolar

HDB3 (High Density Bipolar 3 zeros)

Table 5.4 HDB3 Substitution Rules

	Number of Bipolar Pulses (ones) since Last Substitution	
Polarity of Preceding Pulse	**Odd**	**Even**
−	000−	+00+
+	000+	−00−



*(odd number of 1 since last substitution)

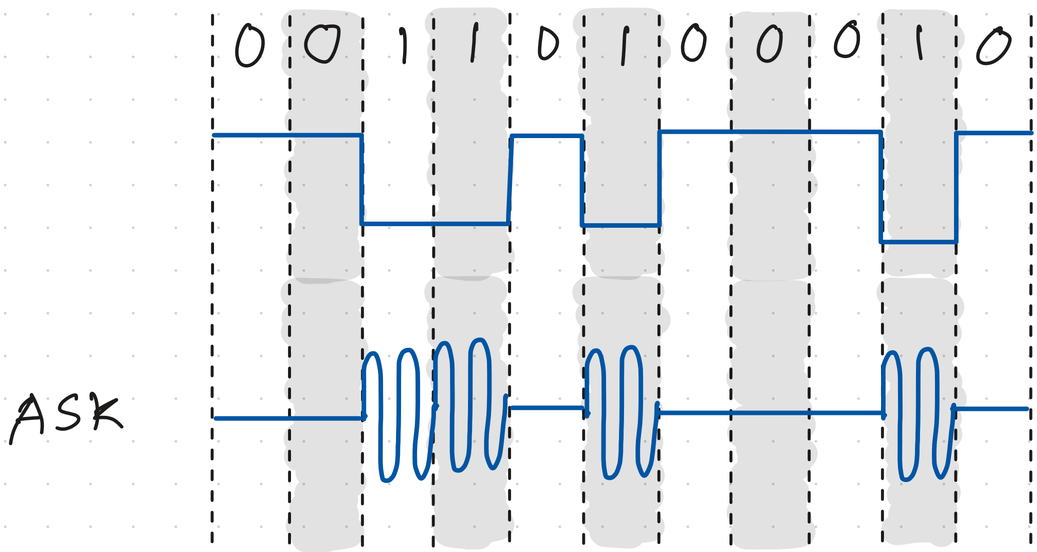
In this case, the HDB3 replaces string of four zeros with sequence of one or two pulses. Here for the first four zeros, the number of preceding pulses after last substitution was odd. Also the last pulse was negative which applies the substitution of (000−) according to the table 5.4.

DIGITAL DATA ANALOG SIGNAL

AMPLITUDE SHIFT KEY (ASK)

In ASK, the two binary values are represented by two different carrier frequency.

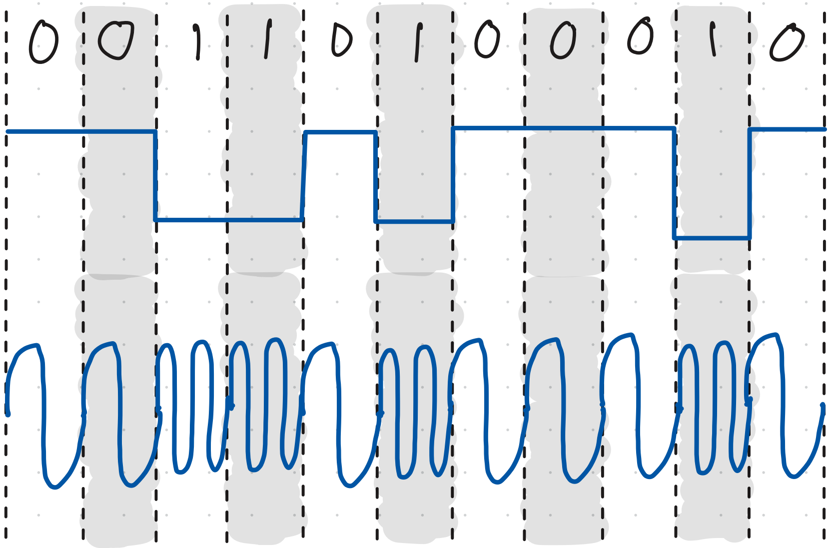
$$\text{ASK} \quad s(t) = \begin{cases} A\cos(2\pi f_c t) & \text{binary } 1 \\ 0 & \text{binary } 0 \end{cases}$$



