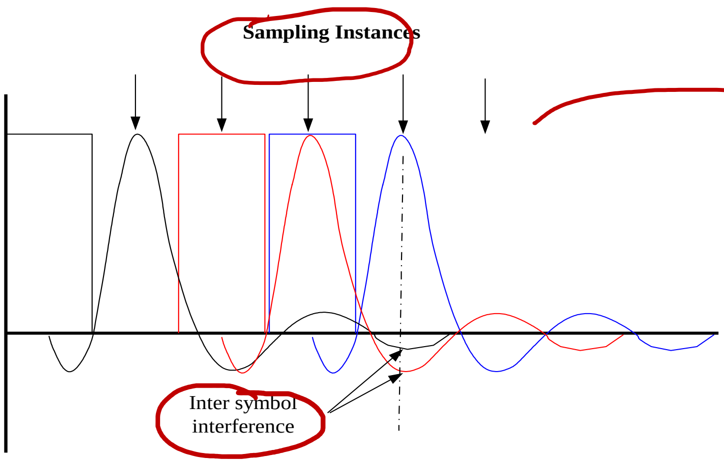
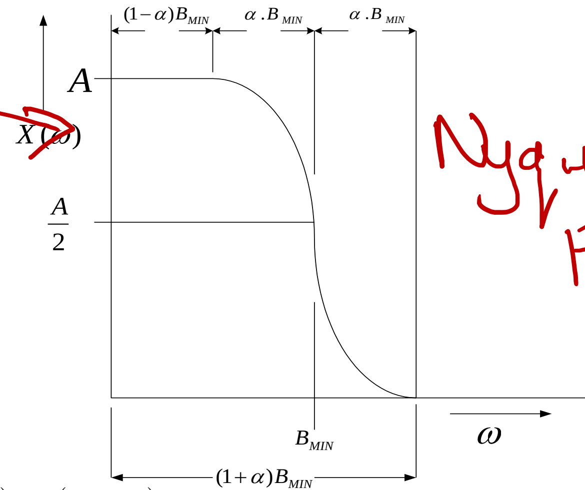
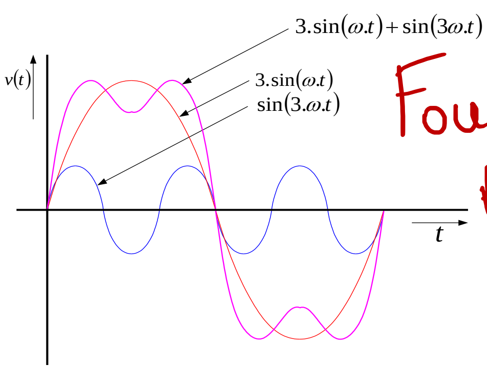
Spectrum from DC (0Hz) → not suitable for most transmission media ⇒ bandpass

Baseband Data Transmission

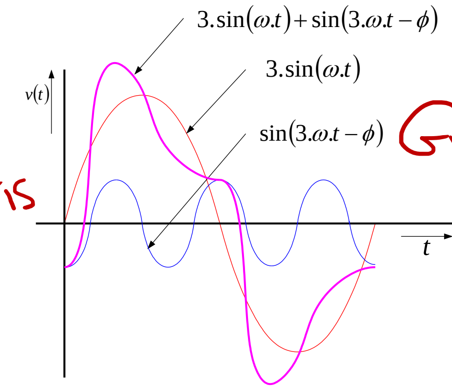




Nyquist Filter



Fourier Analysis

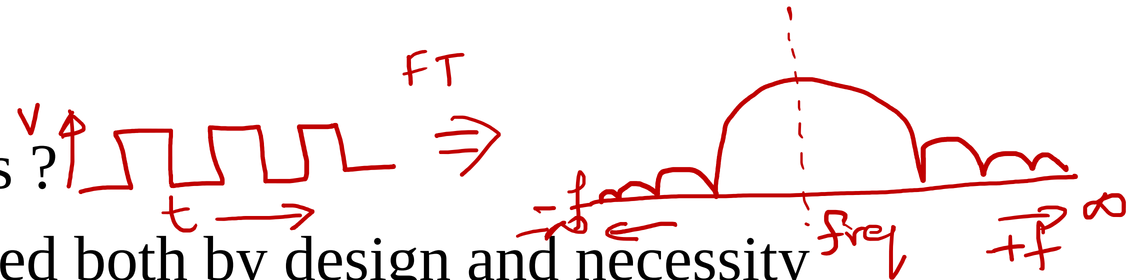


Group delay

Inter Symbol Interference
(ISI)

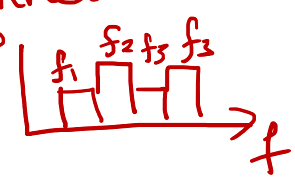
Square Data Pulses ?

- Digital Communications
  - Square voltage waveforms ?



  - Filtered waveforms are used both by design and necessity

share channels
FDMA



- The Transmission Channel
  - This has finite bandwidth
  - Combating Inter Symbol Interference (ISI)
- Digital Communication System Design Tool Box
  - Channel Filters

Control Tx BW; Control ISI, Control/limit noise in Rx

  - Performance Assessment/Monitoring

BER Vs E_b/N_0, MOS, Eye Diagram ($P_n = kTB$)

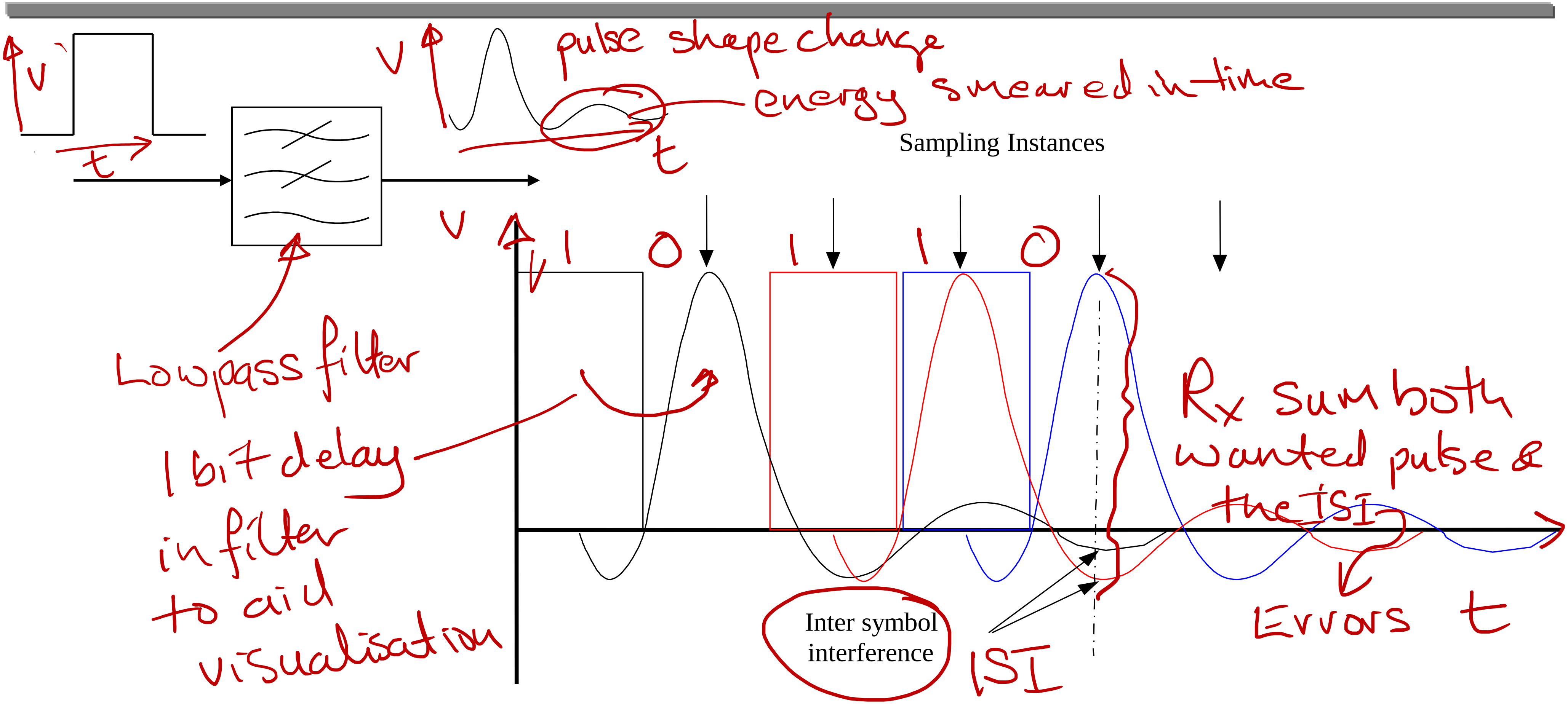
twisted cable (wire)

