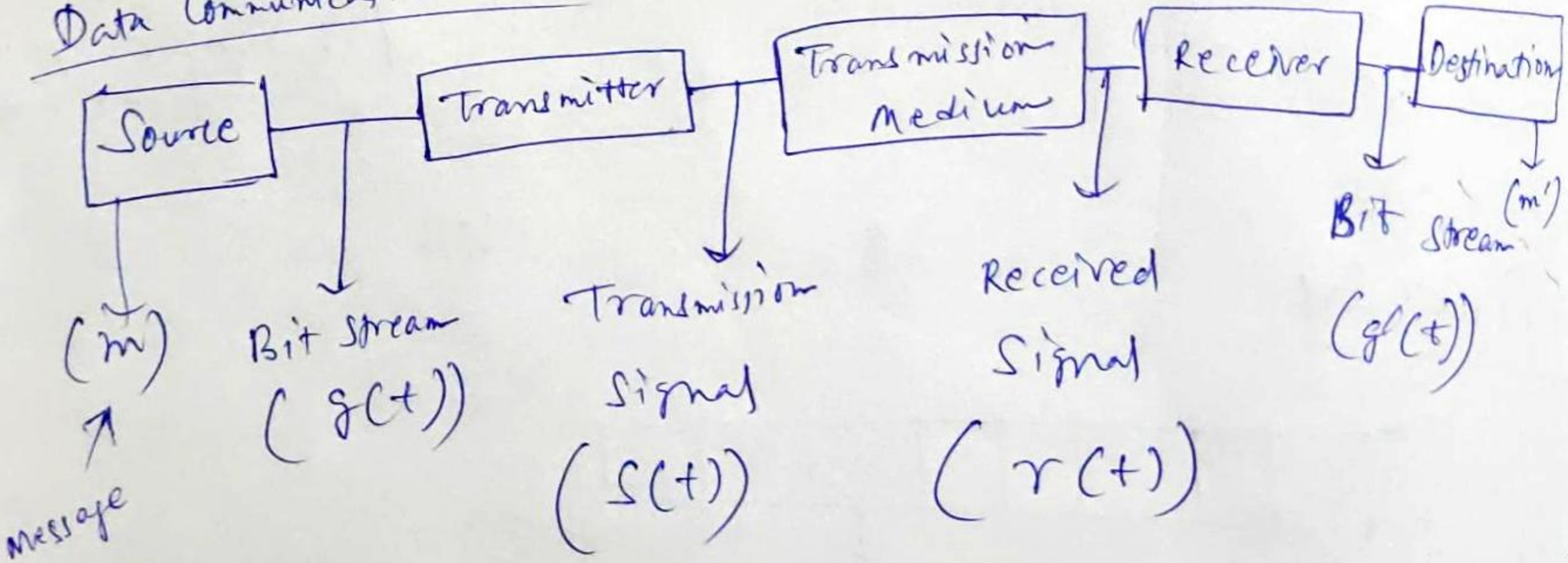
27/01/20

~~CN DC~~ CN

Data Communication Basics



- Guided & Unguided Transmission Medium.
- Infos will be carried by the Guided medium as Electro-magnetic signals.
- Simplex, Half Duplex, Duplex.

Simplex

$T_x \longrightarrow R_x$

(Transmitter) (Receiver)

Half Duplex

$T_x \longrightarrow R_x$ / $R_x \longleftarrow T_x$ } Either occur not simultaneously

Duplex

$T_x \longleftrightarrow R_x$ Simultaneously.

Function of time

- Analog Signal → Smooth continuous function.
- Digital Signal → Discrete values (or +ve / -ve pulse).
  (Represented by set of Discrete Data)

Function of frequency

~~Freq~~ ~~Absolute~~

~~Spectrum~~

Bandwidth : Absolute frequency $(f_n - f_1)$ — f_n: Highest freq., f_1: lowest freq.

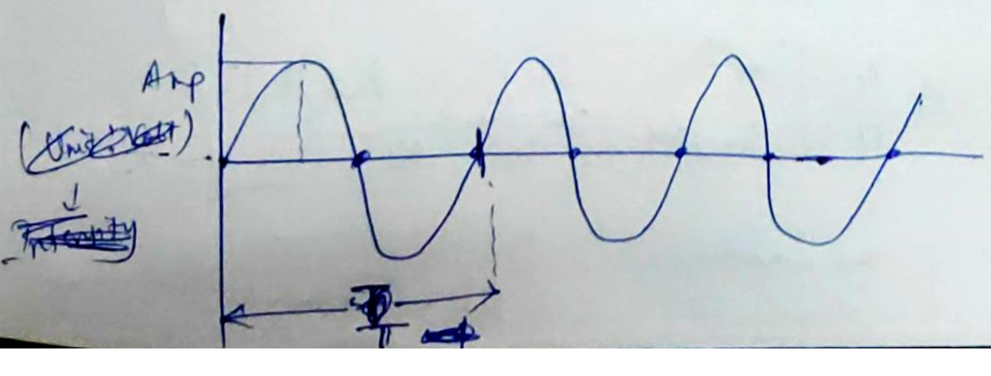
Spectrum : Collection of all frequencies.

middle frequency of a spectrum is the Carrier freq.

$$S(t) = A \sin(2\pi f t + \phi)$$

A → Amplitude, f → freq., ϕ → phase.

Signal consists of different components having diff Amp, freq & phase.



Amplitude: Intensity (unit: Volt).

- periodic signal

$$s(t) = s(t+T)$$

$$-\infty < t < +\infty$$

smallest T: period.

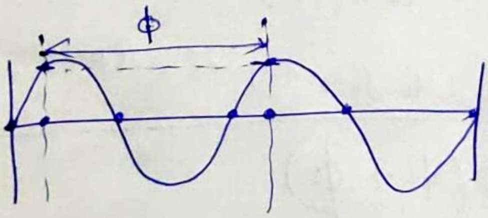
$T = 1/f$

here $f = 2$ for a unit time interval.

~~Unit: Cycles second~~

Unit: Cycles/second or Hertz (Hz).

If: $\phi \rightarrow$ phase $= \pi/4$



It has no unit.

$$s(t) = A\frac{4}{\pi}\left[\sin(2\pi f t) + \frac{1}{3}\sin(2\pi(3f)t)\right]$$

$$s(t) = A\frac{4}{\pi}\left[\sum_{K=1,\,odd}^{\infty} \frac{\sin(2\pi(Kf)t)}{K}\right]$$

$1/K \rightarrow$ is the Amplitude. (We will eliminate later terms).

Case 1: $f = 10^6$ Cycles/sec or Hz.

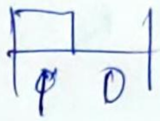
(upto third term) ~~Second Term~~

$f, 3f, 5f$ / Bandwidth $= 4\times10^6$ Hz $=$ 2 MHz $= 5f - f = 4f$

$$T = \frac{1}{f} = 10^{-6} \text{ sec} = 1\ \mu s.$$

Bit duration $t_b = \frac{1}{2f}$ $\qquad$ Bitlength $= 1/2$ as 2 bits are occured.

$= 0.5\ \mu s.$



$R = 2$ Mbps. $= \frac{10^{-6}}{0.5}$

Data Rate.

Case 2:

(upto 3rd term) $f, 3f, 5f$

$$S(t) = A\frac{4}{\pi}\left[\sin(2\pi f t) + \frac{1}{3}\sin(2\pi(3f)t) + \frac{1}{5}\sin(2\pi(5f)t)\right]$$

Doubling the Bandwidth.

$$f = 2\times10^6 \text{ cycles/sec.}$$

$$B = 2\times10^6\times(5-1) = 8 \text{ MHz}.$$

$$T = \frac{1}{f} = \frac{10^{-6}}{2} = 0.5\ \mu s.$$

2 Cycles completed.

for 2

$$t_b = \frac{1}{2f} = 0.25\ \mu s.$$

$R = 4$ Mbps.

Case 3: 2nd term $(f, 3f)$.

$f = 2\,MHz$.

$B = 3f - f = 2f = 4\,MHz$.

$T = 0.5\,\mu s$

$t_b = 0.25\,\mu s$

$R = 4\,Mbps$.

for $f, 3f, 5f, 7f \ldots$

... f is called as Fundamental frequency as (ind * f) rely remains frequencies.

- Same Bandwidth may give us Different Datarates.
- Few terms will give better datarate but error chance will be higher for less approximation.

- Sampling Theorem:

For 4 Mbps $\rightarrow 2 \times 4 = 8\,MHz$ Bandwidth

~~for b data~~ for Datarate B

~~Nyquist~~

- Nyquist Theorem:

$C = 2B \log_2 M$

max Channel Capacity ~~Data Rate~~.

