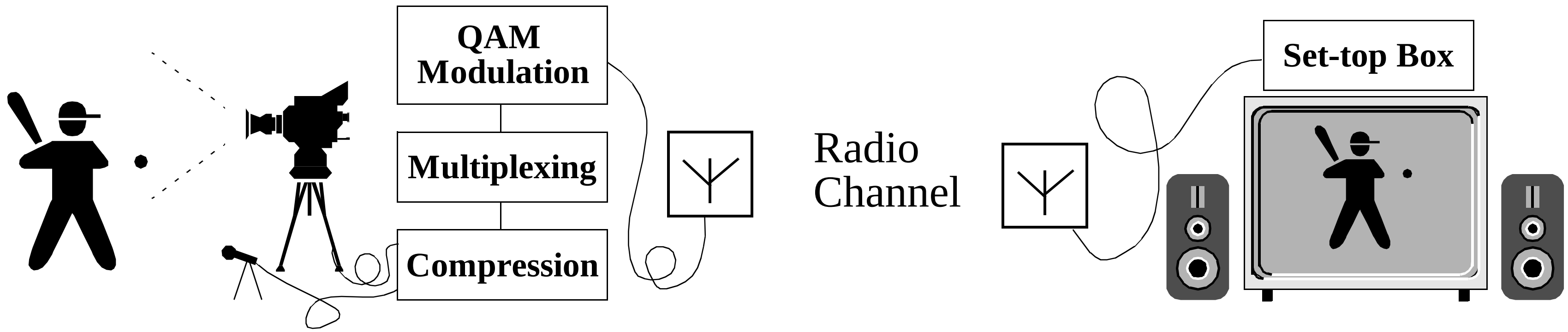
QAM Demodulation

- Application area
- What is QAM?
- What are QAM Demodulation Functions?
- General block diagram of QAM demodulator
- Explanation of the main function

  (Nyquist shaping, Clock & Carrier Recovery, AGC, Adaptive Equaliser)
- Performance
- Conclusion

Example Application Area

"Wireless Cable" Digital TV using Microwave Transmission



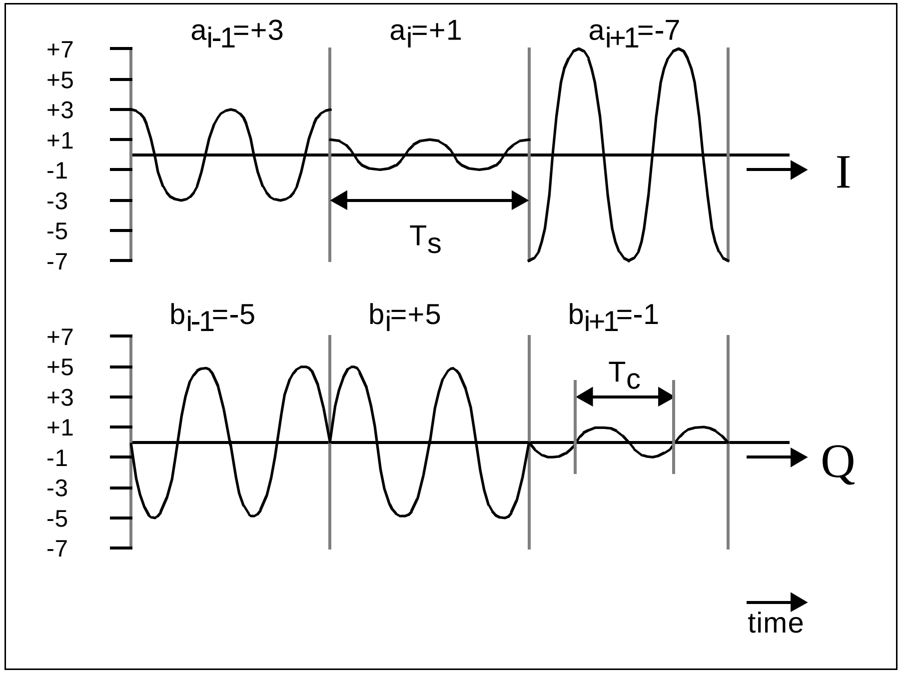
- Compression = bit rate reduction
- Multiplexing = assembly of multiple programs
- Modulation = conversion to transmission format

- Set-top Box = Integrated Receiver Decoder (IRD),
  provides a subscriber access to a wide range of programs

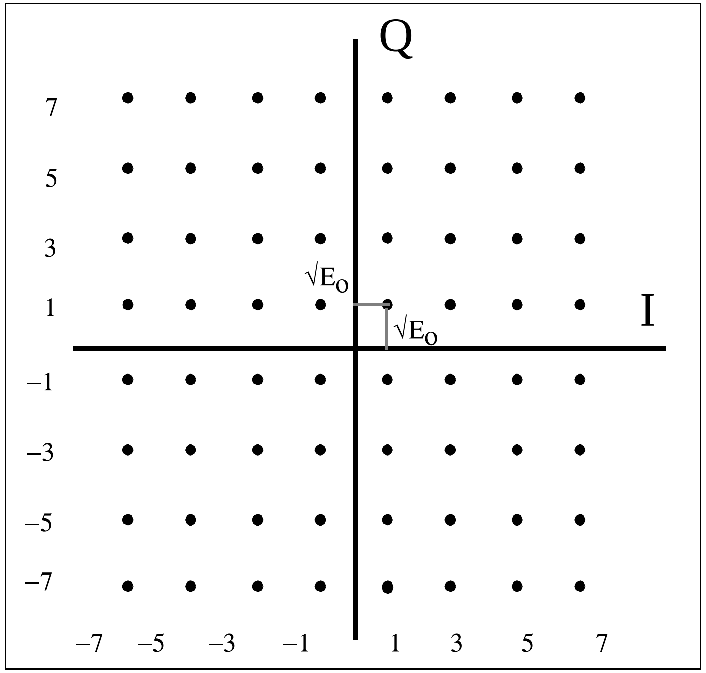
What is QAM?

- o Amplitude Modulation of
- o Two Orthogonal Carriers

$$x_i(t) = \sqrt{\frac{2E_o}{T_s}} a_i \cos(w_c t) + \sqrt{\frac{2E_o}{T_s}} b_i \sin(w_c t)$$