LC Ladder network

Inter Symbol Interference (ISI)

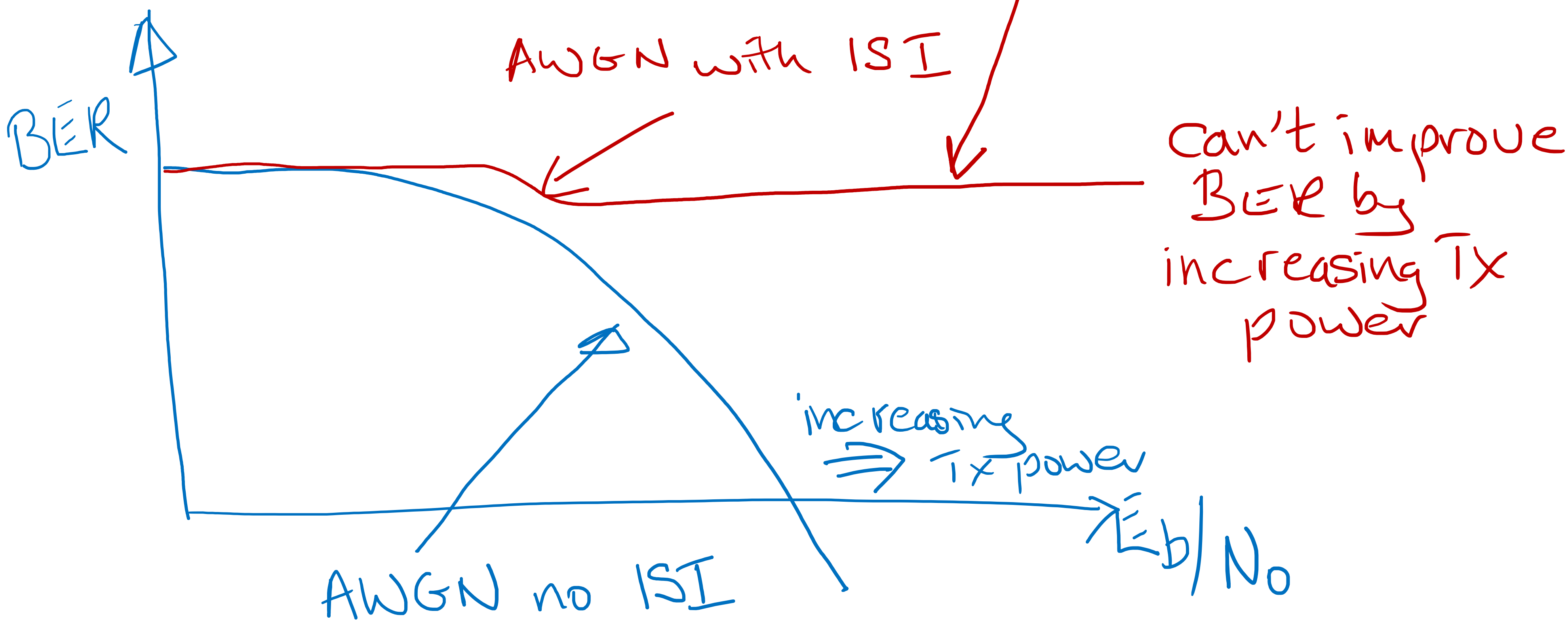
- All line circuits will have some bandwidth limitation.
- Usually this limitation is deliberately introduced via a line filter.
- Careful consideration needs to be given to the design of this filter to avoid smearing of the pulse energy such that enough of the pulse energy of the previous pulse remains, whilst the current pulse is being sampled, to cause an error to occur.

Inter-symbol Interference (ISI)



