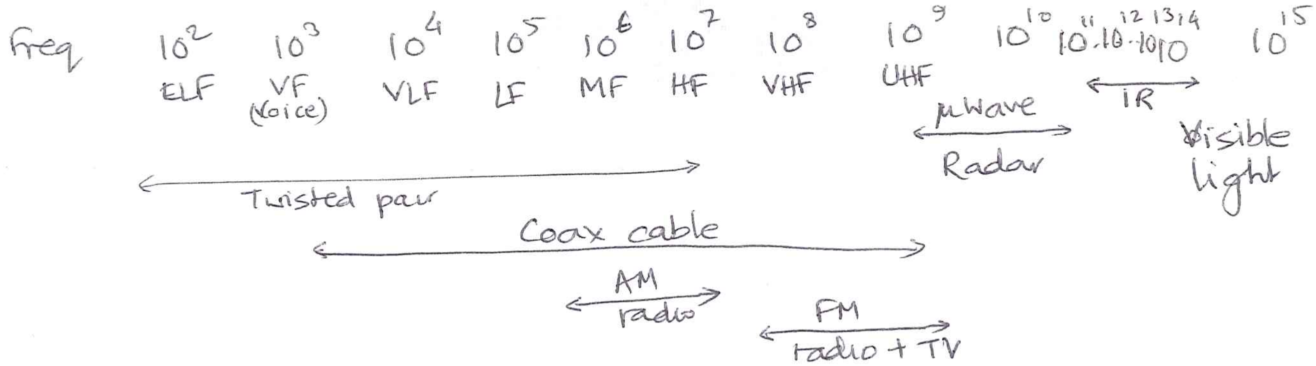
Unguided transmissions & guided transmissions



Directionality of signals

Low freq ⇒ more omni

High freq ⇒ more directional

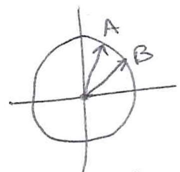
1GHz → 100 GHz
μwave freq.

30MHz → 1 GHz
radio freq.

~~Loss $L = 10 \log \left(\frac{4\pi d}{\lambda} \right)^2$ dB μwave, radio~~

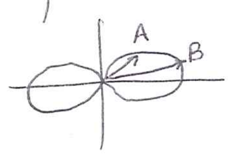
Antennas

Omni



$|A| = |B|$ isotropic

Directional

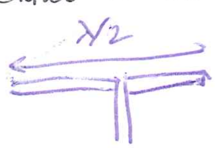


$|A| \neq |B|$

Beam width → measure of directivity

or

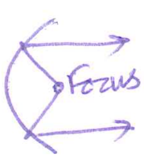
half power beam width → angle within which power radiated by the antenna is at ~~too~~ least half of most preferred direction.



Half wave dipole

Quarter wave antenna

Parabolic grid antenna



Gain, $G = \frac{4\pi A_e}{\lambda^2} = \frac{4\pi f^2 A_e}{c^2}$

A_e : effective area

f : frequency of carrier

c : speed of light

λ : carrier wavelength

Loss (other antenna)

$$\frac{P_t}{P_r} = \frac{(4\pi)^2 d^2}{G_r G_t \lambda^2}$$

But $G = \frac{4\pi A_e}{\lambda^2}$ then $\frac{P_t}{P_r} = \frac{(\lambda d)^2}{A_r A_t} = \frac{(cd)^2}{f^2 A_r A_t}$

Thus for same antenna size (A_r, A_t), $f \uparrow \Rightarrow$ loss $\downarrow$

Compare

$$L_{dB} \text{ (isotropic)} = 20 \log(f) + 20 \log(d) - 147.56 \text{ dB}$$

$$L_{dB} (A_r, A_t) = -20 \log(f) + 20 \log(d) - 10 \log(A_t A_r) + 169.54 \text{ dB}.$$

What is the isotropic free space loss at 4GHz for shortest path to a synchronous satellite from earth (35,863 km).

$$L_{dB \text{ (free space)}} = 20 \log(4 \times 10^9) + 20 \log(35.853 \times 10^6) - 147.56 = 195.6 \text{ dB}$$

Consider antenna gains (satellite & ground) of 44 & 48 dB

Then $L_{dB \text{ (antenna)}} = 195.6 - 44 - 48 = 103.6 \text{ dB}$

If Tx power at earth station = 250W, what is Rx power?

