Principles of Communication Systems

Elements of a Communication System and Data Fundamentals

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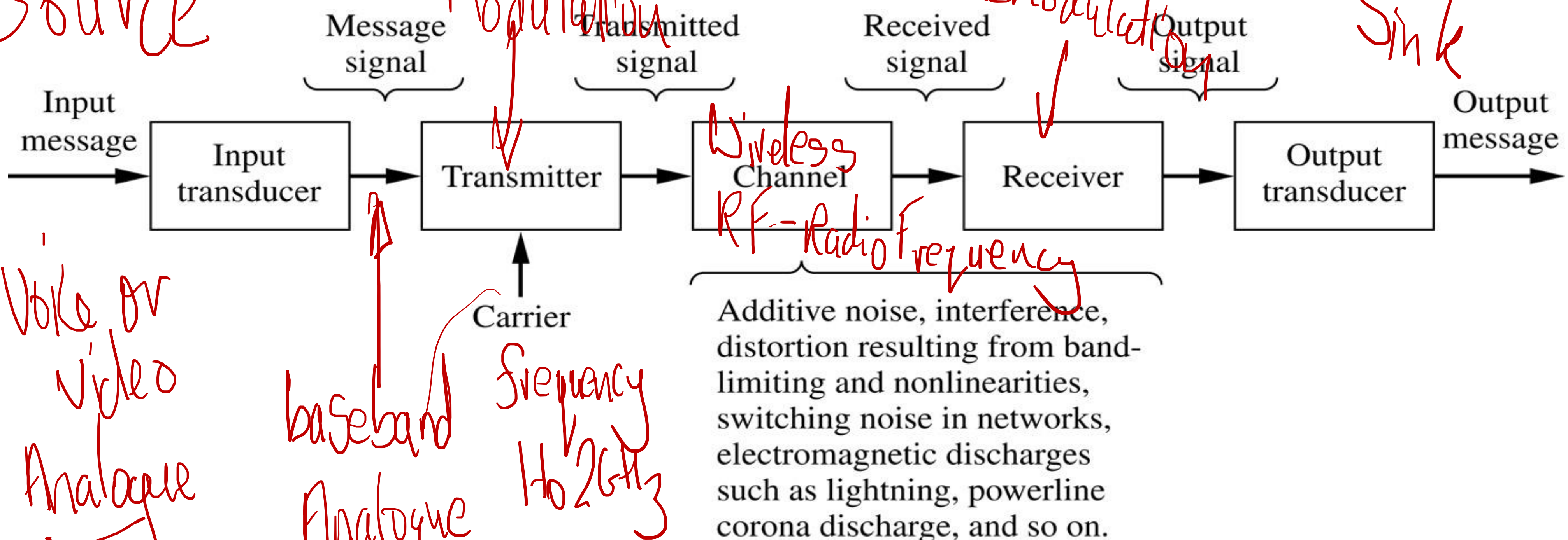
Communication Systems
& Message types