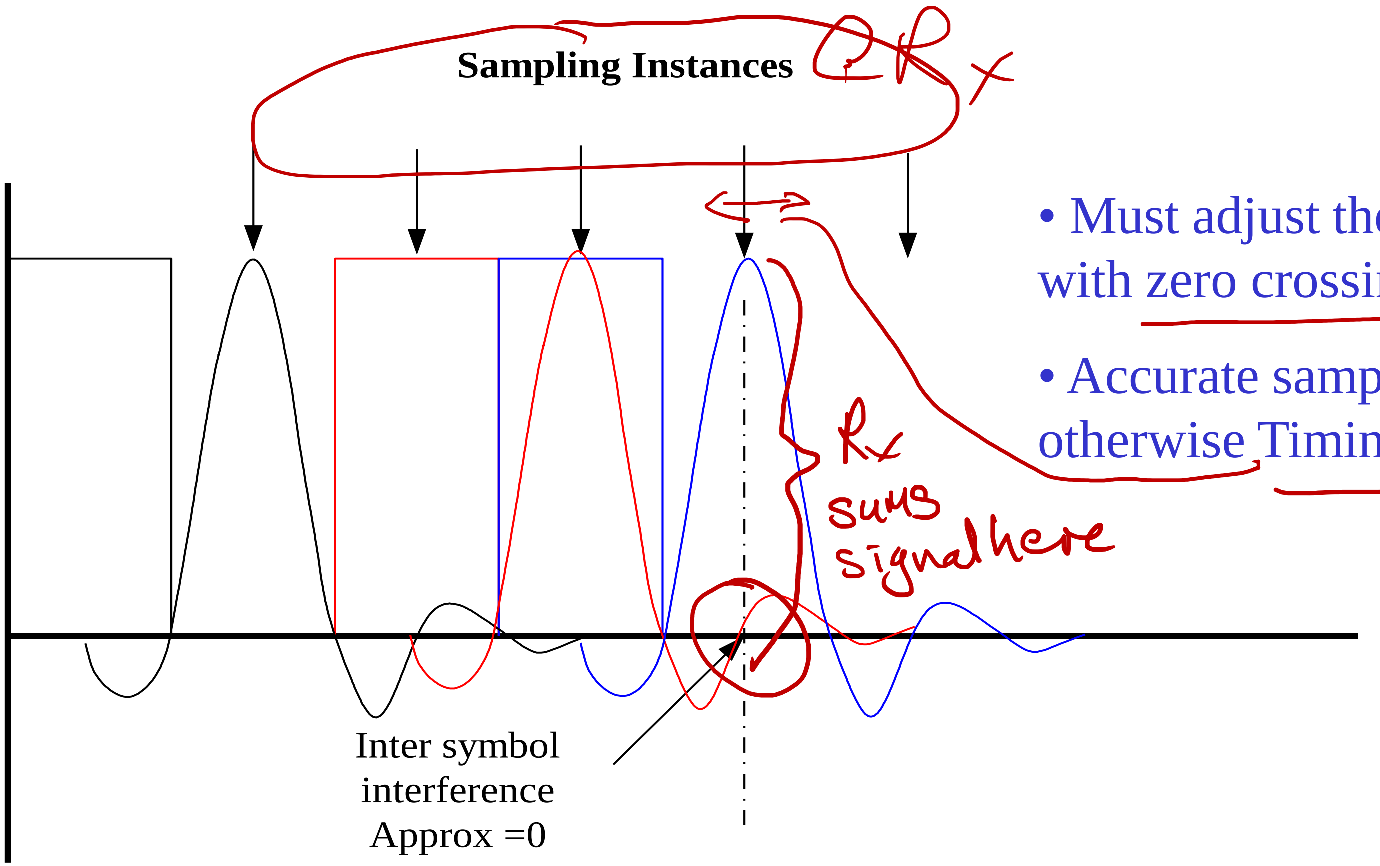
- **Irreducible Error Rate**

Irreducible Error Rate



ISI with Nyquist Filters

ISI with Nyquist Channel Filtering

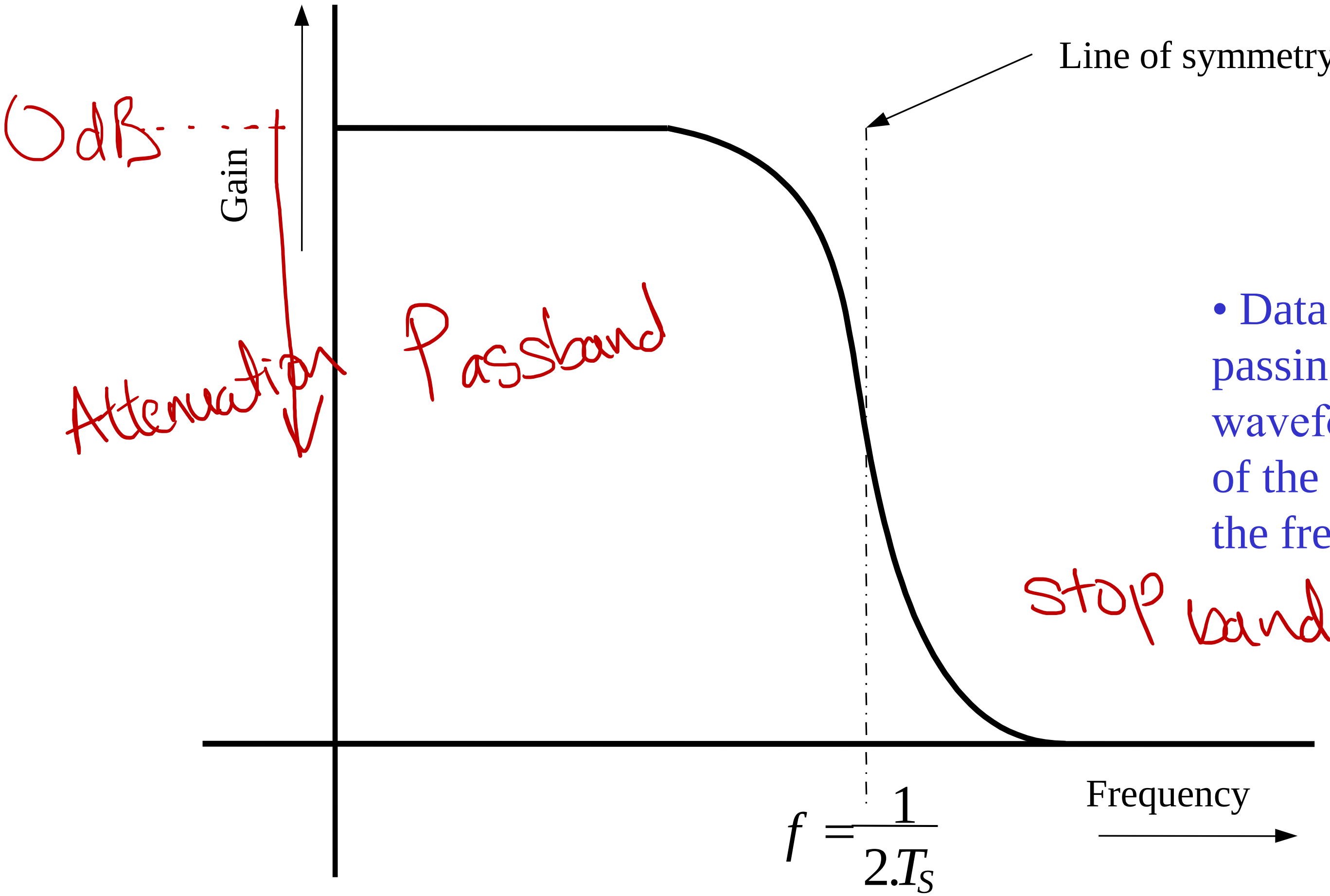


- Must adjust the sampling to coincide with zero crossings of ISI
- Accurate sample timing required, otherwise Timing Jitter will occur

Nyquist Channel Filtering

- A Nyquist filter is a family of filter designs that avoid inter symbol interference by their pulse response passing through zero at multiples of the sampling period (T_S). → Time Domain
- A Nyquist filter is characterised by the transfer function having a transition from the passband to the stopband which is symmetrical about a frequency equal to $1/2.T_S$. → Frequency Domain

Nyquist Channel Filtering

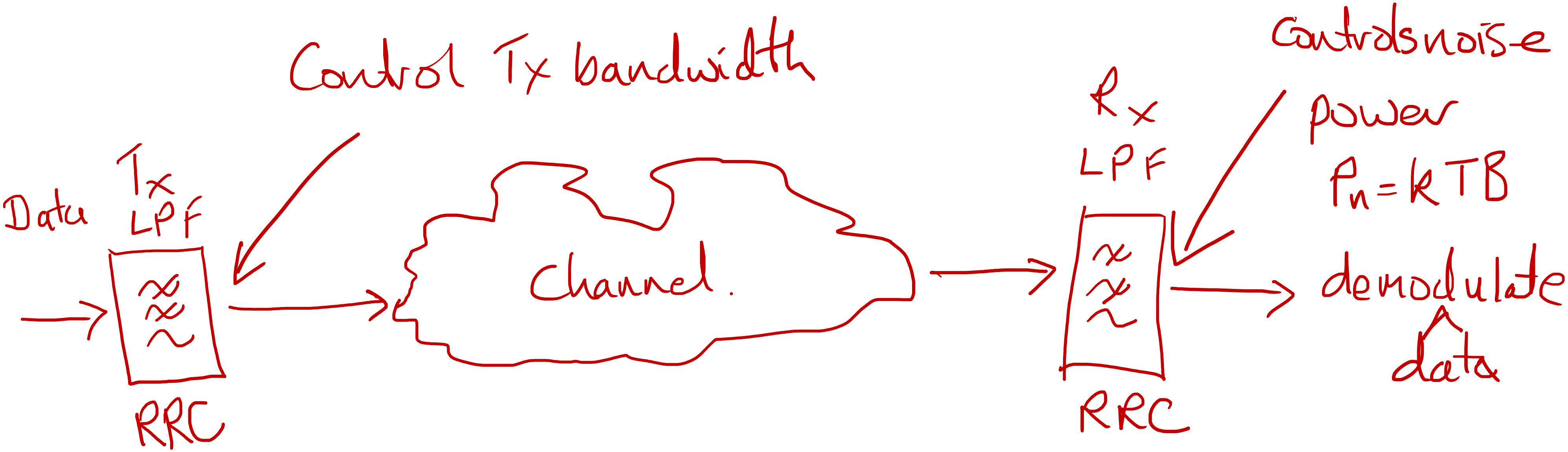


- Data symbols are still smeared after passing through this filter, however the waveform now has ‘zeros’ at multiples of the symbol period when observed in the frequency domain.

Achieving a Nyquist Channel Response

- It is important that the overall response of the receiver and the transmitter chain are Nyquist in nature when taken together.
- RRC filters (Root Raised Cosine) filters are frequently employed as pulse shaping filters.
- 2 RRC filters in the signal path will lead to an overall Raised Cosine response which will provide to a Nyquist channel.