~~Signal Attenuation:~~ Signal Attenuation:

Attenuation: Signal strength decreases over ~~time~~ distance.

$$\frac{1}{d^{\alpha}} \quad \text{where } \alpha > 1.$$

Wavelength: Distance traverse by Signal over time T.

wavelength $\rightarrow \lambda = v T = v/f$

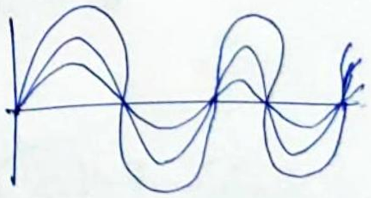
$\Rightarrow \boxed{v = f\lambda}$

30 - 300 GHz $\rightarrow$ Can't penetrate any wall.
(Milimeter Wave)

(Too much Attenuation for very high freq).

Mobile freq — 2 MHz. (lower freq can penetrate any wall)

Delay Distortion:



Diff freq arrives at the receiver at diff point.

Velocity is dependent on freq.

Noise: Unwanted Signal.

- Interference. (Approximate to zero).
- White Noise. (Can't appox to zero).
- Intermodulation Noise.
- Cross Talk.
- Impulse Noise.

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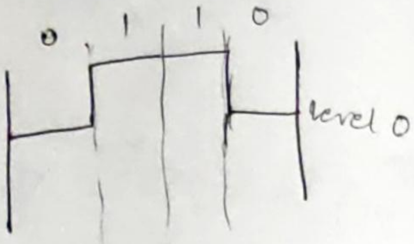
~~Two level Binary~~

NRZ-L →

(Non Return to Zero - Level)

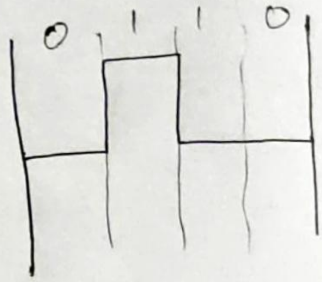


No transition between any bit interval.

NRZ-I →

~~(Invertible)~~
(Inverted)

(Differential Encoding Scheme)



(Sampling from middle of the Signal)

(The Receiver's job is to conclude whether there is a transition or not at the start of the ~~data~~ data signal).

- That's why NRZ-I is better than NRZ-L.

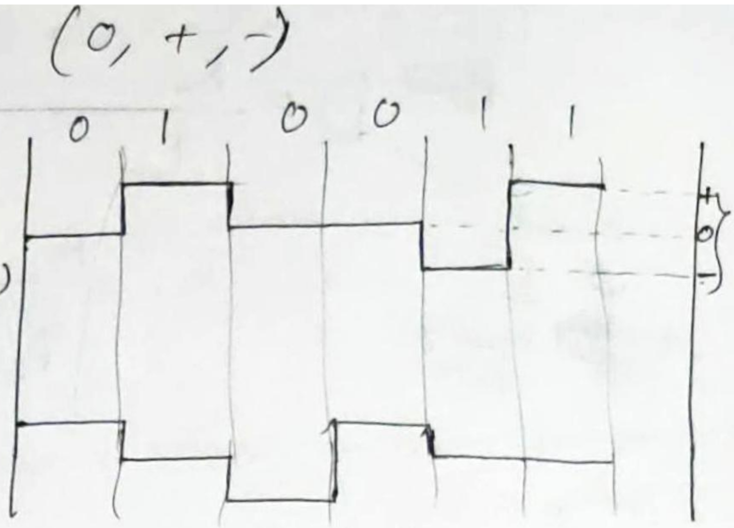
- DC - Component (that has ~~element~~ a component of zero freq)

- NRZ-~~L~~ Can produce DC - Component.

- For NRZ-L long sequence of 0/1 Can create Lack of ~~Synch~~ Sync

- For NRZ-I Long Sequence of 0 Can create Lack of Sync.

Multi-level Binary (0, +, -)



Bi-polar AMI →
(0 - No Line signal, 1 - Alternate +ve/-ve)

~~Pseudo-ternary~~

Pseudo-ternary →
(Reverse AMI)
(0 - Alternate, 1 - No Line)

AMI → Alternate Marked Inversion.

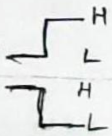
~~No DC.~~

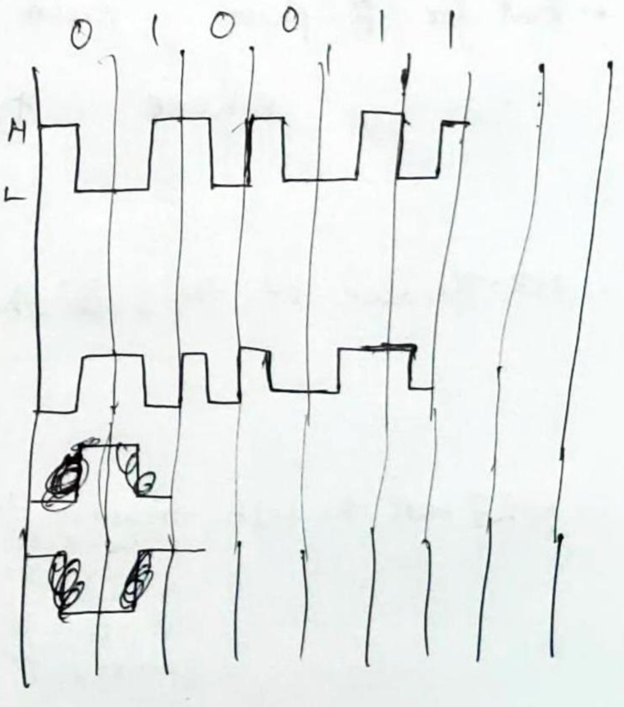
- These will not produce any DC-component.
- Synchronization problem remains here — long string of 0 for AMI, long string of 1 for pseudo

Biphase Techniques
(mid-bit Transition)

Manchester →

Low-High → 1 →
High-Low → 0 →





Differential Manchester →

1 → No Transition at the beginning
0 → Transition at the ~~beg~~ beginning.

- **Bit Rate**: No of bits transmitted per unit time → bps (unit).
- **Baud Rate**: No of signal ~~transmitted~~ elements transmitted per unit time ~~baud~~
  ↓
  baud (unit)

$$D = \frac{R}{L}$$ → bps → data rate

baud ↓ signaling rate

$$= \frac{R}{\log_2 M}$$

for 2 bit → 00
01
10
11

where → $L = 2$ bit, $M = 4$ diff signal element

- Data Rate is higher than Baud Rate (usually)

- But for Bi-phase each signal element have 2 bits

where $D = R/\frac{1}{2} = 2R$

- Because of this, Bi-phase is used for shorter distance communications only.
(e.g. → LAN)

- NRZ - is the best transition technique for long distance communication
(If ~~bit pro~~ Sync & DC-component problem is sorted).

Sampling Techniques

Bipolar with 8 Zeros Substitution (B8ZS)

Bi-polar-AMI

Code-violation

+, | 0000 + − 0 − +

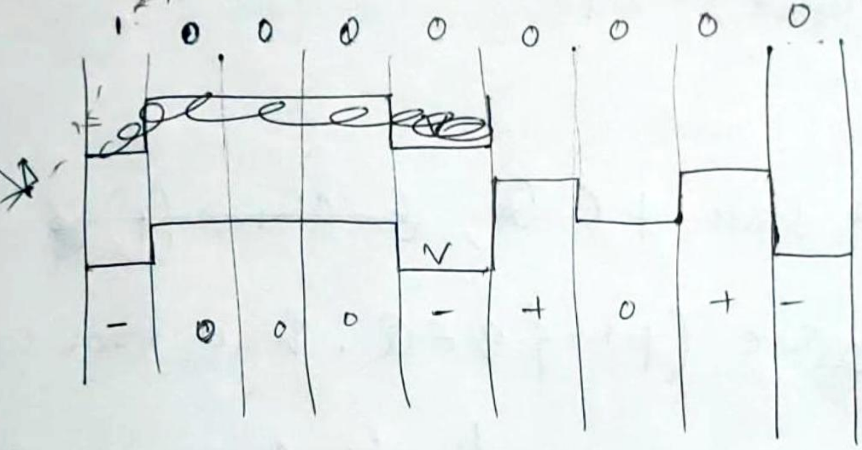
Code-violation

as no two +ve or −ve signal can appear correspondently (if we eliminate zeroes).

no 4 consecutive 0's are allowed

or, −, | $\overbrace{0000}$ − + 0 + −

previous



← o/p have max 8 consecutive zeroes

High Density Bi-polar 3 Zeros (HDB3)

−, 000 −

Code-violation

or,

+, 000 +

} Odd no of 1's since last code violation.