Elements of a Communication System



Source

Modulation

demodulation

Sink

Wireless

RF - Radio frequency

Voice or video

Analogue or digital

baseband

Analogue or Digital

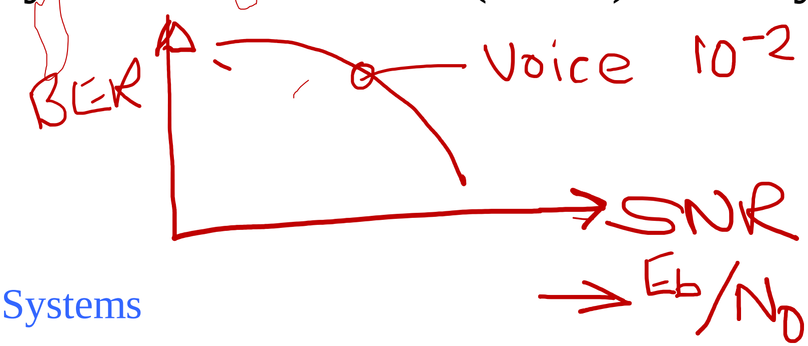
frequency 1 to 2GHz

Other users

→ co-channel interference

Characteristics of Message Type

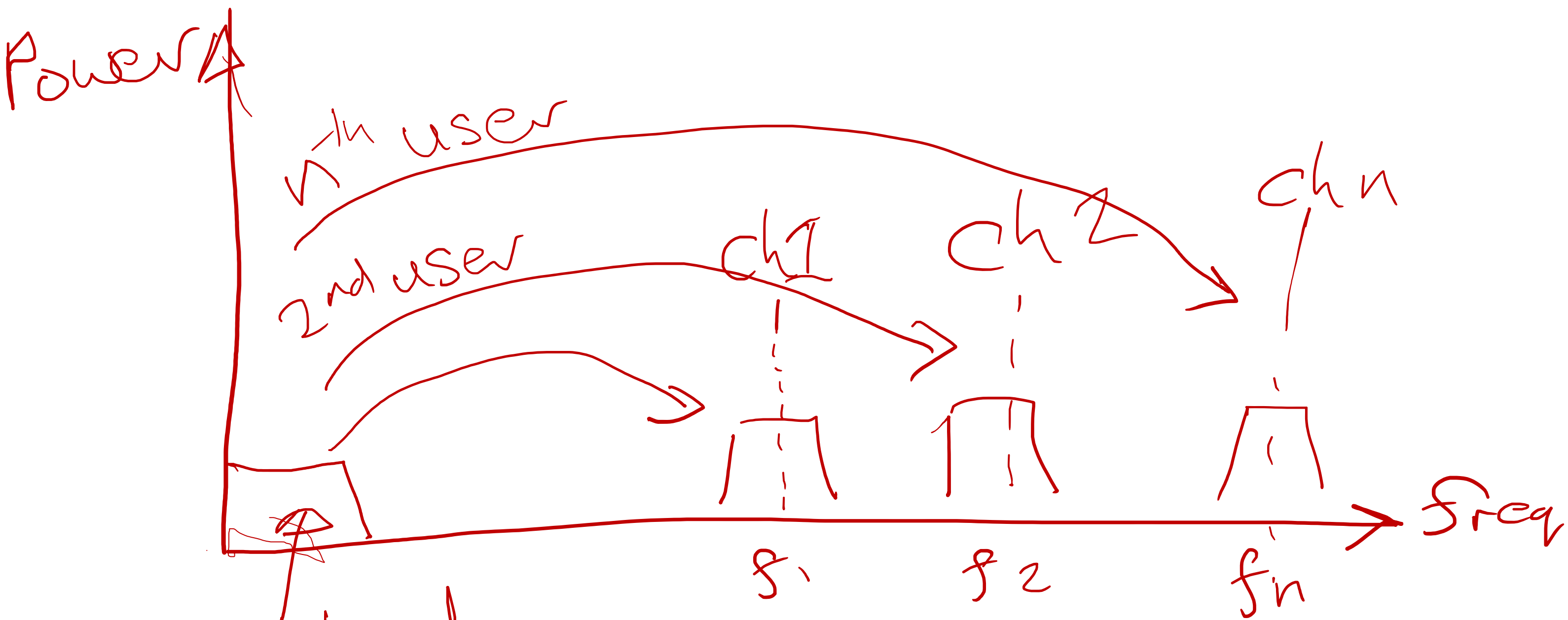
- Analogue: Electrical analogue of physical signal (e.g. light intensity, sound level). SNR
  - Characterised by: Distortion, Signal to noise ratio, fidelity, Mean Opinion Score. MOS → cell phone 3.2 to 3.4
- Digital: Discrete symbols selected from a finite set (e.g. letters of the Alphabet, binary numbers).
  - Characterised by: Bit Error Rate (BER) and Symbol Error Rate (SER).



Elements of the Communication Link: The Transmitter

- Processes the message signal to produce a signal suited to the characteristics of the channel.
  - The process will involve modulation and may involve coding and interleaving.

1 to 2 GHz → best propagation & Antenna characteristic



Frequency Division Multiple Access (FDMA)

Transmitter, Channel & Receiver

Elements of the Communication Link: The Transmitter

- Processes the message signal to produce a signal suited to the characteristics of the channel.
  - The process will involve modulation and may involve coding and interleaving.

channel error → burst errors (mobile deep fading)
impact on adacent data bit
inter leave to avoid burst error

Elements of the Communication System: The Transmission Channel

- The Electrical media between the source and the destination of the message.
  - Examples: Fibre Optic cable, Terrestrial microwave links, Satellite links, Coaxial cable, Mobile radio.
  - Media characterised by: Loss/Attenuation, Bandwidth, Noise/Interference, Distortion.

Wireless → channel attenuation ∝ (frequency)^2

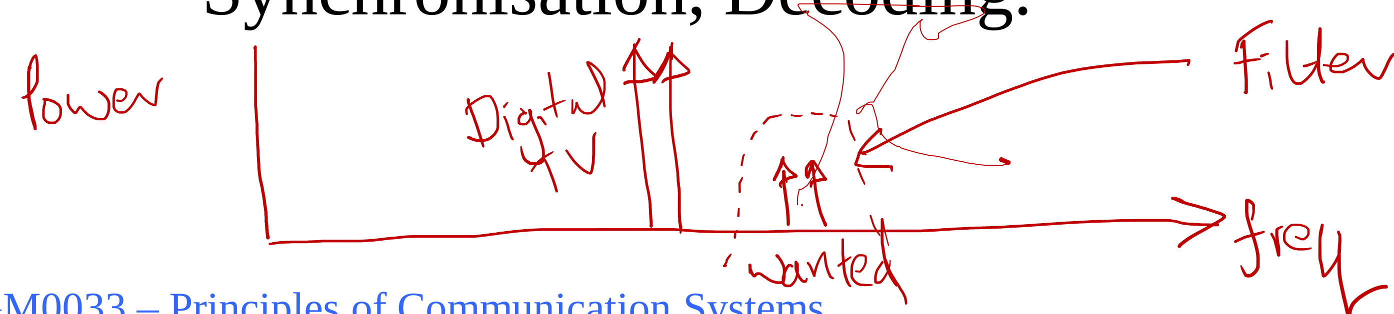
5G New Radio (NR) → Sub 6GHz (FR1)