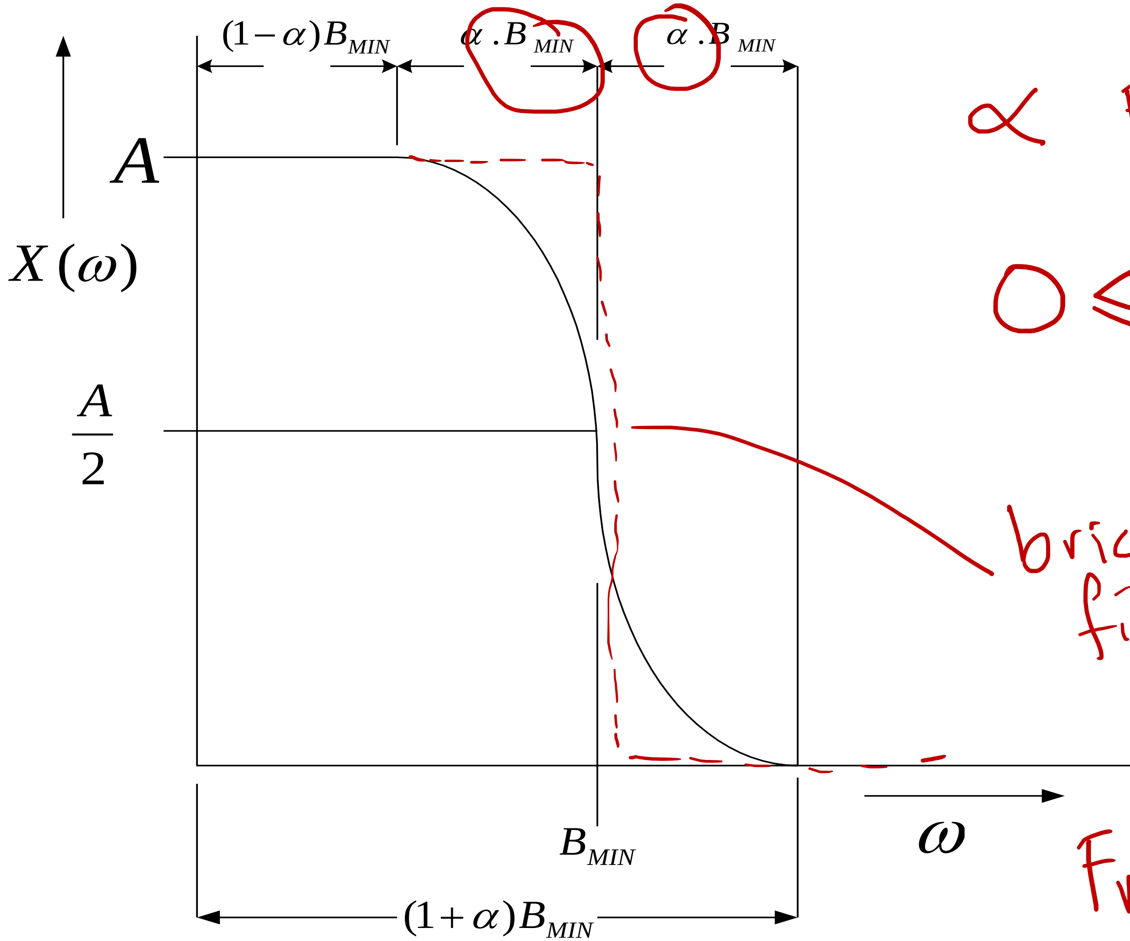
Achieving a Nyquist Channel Response



Raised Cosine response → Nyquist Filter

- Removes ISI
- controls Tx Bandwidth
- limits AWGN at Rx

Raised Cosine Filter Response



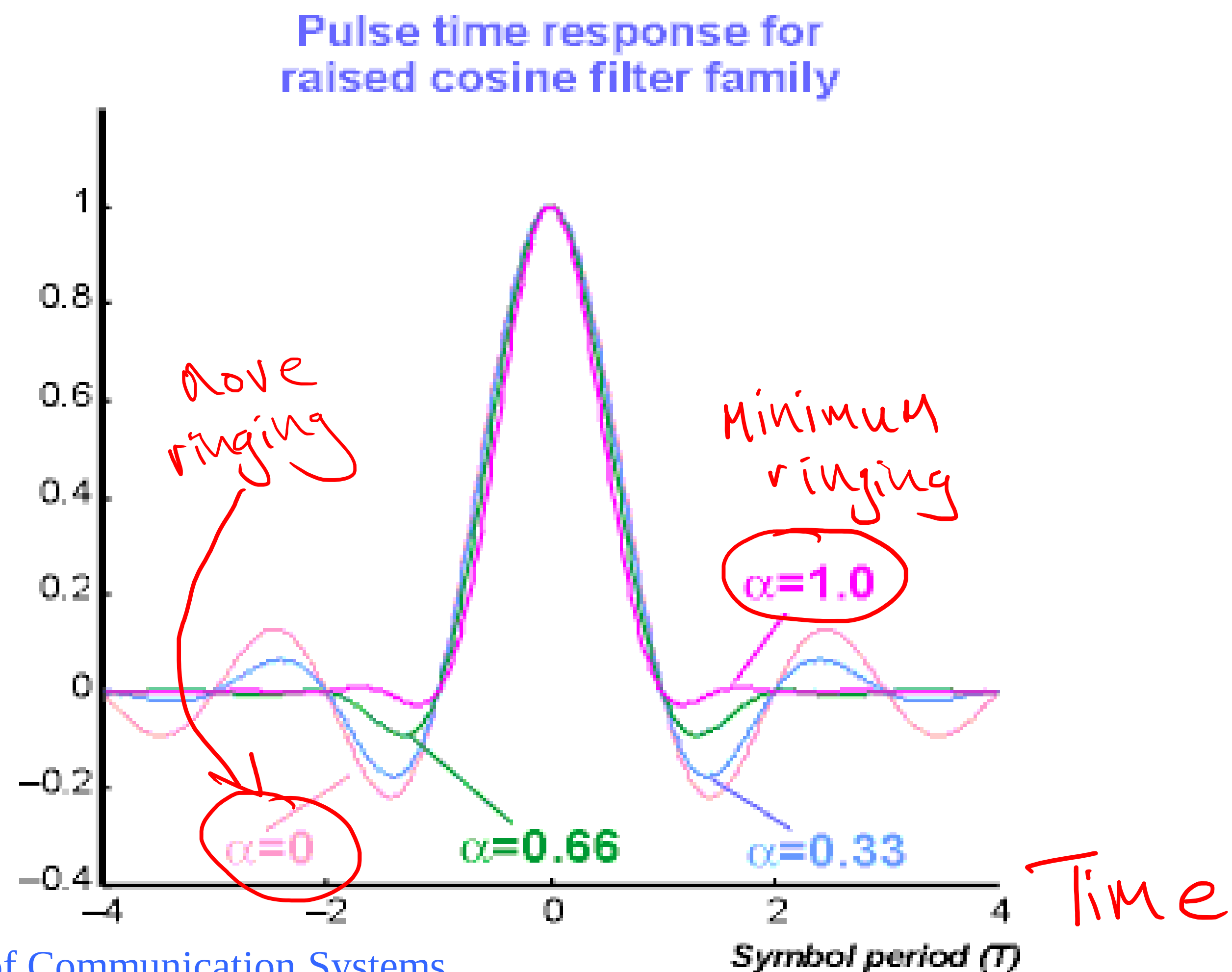
α Filter roll off

$0 \leqslant \alpha \leqslant 1$

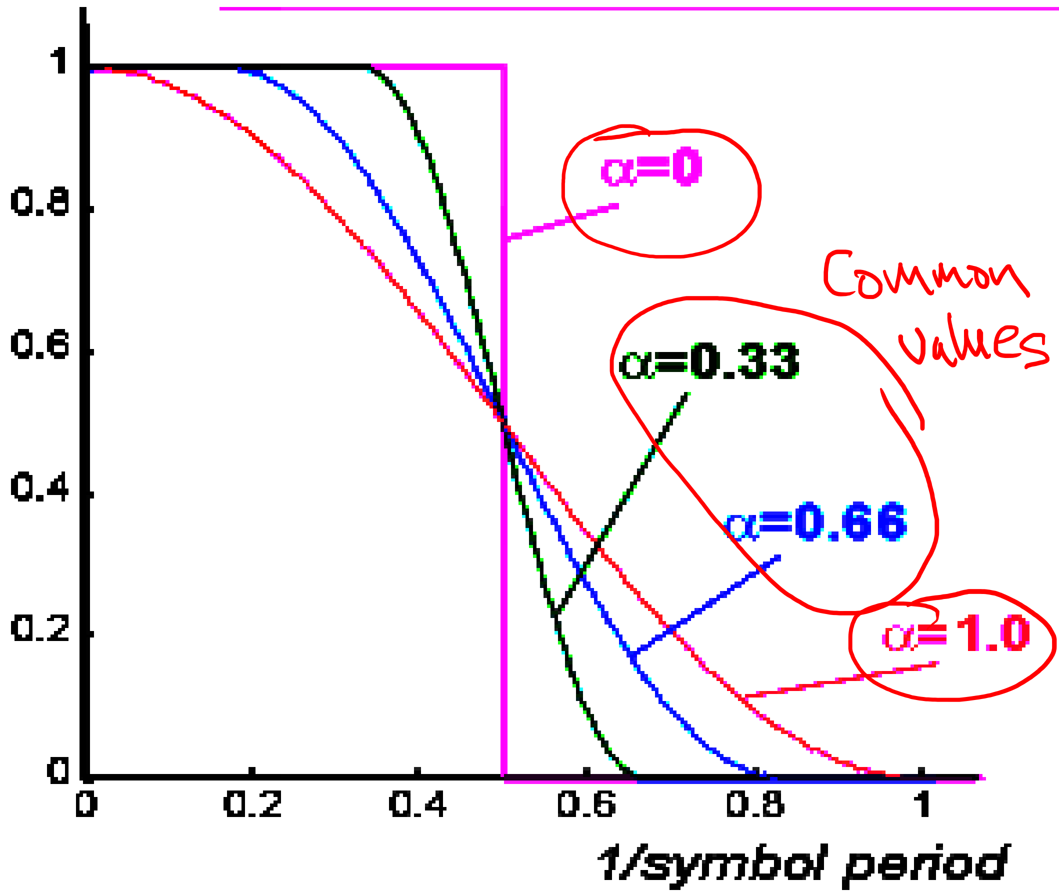
brickwall filter $\alpha = 0$

Freq

Raised Cosine Filter: Time Domain



Raised Cosine Filter: Frequency Domain



Note that a high α leads to a high bandwidth, but not so much energy smearing or "ringing of the pulse, compared with a small value of α. A small value of α needs a small bandwidth but means the pulse response has a large amount of ringing. This may possibly generate ISI if the timing is a bit out at the receiver.