FREQUENCY SHIFT KEYING (FSK)

The most common form of FSK is Binary FSK (BFSK), in which two binary values are represented by two different frequency near the carrier frequency.

$$\text{BFSK} \quad s(t) = \begin{cases} A\cos(2\pi f_1 t) & \text{binary } 1 \\ A\cos(2\pi f_2 t) & \text{binary } 0 \end{cases}$$

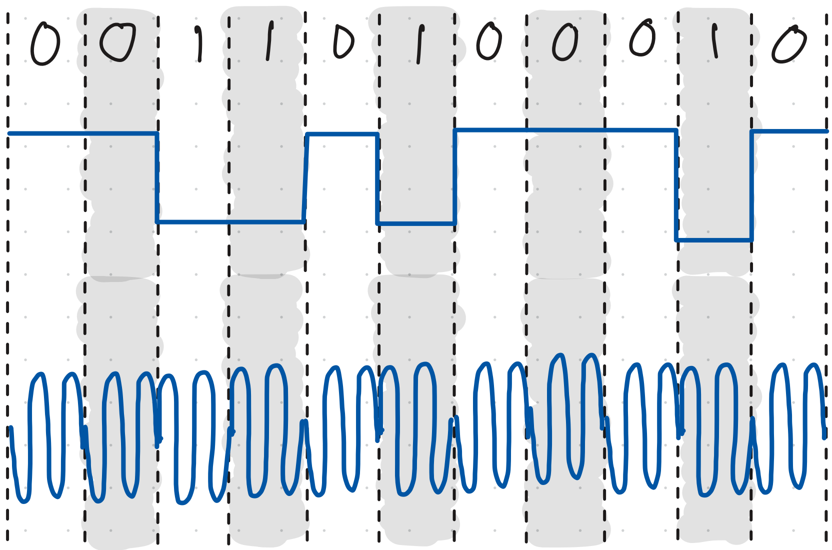


BFSK

PHASE SHIFT KEYING (PSK)

In PSK, the phase of the carrier signal is shifted to represent data.

BPSK $s(t) = \begin{cases} A\cos(2\pi f t) & \text{binary } 1 \\ -A\cos(2\pi f t) & \text{binary } 0 \end{cases}$



BPSK

MATH PROBLEMS

Baud rate $\leq$ Bit rate

$$\boxed{S = N \times \frac{1}{r}}$$

where,

S = Baud rate

N = Bitrate (bps)

r = Bits / signal (coding rate)

\# For a modem, if, Baud rate = 40 signal /element (S)

BPS = 1600 (N)

Find out no of Bits /signal (r).

$$S = N \times \frac{1}{r}$$

$$r = \frac{N}{S} = \frac{1600}{40}$$

$$\boxed{r = 40 \text{ bits / signal}}$$

\# BPS = 2000 (N)

Transmission mode = half duplex ($r = 1$)

Find out minimum Bandwidth.

ASK

$$S = N$$

Bandwidth = Bit / second

$$\boxed{\text{Bandwidth} = 2000}$$

If BW = 5000 Hz, find out baud rate (S) and bit rate (N). $\longrightarrow$ ASK $(r=1)$

$\therefore$ BW = bitrate = baud rate = 5000

If BPS = 2000 (N)

Transmission mode = Half Duplex
carrier separation = 3000 Hz

$\Bigg\}$ 2FSK $(r=1)$

Find out minimum Bandwidth.

Bandwidth = bit rate (N)

$\therefore$ Bandwidth = 2000 Hz

minimum bandwidth,

$$2000 + 3000 = 5000 \text{ Hz}$$

BW = 12000 Hz

Full Duplex
carrier separation = 2000 Hz

$\Bigg\}$ 2-FSK $(r=1)$

Find BPS (N).

$$\text{Bandwidth} = \frac{12000}{2} = 6000 \text{ Hz}$$

$$\text{BPS} = (6000 - 2000) = 4000 \text{ bps}$$

BPS = 2000 (N)

Half Duplex

Find Bandwidth.