B00V } Even no of 1's since last code violation

B → valid Bi-polar signal

V → violation.

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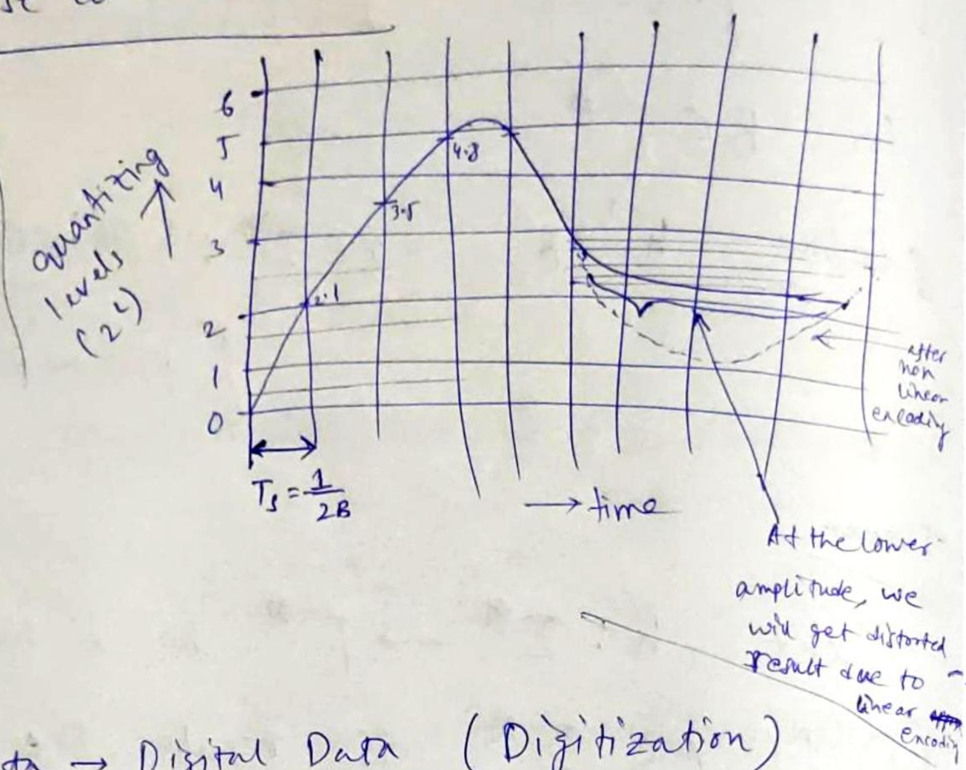
1> PCM (Pulse code modulation)

- Analog Data
  ↓
  Digital Signal



Analog Data → Digital Data (Digitization)

- ~~COD~~ CodeC (Coder-decoder)

2> ~~Delta Modulation (DM)~~

- Modulating Signal (original Signal).
- Modulated Signal (O/P signal).

- PAM (Pulse Amplitude Modulation) Sample.
- for L - bit → $2^L = M$ no of ~~labels~~ levels will be there.

- ~~Q~~ Quantizing noise (Generated by Quantization)
  if the data is mapped to 2^L ~~bits~~ levels, then the error rate is lower.

- If we Increase the level, we can control the Quantization noise.

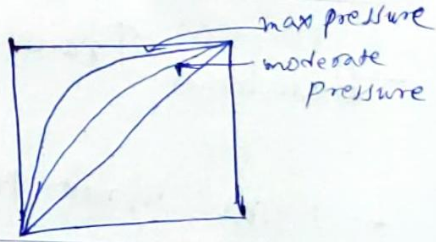
- Data rate = ~~2BM = 2B log~~
$$= 2BL = 2B \log_2 M$$

- Increasing L can causes higher data rate so as error.

- $$\boxed{SNR_{dB} = 6.02L + 1.76\ dB}$$

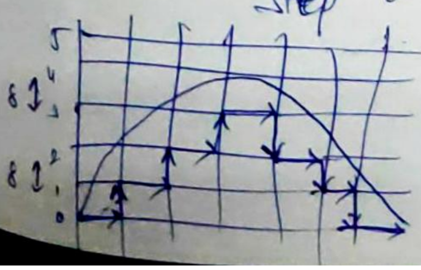
- So we have to use Non-Linear Encoding i.e. Increase the levels in lower amplitudes & at the higher level, we will provide less levels. (Keeping the ~~level~~ no of levels fixed).

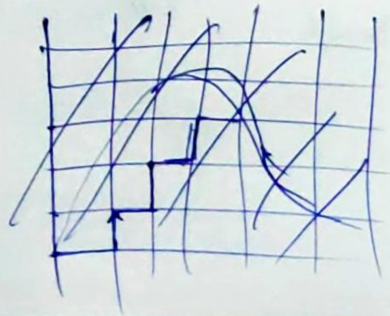
- Compinding



2) Delta modulation (DM)

- It is a ~~Stare-case function~~ Stair-Case function.
- If the Current value is higher than the previous one, then we will move one step higher else move one step lower.





- Slope Overhead Noise
- Quantizing Noise.

δ : ~~Qan~~ Quantization Space.

δ - Small is problem for Slope overhead noise. better for Quantization noise

δ - big is problem for ~~Q~~ Quantization noise but ~~not~~ good for Slope Overhead noise.

Analog Data → Analog Signal

- Baseband Transmission (~~Transmitted using~~ generally Captured using km-radius antenna)
- FDM is not possible for Baseband Transmission.
- Bandpass filter. (only the frequency within the defined range, will pass through. Others are eliminated)

- Amplitude Modulation (AM)
  ~~P~~ Frequency " (FM)
  Phase " (PM)

~~AM~~

~~$S(t) = [1 + n_a * m(t)] (\cos(2\pi f_c t))$~~

~~Modulated signal~~

~~Modulating signal.~~

~~fc~~

AM

$$s(t) = [1 + n_a \cdot m(t)] \cdot (\cos(2\pi f_c t))$$

$m(t) \to$ Modulating signal

$s(t) \to$ Modulated signal

$n_a \to$ Amplitude Modulation Index $\to \dfrac{\text{Amplitude of entry signal}}{\text{Amplitude of Carrier signal}}$

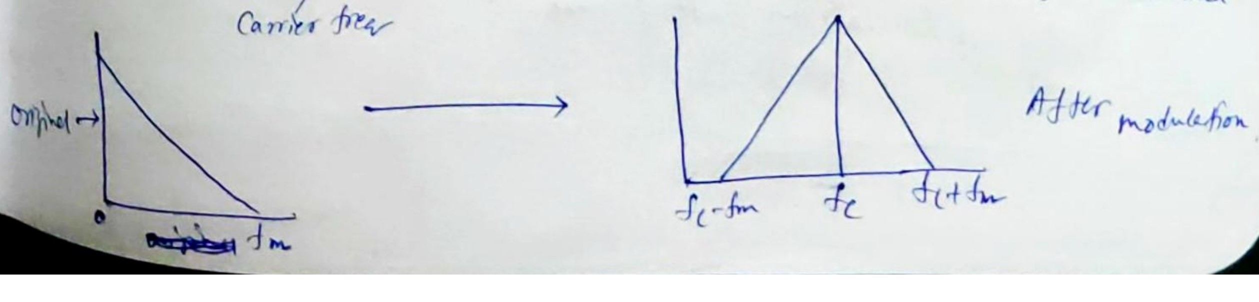
~~fc → Carrier~~ So, $n_a < 1$ as Carrier Signal is strongest

$f_c \to$ Carrier frequency. $|f| < |f_c|$

Let, $m(t) = \cos(2\pi f_m t)$

$$\therefore s(t) = [1 + n_a \cos(2\pi f_m t)] \cdot (\cos(2\pi f_c t))$$

$$= \underbrace{\cos 2\pi f_c t}_{\text{Carrier freq}} + \underbrace{\frac{n_a}{2} \cos(2\pi(f_c - f_m)t)}_{\text{lower side band}} + \underbrace{\frac{n_a}{2} \cos(2\pi(f_c + f_m)t)}_{\text{higher side band}}$$



- Double side band.

- Angle Modulation (~~Ampli~~ Freq

  ↳ Both frequency & phase modulations are Called Angle Modulation

$$\boxed{s(t) = A_c \cos\left(2\pi f_c t + \phi(t)\right)}$$

frequency is defined as a rate of changes of frames.

For phase modulation → $\phi(t) = n_p \cdot m(t)$

n_p → Phase Modulation Index

For freq modulation → $\phi'(t) = n_f \cdot m(t) = \frac{d\phi(t)}{dt}$

n_f → Freq Modulation Index.