→ millimetre channel 26GHz / 28GHz FR2

28dB more attenuation at mmwave than sub-6GHz

Elements of the Communication Link: The Receiver

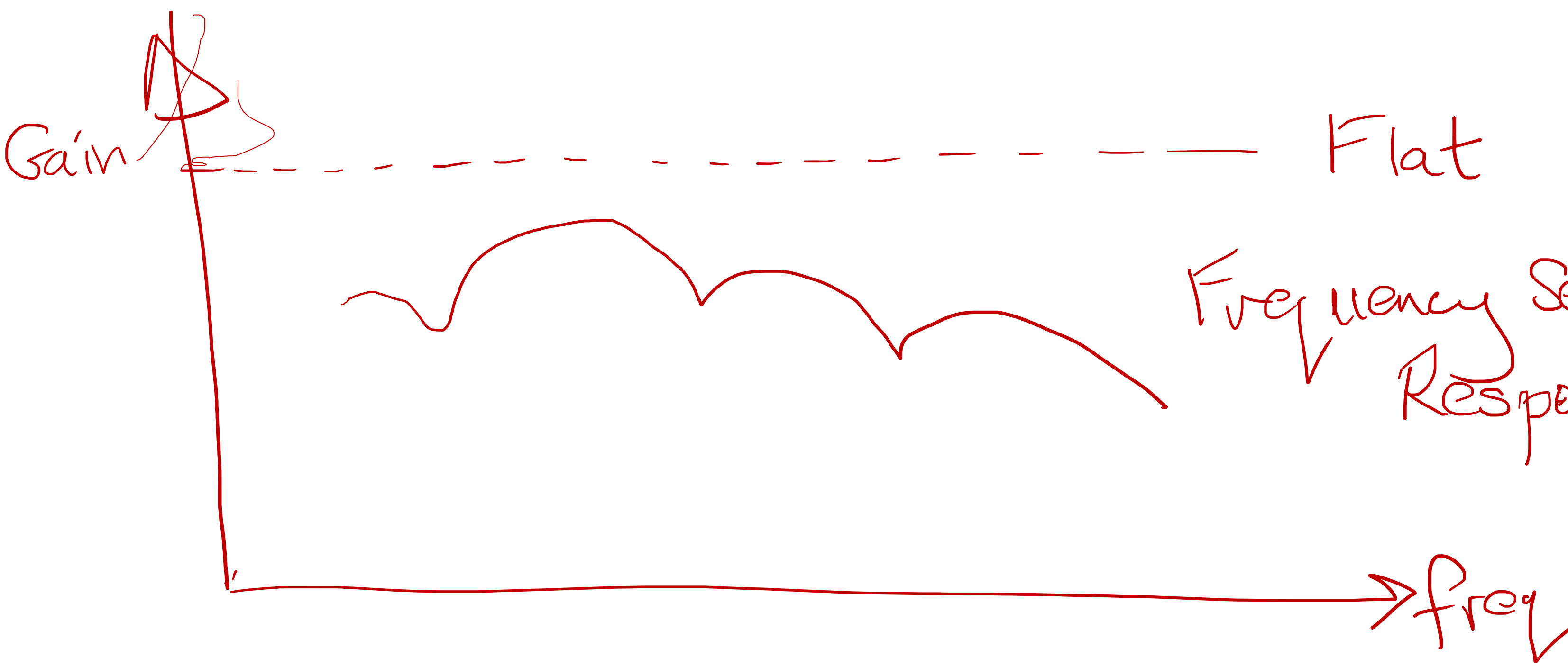
- The receiver extracts the message.
  - The processes that occur within a receiver are thus essentially the reverse of what happens in the transmitter.
  - The following processes are usually involved: Amplification, Filtering, Demodulation, Synchronisation, Decoding.



Select the wanted channel.

Sources of Link Degradation

- Distortion
  - Gain variations with frequency and with time.
  - Frequency dependant phase shift which gives differential group delay.
  - Frequency offsets due to Doppler shift or local oscillator errors.
  - Distortion generated within the communications hardware (Tx and Rx)


Gain
Flat
Frequency Sensitive Response
freq

Sources of Link Degradation

- Distortion
  - Gain variations with frequency and with time.
  - Frequency dependant phase shift which gives differential group delay.
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phase
linear phase
non-linear groupdelay
Frequency

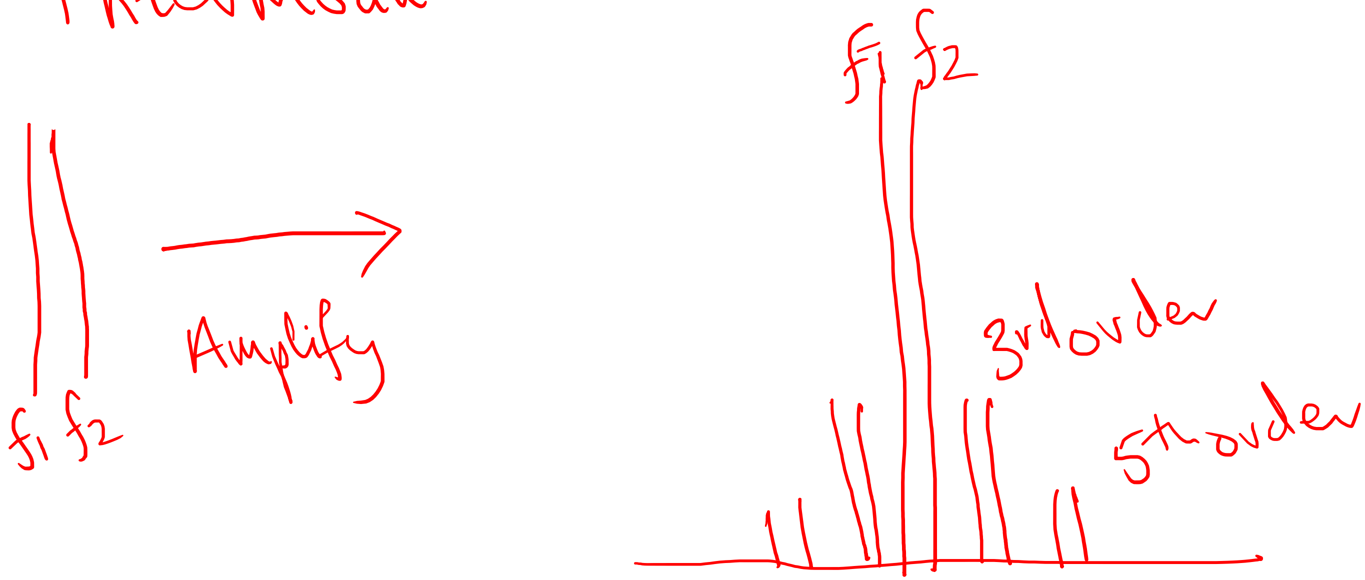
Imperfections, Distortion & Duplexing

Sources of Link Degradation

- Distortion
  - Gain variations with frequency and with time.
  - Frequency dependant phase shift which gives differential group delay.
  - Frequency offsets due to Doppler shift or local oscillator errors. Crystal osc 1 ppm error
    1Hz error @ 1MHz ⇒ 1GHz → 1kHz
  - Distortion generated within the communications hardware (Tx and Rx)