$\Big\}$ 4 PSK ($r=2$)

here, $M=4$

$= 2^r$

$\therefore r=2$

For MPSK,

$$S = \frac{N}{\log_2 M}$$

$$= \frac{2000}{\log_2(4)}$$

$$S = 1000 \text{ signal/sec}$$

$\therefore$ Bandwidth = 1000 Hz

BW = 5000 Hz

Find baud and bitrate.

$\Big\}$ 8-PSK

$\therefore M = 8$ ($r=3$)

Baud rate = 5000

$$\therefore \text{Bitrate } (N) = S \cdot \log_2(M)$$

$$= 5000 \times \log_2(8)$$

$$N = 15000$$

Baud rate = 1000

BPS = ?

$\Big\}$ 16 PSK

M = 16

$$N = 1000 \times \log_2(16) = 4000 \text{ bps}$$

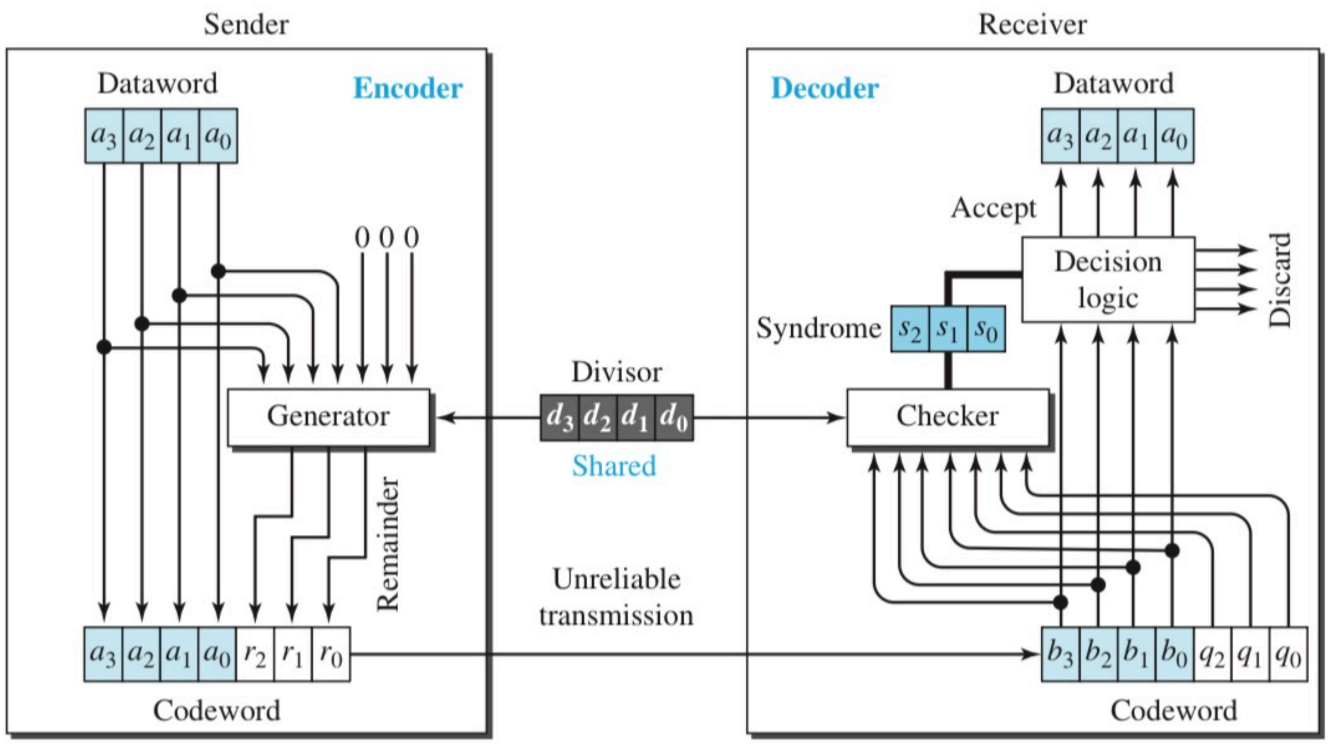
CHAPTER 6

ERROR DETECTION

Cyclic Redundancy Check (CRC)

