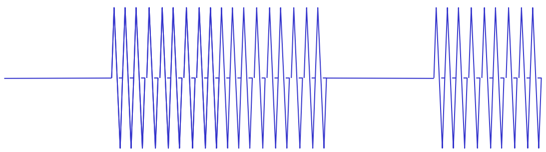
Modulating on to a carrier

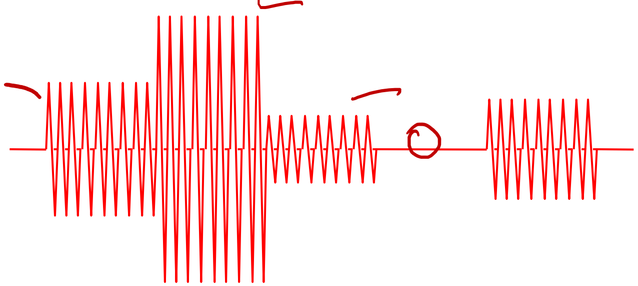
Bandpass Digital Modulation

Discretes

Amplitude shift keying

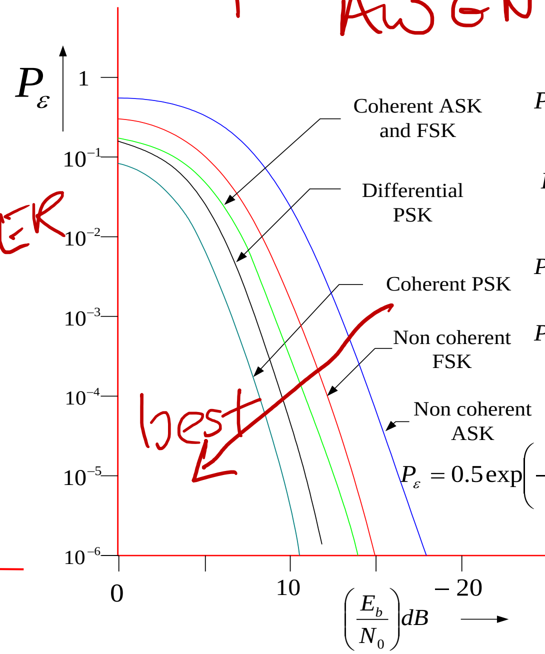


Multi-level ASK



Performance in AWGN

BER



$$P_\varepsilon = 0.5\,erfc\left(\sqrt{\frac{E_b}{2.N_0}}\right)$$

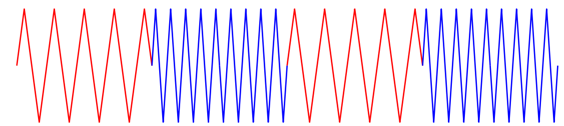
$$P_\varepsilon = 0.5\exp\left(-\frac{E_b}{N_0}\right)$$

$$P_\varepsilon = 0.5\,erfc\left(\sqrt{\frac{E_b}{N_0}}\right)$$

$$P_\varepsilon = 0.5\exp\left(-\frac{E_b}{2.N_0}\right)$$

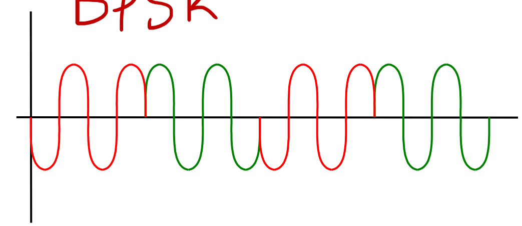
$$P_\varepsilon = 0.5\exp\left(-\frac{E_b}{4.N_0}\right) + 0.5\,erfc\left(\sqrt{\frac{E_b}{2.N_0}}\right)$$

FSK



f_1 f_2

BPSK



Digital Modulation

Mathematical Background: Orthogonality (1)

- Two signals $a_i(t)$ and $a_j(t)$ are said to be orthogonal if:

$$\left[\int_0^{T_S} a_i(t).a_j(t).dt = 0\right]_{i \neq j}$$

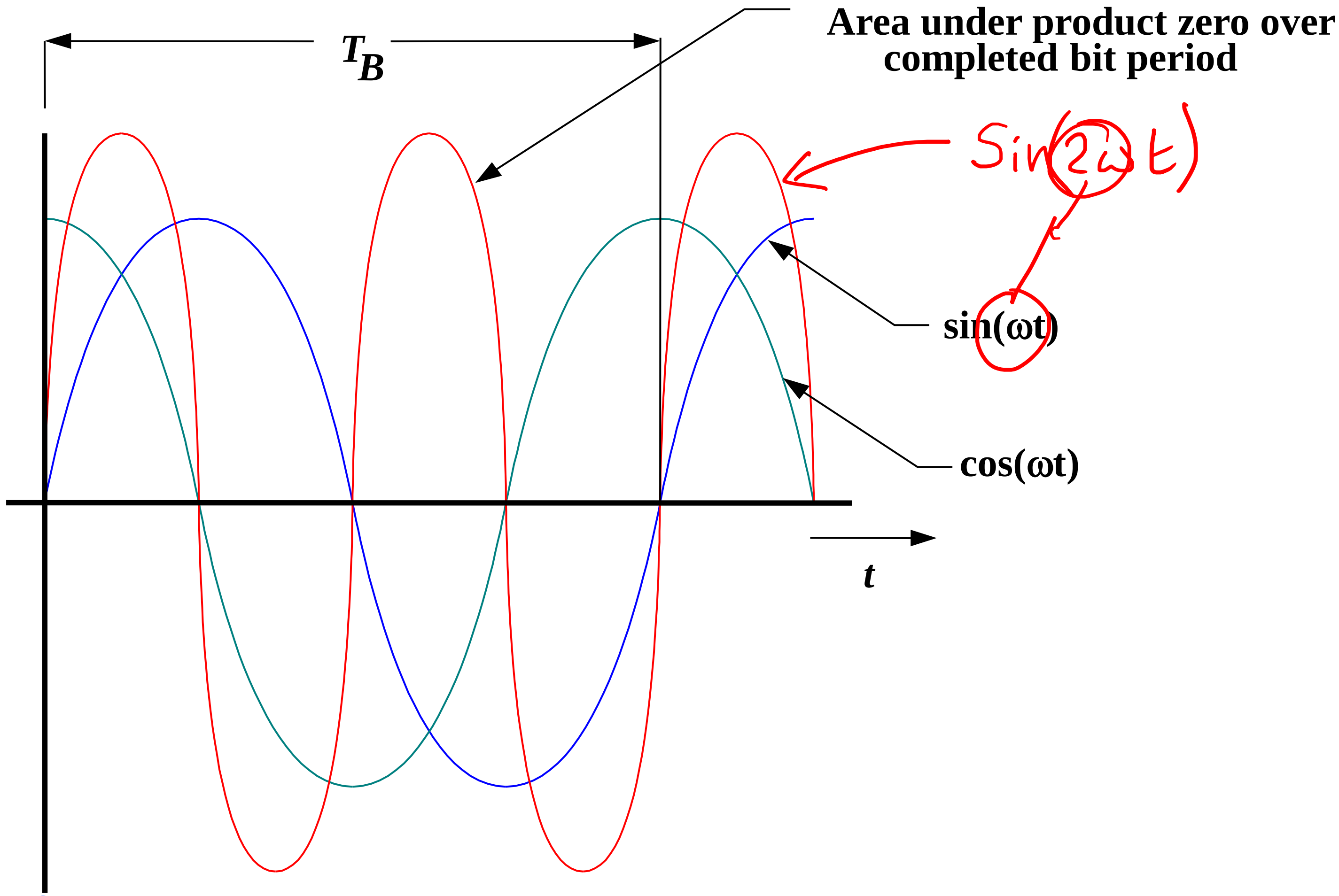
- Examples of orthogonal signals are:

$a_i(t) = \cos(2\pi ft)$ I and $a_j(t) = \sin(2\pi ft)$ Q

$a_i(t) = \cos(2\pi f_i t)$ and $a_j(t) = \cos(2\pi f_j t)$

where $f_i, f_j = \{1,2,3,\ldots\}$; $f_i \neq f_j$ Cos f_c Cos $2f_c$ Cos $3f_3$

Mathematical Background: Orthogonality (2)