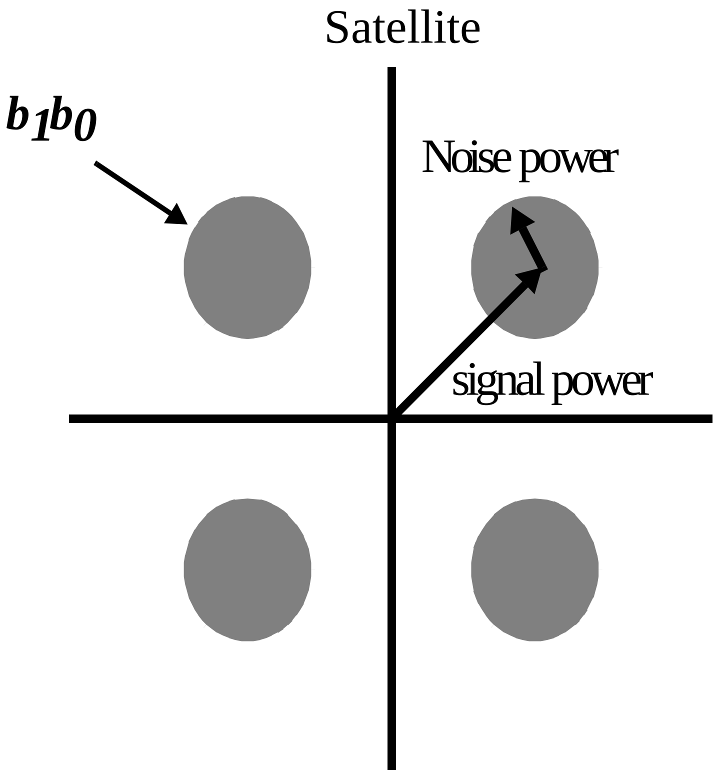


64QAM in time domain

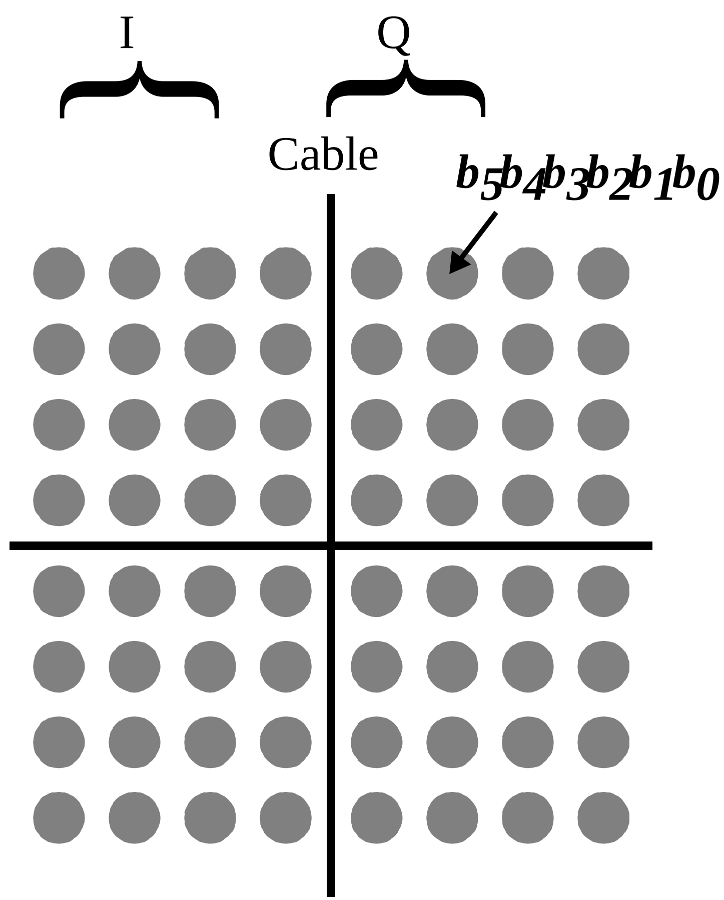


64QAM Constellation diagram

M-ary QAM



$S/N > 3$ dB for M=4



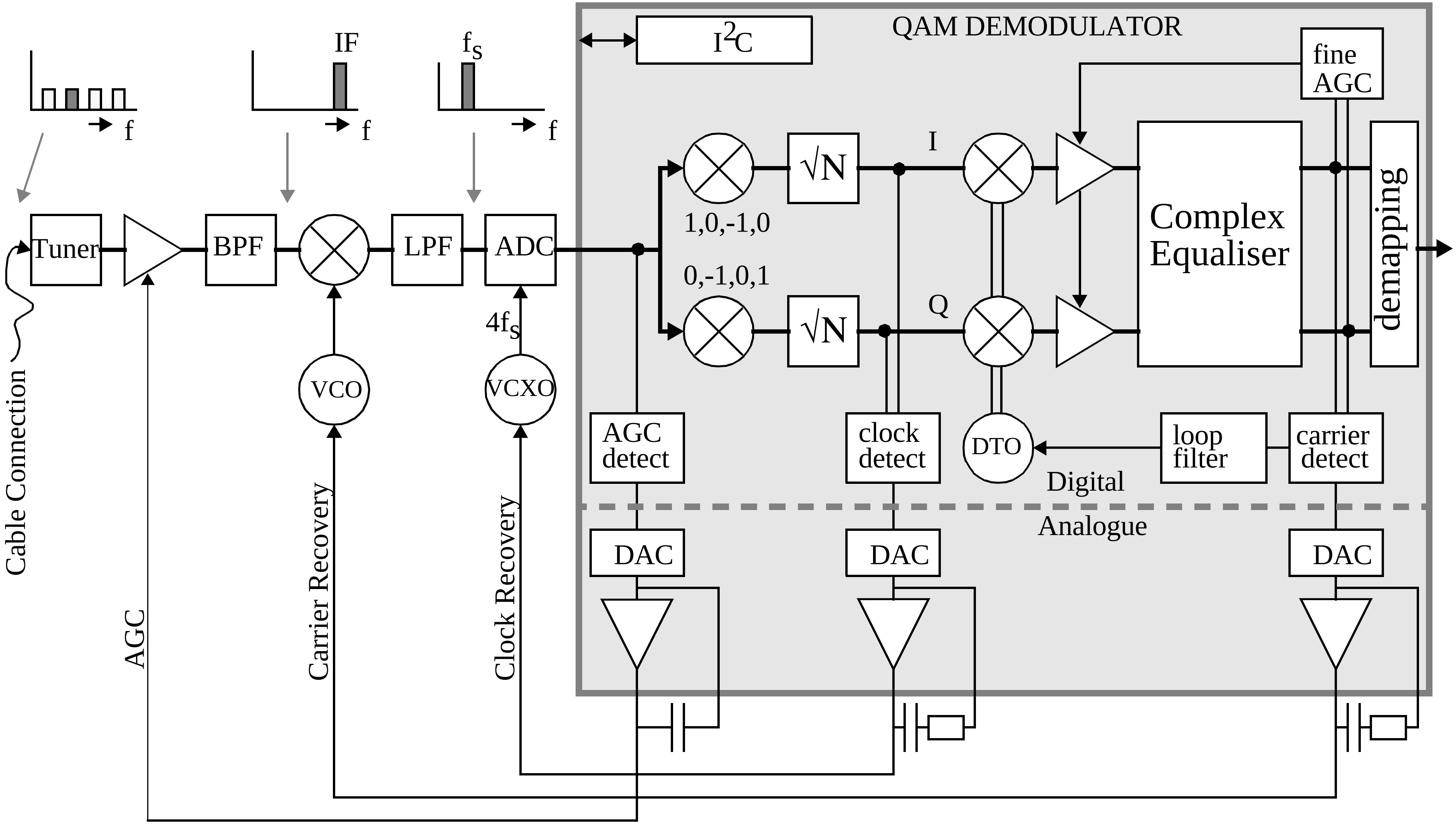
$S/N > 21$ dB for M=64

$S/N > 27$ dB for M=256

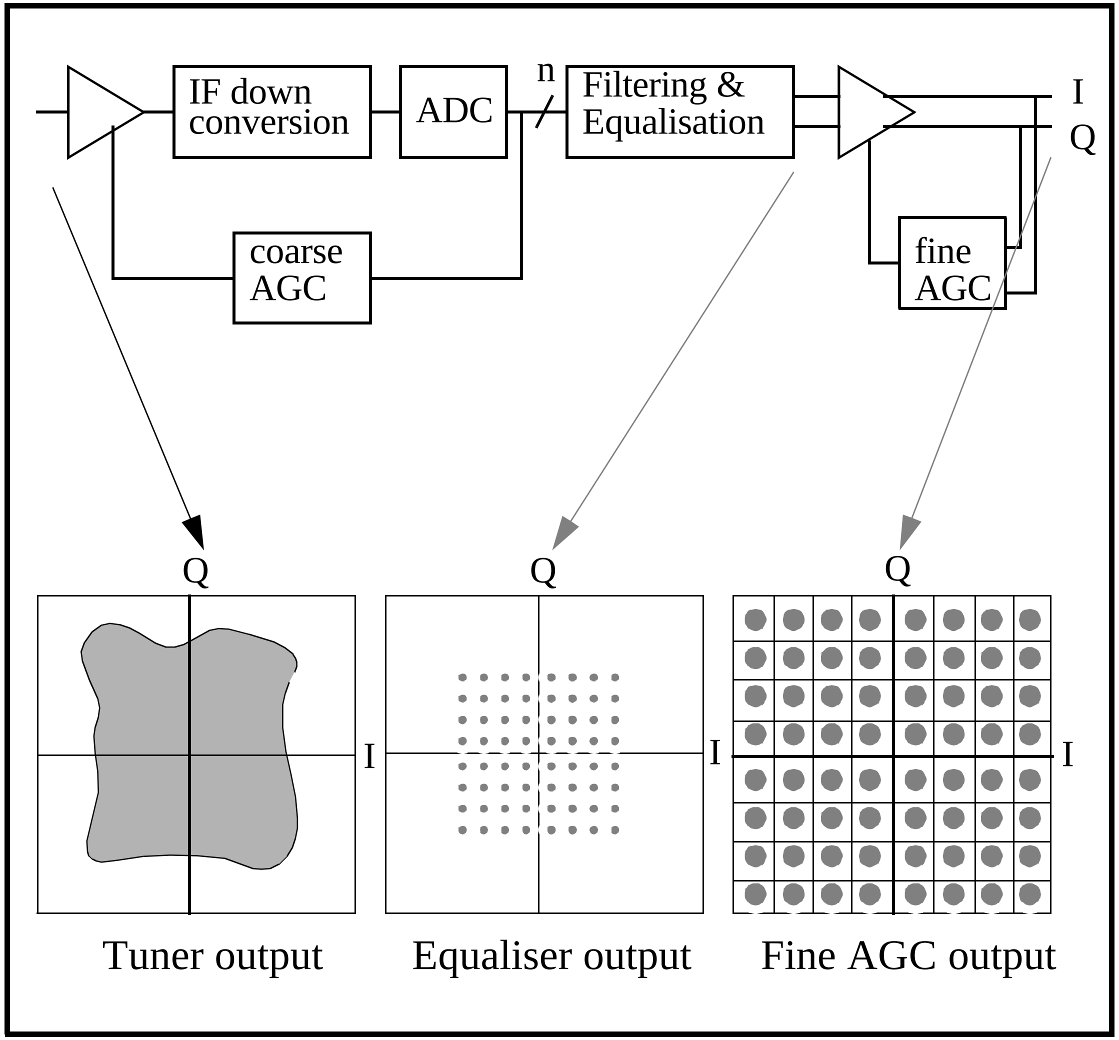
What to do to recover the information?