Given a k-bit blocks of bits, or message, the transmitter generates an (n-k) bit sequence, known as a frame check frequency (FCS), such that the resulting frame consisting on n bits is exactly divisible by some predetemined number. The receiver then divides the incoming frame by that number and, if there is no reminder, assume there was no error.

Figure 10.5 *CRC encoder and decoder*



sample: $\overbrace{\underbrace{1\,0\,1\,0\,0\,0\,1\,1\,0\,1}_{D}\;\underbrace{0\,1\,1\,1\,0}_{F}}^{T}$

T = n-bit data to be transmitted

D = K-bit block of data, or message, the first k bits of T

F = (n-k) bits FCS, the last (n-k) bits of T

P = pattern of n-k+1 bits, this is the predetermined divisor.

we would like T/P to have no reminder. So,

$$T = 2^{n-k} \cdot D + F \qquad (1)$$

EXAMPLE

Given,

Message D = 1010001101 (K) [K = 10 bit]

Pattern P = 110101 [n-K+1 = 6 bit]

FCS R = to be calculated (n-K) [n-k = 5 bit]

* R means reminder

Thus, n = 15, K = 10, and (n-K) = 5

According to the formula (1), we have to multiply D with 2^{n-k} bits

$= 2^{n-k} \cdot D = 2^5 \cdot D = \underbrace{1010001101}_{D}\underbrace{00000}_{2^5}$

[simply add n-k bit at the end of Data block D]

Now the product $2^5 D$ will be divided by P.

$$
\begin{array}{rll}
 & 1101010110 & \leftarrow Q \\
P \rightarrow 110101 & \overline{)101000110100000} & \leftarrow 2^{n-k}D \\
 & -110101 & \\
 & 111011 & \\
 & -110101 & \\
 & 111010 & \\
 & -110101 & \\
 & 111110 & \\
 & -110101 & \\
 & 101100 & \\
 & -110101 & \\
 & 110010 & \\
 & -110101 & \\
 & 01110 & \leftarrow R
\end{array}
$$

* Subtract = XOR

Then the reminder R is added to $2^5 D$ to form T.

[Here R is FCS F]

$$T = 2^5 D + R$$

$$= 101000110100000 + 01110$$

$$T = 101000110101110$$

If there is no error, the receiver receives T intact. The T is divided by P again to check for error at receivers end.

```
                 1101010110
           ____________________
P → 110101 ) 101000110101110   ← T
             110101
             ------
              111011
              110101
              ------
                111010
                110101
                ------
                  111110
                  110101
                  ------
                    101111
                    110101
                    ------
                     110101
                     110101
                     ------
                          0   ← R
```

Because there is no reminder, it is assumed that There have been no errors.

EXAMPLE

Given,

Data $D = 1001$ (K) [$K = 4$ bit]

Pattern/Divisor $P = 1011$ [$n-K+1 = 4$ bit]

FCS $F = ?$ $(n-K)$ [$n-k = 3$ bit]

Thus, $n = 7$ bit

$K = 4$ bit

$n-k = 3$ bit

So, $2^{n-k}D = 2^3 \cdot 1001$

$= 1001000$

$$
\begin{array}{rrl}
 & 1010 & \\
P \rightarrow & 1011\overline{)1001000} & \leftarrow 2^3D \\
 & 1011 & \\
 & \overline{1000} & \\
 & 1011 & \\
 & \overline{110} & \leftarrow R
\end{array}
$$

The reminder R is a added to the 2^3D to form T.