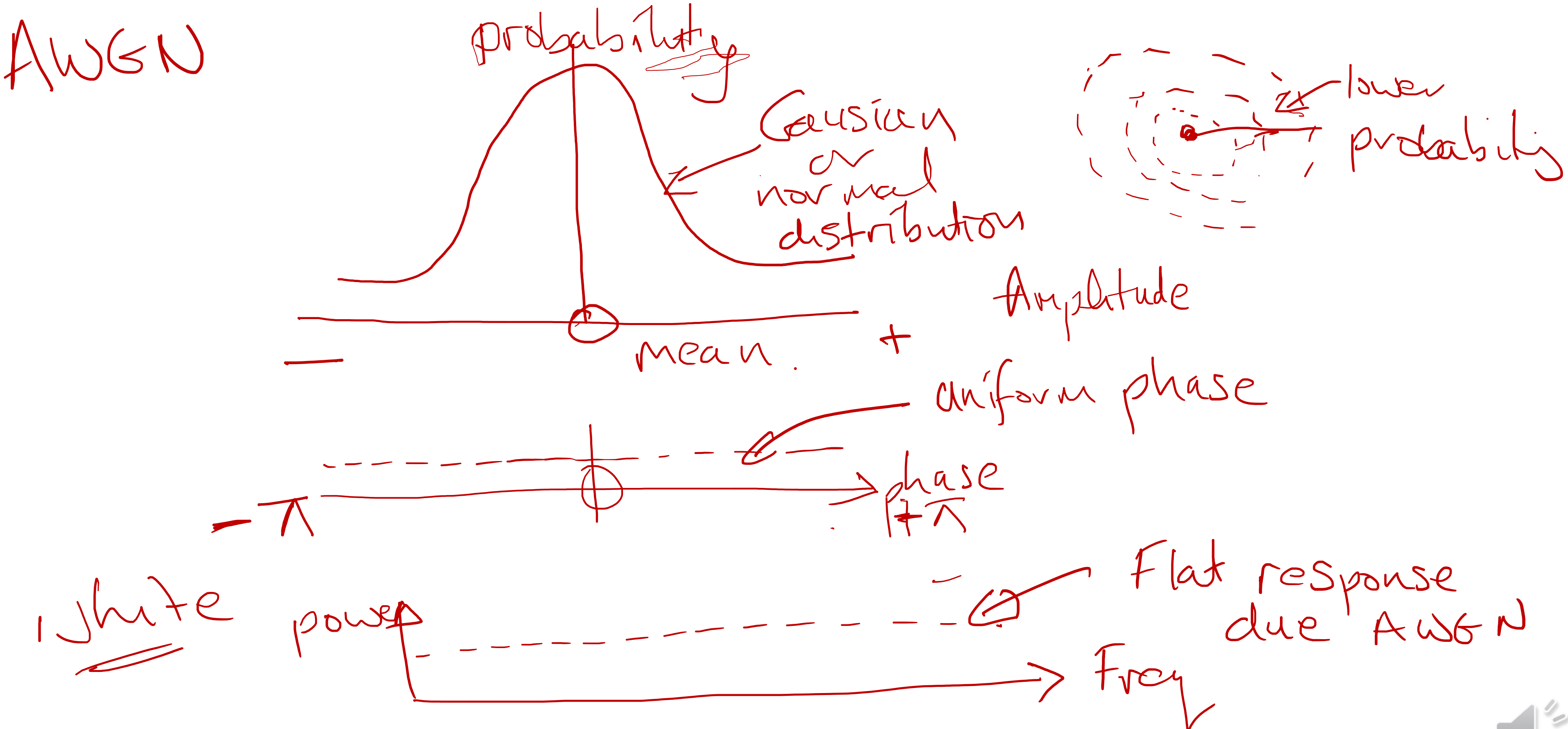
Harmonic distortion f_1, harmonics $2f_1$, $3f_1$, $4f_1$

Intermodulation Distortion (IMD)