Functions	**Result**
Automatic Gain Control	Optimal position of constellation diagram in reception window
Quadrature down conversion	I & Q base band signals
(Half) Nyquist Filtering	Pulse shaping
Clock Recovery	Sampling reference for A/D Converter
Carrier Recovery	Carrier frequency reference
Adaptive Equaliser	Compensate for channel distortion
Demapping	Representation of received data in bits

System Block Diagram



Automatic Gain Contrd



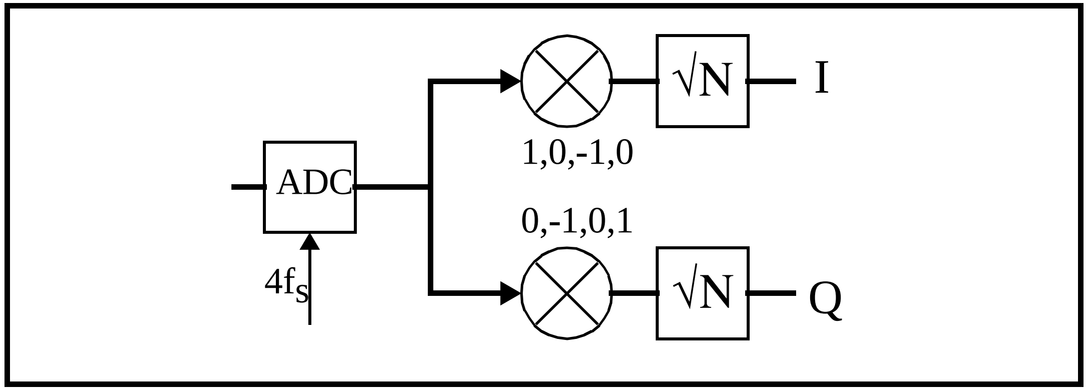
* 2 loops AGC

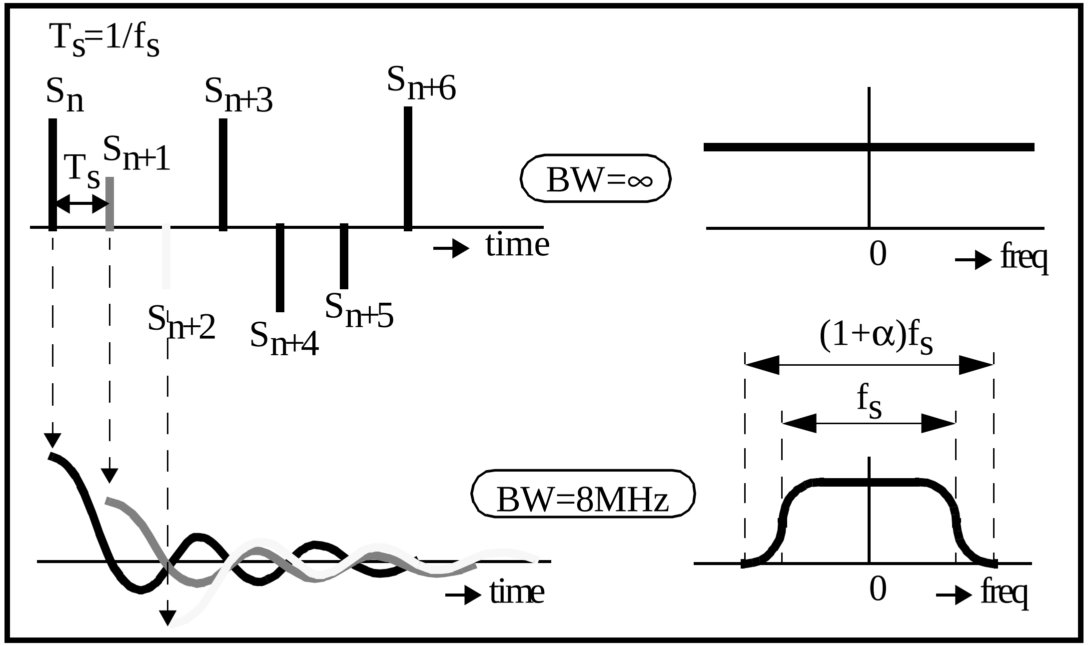
* Coarse AGC to prevent ADC from overloading

* After Nyquist filtering and Equalisation 'small' QAM remains.

* Fine AGC to position contella-tion diagram to decision window

(Half) Nyquist Filtering





* Pulse Shaping required to realise ISI=0 in limited BW

* ISI=0 when zero crossings occur at multiples of $T_S=1/f_S$

* Achieved with Nyquist Criterion

(DVB: α = 15%)

* Cascade of Transmitter & Receiver fulfil Nyquist Criterion

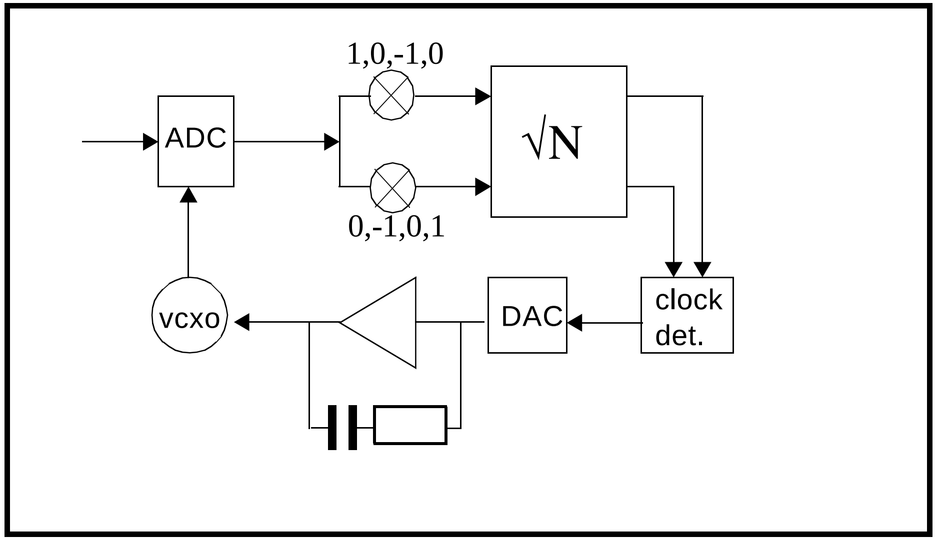
(Half Nyquist each)