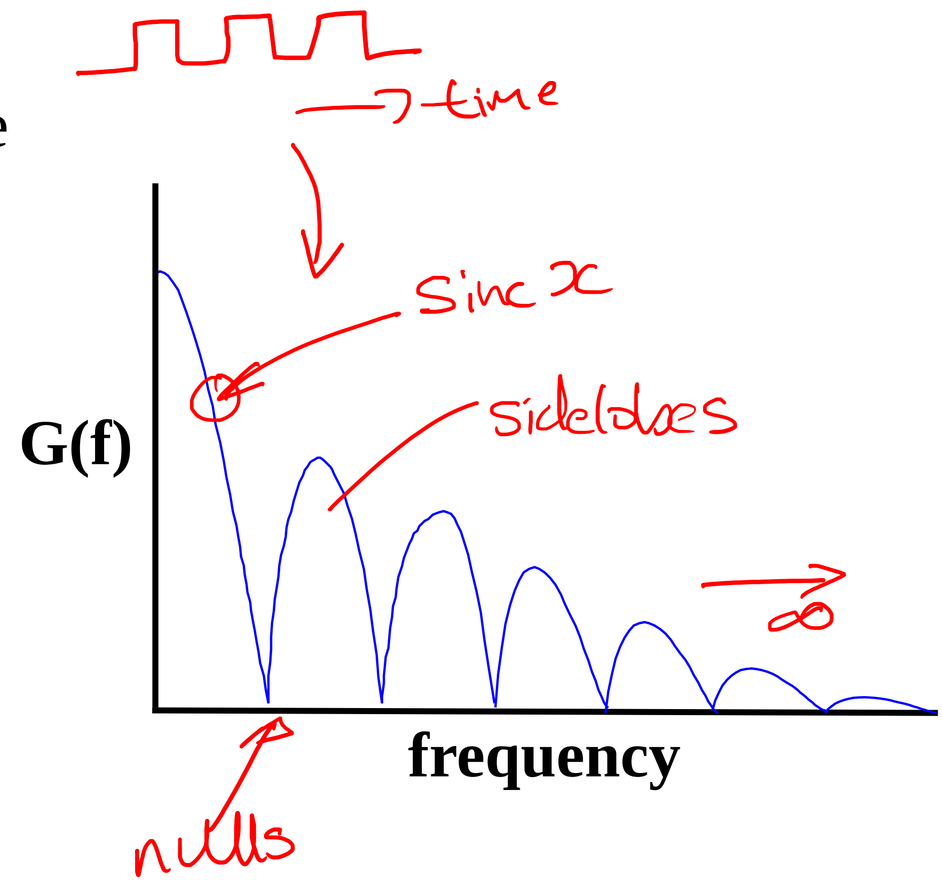


Mathematical Background: Spectrum of a Baseband Square Wave

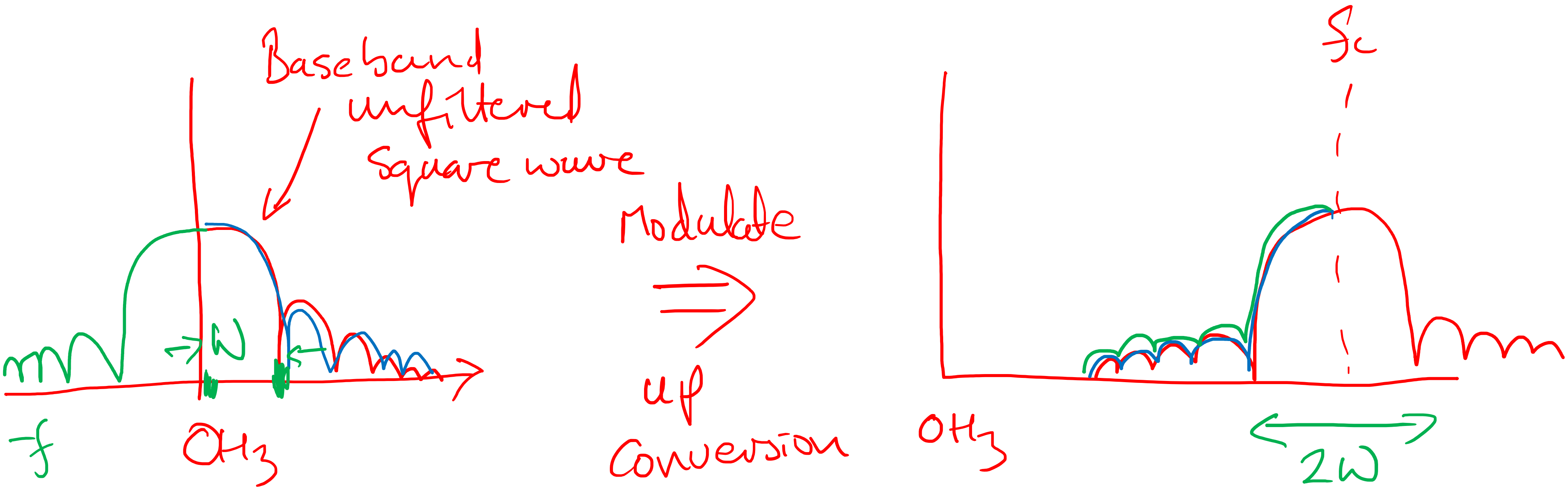
- It can be shown by fourier analysis that the spectrum of a (baseband) square wave signal is described by a sinc or sin(x)/x function:

$$G(f) = T.A.\left[\frac{\sin(\pi.f.T)}{\pi.f.T}\right]$$

- This spectrum extends to infinity. It is often necessary to apply a pulse shaping (band limiting) filter to this signal.