- AM is Long distance transmission.
- FM is Short distance transmission.

- making freq low, ~~& high amplitude~~ signal can travel larger distance.

- Inter-modulation Interference.

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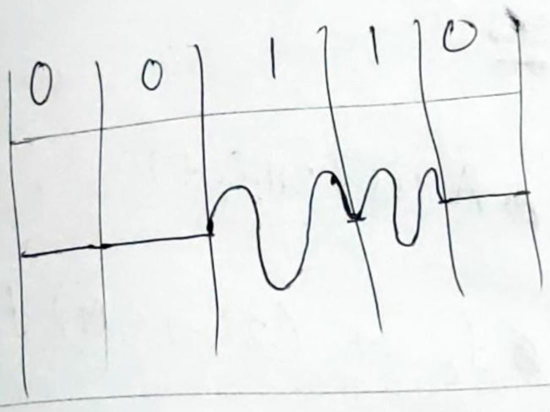
Digital Data ⟶ Analog Signal

MODEM → Modulation – De-modulation.

- Amplitude Shift keying (ASK)

$$S(t) = A\cos(2\pi f_c t) \longrightarrow 1$$
$$= 0 \longrightarrow 0$$



- Frequency Shift keying (FSK)

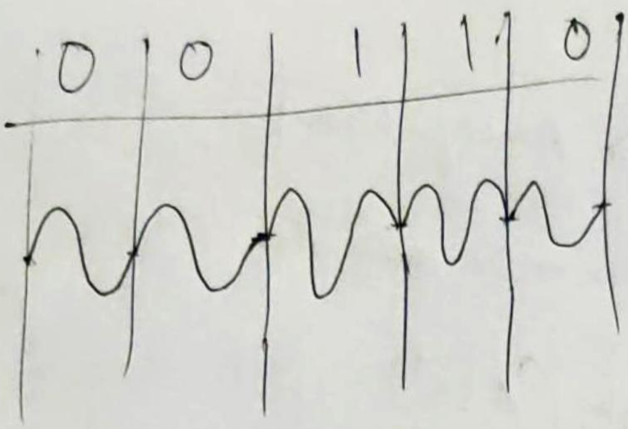
- Binary FSK (BFSK)

$$S(t) = A\cos(2\pi f_1 t) \rightarrow 0$$
$$= A\cos(2\pi f_2 t) \rightarrow 1$$

$$f_1 = f_c - f_d \quad | \quad f_2 = f_c + f_d$$

~~Difference~~

Difference frequency.



for 0 & 1, different ~~signal wit~~ frequency signal with same amplitude.

— MFSK (Multiple FSK)

$$S_i(t) = A\cos(2\pi f_i t) \quad , 1 \leq i \leq M$$

$$f_i = f_c + (2i-1-M) f_d$$

Let $L=3$, $M=8$, $f_c = 250$ KHz,
$f_d = 25$ KHz.

000 ← $f_1 = 250 + (2.1 - 1 - 8) 25$
$= 250 - 175$
$= 75$ KHz

50	75	100
↓	↓	↓
$f_1 - f_d$	f_1	$f_1 + f_d$

001 ← $f_2 = 250 - 125 = 125$ KHz.
010 ← $f_3 = 175$ KHz.
011 ← $f_4 = 225$ KHz.

100 ← $f_5 = 275$ KHz
101 ← $f_6 = 325$ KHz
110 ← $f_7 = 375$ KHz

$f_8 = 425$ KHz

$\text{min freq} = f_1 - f_d = 50\,\text{KHz}.$

$\text{Max freq} = f_p + f_d = 450\,\text{KHz}.$

$\text{Bandwidth} = 400\,\text{KHz}.$

$= \underline{M \cdot (2 f_d)}$

$= 8 \cdot 2 \cdot 25 = 400\,\text{KHz}.$

$$\boxed{T_s = L \cdot T_b}$$

Modulation T_s : Duration of 1 signal element.

T_b : Duration of 1 bit.

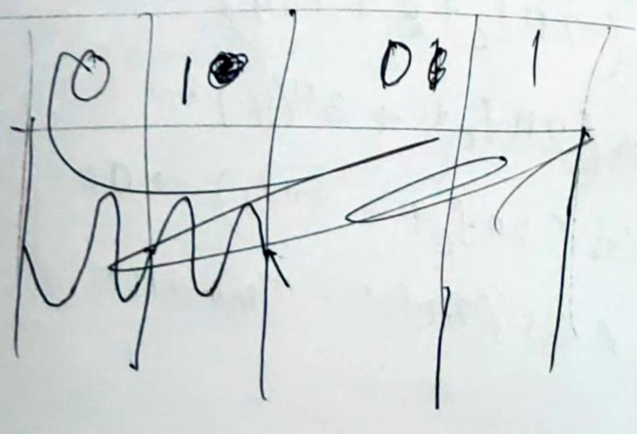
- TDMA / FDMA. (Time & Freq Division Multiple Access).

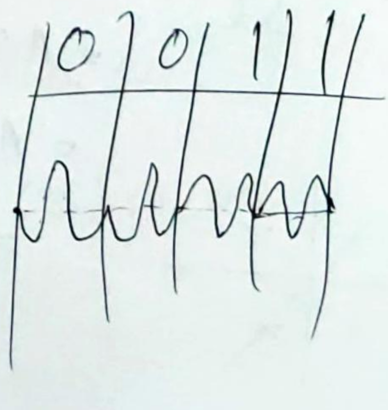
- Phase Shift keying (PSK)

$S(t) = A \cos(2\pi f_c t) \longrightarrow 1$

$= A \cos(2\pi f_c t + \pi) \longrightarrow 0$

Binary PSK (BPSK)

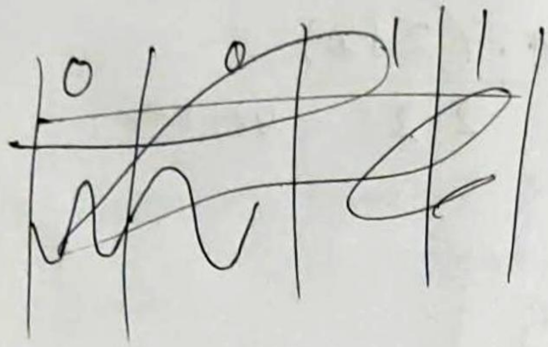


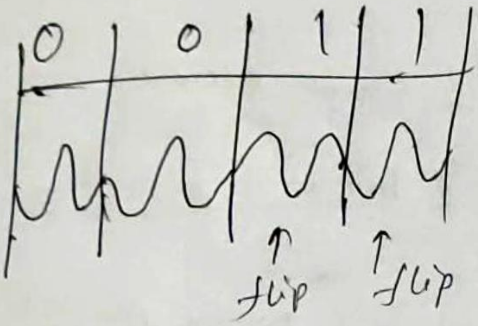


Differential PSK (DPSK)

0 → No change

1 → Flip the signal



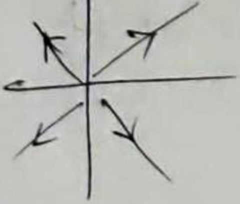


- Memoryless.

Quadrature PSK (QPSK)

Here $\pi/2$ or $90°$ phase shift is applied.

$$s(t) = A\cos(2\pi f_c t + \pi/4) \longrightarrow 4$$
$$= A\cos(2\pi f_c t + 3\pi/4) \rightarrow 01$$
$$= A\cos(2\pi f_c t - 3\pi/4) \rightarrow 00$$
$$= A\cos(2\pi f_c t - \pi/4) \rightarrow 10$$

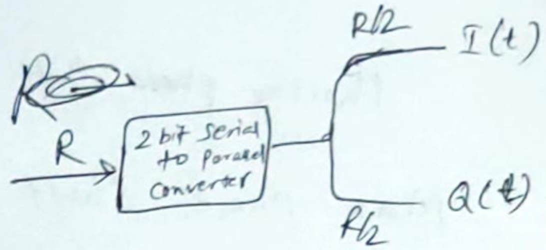


~~$s(t) = \frac{I(t)}{\sqrt{2}} \cos t$~~

$$S(t) = \frac{I(t)}{\sqrt{2}} \cos(2\pi f_c t) - \frac{Q(t)}{\sqrt{2}} \sin(2\pi f_c t)$$

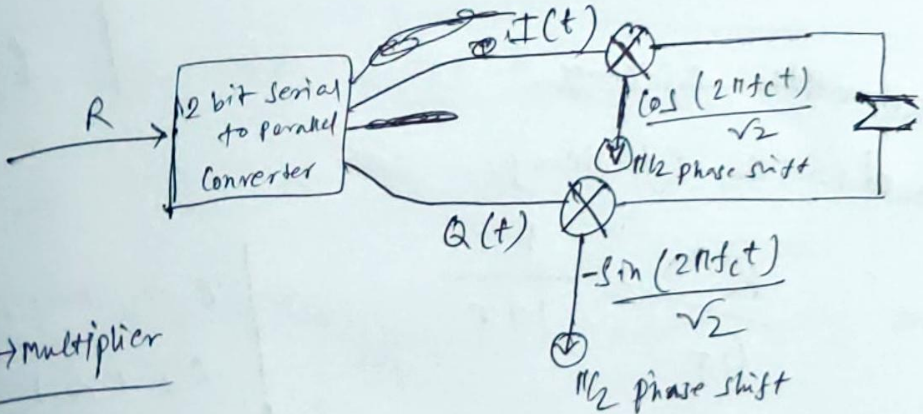
$11 \rightarrow 1\ 1$
$01 \rightarrow -1\ 1$
$00 \rightarrow -1\ -1$
$10 \rightarrow 1\ -1$

first bit $I(t)$ second bit $Q(t)$.