250W = 24 dBW

So Rx Power at satellite is $24 - 103.6 = -79.6$ dBW $= -49.6$ dBm

(6)

Noise : unwanted additional signals that distorts main signal

- Thermal noise → thermal agitation of electrons (present in all electronic devices & is a function of temperature)

  uniformly distributed across all frequencies (hence, called white noise)

  Cannot be eliminated & places an upper bound on communication systems performance

  Since signal from satellite to ground weakens a lot, thermal noise becomes important in satellite communications.

  $N_0 = kT$ (W/Hz) → T: temperature in K

  k: Boltzmann's constant 1.38×10^{-23} J/K

  Room temp = 17°C = 290 K

  $N_0 = 1.3803 \times 10^{-23} \times 290 = 4 \times 10^{-21}$ W/Hz $= -204$ dBW/Hz

  $N = kTB$ → B: bandwidth

  In dBW, $N = 10 \log k + 10 \log T + 10 \log B$

  $= -228.6 \text{ dBW} + 10 \log T + 10 \log B$.

  At 21°C (294K), 10 MHz bw,

  $N = -228.6 + 24.7 + 70 = -133.9$ dBW

- Intermodulation noise $\xrightarrow{\text{due to}}$ non-linearity of transmitter, receiver or intervening Tx system

  (often due to malfunction or use of excessive signal strength)

- Crosstalk

  ↳ can dominate in ISM band

- Impulse noise → irregular pulses/spikes of high magnitude (eg. lightning)

E_b/N_0

E_b: energy per bit $= \frac{S}{R}$ ← S: signal power; R: Rate $= \frac{1}{T_b}$ → T_b: time for 1 bit

$\therefore \frac{E_b}{N_0} = \frac{S}{RN_0} = \frac{S}{kTR}$

in dB ⇒ $S_{dBW} - 10 \log R + 228.6 \text{dBW} - 10 \log T$.

BER depends on E_b/N_0

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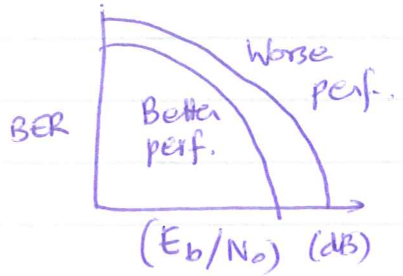


Different Tx/Rx systems have different curves

$$\frac{E_b}{N_o} = \frac{B}{C}\left(2^{C/B} - 1\right)$$ → under Shannon capacity

C/B = Spectral efficiency

$$\frac{E_b}{N_o} = \frac{SB}{RN}$$ (B → bandwidth)

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

i.e. $\frac{S}{N} = 2^{C/B} - 1$

by making $R = C$, we have $\frac{E_B}{N_o} = \left(2^{C/B} - 1\right)\frac{B}{C}$

Atmospheric absorption

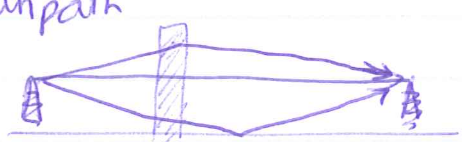
With water : peak attenuation around 22 GHz

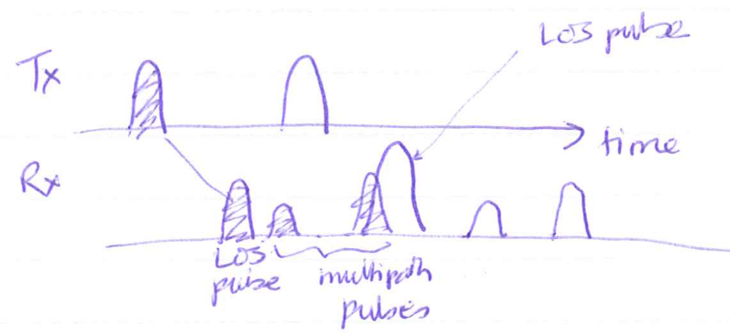
~~Wat~~ With O_2 : " " " 60 GHz, but less below 30 GHz