Trade off between Time & Frequency domains for selection of α

Raised Cosine Filters

- Choice of α.
  - Benefits of small α.
    - Maximum Bandwidth Efficiency.
  - Benefits of Large α.
    - Simpler filter which means less delay line taps.
    - Wider eye opening hence less sensitivity to timing accuracy.
    - Less signal over shoot hence lower peak to mean excursion of the transmitter signal.

eye opening

→ Peak to Average Power Ratio (PAPR)

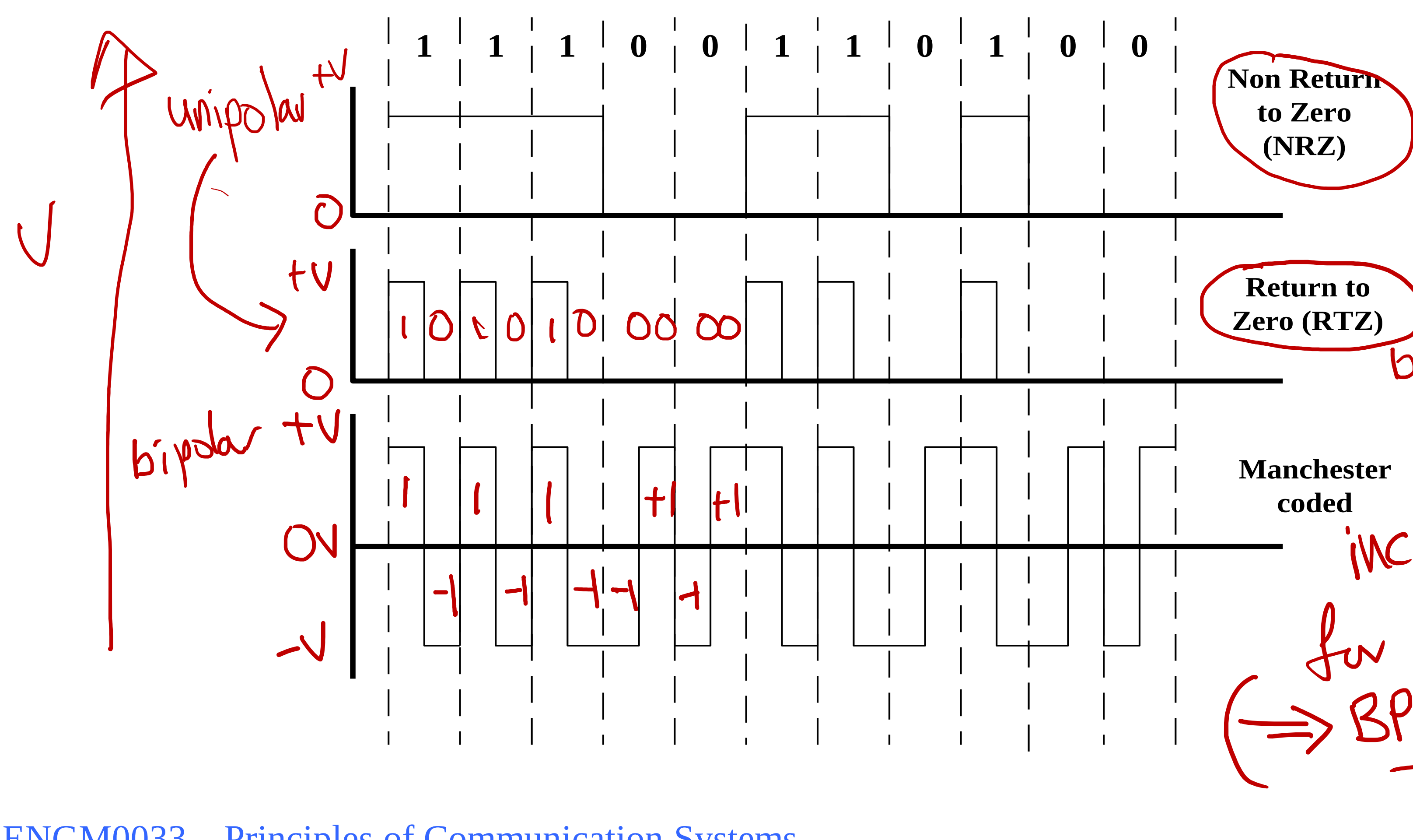
$$= \frac{\text{Peak Power}}{\text{mean or average Power}}$$

AC Channels & Eye Diagrams

Sources of Channel Degradation
AC - coupled channel

- To send data over a telephone link which has no response at DC means that it must be scrambled or encoded such that there is little energy at DC.
- That is, the transmitted string of data must look like an AC waveform, with no long strings of ones or zeros
- Two possible schemes for reducing the DC content of a data stream are:
  – Return To Zero (RTZ)
  – Manchester encoding.

Line codes: Return to zero and Manchester encoding



long runs of '1' or '0' ⇒ high DC component in freq Domain

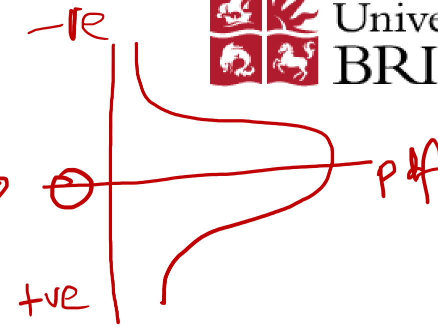
Removes DC but doubles the bandwidth

includes energy for logic '0' tx.
(⇒ BPSK modulation)

Eye Diagrams - Diagnostic Tool

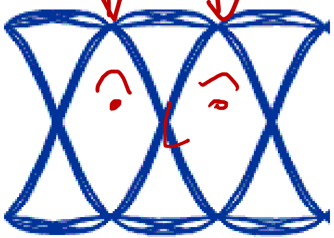
- An eye diagram is a useful method of diagnosing data transmission errors.
- An eye diagram is generated using an oscilloscope connected to the demodulated filtered data stream.
- The oscilloscope is triggered every symbol period or multiples of the symbol period by a timing signal derived from the received waveform.

Eye Diagrams - Examples



Eye Diagrams - no bandwidth constraints

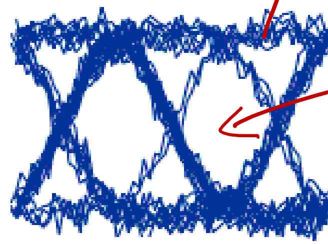
V 5V 0



Signal

t

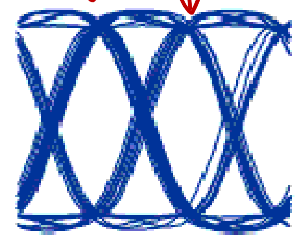
2 levels binary signal.



eye closure

Signal & Noise

AWGN



Signal & timing Error

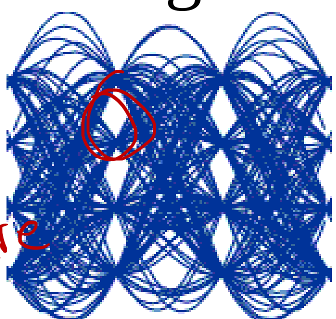
Jitter small α

sampling point move critical.

Eye Diagrams - Multi-level & bandwidth constraints

V

eye closure

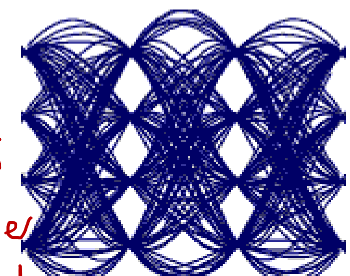


α=0.1

t

4 levels

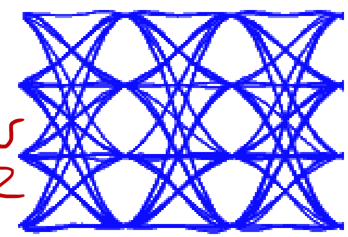
2bits per symbol



α=0.5

wide eye

much wider eye



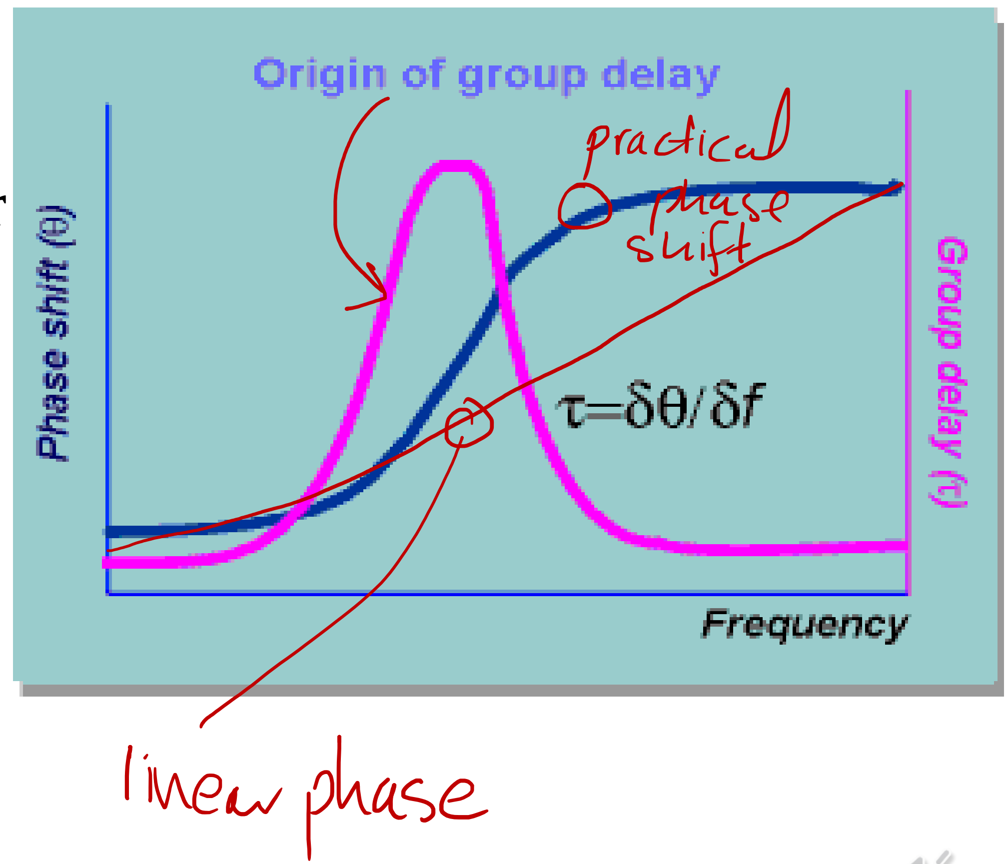
α=1

but more ~~signal~~ frequency regrowth.