Baseband to Bandpass Spectrum



Bandpass and Baseband Signalling

- With baseband signalling the channel is assumed to extend from 0Hz upwards.
- Transmitting this type of data over conventional media, such as radio channels, requires a shift in frequency.
  - This process is called 'carrier modulation' or just 'modulation'.
- Often the process of modulation takes a band of signals based on zero Hz and shifts them to occupy twice the bandwidth centred on a carrier frequency.
- A corresponding 'demodulation' or 'detection' process is required to recover the data.

Carrier Modulation (1)

- The carrier signal is typically a sine wave. The transmitted signal can be described by:

$$s(t) = A\cos(\omega t + \theta)$$

- This signal has three properties which we can modulate.
  - Amplitude, A.
  - Frequency, ω.
  - Phase, θ.
- Initially we will consider modulation schemes which modulates only one of these three properties.
- Also, we will first consider binary modulation schemes. M-ary modulation will be covered later.

Carrier Modulation (2)

- If we modulate just one property of the signal, we can modulate our data signal onto this carrier signal in one of three ways:
  - By modulating the amplitude of the carrier wave. Thus, A is a function of the modulating signal. This is known as Amplitude Shift Keying (ASK).
  - By modulating the frequency of the carrier wave. Thus, ω, is a functions of the modulating signal. This is known as Frequency Shift Keying (FSK)
  - By modulating the phase of the carrier wave. Thus, θ, is a function of the modulating signal. This is known as Phase Shift Keying (PSK)

Amplitude Shift Keying (ASK)
Generation

Amplitude Shift Keying (ASK)

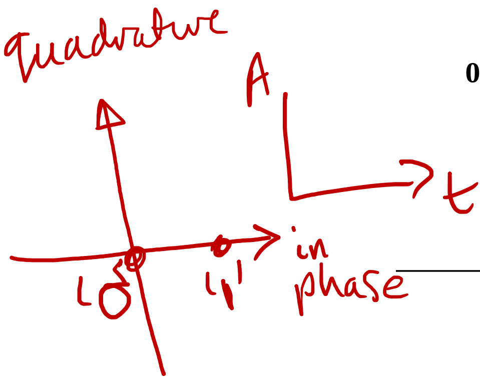
- The simplest form of bandpass modulation is Amplitude Shift Keying (ASK). With this modulation the data is represented as various (discrete) amplitude levels of a fixed frequency carrier.
- The simplest form of ASK is to switch a fixed frequency oscillator ON for a ‘one’, and OFF for a ‘zero’. This is known as ON-OFF KEYING (OOK).
- If more than two symbol states are used, then M-ary ASK is generated.

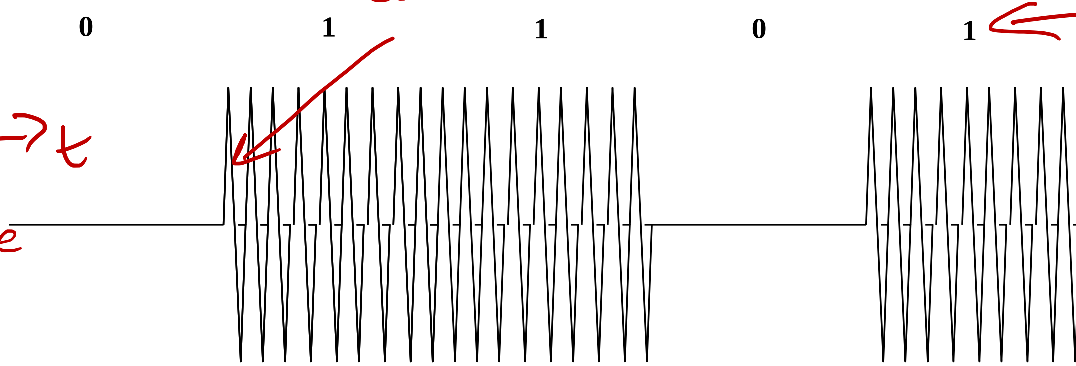
Amplitude Shift Keying (ASK)