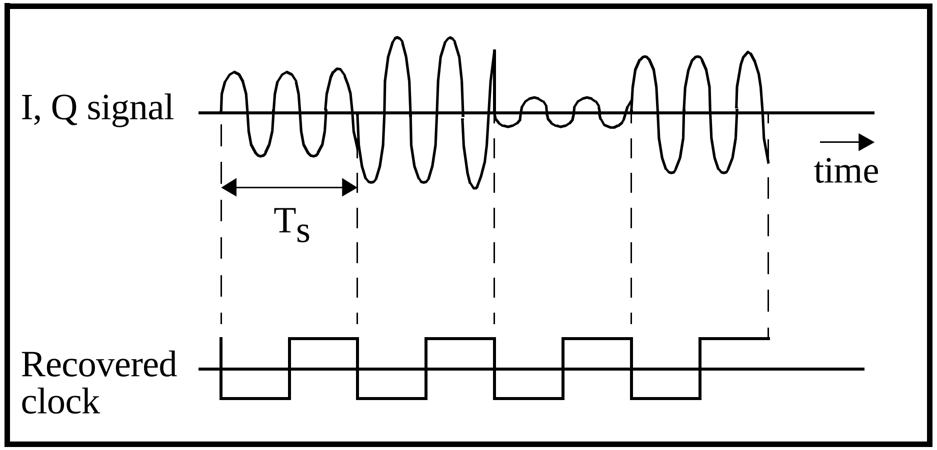
* Digital implementation

(T_{delay} = 9 T_{symbol})

* *This delay is in the loops and thus influences the demodulator architecture*

Clock Recovery





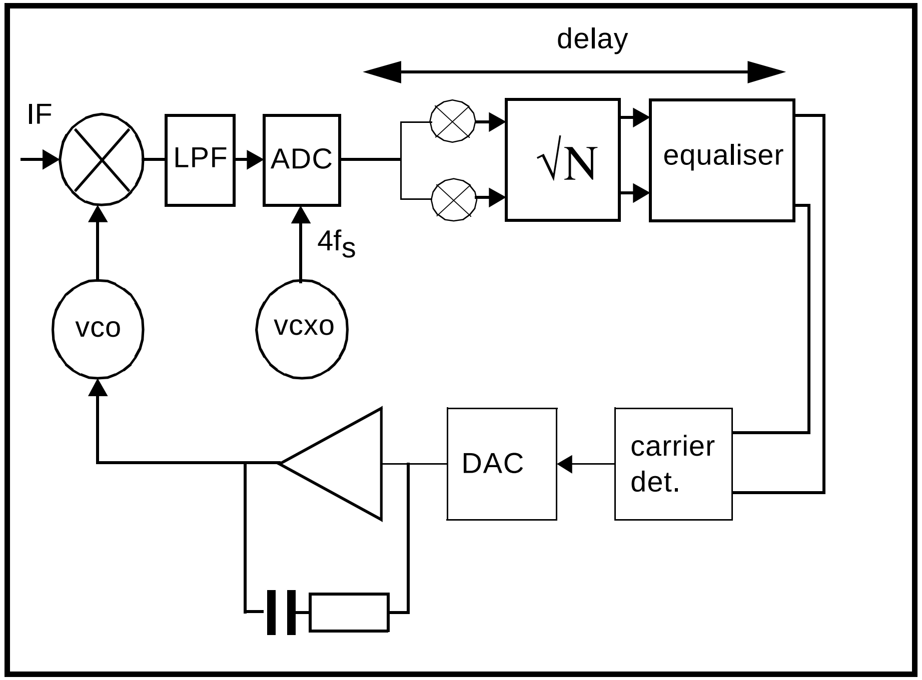
* Recovery with 2nd order PLL

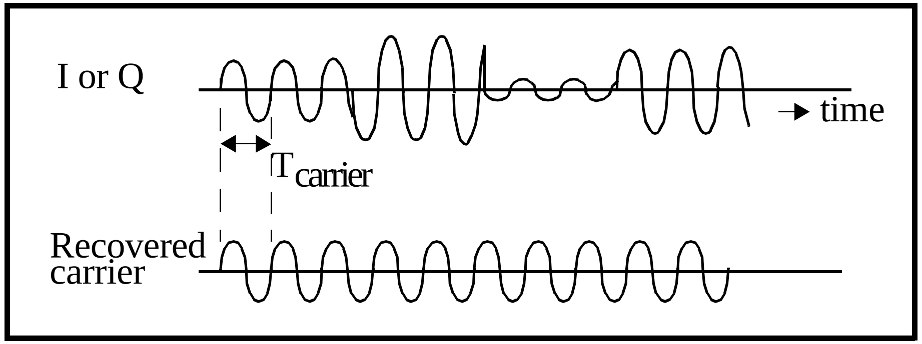
* Clock Detector
- Energy Maximization algorithm
- After Half Nyquist Filter to achieve ISI=0 at detector input

* Half Nyquist Filter in loop is allowed
- Received clock has crystal accuracy (100 ppm at 7 Msym/s))
- Loop BW may be small
- Delay in loop is allowed (no instability)

* Quadarture Demodulation
- $f_{clock} = 4\ f_{symbol}$
- Simple with j^{-n} (n=0,1,2,3,...)

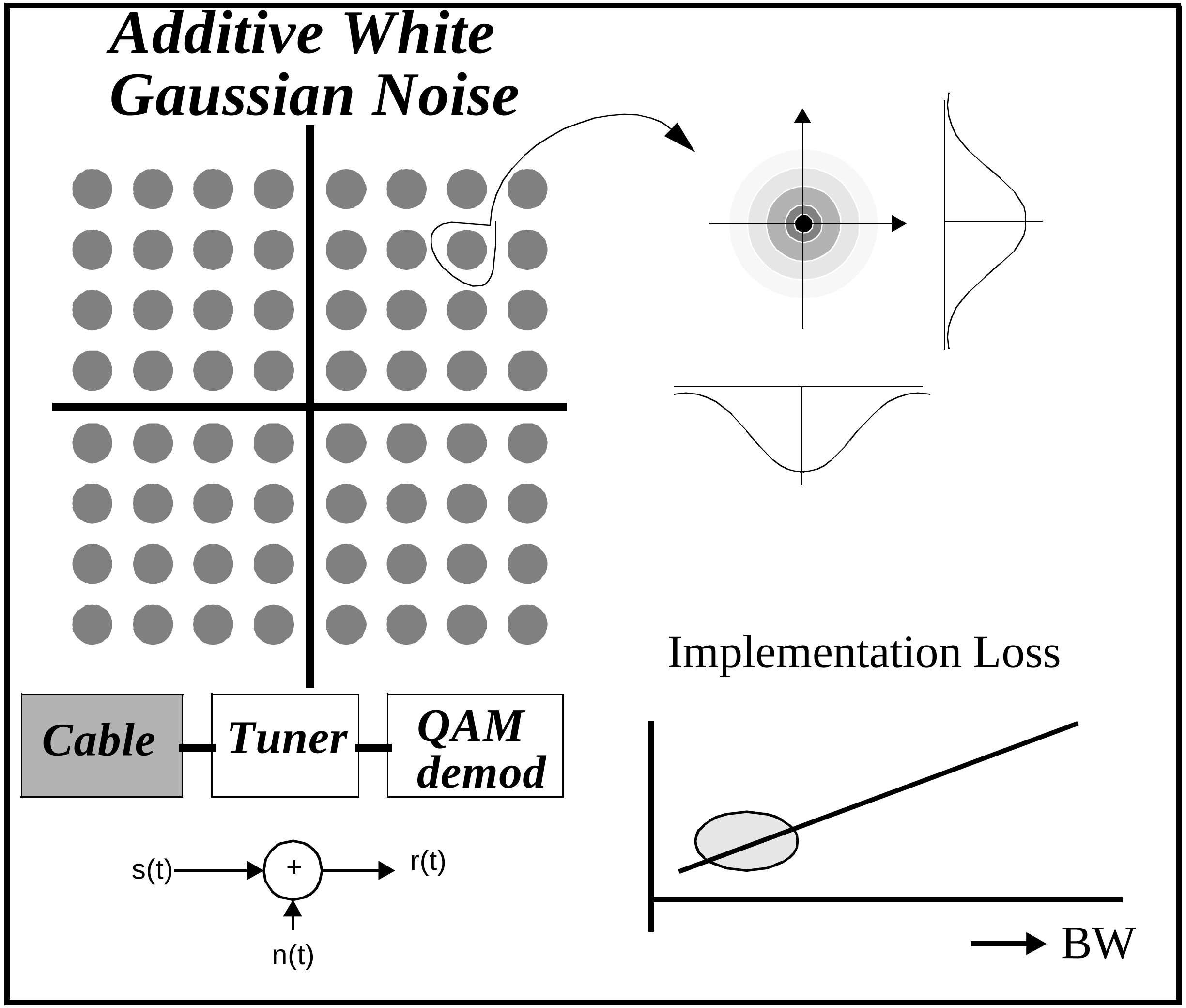
Carrier Recovery





- Recovery with 2nd order PLL
- Carrier Detector
  - Decision directed
  - After equaliser
  - PD (lock) and PFD (unlock)
    - PFD for large acquisition range (100 kHz)
    - PD for stable behaviour once in lock
- Half Nyquist & Equaliser in loop
  - Large delay causes problems for disturbances like:
    - phase noise
    - microphonics (mechanical vibrations)
- *Alternative solution required*