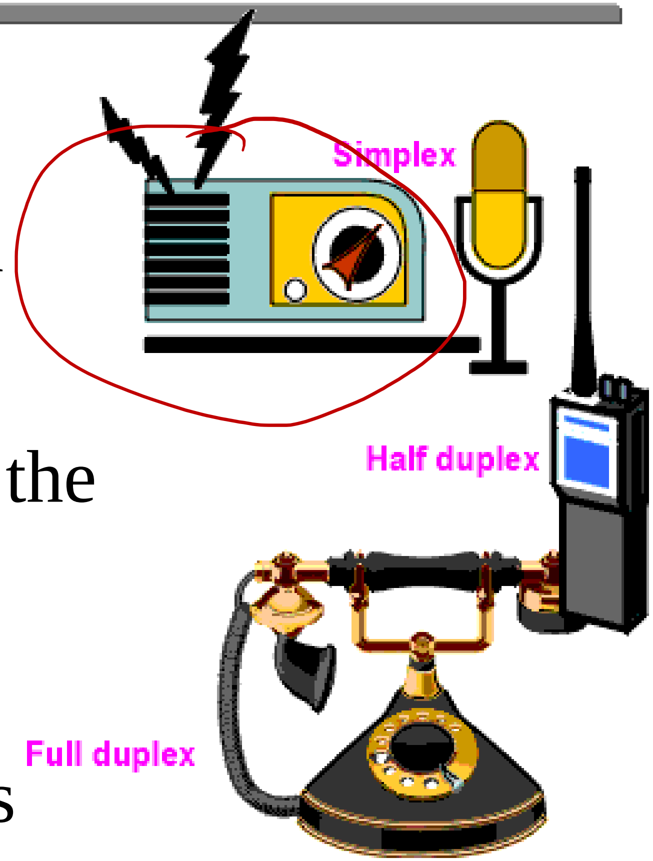
Sources of Link Degradation

- Noise
  - Characterised as random signals from natural sources.
    - Thermal noise: Due to the thermal agitation of electrons in the signal processing circuits.
    - Atmospheric noise: Caused by random electrical processes in the atmosphere at which an antenna is pointing.
  - Modelled as 'Additive White Gaussian Noise (AWGN)


AWGN
probability
Gausian
or
normal
distribution
mean
−
+
lower
probability
Amplitude
uniform phase
phase
−π
+π
white
power
Freq
Flat response
due AWGN

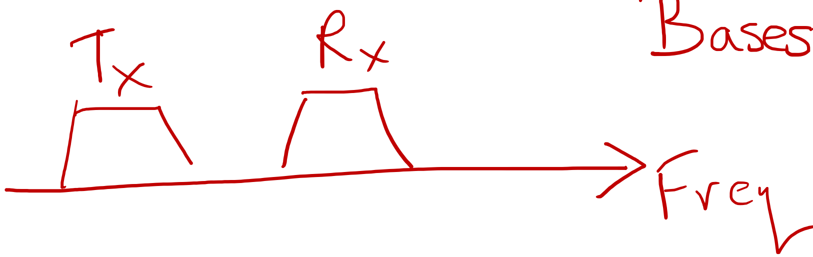
Transmission Protocols or Duplexing

- Simplex
  - Communication Flow in ONE direction
- Half Duplex
  - Two way communications, but NOT at the same time
- Full Duplex
  - Simultaneous two-way communications



Duplex:

Freq Duplex



Basestation

pair of frequencies per active user

Time Division Duplex

on same frequency channel

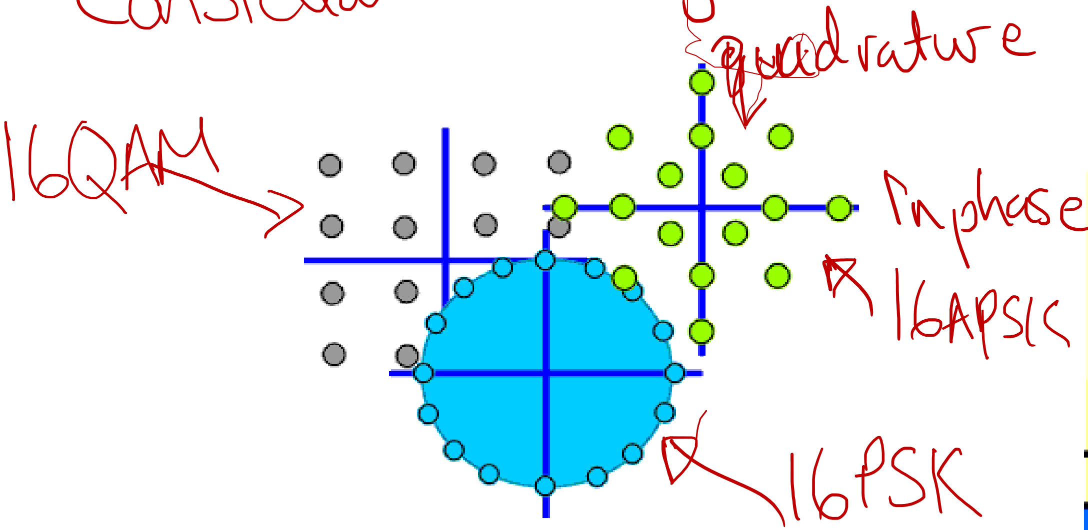
Data Fundamentals
(bits and Symbols)

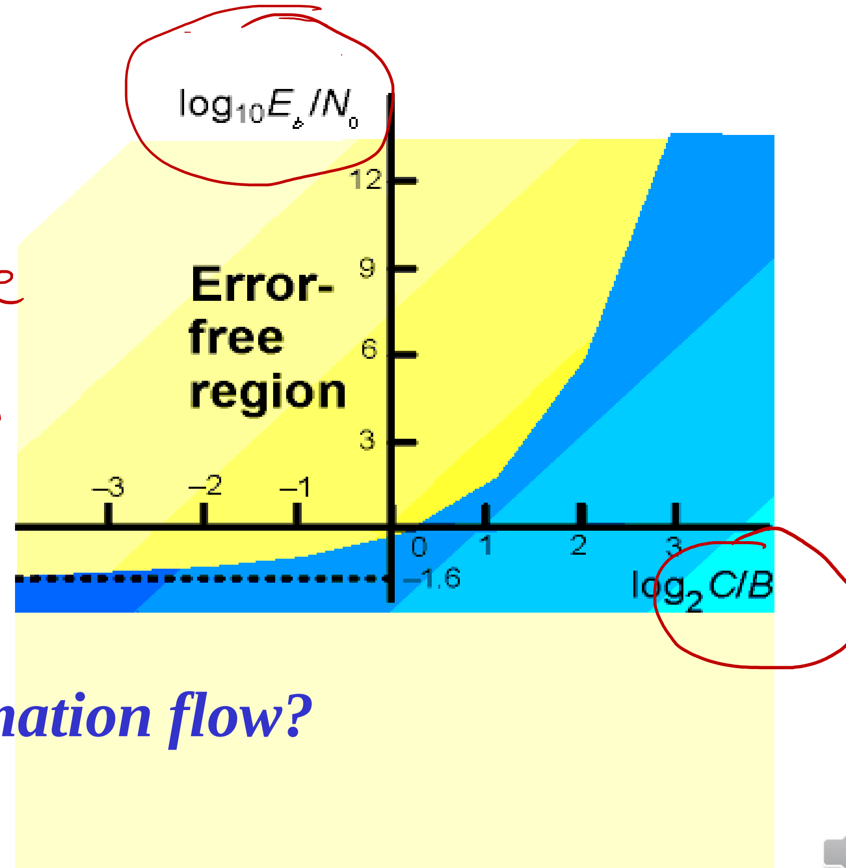
Factors Affecting System Design: Bandwidth