$I(t)$: In phase (No phase shift will done here)

$Q(t)$: Quadratic Phase. (Phase shift will done here)



$\otimes \rightarrow$ multiplier

If $I(t) = Q(t) = 1$

As amplitude $= 1/\sqrt{2}$
Phase $= \pi/4$.

$$\Rightarrow S(t) = \frac{1}{\sqrt{2}} \cos(2\pi f_c t) - \frac{1}{\sqrt{2}} \sin(2\pi f_c t)$$

$$= \cos(\pi/4) \cos(2\pi f_c t) - \sin(\pi/4) \sin(2\pi f_c t)$$

$$= \cos(2\pi f_c t + \pi/4)$$

If $I(t) = Q(t) = -1$

$$S(t) = \cos(2\pi f_c t - 3\pi/4).$$

Orthogonal QPSK

phase shift delay

$$Q(t) = Q(t - t_b)$$

- Shorter phase shift is easy for implimentation.

- Max phase shift $= \pi/2$

---

for ASK, BPSK

$$B_T = (1+r)R \quad \text{--- (1)}$$

$R \to$ Data Rate

$B_T \to$ Transmission Bandwidth (Bandwidth of Modulated Signal)

~~Band width efficiency~~

Band width Efficiency,

$$\frac{R}{B_T} = \frac{1}{1+r}$$

$r \to$ filtering parameter

$0 \leq r \leq 1$

$r = 0$, no error

$r = 1$, full error

$r =$ How good the filtering can be done on the resulted signal

If, $r \to 0$

$$\frac{R}{B_T} \sim 1$$

for MPSK, $B_T = \left(\frac{1+r}{\log_2 M}\right) R$ --- (2)

if $M=2$, it is equal to BPSK.

f (TiFR, India)

Efficiency, $R/B_T = \frac{\log_2 M}{1+r}$

if M increasing, Bandwidth ~~to~~ efficiency is increasing.

for BFSK

$B_T = (1+r)\,2R$

for ~~MSF~~ MFSK

$B_T = \left(\frac{(1+r)M}{\log_2 M}\right)R$.

- Bit Error Rate (BER) = 10^{-6}

$\frac{E_b}{N_0}$ is function of BER

$E_b \rightarrow$ Energy per bit

$N_0 \rightarrow$ Noise power density per Hz.

$$E_b = \underset{\substack{\uparrow \\ \text{Signal strength}}}{S} \cdot T_b = \frac{S}{R}$$

$$N = N_0 \cdot \underset{\substack{\uparrow \\ \text{Bandwidth}}}{B}$$

$$\frac{E_b}{N_0} = \frac{S/R}{N/B} = \frac{S}{R} \cdot \frac{B}{N}$$

Shanon's capacity formula

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

$\Downarrow$ S/N

largest possible bandwidth

SNR → Signal to Noise Ratio

$$\therefore C = B\log_2 (1+S/N)$$

C → bps

B → Hz.

$$\therefore S/N = 2^{C/B} - 1$$

$$\frac{E_b}{N_0} = \left(2^{C/B} - 1\right) B/R$$

$$= \left(2^{R/B} - 1\right) B/R$$

But $R \leq C$ always

↓

when $C = R$

↑

fully utilizing the full channel

Here → R/B = Bandwidth Efficiency

when $C = R$ → Spectral efficiency.

So, $\frac{E_b}{N_0}$ is a function of Bandwidth Efficiency.

- So for increasing slight bandwidth, the energy per bit needs to increase exponentially in power of 2.

2.4 dB SNR

~~dB = log~~

S/N is unitless.

$$2.4 = dB = 10 \log_{10}(S/N)$$

$$\Rightarrow \frac{S}{N} = 10^{0.24}$$

13/02/20

CN

Q1) Consider an audio signal with freq components within the range of 300 - 3000 HZ. Suppose we generate ~~a~~ PCM signal with 6000 Samples/sec. So what is the min no of uniform Quantization levels needed to ~~ach~~ achieve a data rate of 30000 bps.

→ Each sample represents $= \frac{30000}{6000} = 5$ bits

No of Quantization levels $= 2^5 = 32$

$\therefore$ 32 different Quantization level is required.

Q2) Audio signal, freq below 4000 HZ.
PCM signal using 5 bit PAM samples is used.
If samples are taken according to Sampling theorem, what data rate will be achieved?

→ $\therefore$ 8000 Samples/sec is required (2 × highest freq)

$\therefore$ Data rate $= 8000 \times 5 = 40$ Kbps.

Q.3) What is the Bandwidth efficiency for a PSK on a channel with SNR 12dB & $BER = 10^{-7}$

→ Assume that $E_b/N_0 \sim BER = 10^{-7}$

$\downarrow$

$E_b/N_0 = 11.2$ dB

$\frac{E_b}{N_0} = \frac{S}{R} \cdot \frac{B}{N}$

$= \frac{S}{N} \cdot \frac{B}{R}$

$$E_b = S \cdot T_b$$
$$N = N_0 \cdot B$$
$$\Rightarrow N_0 = N/B$$

$\Rightarrow 10 \log_{10}(E_b/N_0) = 10 \log_{10}(S/N) - 10 \log_{10}(R/B)$

$\Rightarrow 11.2 = 12 - 10 \log_{10}(R/B)$

$\Rightarrow -10 \log_{10}(R/B) = 0.8$

$\Rightarrow \log_{10}(R/B) = 0.08$

$\Rightarrow R/B = 10^{0.08} = 1.2$

Q.4) Television channels are 6 MHz wide. 4-level digital signals are used. Assume noiseless channel, derive max data rate?

$\rightarrow$ $B = 6$ MHZ.

$M = 4$ - level

$R = 2B \log_2 M = 2 \times 6 \times \log_2 4$

$= 24$ Mbps

Q.5) If a Binary signal is sent over a 3 KHz channel whose SNR is 20 dB. What is the max achievable data rate?

→ $B = 3\ KHz$, $SNR = 20dB$

$$10 \log_{10}(SNR) = 20$$

$$\Rightarrow SNR = 10^2 = 100 = S/N$$

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

$$= 3000 \times \log_2 101 = 3000 \times \log_2 101$$

$$\approx 3000 \times 6.658$$

$$\approx 19.975\ Kbps.$$

For Nyquist, (noiseless)

Binary signal, so $M = 2$

$$R = 2B \log_2 M = 2 \times 3 \times \log_2 2 = 6\ Kbps.$$

– Max achievable data rate = min (Shannon, Nyquist)

= 6 Kbps.

Q.6) Derive an expression for Baud Rate as a function of Bit Rate for QPSK ~~~~ using NRZ-L (Digital Encoding)

→ $M = 4,\ L = 2$ for QPSK (2 bits required to represent signal 00, 01, 10, 11)

$$D = \frac{R}{L} = R/2$$

→ $D = R/2$

Q.7) Consider a periodic signal $x(t)$ whose period is ~~5ms~~ 5 mS. ~~frequency range f to 8f~~ frequency range 'f' to '8f'. What is the effective bandwidth / absolute bandwidth?

→ Effective bandwidth $= 8f - f = 7f$

$= 7/0.005$

$= 1.4$ KHZ.

we know;

$f = 1/t$

$= \frac{1}{5\times10^{-3}}$

Q.8) State the relation b/w E_b/N_0 & Spectral efficiency C/B?