A cos ωc t

Carrier

data

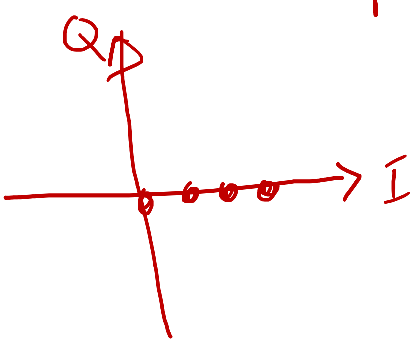


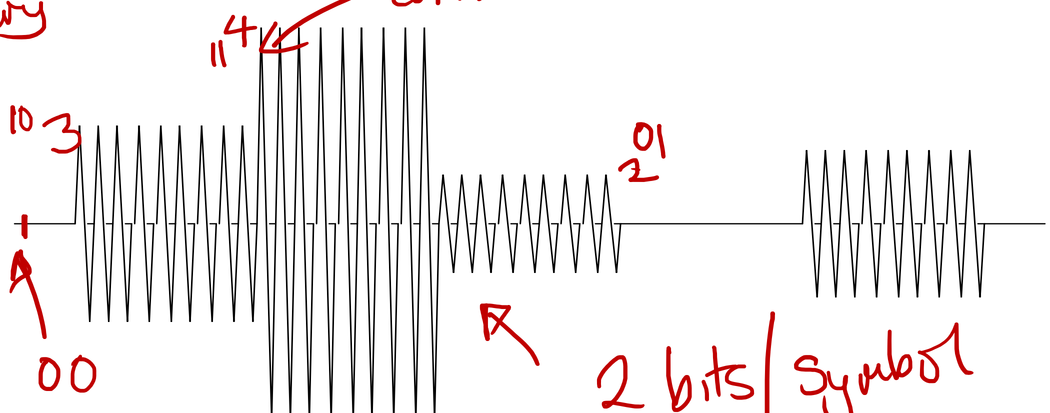


Binary ASK or OOK

M-ary

carrier



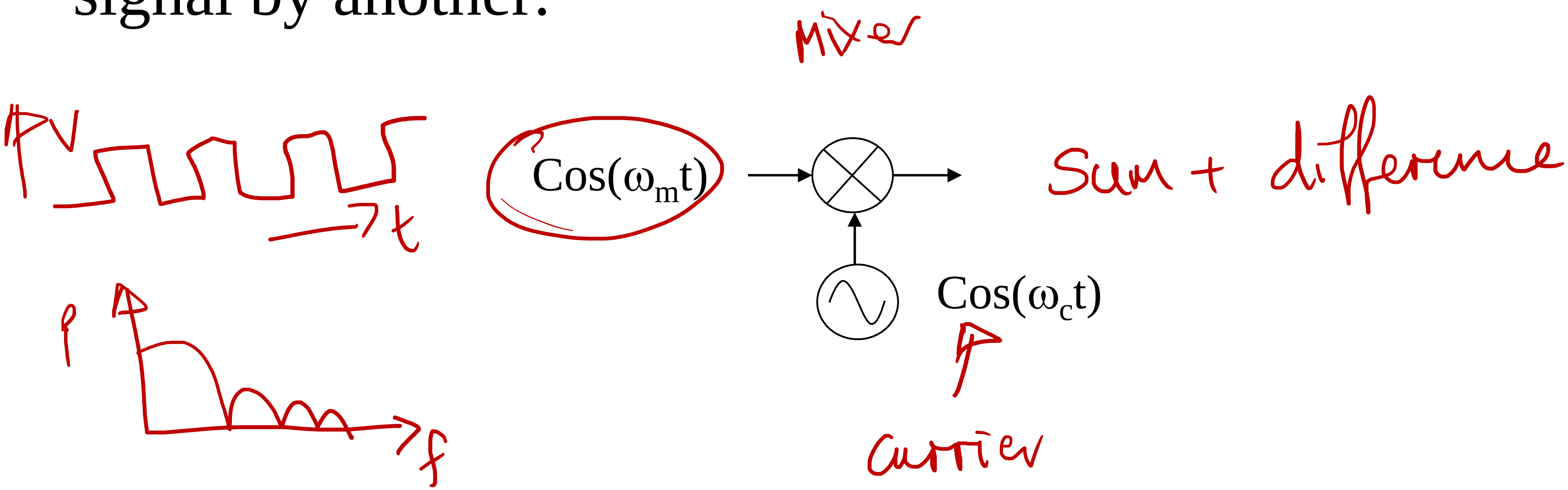


2 bits/symbol

M-ary ASK

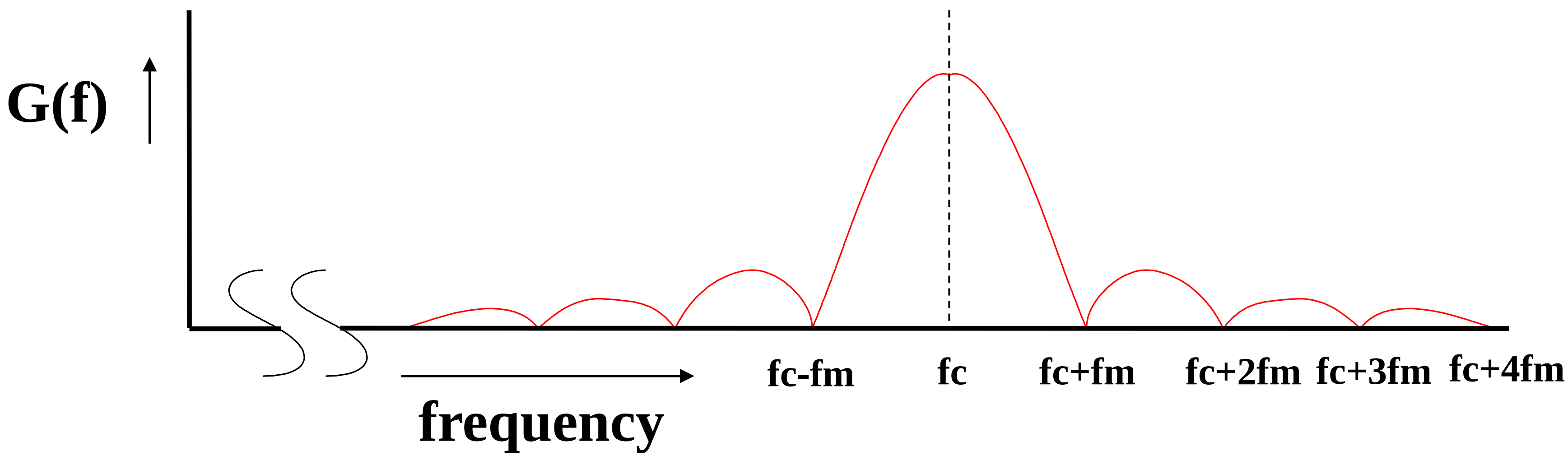