Carrier Phase Disturbances (1)

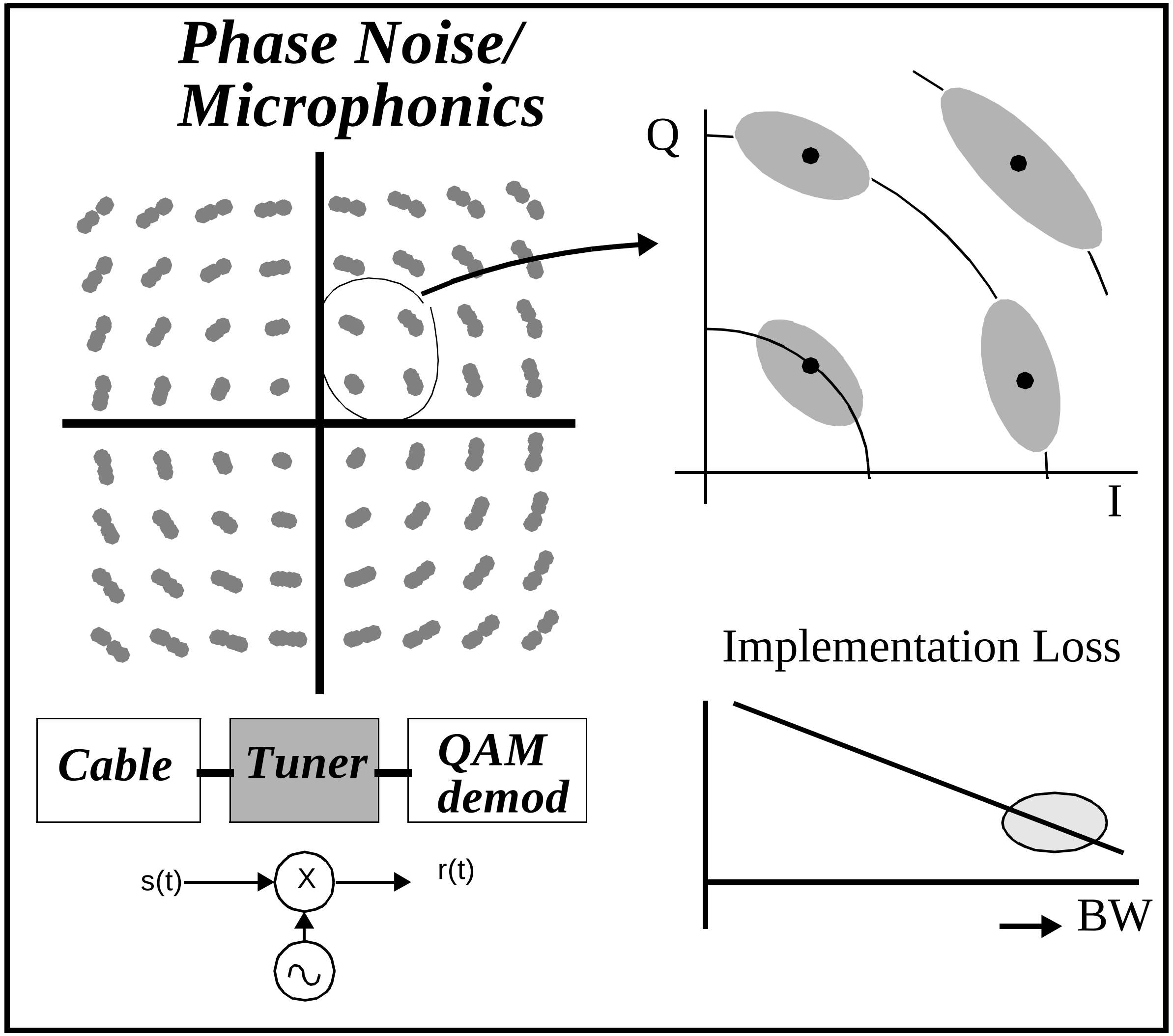


* AWGN Disturbance
  - Random distribution
  - Mainly inserted in the cable channel

* Result
  - Enlarged constellation points

* PLL Properties
  - Average the noise
  - Loop BW small
  - Low IL

Carrier Phase Disturbances (2)



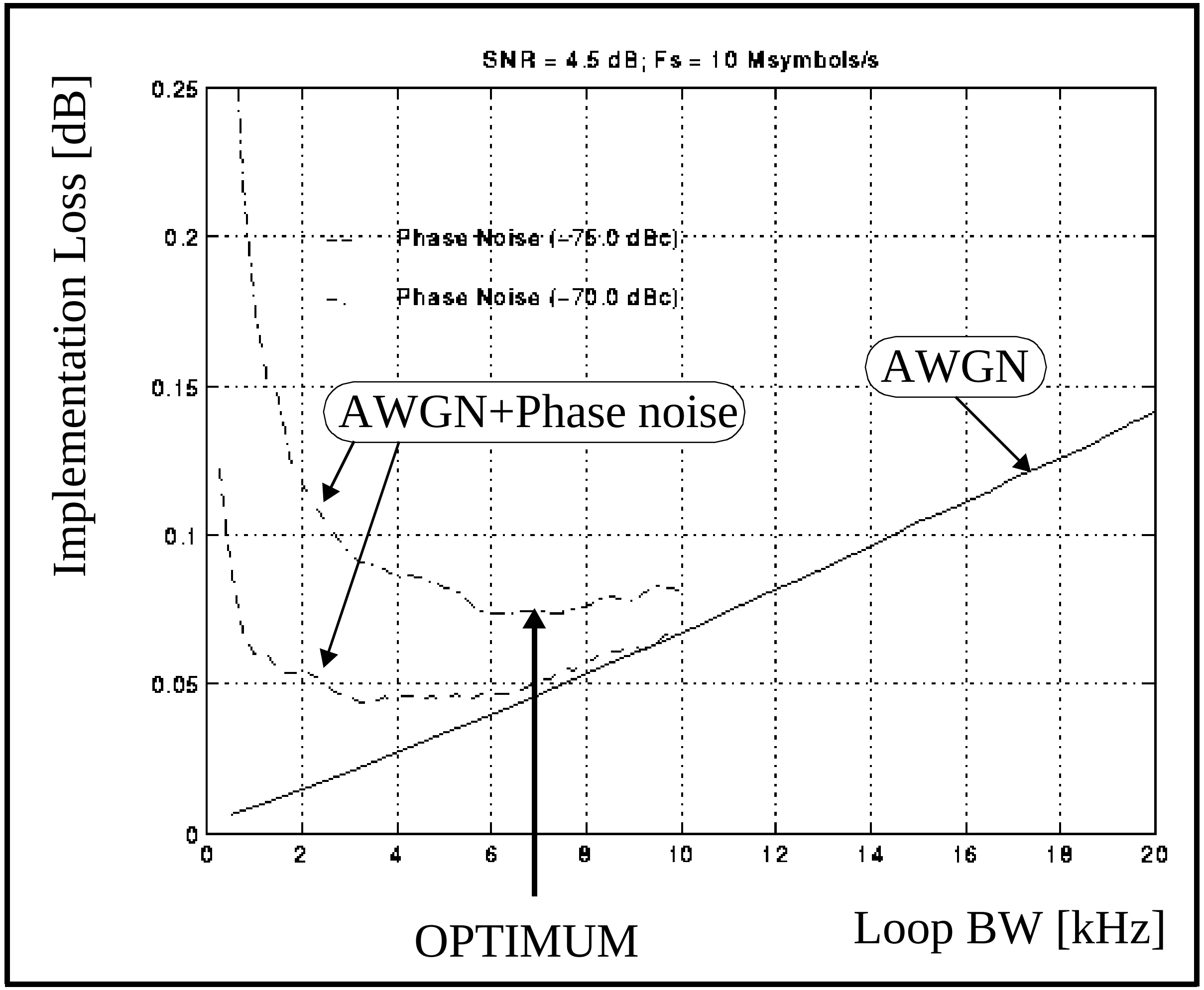
* Phase Noise & Microphonics
- No random distribution
- Mainly inserted in the tuner by LC oscillators which are sensative for mechanical vibrations (Microphonics)

* Result
- Rotation of constellation diagram.