→ $E_b/N_0 = \left(2^{C/B} - 1\right) B/C$

$E_b/N_0 = \frac{S}{N} \cdot B/R$

Using Shanon's Capacitance → $C = B\log_2(1+S/N)$

$$\Rightarrow \frac{S}{N} = 2^{C/B} - 1$$

$$\therefore \frac{E_b}{N_0} = (2^{C/B} - 1)\frac{B}{R}$$

$$= (2^{C/B} - 1)(B/C)$$

when the Channel is fully utilized.

Q.9 Consider a channel with 1 MHz capacity & SNR of 63. What is the upper limit of data rate of channel. What signal levels are required to achieve the data rate.

Shanon $C = B\log_2(1+S/N) = 1 \times \log_2 64$
$= 6$ Mbps

Nyquist $C = 2B\log_2 M$

$\Rightarrow 6 = 2 \times 1 \times \log_2 M$

$\Rightarrow \log_2 M = 3$

$\Rightarrow M = 8$

Q.19 Consider a cable where signal is attinuated at a rate of ~~-0.3 dB/Km~~ -0.3 dB/Km. If the signal of the beginning has power 2mW What is the power of the signal at 5Km?

→ At the end of 5Km → -1.5 dB attinuation.

attinuation $10 \log_{10}\left(\frac{P_2}{P_1}\right) = -1.5$

P_1 → Power at beginning
P_2 → Power at end

$\Rightarrow \frac{P_2}{P_1} = 10^{-0.15}$
$= 0.71$

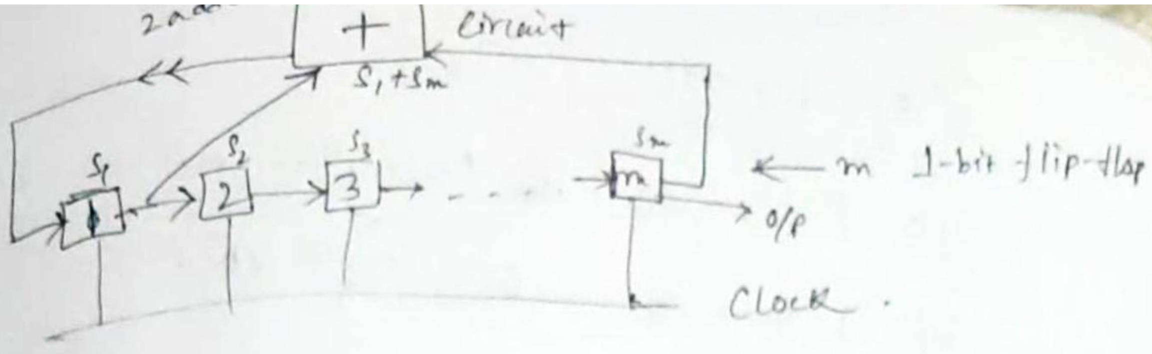
$\Rightarrow P_2 = 0.71 \times P_1$
$= 0.71 \times 2$
$= 1.42$ mW

Spread Spectrum

$m(t) \cdot c(t)$

↑ PN-sequence (Pseudo-Noise Sequence)

- It is a periodic sequence.
- Largest possible period = $2^m - 1$
- All 0's are not a valid string.
- m-sequence (maximal PN sequence) has $2^m - 1$ i.e. highest possible sequence.
- Linear Feedback Shift Register.



~~To~~ - for this reason all 0's are not allowed.

So for m - flip flops total combinations possible

$$= 2^m - 1$$

(All possible combination on m-f/f) (only all 0's sequence is not allowed)

---

for, $m = 3$,

for m-sequence, $S_1 + S_3$ is the only solution.

for bit sequence ▷

1	0	0 ← o/p
1	1	0
1	1	1
0	1	1
1	0	1
0	1	0
0	0	1
1	0	0

After 7 sequence i.e. $(2^3 - 1)$.

2^{m-1} many 1's
$2^{m-1}-1$ many 0's
for m-seq

O/p: ~~0111000~~ $\boxed{0011101}$ ← $C(t)$.

Property:

1) Balance Property: No of 0's & 1's are nearly same. (2^{m-1} many 1's & $2^{m-1}-1$ many 0's)

2) ~~Run property:~~

2) Run Property:

(a) 1 run of 1 → length m

(b) 1 run of 0 → length $m-1$

(c) 2^{m-i-2} run of 1 → length i, $1 \le i \le m-2$

(d) 2^{m-i-2} run of 0 → length i, $1 \le i \le m-2$

$c(t) \rightarrow \underbrace{0\,0}_{(b)}\ \underbrace{1\,1\,1}_{(a)}\ \underbrace{0}_{(d),\,i=1}\ \underbrace{1}_{(c),\,i=1}$

3) Auto-Corelation Property:

$B_1\ B_2\ \ldots\ B_m$ ±1 | 0 is replaced by −1

$$R(\tau) = \frac{1}{N} \sum_{i=1}^{m} B_K \cdot B_{K-\tau}$$

for m-sequence,

$$\begin{cases} R(\tau) = 1, & \tau = 0, m, 2m, \ldots \\ \quad\ = -\dfrac{1}{m}, & o/w \end{cases}$$

$c(t) \rightarrow -1\ -1\ \ 1\,1\,1\ \ -1\ \ 1 \leftarrow B_K$

for $\tau = 0 \rightarrow -1\ -1\ \ 1\,1\,1\ \ -1\ \ 1 \leftarrow B_{K-0} = B_K$

$1\ \ 1\ \ 1\,1\,1\ \ 1\ \ 1$

As everything is identical, so, $R(\tau) = 1$

$$c(t) = -1 \quad -1 \quad 1\,1\,1 \quad -1 \quad 1$$

for $\tau = 1$ (1 shift) $= 1 \quad -1 \quad -1\,1\,1 \quad 1 \quad -1$

$$-1 \quad 1 \quad -1 \quad 1\,1 \quad -1 \quad -1$$

No of $(-1) = 4$

No of $(+1) = 3$

$$R(\tau) = 3 - 4 = -1 = -\frac{1}{m} \quad \text{where } (m = 1)$$

- we need $R(\tau)$ as much lower.

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Spread Spectrum

1) DSSS (Direct Sequence Spread Spectrum)

2) FHSS (Frequency Hoping Spread Spectrum)

1) DSSS

$C(t)$

$\{b_K\}$ → Data sequence

$\{c_K\}$ → PN-sequence. (Pseudo Noise ~~of~~ sequence)

$b(t)$ → Data signal

$c(t)$ → PN-signal.

using (NRZ ±1)

$m(t) = b(t) \cdot c(t)$

↑ Transmitted Signal

$r(t) = b(t) \cdot c(t) + i(t)$ ← Interference b/w Sender & Receiver.

↑ Received Signal

At the receiver end we get $r(t) \cdot c(t)$

i.e. $= b(t) \cdot c^2(t) + i(t) \cdot c(t)$

& $c^2(t) = 1, \forall i$

$$= \underbrace{b(t)}_{\text{Narrow Band}} + \underbrace{i(t).c(t)}_{\text{wide Band}}.$$

~~wide Band~~.

If we use a low-pass filter w.r.t. the Narrow Band Signal, then ~~most~~ most of the components of $i(t).c(t)$ will eliminate. (not all the components will be deleted)

↓

Bit Duration

$$\int_0^{T_b} Z(t)\, dt \rightarrow \text{Average amplitude for the bit interval } (0, T_b).$$

$$= v \rightarrow \text{~~Aug~~ Approximated Sample Value.}$$

Narrow. Narrow = Narrow

Narrow. wide = wide

wide. wide = wide.

if $v > 0 \longrightarrow 1$

$v < 0 \longrightarrow 0$

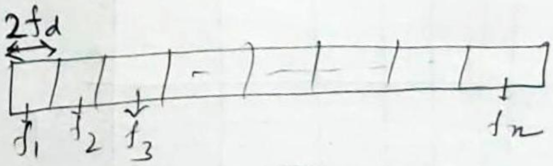
& $v = 0 \longrightarrow$ either 0/or 1.

---

2) FHSS (Used for Short Range → Bluetooth, wifi).

Only on Un-licensed Spectrum

MSFK:



$$\begin{pmatrix} f_1 - f_d \\ f_1 + f_d \end{pmatrix}$$

000
001
.
.
.
111

Modulation Rate

No of bits

$$T_s = 3 \cdot T_b$$

$T_c \rightarrow$ Hopping Rate

After Tc interval, the freq will be changed.

– Using PN-Sequence.

if $T_c = T_b$, Hopping will be very small

for $T_c < T_s \rightarrow$ Fast Frequency Hopping.

$T_c > T_s \rightarrow$ Slow Frequency Hopping.

Here, $M = 4$, for MFSK & $L = 2$.

for $T_s = T_b$

i.e. BFSK.