Rain & fog causes scattering of radio waves

So in areas of high rain/fog, use lower frequency or small hops

Multipath



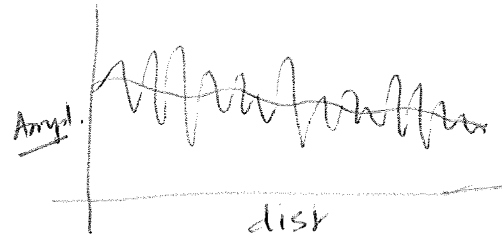


Types of fading

Fast fading → order of a wavelength. eg. due to multipath

2.4 GHz → 0.15m (approx).

Slow fading → SNR reduces ~~and so~~
↳ well over a wavelength

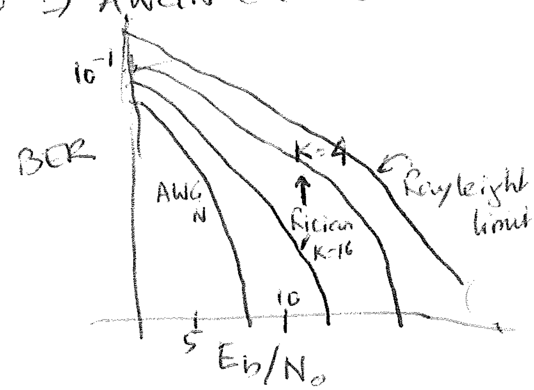


Rayleigh fading
→ No LOS path ↘
↗ + other multi-paths
Rician fading → a direct LOS path

$K = \frac{\text{power in dominant path}}{\text{power in scattered paths}}$

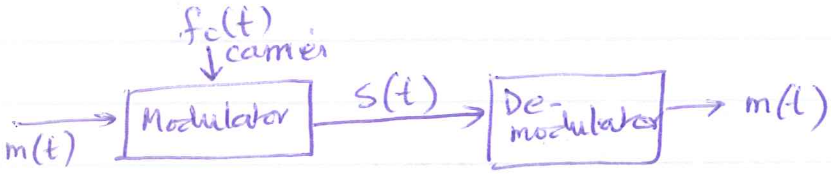
$K = 0 \Rightarrow$ Rayleigh

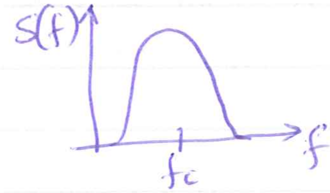
$K = \infty \Rightarrow$ AWGN channel



Encoding : Digital / analog data → Digital form

Modulation : transform a baseband signal to a carrier signal





Data rate ↑ ⇒ BER ↑

SNR ↑ ⇒ BER ↓

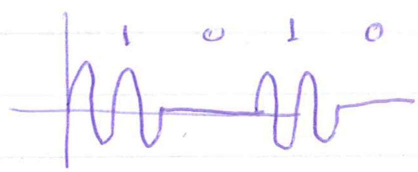
Bandwidth ↑ ⇒ Data rate ↑

Digital data using analog signals : Data on Public Telephone Networks

So data need to be modulated to this frequency (modems)] 300 – 3400 Hz target frequencies to carry voice

ASK → eg. optical fiber LED
amplitude shift keying

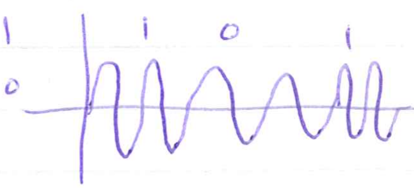
$$s(t) = \begin{cases} A\cos(2\pi f_c t) & \text{bit 1} \\ 0 & \text{bit 0} \end{cases}$$