* PLL Properties
- Follow the phase disturbance
- Loop BW large
- Low IL

* *PLL properties for AWGN and phase noise are in contradiction*

Phase noise versus AWGN



* Loop BW trade of between:
  a. Ability to follow phase noise
  b. Ability to average AWGN

* Rule of thumb:

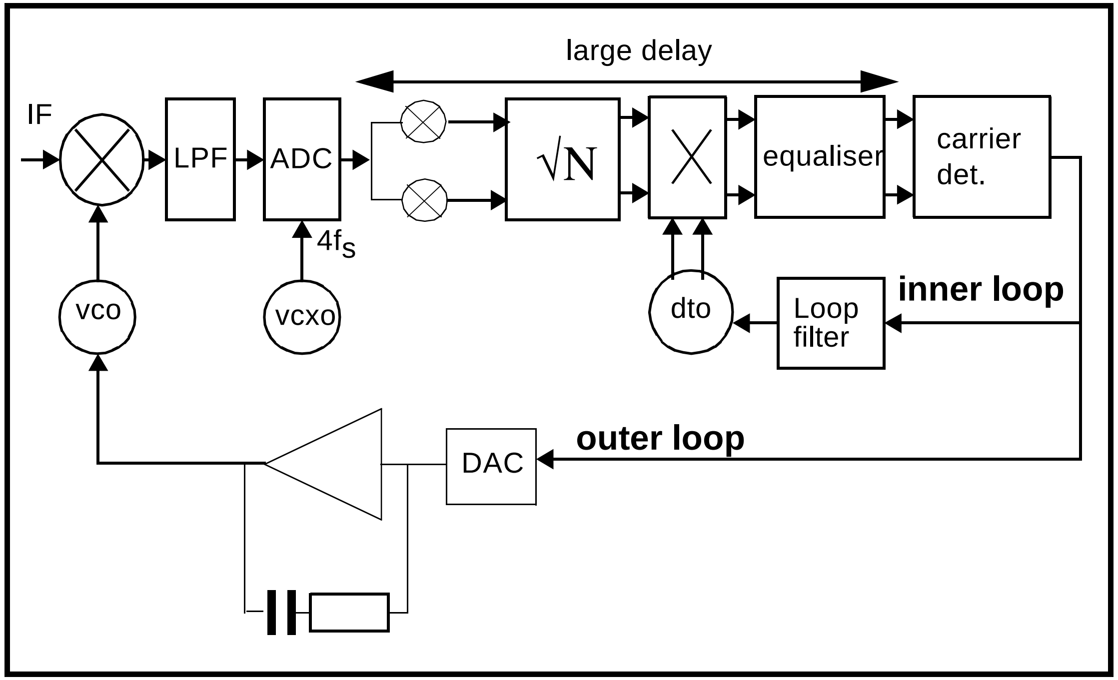
$$BW = \frac{1}{1000} f_{symbol}$$

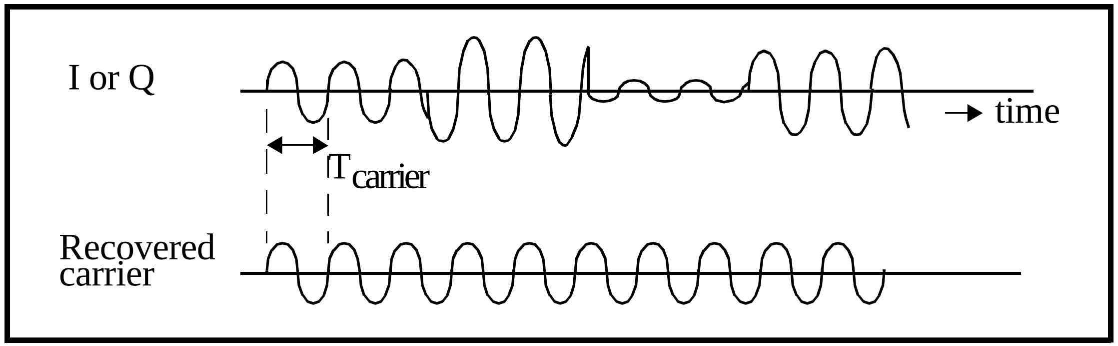
* Simulations show this is approximately correct

* Optimum depends on S/N and amount of phase noise

* *Problem: Optimum loop BW instable due to large delay in the loop (Half Nyquist + Equaliser).*

Double Loop Carrier Recovery





* Introduction of second loop with (relatively) small delay

* <u>Outer loop</u>
  - -Adjust (static) frequency offset
  - -Small loop BW due to large delay
  - -PD/PFD

* <u>Inner Loop</u>
  - Optimum loop BW as trade off between phase noise & AWGN
  - Large Loop BW due to small delay
  - PD only

* *Conclusion: optimum loop BW can be selected and causes no instability*

Equalisation

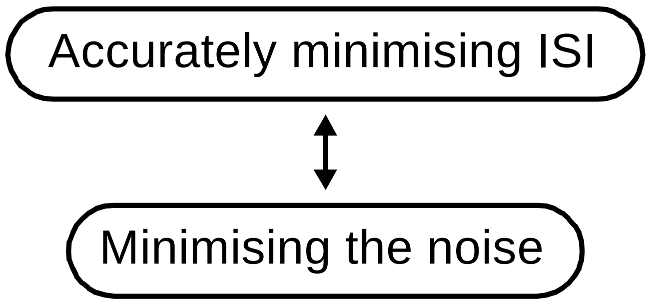
* Nyquist Criterion specifies a frequency domain condition on the received pulses to achieve ISI=0

* Generally this is NOT satisfied unless the channel is equalised

* Equalise the channel = compensate for channel distortion

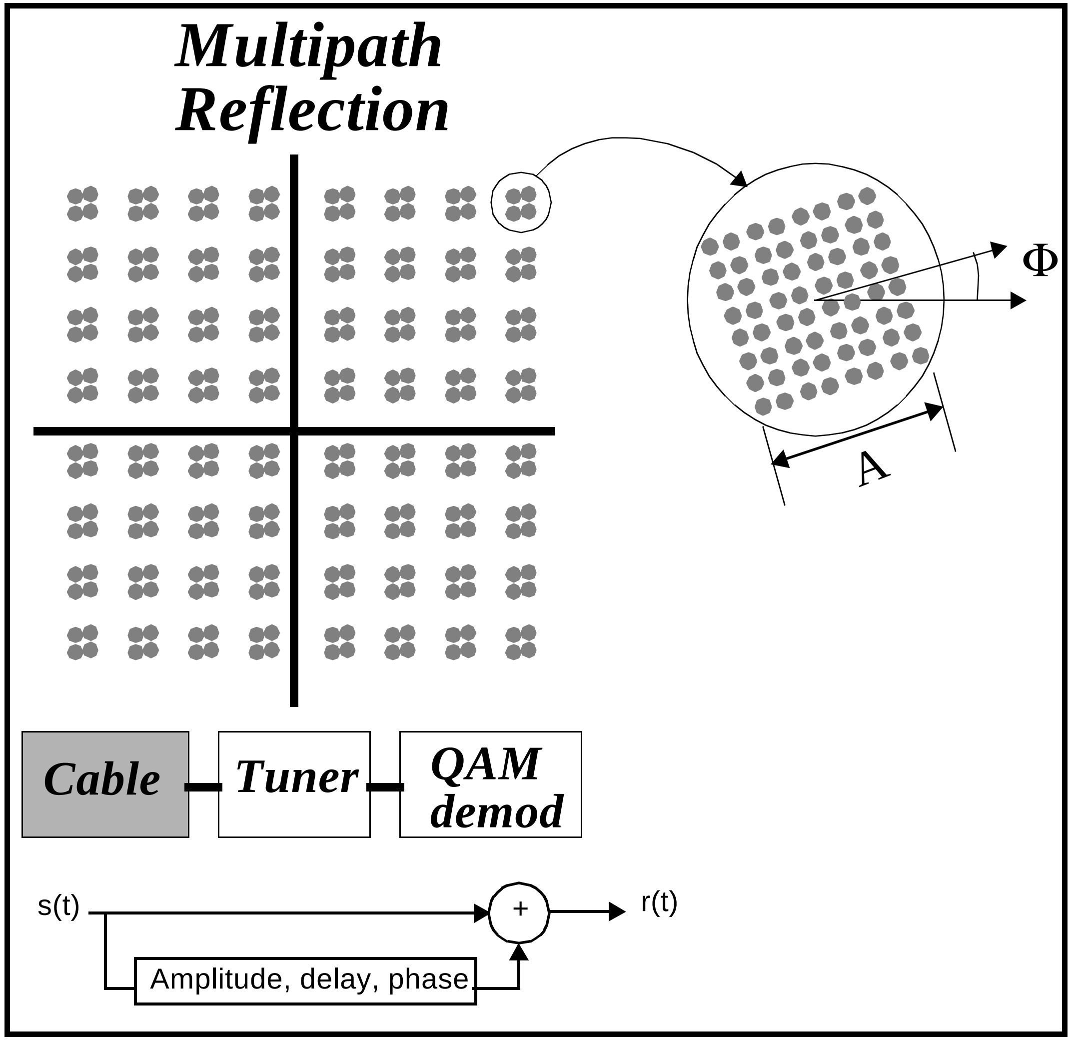
* Unfortunately, any equalisation enhances noise from the channel