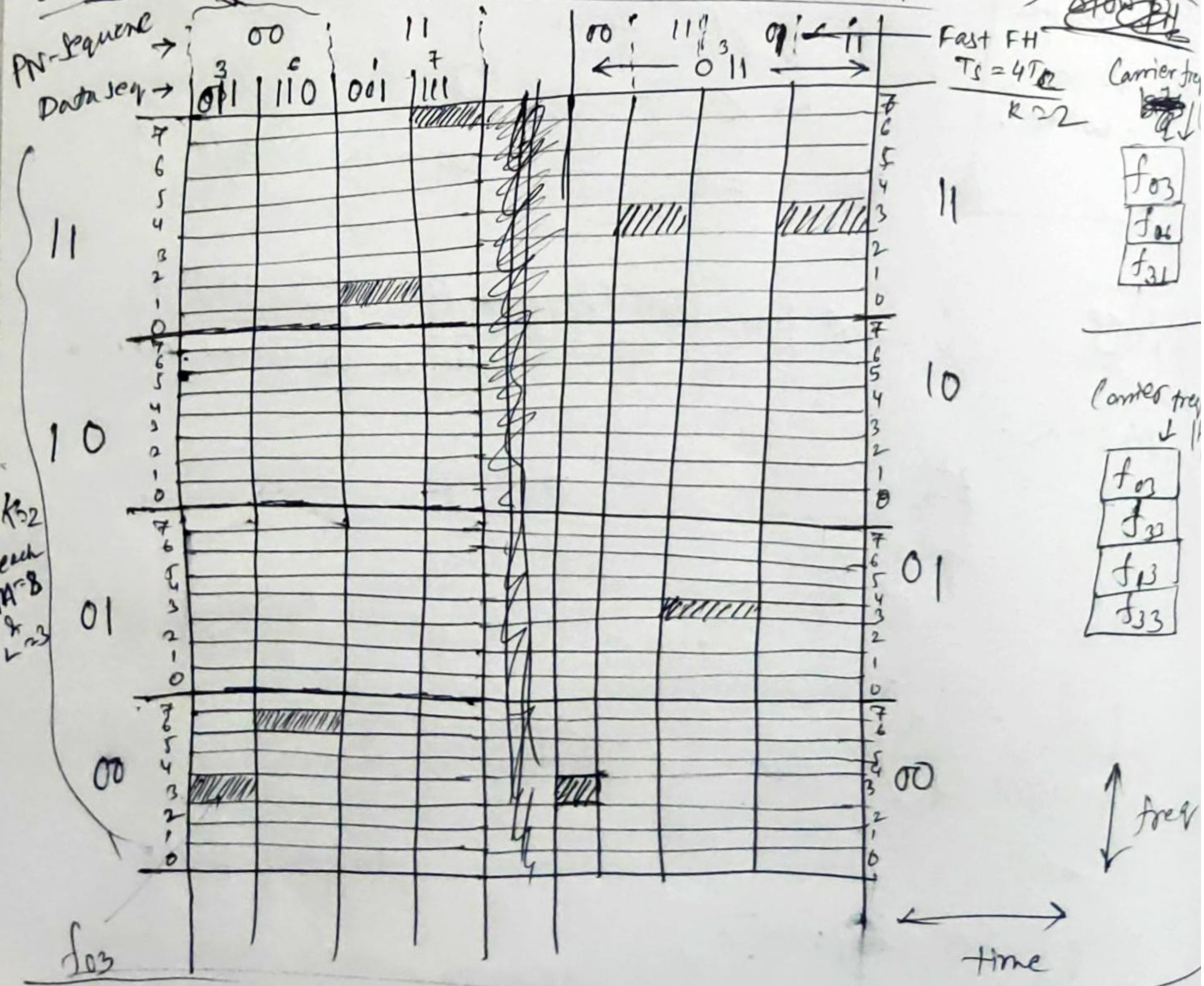
Let $T_c = 2 \cdot T_s$, for $\boxed{000 \mid 101}$

2 symbols will have same carrier freq.

- Slow FH → Lower security / weaker security.
- Fast FH → Higher security / stronger security.

$T_c = 2 \cdot T_s$ Slow FH

MFSK, $M = 8$ bit, $L = 3$, $k = 2$ bit $\rightarrow (0-3)$



f_{03}

$f_{ij} \Rightarrow i \rightarrow$ PN-seq, $j \rightarrow$ Data seq, $0 \le i \le 3$, $0 \le j \le 7$

$f_{03} = 3$ in 00 (K)

For $K = 2$

Bandwidth =

for $K = 3$

Bandwidth =

Wifi has 14 Signal

3 - non-overlapped signals

1 2 3 4 5 6 7 8 9 10 11 12 13 14

$\xleftrightarrow{\quad 5 \quad}$ $\xleftrightarrow{\quad 5 \quad}$

1, 6 & 11 are non-overlapping freq.

- This is a 3-colorable Graph (NP-Hard).

- 5G-NR (New Radio). — Spreading Code,

20/02/20 CN

Framing Techniques

① Character Based framing

a> Character Count.
b> Flag Byte with Byte Stuffing.

- length of frame = integer multiple of no of characters.
(Frame size)

- Unicode → 16-bit character encoding/mapping.

- ESC (Escape Character) - Inserted before the flag.
(1 byte size)

- Single ESC - Framing Escape.
- Two Consecutive ESC - One ESC is removed & another ESC is considered as Data

② Length Based Framing

- Disadvantage - Error Prone.
- Advantage - Multi-character encoding.

(3) Fixed Length Based Framing.

ATM → 53 Bytes.
(Asynchronous Transmission Mode)

- Padding (to make ~~for~~ all frames as size of 53 bytes)

(4) Flag Byte with Bit Stuffing

Flag → 0 111 111 0 (Starts & ends with same bit)
→ $0 1^6 0$

~~Rule → $0 1^5$ 0 ← (bit stuffing with 0 bit)~~

Rule : $0 1^5 \overset{\downarrow}{0}$ ← (bit stuffing with 0 bit)

- If zero is preceeded by ~~at most~~ 5, ~~~~ one's, That zero will be removed (as it is stuffed bit)

- If zero is preceeded by 6 one's then ~~~~ the whole byte will be considered as flag.

original 1 → 0 11111 11

after 0 stuff into original 1 → 011111 $\overset{\downarrow}{0}$ 11

Original 2 → 011111 0 11

} The Receiver won't be able to distinguish b/w these two as the first one is ~~Stuffed~~ Stuffed i/p & the second one is ~~~~ another original i/p.

For sending L bits, ~~Bits~~ stuff bit's occurs $\left(01^{k}\right)$ times.

This will occur with probability $= \frac{1}{2^k}$

This ~~stre~~ stream will occur for bit length L $= \frac{L}{2^k}$ ~~+~~ (overhead due to no of ~~to~~ stuffed bits)

Flag length $= (K+2)$ (overhead due to flag length)

The total no bits. transmitted (Expected overhead) $= \frac{L}{2^k} + K + 2$

For length K, Flag ~~Edg~~ $= 01^{K}0$

By ~~Calculus~~ Calculus, $K = \log_2 L$ (for optimum value)

BER $= 10^{-2}$

BER $= 10^{-12}$, Data Rate $= 10$ G bps $\rightarrow$ Error will occur after 100 sec.

Binary Symmetric channel (BSC)

$\epsilon \rightarrow$ Bit error probability.

$L \rightarrow$ length

if $|\epsilon| \ll 1$

~~$1-\epsilon$~~ Probability of Success $= 1 - \epsilon^{L} = 1 - \epsilon L$

~~So~~ Failure Probability $= \epsilon^{L} = \epsilon L$ if $|\epsilon| \ll 1$

$(1+x)^n = 1 + nx$ if $|x| << 1$

for j-hops, $(j-1)$ intermediate nodes will be there.

~~$k \to$ frame length~~

$V \to$ Overhead per frame

$L \to$ frame length

$M \to$ Message with multiple frames.

K_{max} = Max length of a frame.