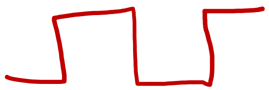
Group Delay & Equalisation

Sources of Channel Degradation Group delay distortion

- The phase response of a channel is important in transmitting data.
- Many channels have a ‘non-linear phase response’, or ‘non flat group delay’.
- Group delay is defined as ‘rate of change of phase shift with frequency.

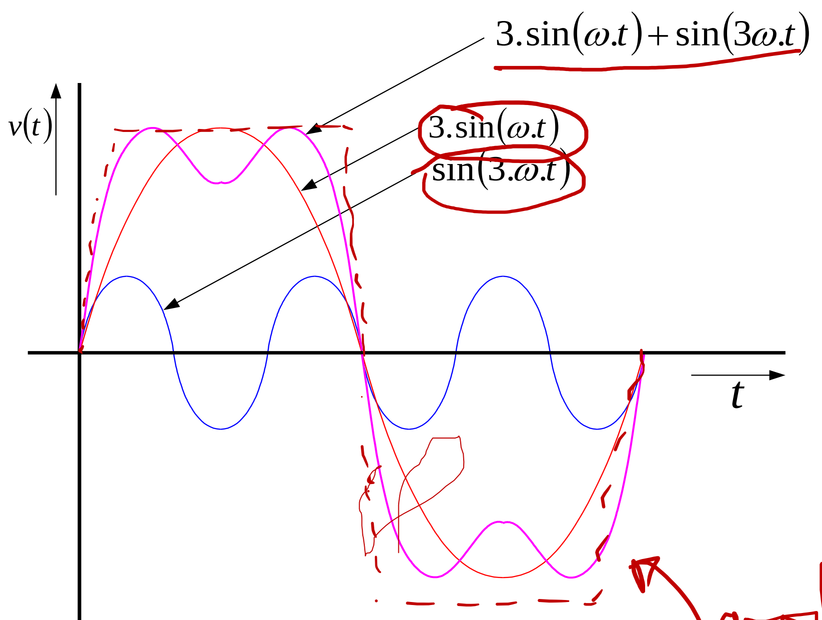


Group delay distortion - Example

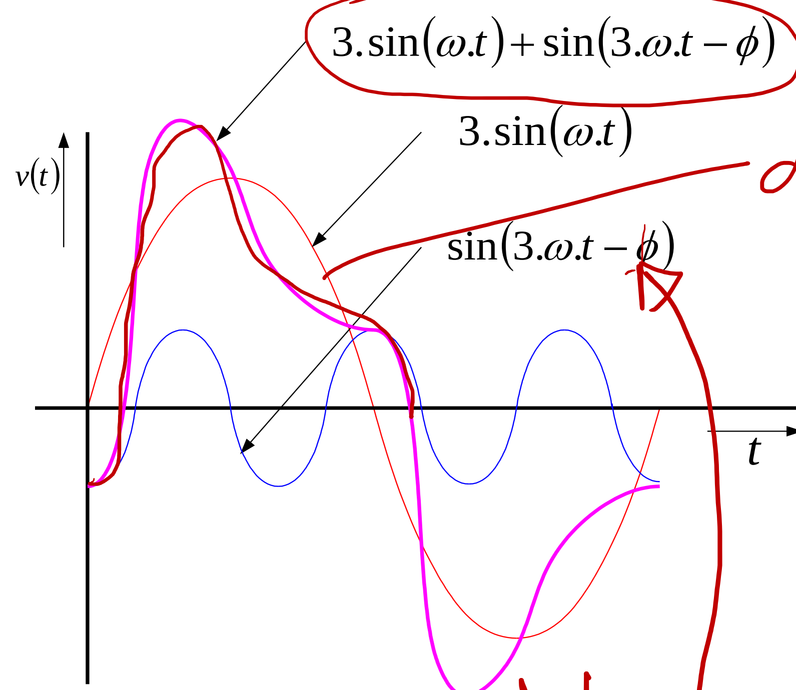


→ Fourier transform

resultant



good approximation to squarewave.



distorted

group delay on $3\omega t$ term

University of BRISTOL

Group delay distortion - Problems

- This is not a problem with audio reproduction as the ear is insensitive to phase.
- The same is not true with video, and data transmission.
- With data transmission, phase distortion may cause intersymbol interference.

Group delay distortion

- To eliminate group delay distortion, the phase lag of the channel must increase linearly with frequency.
- This is because time delay is given by:

$$T_D = \phi/\omega$$

where ϕ = phase shift

and ω = angular frequency

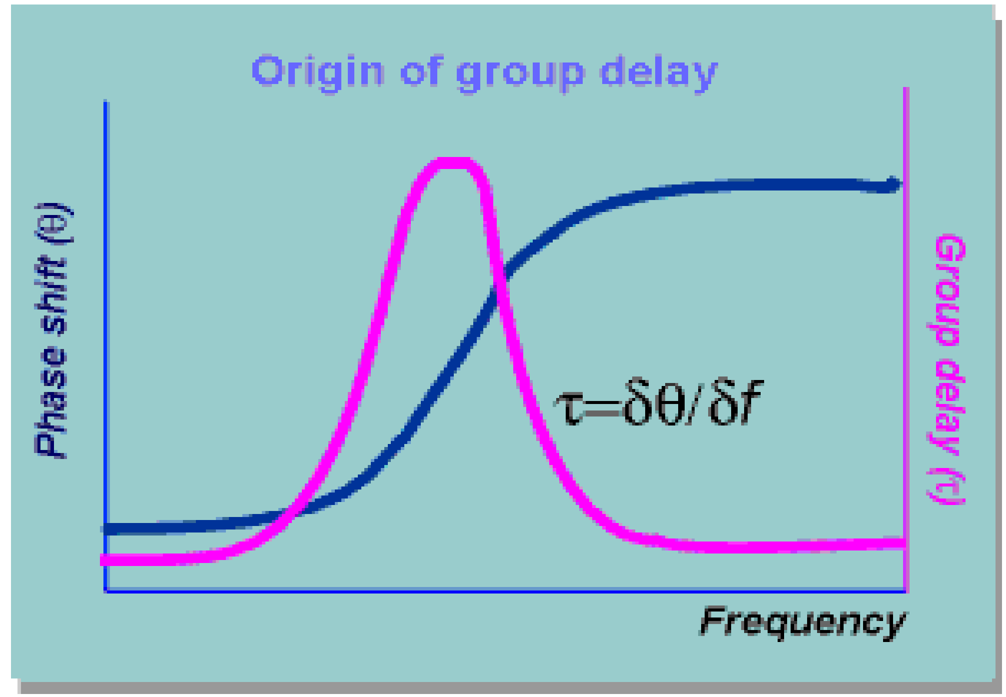
Group delay distortion

- If the time delay is constant for all the Fourier components of a signal, then they will all arrive at the receiver at the same relative time, and hence the waveform will be undistorted.
- For constant time delay, the phase lag must increase linearly with frequency.