ASK Spectrum (1)

- The spectrum of an ASK signal can be calculated using trig identities.
- Amplitude modulation is essentially the multiplication of one signal by another.



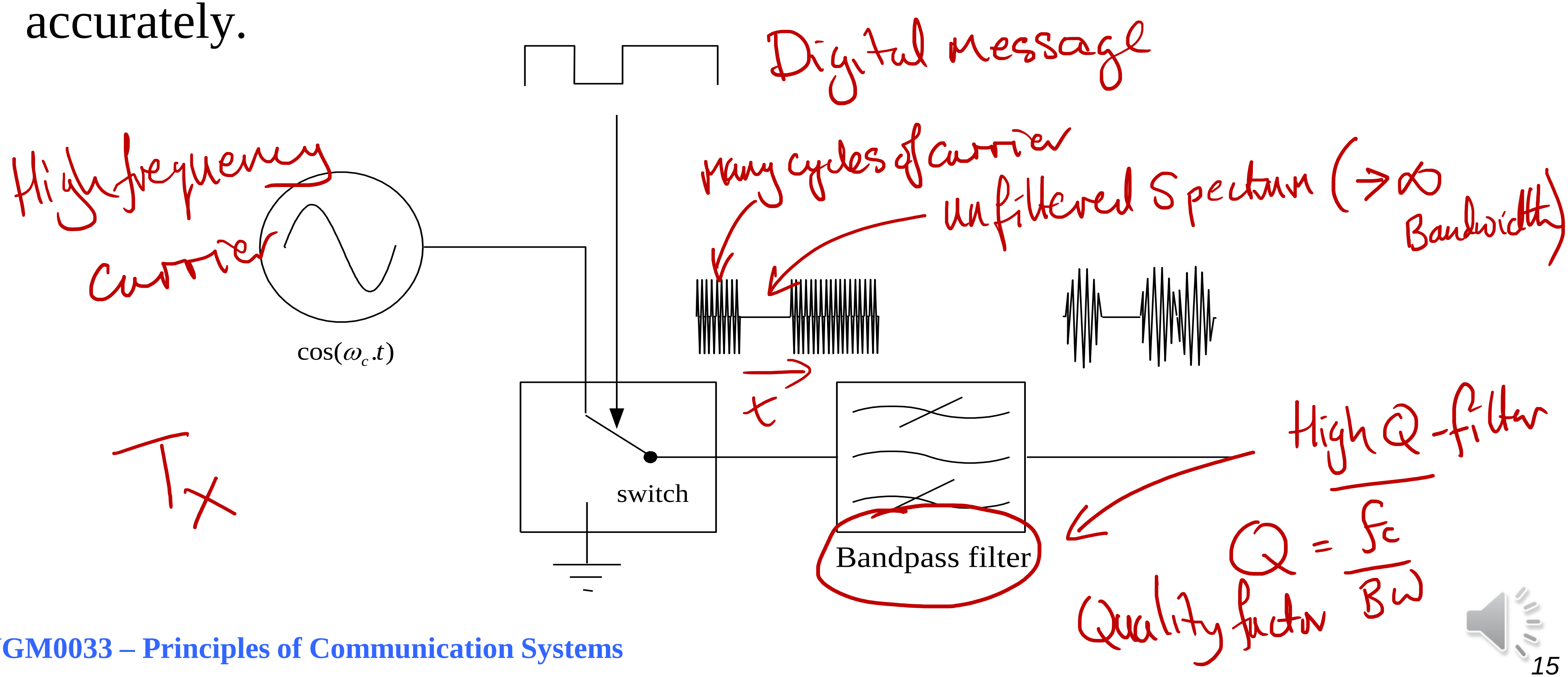
ASK spectrum (2)