No of frames $= \lceil M / K_{max} \rceil$

Total overhead $= \lceil M / K_{max} \rceil * V$

Total Data for Transmission (Expected Data overhead) $= M + \left(\lceil M / K_{max} \rceil * V \right)$

~~Delay =~~ $\cancel{K_{max} + M}$

Delay in Intermediate Node (Delay overhead) $= \left(\frac{K_{max} + V}{C} \right) * (j-1)$

C: Channel Capacity for single intermediate frame

End-to-End Delay (Total Delay) $\cancel{\frac{M + \lceil M / K_{max} \rceil V}{C}} + \cancel{\left(\frac{K_{max} + V}{C} \right)(j-1)}$

$$T = \frac{M + \lceil M / K_{max} \rceil V}{C} + \left(\frac{K_{max} + V}{C} \right)(j-1) + P + Q$$

$P \to$ Propagation time

$Q \to$ Queuing Delay

$$\cancel{E[T] = \left(\frac{M}{K_{max}}\right)\left(\frac{V}{C}\right) +}$$

$$E[T] = \left(\frac{E[M]}{K_{max}}\right)\left(\frac{V}{C}\right) + \frac{K_{max} * (j-1)}{C} + *$$

constant

$$K_{max} = \sqrt{\frac{E[M]}{j-1} V}$$

If j is large, K_{max} should be low.
(longer transmission distance)

Problem

Q.) One packet is split into 10 frames & it has 80% chance of arriving successfully. If no error control is done, how many times the packet has to be sent to successfully transmit the message?

→ Success probability = 80%.

Success of all 10 frames $= (0.8)^{10} = p$, say

(in i-th attempt, success occurs)

$$\sum_{i=1}^{\infty} i \cdot p(1-p)^{i-1} = 1/p$$

Q:2) Transmit → 64 bits, Flag : 0111 1110

O(Data size)

What is the largest & smallest no of bits needs to be transmitted? (bit stuff for 01^5 occurs)

→ ~~Min~~ smallest → 64 + 2 × flag size

= 64 + 16 = 80 bits

Largest → ~~64~~ $80 + \cancel{\left\lceil \frac{64}{5} \right\rceil}$

(01^5) occurs

Data stream will be → 0 followed by all 1's

~~0111~~

0111110 ⟷ 0111110

64 ones as data bits

Largest → $80 + \left\lfloor \frac{64}{5} \right\rfloor = 92$ bits

bit stuff for (01^5) occurs

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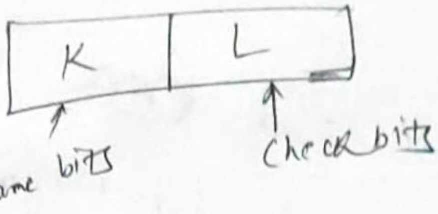
Error Detection:

- Codeword →



- Single parity bit:

Even parity $K = 5,\ L = 1$

$10111\ \boxed{0}$

$11100\ \boxed{1}$

In Binary Symmetric channel model (BSC), no error detected in a string, but prob that there is error
the error is ~~not~~ present =

$$= \sum_{i>0} {}^{K}C_{2i}\, p^{2i} (1-p)^{K-2i}$$

- <u>Data Sensitivity</u> : for K - frame & L - check bits,

total combination $= 2^{K+L}$

Data combinations $= 2^{K}$

as ~~parity~~ check bits are function of Data frame (derived w.r.t. data given).

$\therefore$ Data Sensitivity $= \dfrac{2^{K}}{2^{K+L}} = 2^{-L}$

- If min distance $= d$ ~~(min)~~

if there is $(d-1)$ no of errors, we cannot detect the error.

- <u>Burst Error Detecting Capability</u>:

For length K, General error of Burst K (Single burst error)

$$x^{i}\left(x^{K-1} + \dots + 1\right)$$

$$= x^{i+K-1} + \dots + x^{i}$$

- Error starts from i-th position & till the $(i+K-1)$th position, there may or may not be error.

- The first & last bit has error, in between all bits may or may not have any error.

$n \times m$ matrix

~~n~~ ~~m~~ n rows, m col^n

Even parity

$$
\begin{array}{ccccc|c}
1 & 0 & 1 & 1 & 0 & \boxed{1} \\
1 & 1 & 0 & 1 & 0 & \boxed{1} \\
1 & 0 & 1 & 1 & 1 & \boxed{0} \\
\hline
\boxed{1} & \boxed{1} & \boxed{0} & \boxed{1} & \boxed{1} & \boxed{0}^{*}
\end{array}
$$

Horizontal Check bits

whole Data parity.

vertical check bits

$$\text{Parity Bits} = (\underset{\text{Row}}{n} + \underset{\text{col}^n}{m} + 1) = L$$

$$\text{Data bits} = K = nm$$

- In this particular pattern, 1/2/3 - bit error detected trivially.

For 4-error, if the error bits ~~are squares~~ form a square, we can't detect that.

(If two errors in same row & two errors in same col^n.)

~~Data bits~~:

- $S_{K-1} \ldots S_1 \, S_0 \; C_{i-1} \ldots C_1 \, C_0$

$$\underbrace{S_{K-1} \ldots S_1 \, S_0}_{\text{Data Bits}} \;\; \underbrace{C_{i-1} \ldots C_1 \, C_0}_{\text{Check Bits}}$$

$$C_i = \sum_{j=0}^{K-1} \alpha_{ij} S_j$$

for n-length 2 extreme cases are → All ones

1 1 1 1 1 1 1 1 1 1 111

& Two ones at start & end, all zeroes in between

1 0 0 0 0 0 ... 0 0 0 1

for n bits, for $(n+1)$ ~~pattern~~ error can be detected

for $(n+2)$ only for one configuration, error can be detected.

- To increase the burst error capability by 1 (from n to $n+1$) we have to add m-many bits.

- $S(x) \rightarrow$ Polyⁿ. representation of data bits.

$C(x) \rightarrow$ Check bits (CRC)
Cyclic Redundancy Check bits

$g(x) \rightarrow$ Generator polyⁿ. (Let $g(x) = 1011$
$\therefore g(x) = x^3 + x + 1$)

Let, L be the degree of $g(x)$.

$$C(x) = \underset{\text{Remainder}}{\text{Rem}} \left[\frac{S(x) \cdot x^L}{g(x)} \right]$$

if, $S(x) = 1101$
$L = 3$
Polyⁿ. $= 1101\underbrace{000}_{3 \text{ zeros}}$
$x^6 + x^5 + x^3$
$= (x^3 + x^2 + 1)x^3$
$\quad\; S(x)$
$= S(x) \cdot x^L$

~~Transmitting~~
Transmission Signal $\rightarrow T(x) = S(x) \cdot x^L + C(x)$

- If there is no error, T(x) will be a multiple of g(x)

$$g(x) \overline{\big) S(x)\,x^2 \big(} \; Z(x) \text{ Quotient}$$

$$\vdots$$

$$C(x)$$

$$S(x) \cdot x^2 = g(x) \cdot Z(x) + C(x)$$

$$T(x) = g(x) \cdot Z(x) + C(x) + C(x)$$

$$= g(x) \cdot Z(x) + 0$$

$$= g(x) \cdot Z(x)$$

For modulo 2 string (Binary)

$$\boxed{[C(x) + C(x)]_{\text{mod } 2} = 0}$$

- $T(x) + e(x)$

* - bit error

$T(x) \rightarrow 1\ \underset{*}{0}\ 1\ \underset{*}{1}\ 0$

$+$

$e(x) \rightarrow 0\ 1\ 0\ 1\ 0$

$T'(x) \rightarrow 1\ 1\ 1\ 0\ 0$ → ~~Trans~~ This will be Transmitted

$$\frac{T'(x)}{g(x)} = \frac{T(x)}{g(x)} + \frac{e(x)}{g(x)}$$

one bit error

$$e(x) = x^i$$

$$g(x) = (\ldots\ldots) + 1$$

← $g(x)$ must have the x^0 term.

- So that any single bit error can be detected.

two bit error -

$$e(x) = x^i + x^j$$
$$= x^j\left(x^{i-j} + 1\right) = x^j\left(x^k + 1\right)$$

$\cancel{= x^j(x^k+1)}$

$1 \leq K = (i-j) \leq$ [illegible]

$$g(x) = f(x) + 1$$

$$g(x) = 1 + x^{14} + x^{15}$$ ← It does not have any $(1+x^k)$ as it's factor.

$1 + x^K \longrightarrow K < 32768$.

It can detect all Double bit errors.

Claim

$$g(x) = (1+x)\, q(x)$$

It can detect any error having odd no of terms -

$$g(1) = (1+1)\, q(1)$$
$$= 0$$

$$e(x) = e(1) = 1$$

→ we want, $e(x)/g(x)$ where degree $(g(x)) = L$

$$e(x) = \frac{x^i\left(x^{k-1} + \ldots\ldots + 1\right)}{g(x)}$$

Here degree (Numerator) < degree (Denominator)
So the Remainder will not be zero, it will be detected.

Degree (Numerator)
Degree (Denominator)

$K-1 < L$
$K < L+1$
$K \leq L$

A burst of ~~(L+1)~~ length (L+1) will not be detected

$$= \frac{1}{2^{L-1}}$$