Group delay distortion

- A sensitive measure of the departure of phase shift from linearity is given by what is known as the group delay.
- Group delay τ is defined as:

$$\tau = \delta\theta / \delta f.$$



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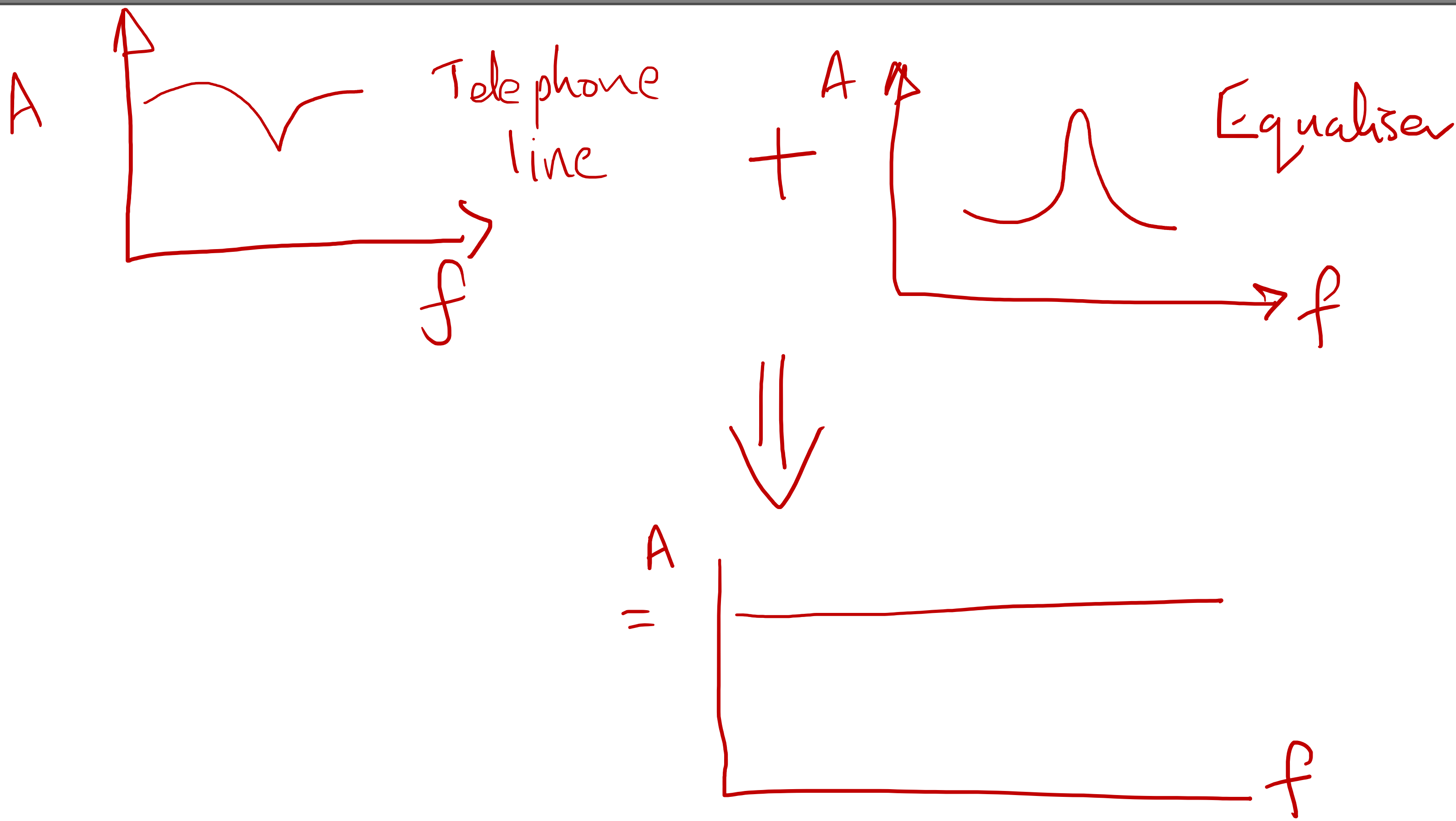
Channel Equalisation

- Normal telephone channels have non flat amplitude and group delay characteristics.
- To transmit data at the maximum speed over telephone channels calls for the use of what is known as adaptive equalisers.
- An adaptive equaliser measures the characteristics of the channel at the start of transmission
- Using tapped delay lines, it generates an inverse filter

Channel Equalisation

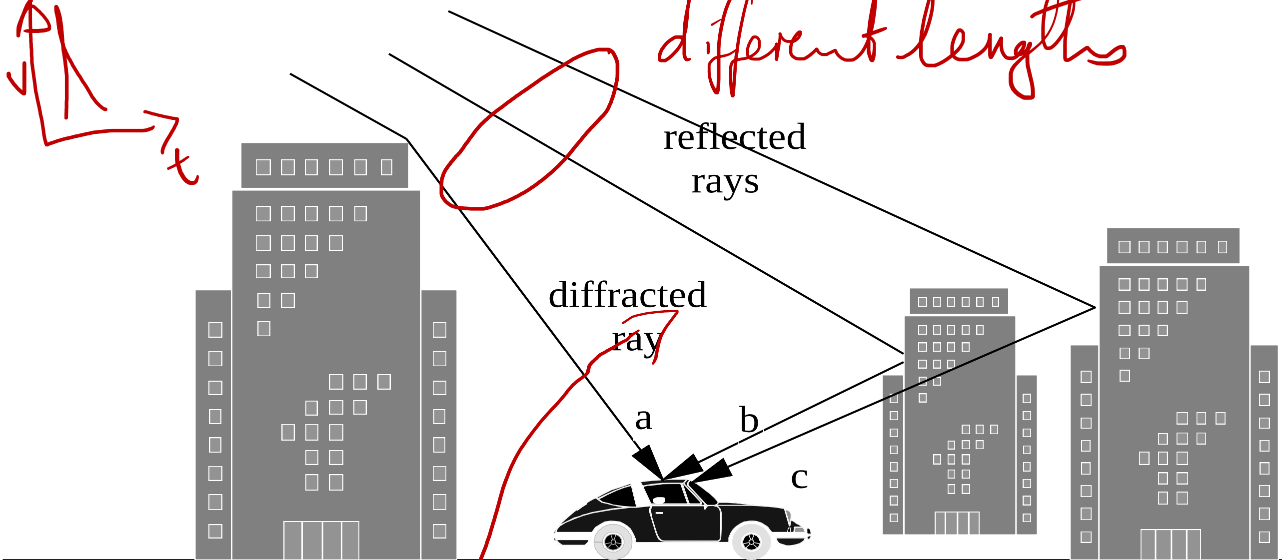


Mobile (Wireless) Channels

Sources of Channel Degradation Mobile or Wireless Channels

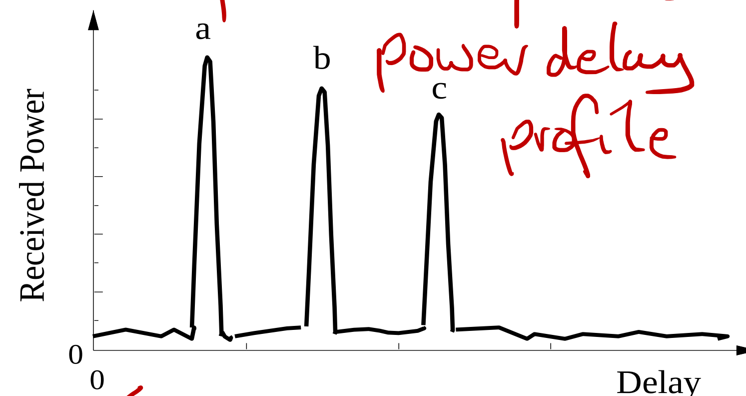
BS

different lengths



Impulse Response

power delay profile



time

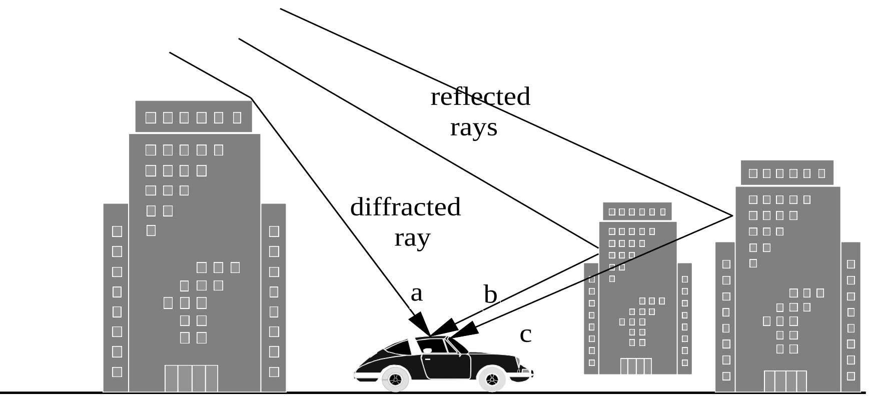
- Mobile channels are additionally effected by multipath propagation.