- Bandwidth dictates how quickly a signal can vary with time.
- All signals must ultimately have some bandwidth limitation as it is not possible for signals to vary instantaneously in nature (requires an instantaneous change of energy level).

Data Transmission Fundamentals

Constellation diagrams





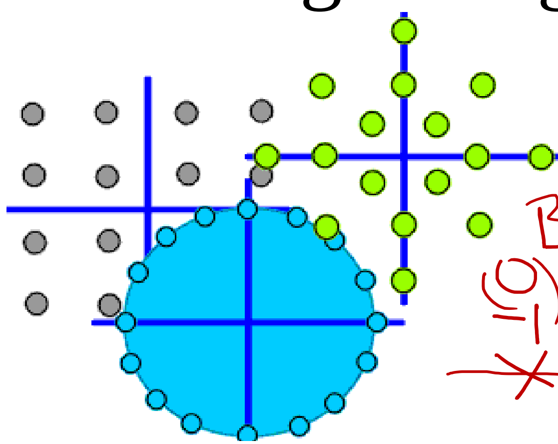
How quickly can information flow?

Methods of Digital Data Transmission

- Binary signalling
- Binary signalling over parallel channels
- Multi-level signalling
- Multi-level signalling over parallel channels

OFDM

2 bits
⇓
1 symbol



'Bits and Symbols'

BPSK

(0) −1

(1) +1

⇒

QPSK

0,1

0,0

1,0

11

Information transfer rate

- Information transfer rate is defined as the speed at which binary information can be transferred from the source to the destination over a particular channel.
  - The units are bits per second.
  - Eg: 6 bits of information sent every 6ms then the channel capacity is:

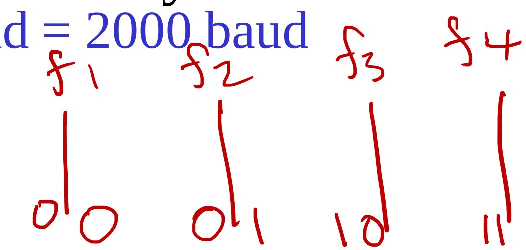
$$C = 6 \text{ bits}/6 \text{ ms} = 1000 \text{ bits/second}$$

Symbol rate (Baud rate)

- The information rate (channel capacity) must not be confused with the rate at which symbols are varied. We can encode many bits onto a single symbol.
- The symbol rate (often called Baud rate) is the rate of change of signal states on a channel.
  - The unit for symbol rate is **symbols /second** or **Baud**.
  - Eg: If we use 4 frequencies to convey 2 bits of information through a channel, and the frequency (symbol) is changed every 0.5ms then:

    Symbol rate =1/0.5ms = 2000 symbols/second = 2000 baud

    Channel capacity is however 4000 bits/sec.