* Tradeoff between:



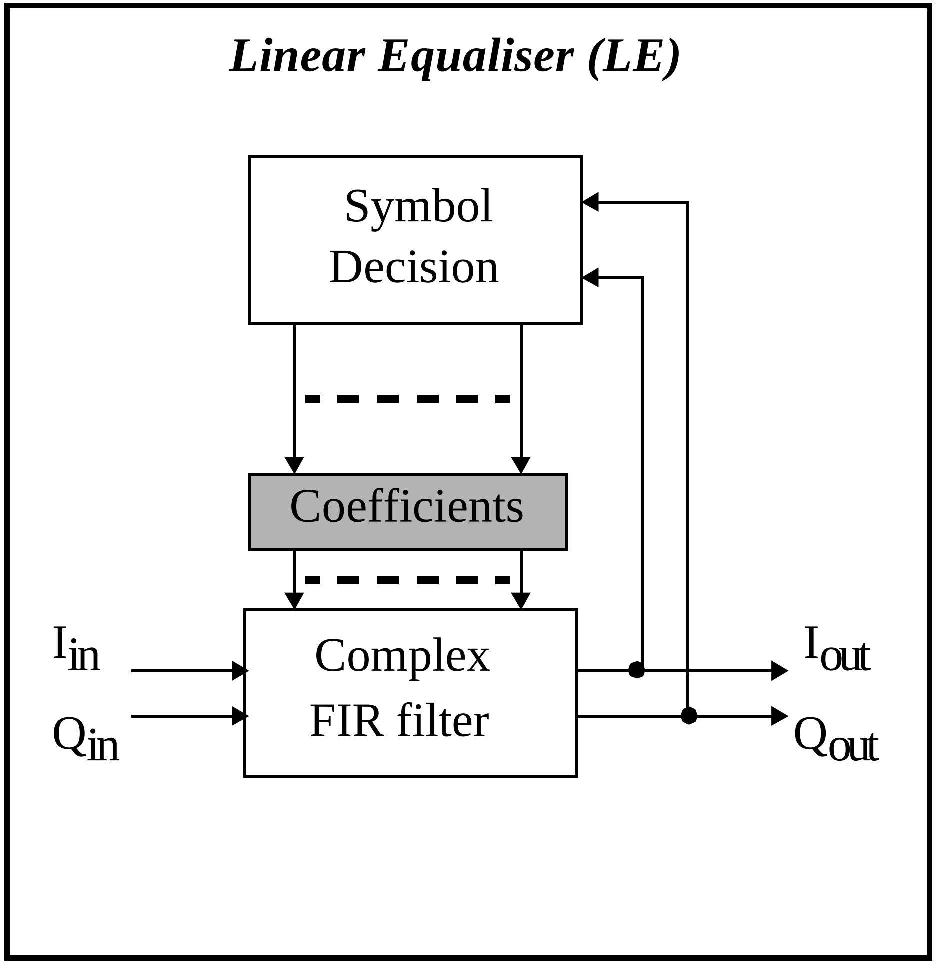
* Different types of Equaliser

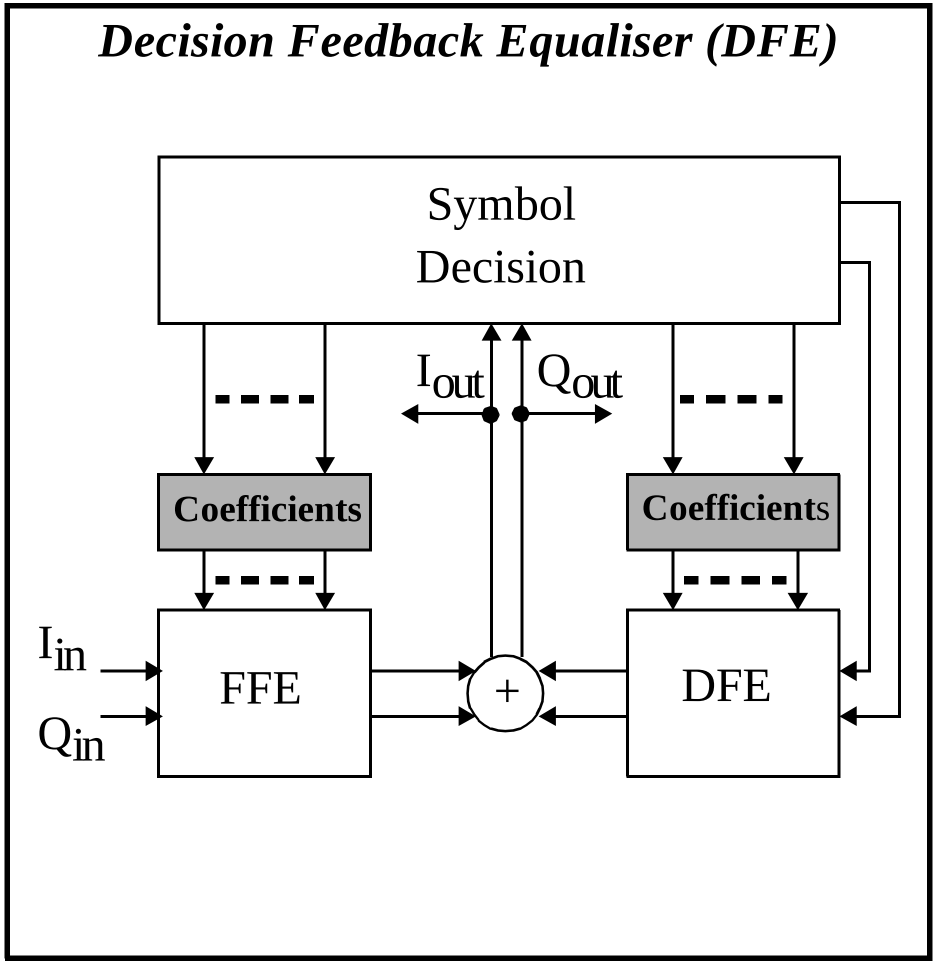
Multipath Distortion



* Multipath distortion causes ISI
* Each original point consists of M new points in the shape of constellation diagram
* Amplitude, delay and phase of the echo determine shape/size of the small constellation diagrams
* Varying channel requires *Adaptive* Equaliser