- Note that the spectrum is two sided, and therefore the bandwidth required to transmit it is $2.\omega_m$. That is, twice the baseband bandwidth. Spectral efficiency is limited to 1bit/s/Hz
- For square wave modulated ASK the spectrum takes the form:



Generation of ASK (1)

- This diagram illustrates one way in which an ASK signal may be generated. However, bandpass filtering at RF is very difficult to achieve accurately.



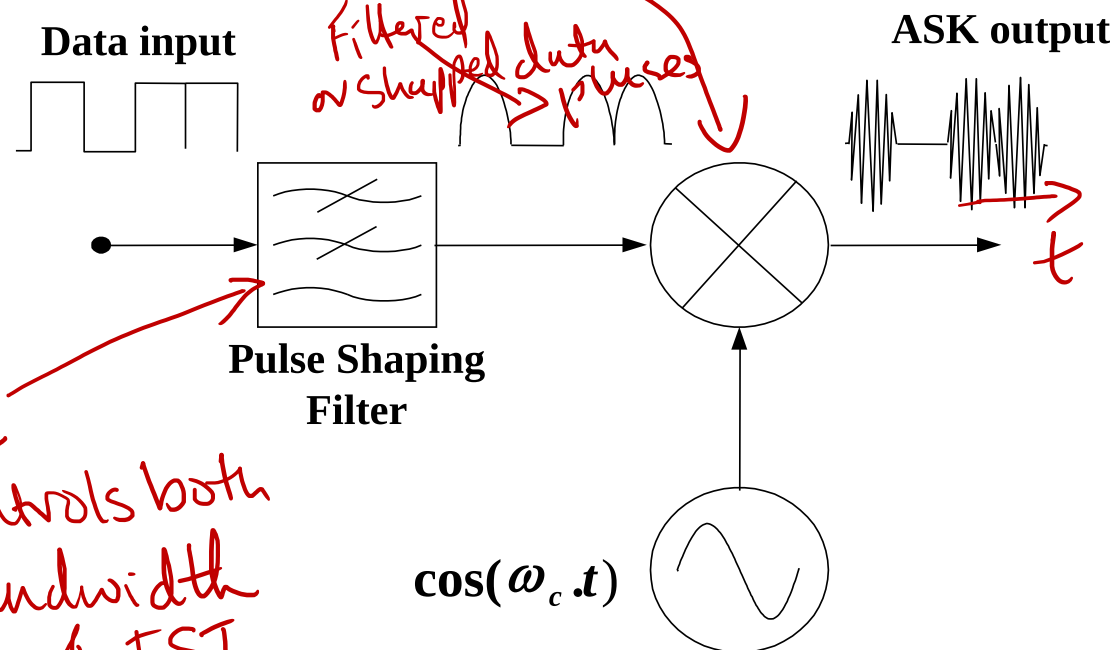
Generation of ASK (2)

- Another method (one we have already discussed), is to multiply a carrier signal by the baseband signal stream. The multiplier is known as a mixer.

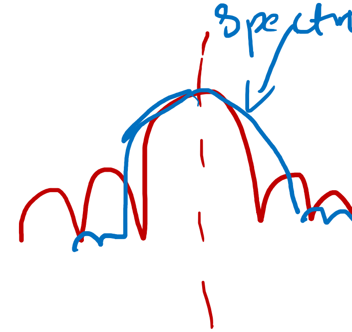
Uni-polar

Filtered or shaped data pulses

Modulator



filtered spectrum



RRC
controls both
bandwidth
& ISI

Amplitude Shift Keying (ASK) Detection

Detection of ASK

University of BRISTOL

- Two methods are available for recovering the base band data stream from ASK.
- The process of recovering the baseband signal is known as demodulation.
- Alternatively it is known as detection.
- The methods fall under the headings 'coherent' and 'non coherent' detection.