$T = 2^{n-k}D + R$

$= 2^3D + R$

$= 1001000 + 110$

$T = 1001110$

1	0	0	1	1	1	0

Dataword   Reminder

The receiver receives T. Then its again divided by P to check whether there is an error or not.

$$
\begin{array}{rrl}
 & 100 & \rightarrow Q \\
P \rightarrow & 1011\overline{)1001110} & \rightarrow T \\
 & 1011 & \\
 & \overline{1011} & \\
 & 1011 & \\
 & \overline{00} & \rightarrow R
\end{array}
$$

As reminder is 0, no error occurred.

EXAMPLE

Given,

$D = 1101011011$ ($K = 10$ bit)

$P = 10011$ ($n-K+1 = 5$ bit)

$FCS\ F = ?$ ($n-K = 4$ bit)

Thus, $T = 14$ bit.

Now, $2^{n-k} D = 2^4 D$

$= 10000 \times 1101011011$

$= 11010110110000$

For reminder

```
            1100001010
10011 ) 11010110110000
        10011
         10011
         10011
          00001
          00000
              10110
              10011
               01010
               00000
                10100
                10011
                 01110
                 00000
                  1110
```

```
          1100000101
10011 ) 11010110111110
        10011
         10011
         10011
             10111
             10011
               10011
               10011
                   0 → 0
```

CRC (Polynomial)

$D(x) = x^5 + x^3 + x^2 + x$ (Data block)

$P(x) = x^3 + x + 1$ (Divisor / CD(X))

$$\therefore D(x) = x^5 + x^3 + x^2 + x$$
$$= x^5(1) + x^4(0) + x^3(1) + x^2(1) + x(1) + 0$$
$$= 101110 \quad \text{(6 bit)}$$

$$\therefore P(x) = x^3 + x + 1$$
$$= x^3(1) + x^2(0) + x(1) + 1$$
$$= 1011 \longrightarrow P(x) \text{ is 4 bit, so } (4-1) = 3 \text{bit}$$

append in $D(x) \longrightarrow x^3 D(x)$

$$x^3D(x) \longrightarrow \begin{array}{ccccccccc} 1 & 0 & 1 & 1 & 1 & 0 & \multicolumn{3}{c}{\overbrace{0\ 0\ 0}^{3\text{bit}}} \\ 8 & 7 & 6 & 5 & 4 & 3 & 2 & 1 & 0 \end{array} \longrightarrow \text{append}$$

$\downarrow$

Convert it into polynomial

$$x^3D(x) \to x^8 + x^6 + x^5 + x^4$$

Now divide $x^3D(x)$ by $P(x)$ to get the reminder $R(x)$.

$$\begin{array}{rl} & x^5 + x \\ P(x) \longrightarrow x^3 + x + 1 \,\big) & x^8 + x^6 + x^5 + x^4 \longrightarrow x^3D(x) \\ & x^8 + x^6 + x^5 \\ \hline & \qquad\qquad\qquad x^4 \end{array}$$

$$\frac{x^4+x^2+x}{x^2+x} \rightarrow R(X)$$

Append the reminder R(X) with $x^3D(x)$ to get T(X). $\longrightarrow$ 1 1 0

$$\left.\begin{array}{l} x^8+x^6+x^5+x^4+\underbrace{x^2+x}_{R(X)} \\ 101110\underbrace{110}_{R(X)} \end{array}\right\} T(X)$$

which will be send to the receiver.

Now at the receiver end,

$$\begin{array}{r|l} & x^5+x \\ \hline x^3+x+1 & x^8+x^6+x^5+x^4+x^2+x \\ & x^8+x^6+x^5 \\ \hline & \qquad\qquad x^4+x^2+x \\ & \qquad\qquad x^4+x^2+x \\ \hline & \qquad\qquad\quad 0 \end{array}$$

$\longrightarrow$ Reminder 0 means no error.

Now if error occers,

$$\begin{array}{r|l} & x^5+1 \\ \hline x^3+x+1 & x^8+x^6+x^5+\overset{\text{Error}}{x^3}+x^2+x \\ & x^8+x^6+x^5 \\ \hline & \qquad\qquad x^3+x^2+x \\ & \qquad\qquad x^3+x+1 \\ \hline & \qquad\qquad\quad x^2+1 \end{array}$$

Here, reminder is not 0, thus error occured.