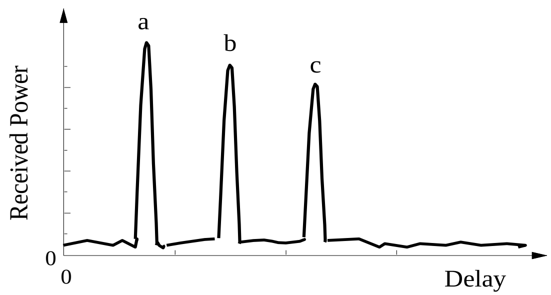
ISI

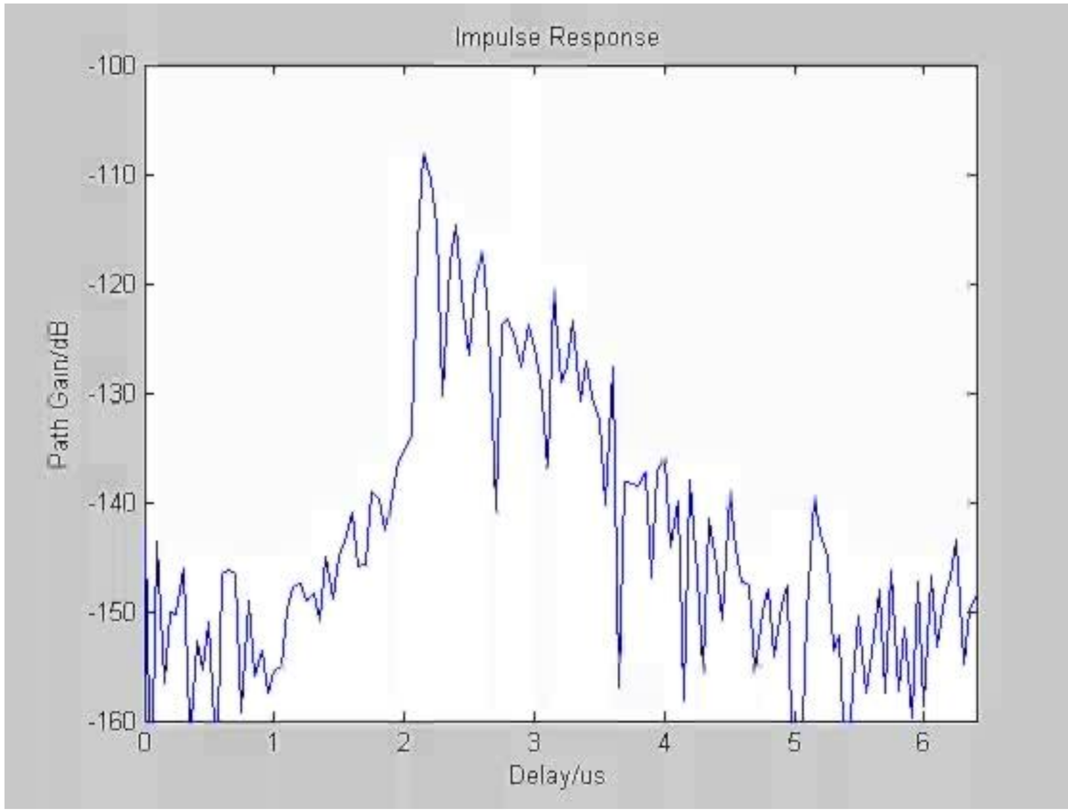
Mobile Channels

- The velocity of light in free space is 3×10^8 m/s
- Path difference of 100m will result in a time delay of 1/3 of a micro- second (or 333 nsec).
- Multipath delays can approach several micro seconds
  - Delays of this order can cause ISI.
    - Data rate must be reduced so that the delay becomes a less significant portion of the symbol period (typically < 10%)
    - Equalisation, Adaptive Modulation, or ……...

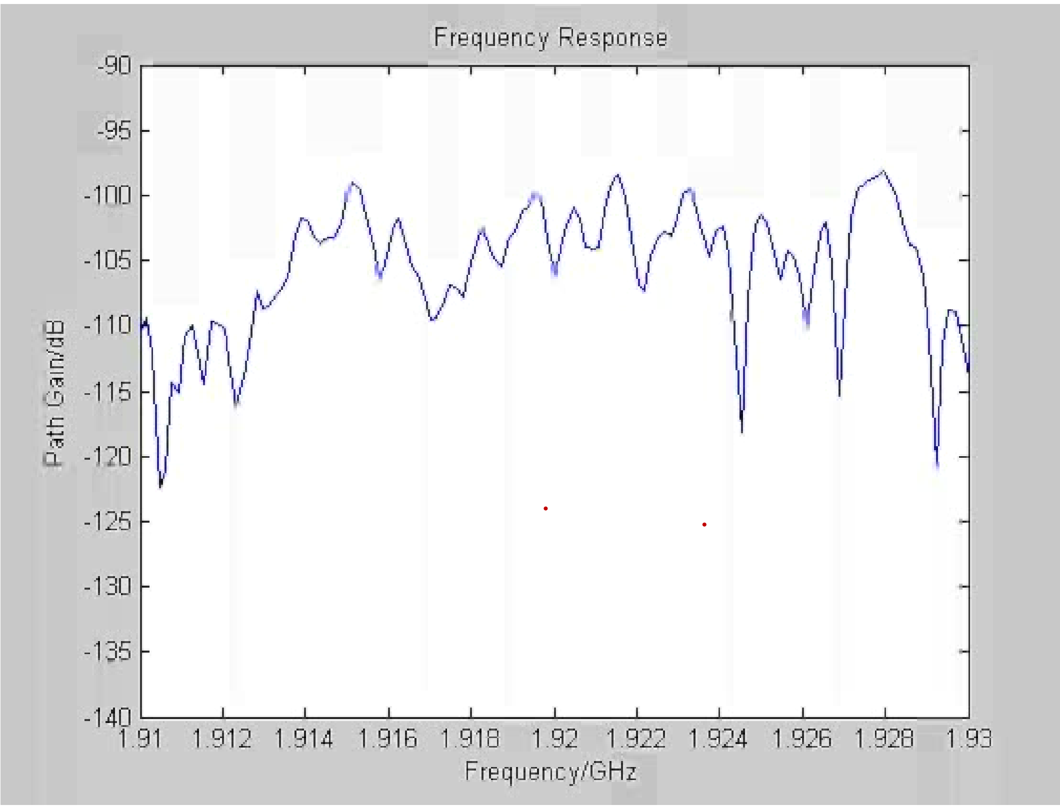
Impulse Response
Mobile or Wireless Channels

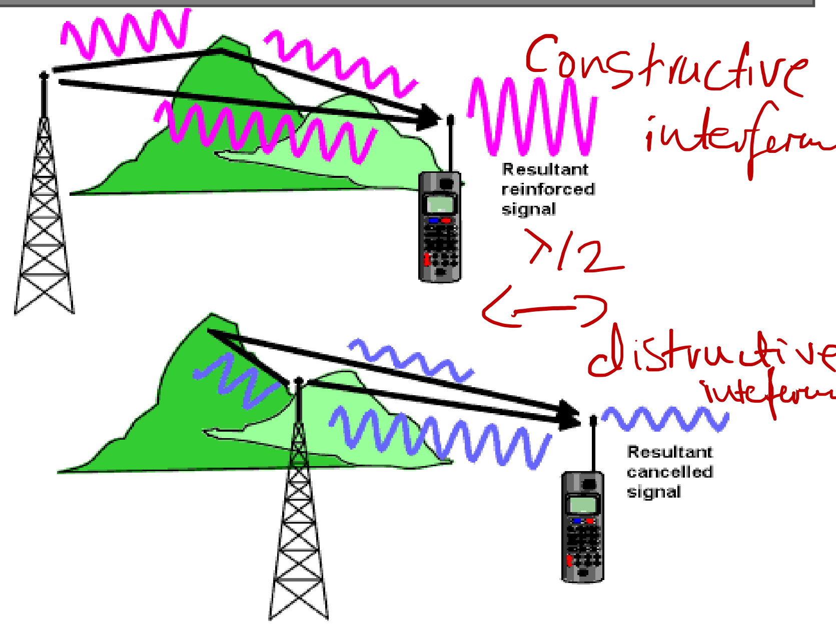


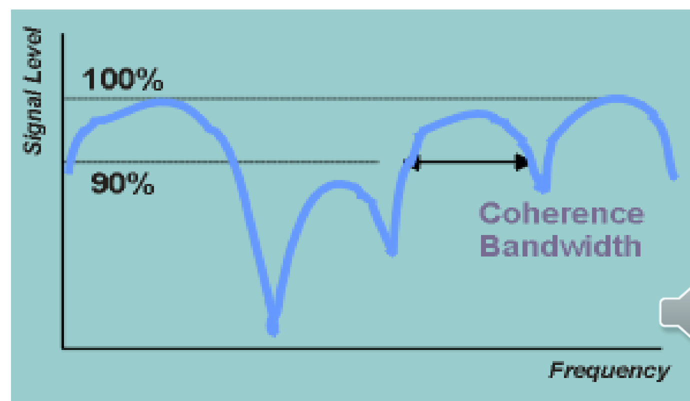




Frequency Response
Mobile or Wireless Channels







Baseband Data Transmission