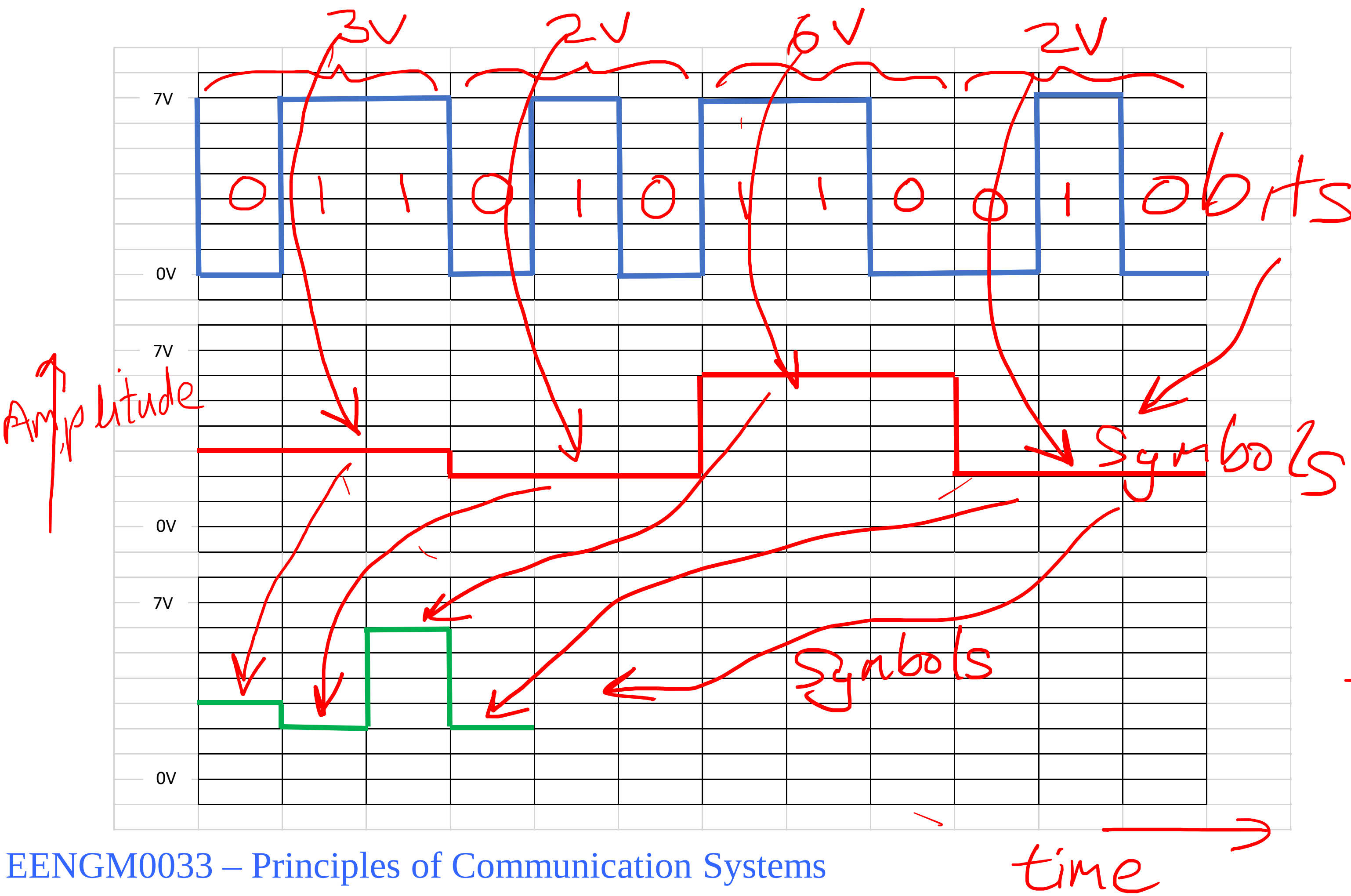


Bandwidth Efficiency

- The bandwidth efficiency of a communications link is a measure of how well a particular modulation format (and coding scheme) is making use of the available bandwidth
  - Units are bits/second/Hz
  - Eg: 4kHz of bandwidth is used to transfer 8000 bits/second,

bandwidth efficiency = 2bits/second/Hz

M-ARY Signalling - Example



reduced bandwidth requirement

reduced transmission time

Advantages of M-ary Signalling

- Higher information transfer rates for a given symbol rate and corresponding channel bandwidth.

OR

- Lower symbol rate leading to a reduced bandwidth requirement for a given information transfer rate
- Both lead to an increase in bandwidth efficiency (bits/sec/Hz.).

M-ary Signalling: Bandwidth Efficiency

University of BRISTOL

- The number of bits per symbol, n, which can be conveyed by M-ary signalling is given by: $M=2^n$

$n=3$

$M=8$

- The data rates of an M-ary signalling scheme is given by:

$$3\,kHz \rightarrow f_d = \underbrace{(\log_2 \overset{8}{M})}_{3}\ fs \quad 1kHz$$

- The bandwidth efficiency of an M-ary signalling scheme is given by:

$$\eta_B = f_d/B = (\log_2 \overset{8}{M})\ \overset{1kHz}{fs}\ /\overset{2kHz}{B} = \underline{4\ bits/Hz}$$

Bandwidth

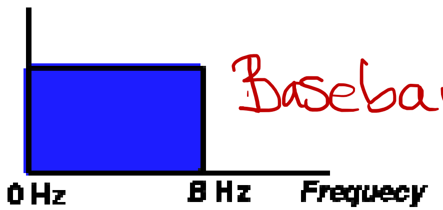
Disadvantages of M-ary signalling

- Reduced noise immunity when compared with binary signalling as it is more difficult to distinguish between the states.
- More complex symbol recovery processing at the receiver.
- Greater requirements for linearity in the communications link

Channel Capacity

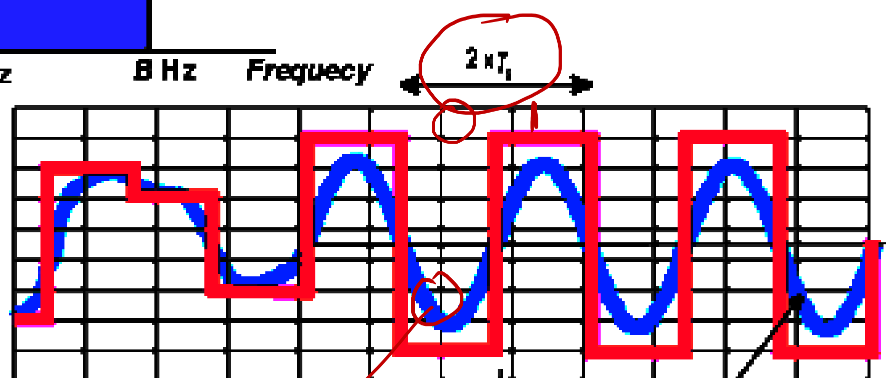
Relationship: Bandwidth to Symbol Rate 'Channel Capacity'

- A fundamental relationship exists between the channel bandwidth and the rate at which symbols can be sent.