EXAMPLE

$D(X) = x^3 + 1$

$P(X) = x^3 + x + 1 \longrightarrow$ 4bit, $(4-1) = 3$bit append to the $D(X)$

$D(X) = x^3 + 1$
$= x^3(1) + x^2(0) + x(0) + 1$
$= 1001$

$P(X) = x^3 + x + 1$
$= x^3(1) + x^2(0) + x(1) + 1$
$= 1010$

$X^3 D(X) = 1001000$
$= x^6 + x^3$

Now for $R(X) \rightarrow$

$$
\begin{array}{r|l}
 & x^3 + x \\
\hline
x^3+x+1 & x^6 + x^3 \\
 & x^6 + x^4 + x^3 \\
\hline
 & x^4 \\
 & x^4 + x^2 + x \\
\hline
 & x^2 + x \longrightarrow R(X)
\end{array}
$$

110

$\therefore T(X) = x^6 + x^3 + x^2 + x$

1001110

At receiver end,

$$
\begin{array}{r|l}
 & x^3 + x \\
\hline
x^3+x+1 & x^6 + x^3 + x^2 + x \\
 & x^6 + x^4 + x^3 \\
\hline
 & x^4 + x^2 + x \\
 & x^4 + x^2 + x \\
\hline
 & 0 \longrightarrow \text{No error}
\end{array}
$$

CHAPTER 8

MULTIPLEXING

FDMA

[Class Note 28.09.25]

①

No of voice frequency = 8

Each carrier = 4 KHz

Guard Band = 1 KHz

8 frequency channel needs 7 Guard band between them to separate

Sol^n

$\therefore$ Total Bandwidth = $8 \times 4 + (8-1) \times 1$

$= 32 + 7$

$\boxed{= 39 \text{ KHz}}$ Ans.

⑪

Total Bandwidth = 48 KHz

No of. frequency = 7

Each frequency = 6 KHz

Guard band frequency = ?

Sol^n

No of Guard band = $(7-1) = 6$

$\therefore 48 = 6 \times 7 + 6 \times$ Gaurd Band

Gaurd Band = $48/48$

$= 1$ Ans.

TDMA

①

Total Bandwidth = 48 bit/s

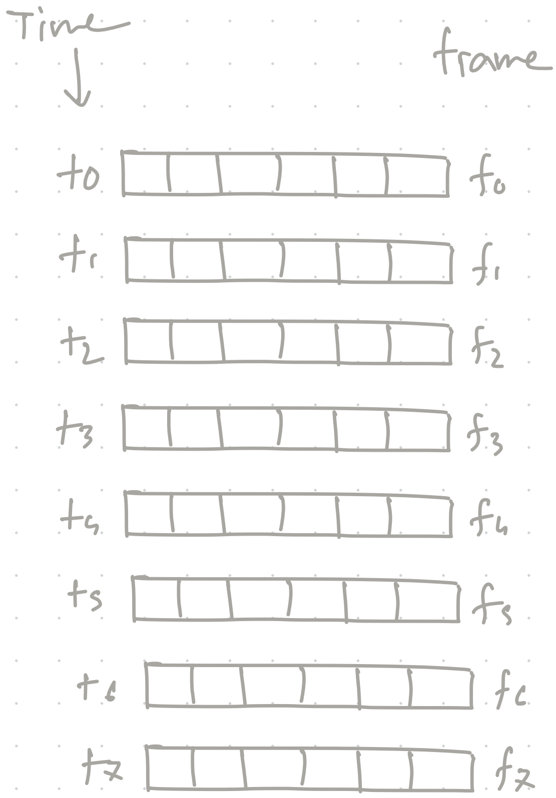
No of station = 6

Each slot size = 1 bit

No of frame ? = 48/6 = 8

No of time slot ? = 8

size of frame ? = 48/8 = 6 bit



Let, slot size = 2 bit

∴ No of frame = 4

No of time slot = 4

size of frame = 48/4 = 12 bit