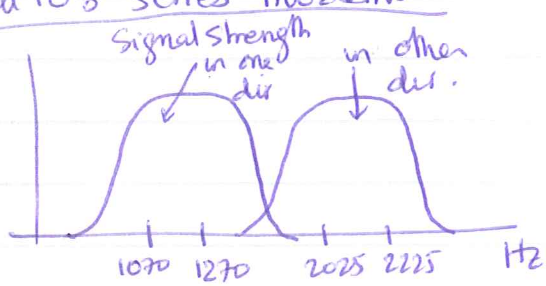
FSK
frequency

Binary FSK

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



eg. Bell 108 series modems



full-duplex communication

BPSK

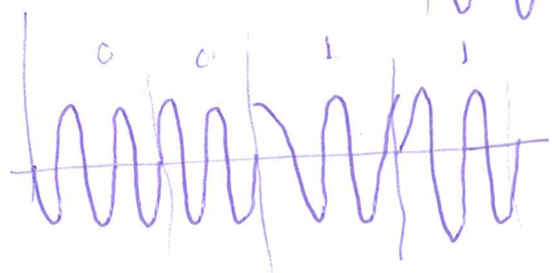
$$s(t) = \begin{cases} A\cos(2\pi f_c t) \\ A\cos(2\pi f_c t + \pi) \end{cases} = \begin{cases} A\cos(2\pi f_c t) & 1 \\ -A\cos(2\pi f_c t) & 0 \end{cases}$$

If $d(t) = \pm 1$

then $s(t) = A\,d(t)\cos(2\pi f_c t)$

DBPSK

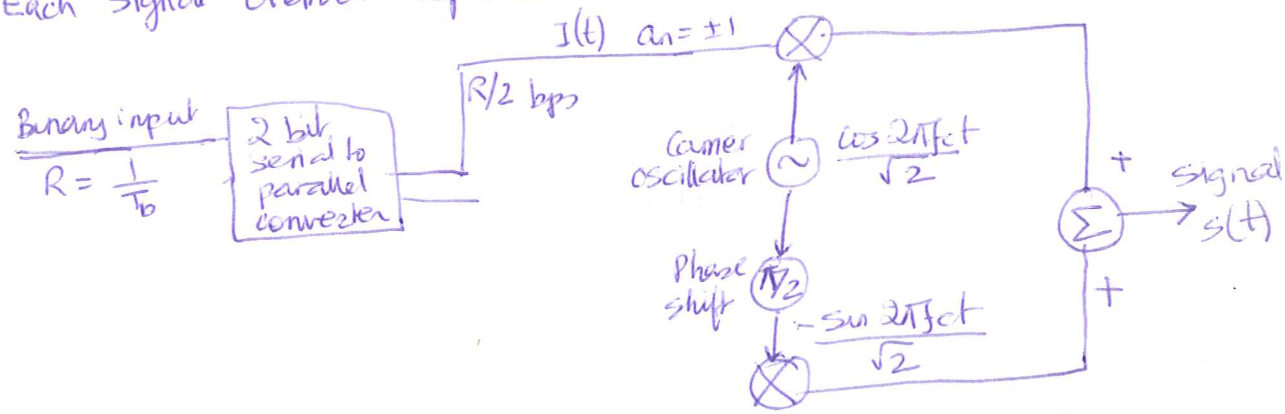
0 ⇒ no transition
1 ⇒ transition



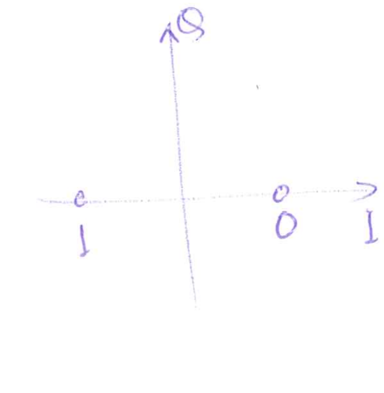
QPSK

$$s(t) = \begin{cases} A\cos\left(2\pi f_c t + \frac{\pi}{4}\right) & 11 \\ \cos\left(2\pi f_c t + \frac{3\pi}{4}\right) & 01 \\ \cos\left(2\pi f_c t - \frac{3\pi}{4}\right) & 00 \\ \cos\left(2\pi f_c t - \frac{\pi}{4}\right) & 10 \end{cases}$$

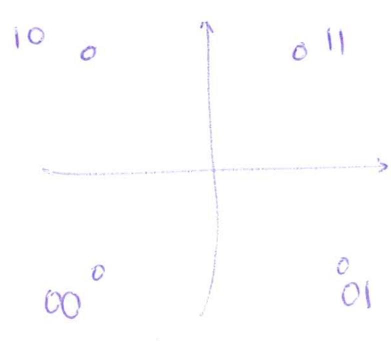
Each signal element represents 2 bits



BPSK



QPSK



16 QAM → Both phase & amplitude