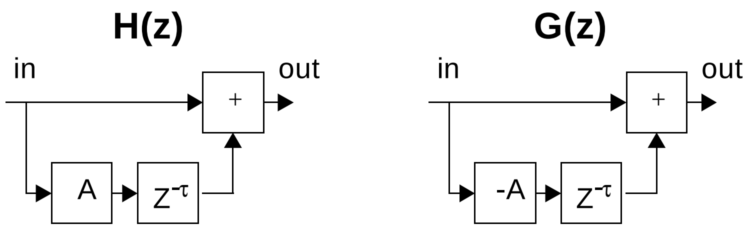
Equaliser Structure





Equaliser Structure

Linear Equaliser (LE)



(-) Residual ISI (A^2,2τ)

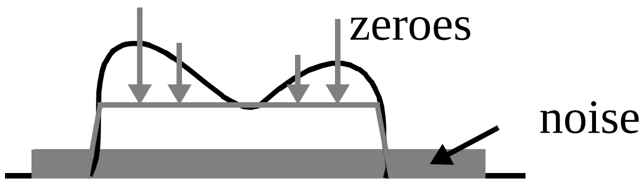
$$H(z) = 1 + Az^{-t}$$

$$G(z) = 1 - Az^{-t}$$

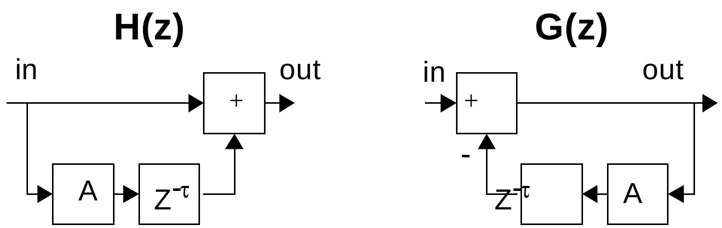
$$H(z)\,G(z) = 1 - A^2 z^{-2t}$$

(+) ‘Fast’ acquisition

(-) ‘High’ noise amplification



Decision Feedback Equaliser (DFE)



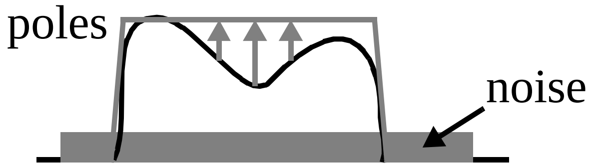
(+) No residual ISI

$$G(z) = \frac{1}{1 + Az^{-t}}$$

$$H(z)\,G(z) = 1$$

(-) ‘Slow’ acquisition

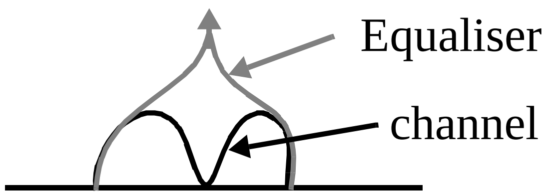
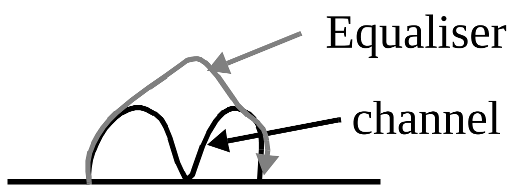
(+) ‘Low’ noise amplification



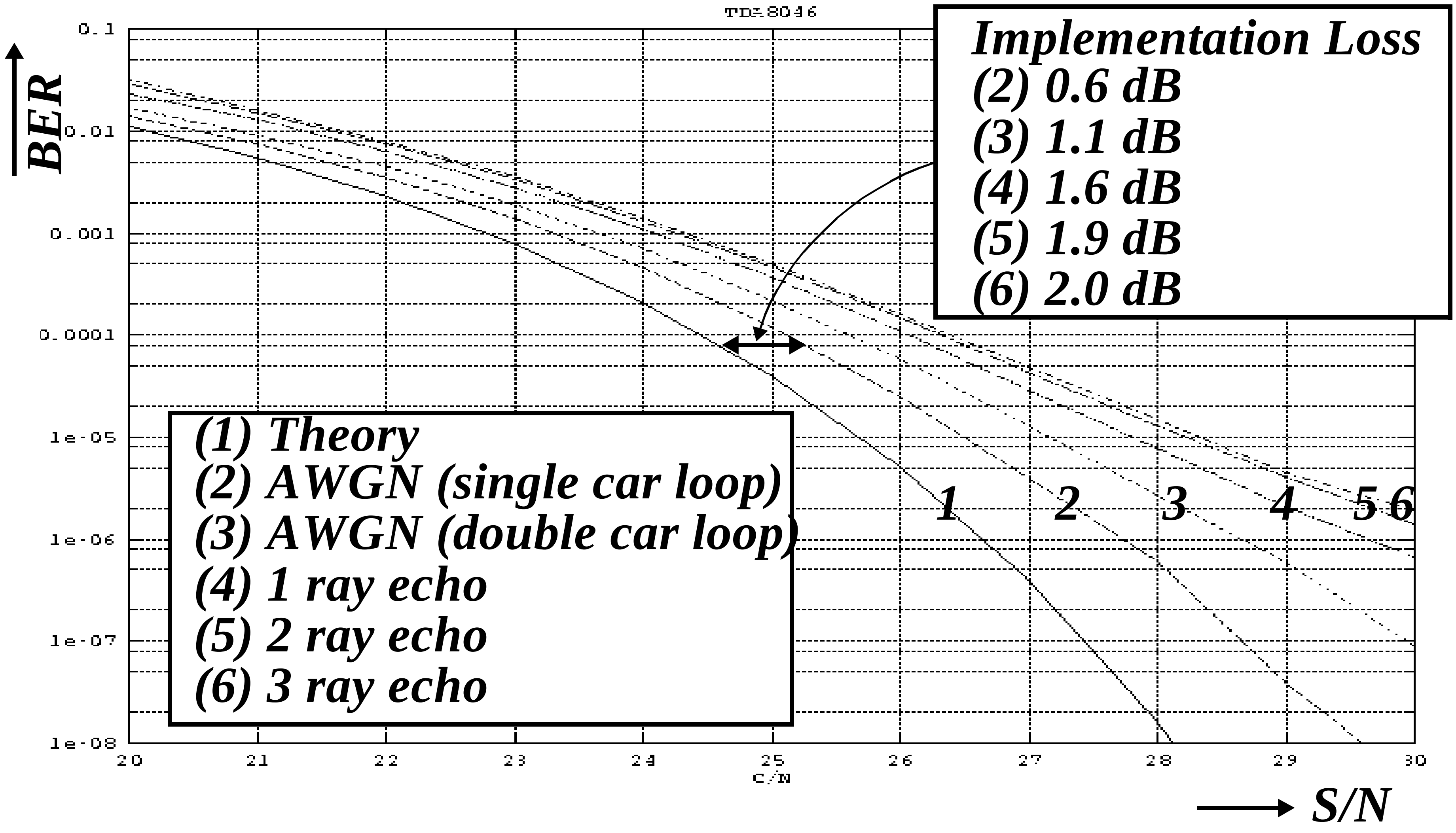
Equaliser Adaptation Algorithm

Zero Forcing (ZF)	***Mean Square Error (MSE)***
(+) Complete elimination of ISI (-) Penalty = Noise amplification	(+) Minimize sum of ISI and noise (+) Less noise amplification by (-) Allowing residual ISI

Adaptive Equaliser

	ZF (Zero Forcing)	MSE (Mean Square Error)
LE	<u>Suited for QAM with M≤64</u> (-) residual ISI does not allow higher M (+) Fast acquisition (+) High stability	<u>Suited for QAM with M≤64</u> (-) residual ISI does not allow higher M (+) Fast acquisition (+) High stability
DFE	<u>No suitable solution</u> (-) Because of complete elimination of ISI system is instable when zero in spectrum 	<u>Required for QAM with M>64</u> (+) Stablity guaranteed when zero in spectrum  (-) 'Slow' acquisition

Measurement Results



Conclusion

Single Chip QAM Demodulator with low Implemenation Loss

- **Double Loop AGC for optimum usage of A/D Converter**
- **Delay in half Nyquist filter and equaliser require double carrier recovery loop structure to achieve high performance on phase noise & microphonics**
- **Adaptive equaliser**

  *** LE/ZF or LE/MSE preferred for QAM with $M \leq 64$**

  *** DFE/MSE required for QAM with $M > 64$**