Baseband

Assume 0, 1, 0, 1, 0, 1 ----.



complete cycle

It can be seen that the relationship is:

$$B = 1/2.T_s$$

Where

B= channel bandwidth, Hz

T_s = symbol period s

At baseband (only)

2 bits/s/Hz

Calculation of channel capacity

- Minimum Transmission Bandwidth for error free transmission in a noise free environment.

$$B_{min} = 0.5*1/T_S \text{ (Hertz)}$$

T_S is the symbol period = 1/symbol rate.

- Maximum symbol rate = $1/T_S = 2.B_{min}$ (bits/sec)
- If each symbol has M levels, then each symbol will transmit $\log_2 M$ (bits).

Therefore Channel capacity (C) is given by:

$$C = 2.B.\log_2 M \text{ (bits/second)}$$

Shannon Hartley Capacity Theorem

The Shannon Hartley equation indicates the highest possible channel capacity (C) for error free communications in AWGN, for a channel bandwidth (B) and signal to noise ratio (S/N):

$$C = B\log_2(1 + S/N) \text{ bits/s}$$

Trading off Signal Power for Bandwidth Efficiency

- For a system transmitting at maximum capacity C, then the average signal power can be written as:

Energy per bit

$$S = E_b \, . \, C$$

Where E_b = the average received energy per bit.

The average noise power can be defined as:

$$N = N_0 . B$$

E_b / N_0

Where N_0 = the noise power density (Watts/ Hertz).

Trading off Signal Power for Bandwidth Efficiency

The Shannon Hartley equation can thus be written as:

$$C/B = log_2(1 + E_b.C/N_0.B)$$

$E_b. /N_0.$ Is a measure of the power efficiency of the system.

- Smaller the ratio, less energy per bit is used power efficient

C/B represents the bandwidth efficiency of the system

- Larger the ratio, the more bandwidth efficient

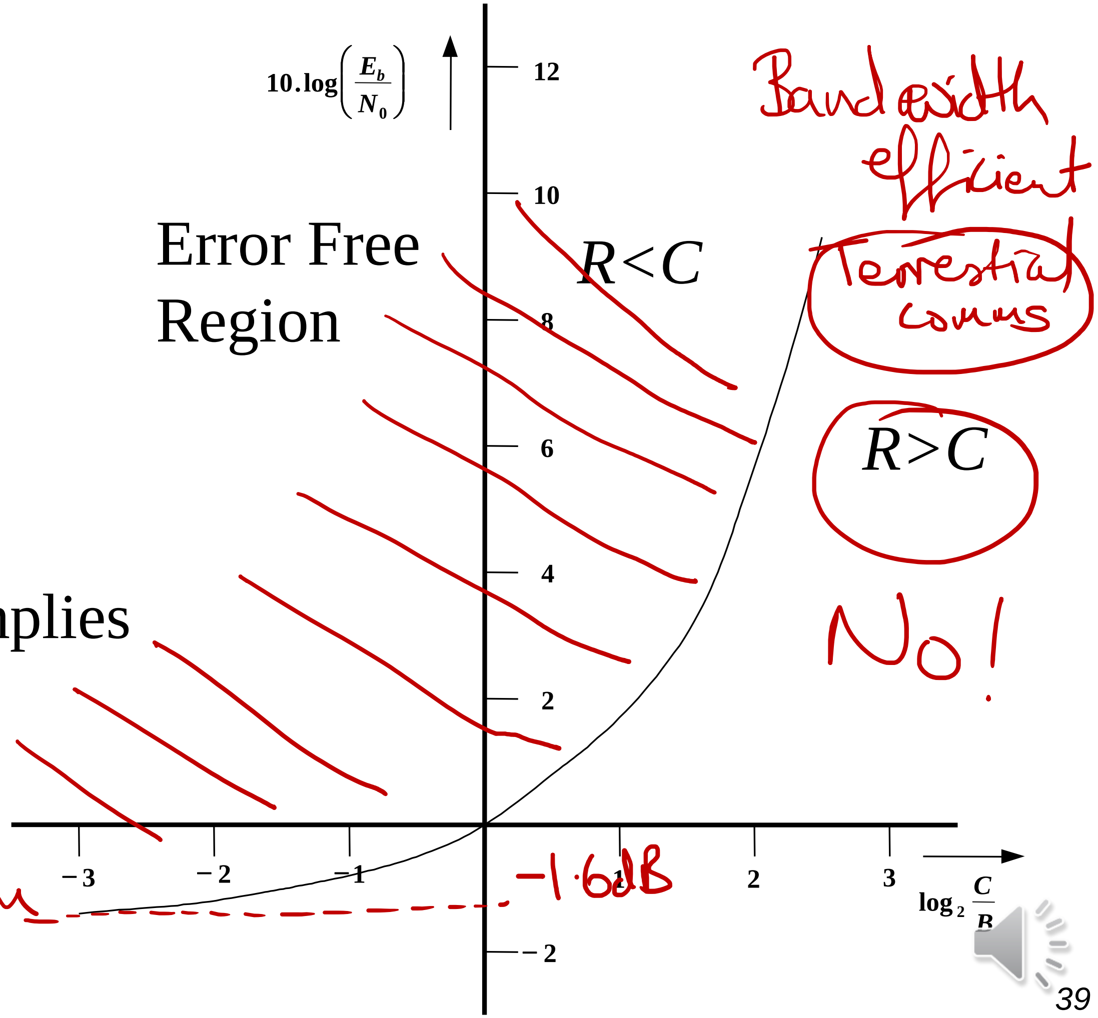
Trade-off, both can't apply

Trading off Signal Power for Bandwidth Efficiency

this curve represents solutions to the equation:

$$C/B = \log_2\left(1 + \frac{E_b C}{N_0 B}\right)$$

Observe: unlimited bandwidth implies minimal E_b. $/N_0$ = -1.6 dB



Space comms

power Efficient Region

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