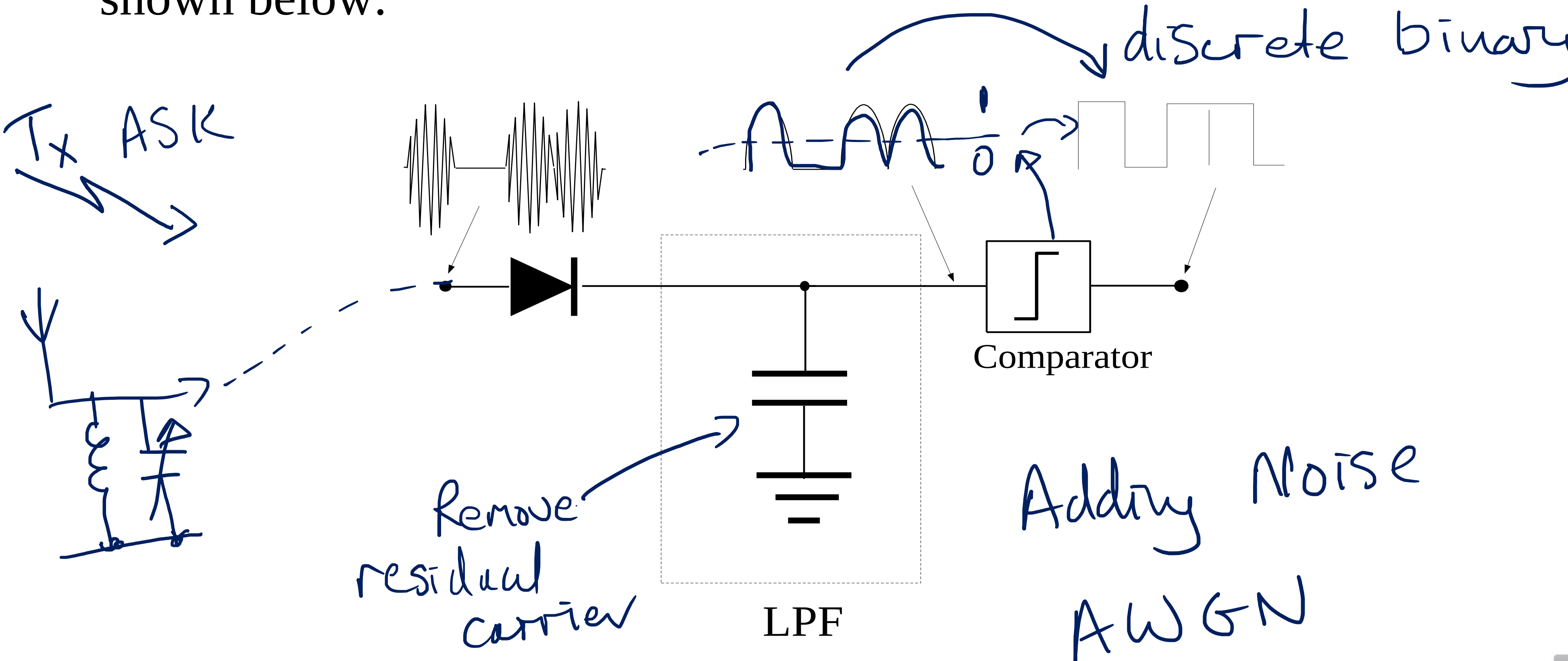
→ envelope detector

Needs a local oscillator (LO)

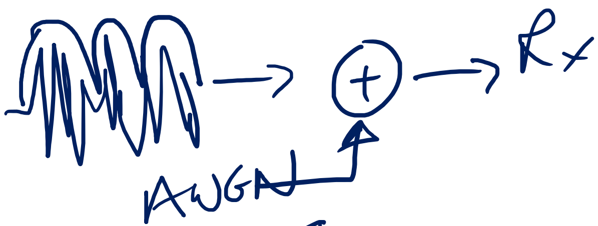
Non Coherent Detection of ASK (1)

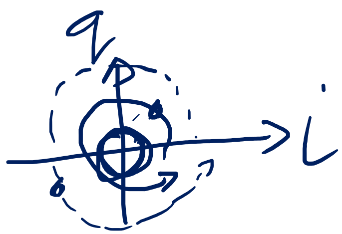
Rx

- Non coherent detection of ASK is straight forward. A circuit to do this is shown below.

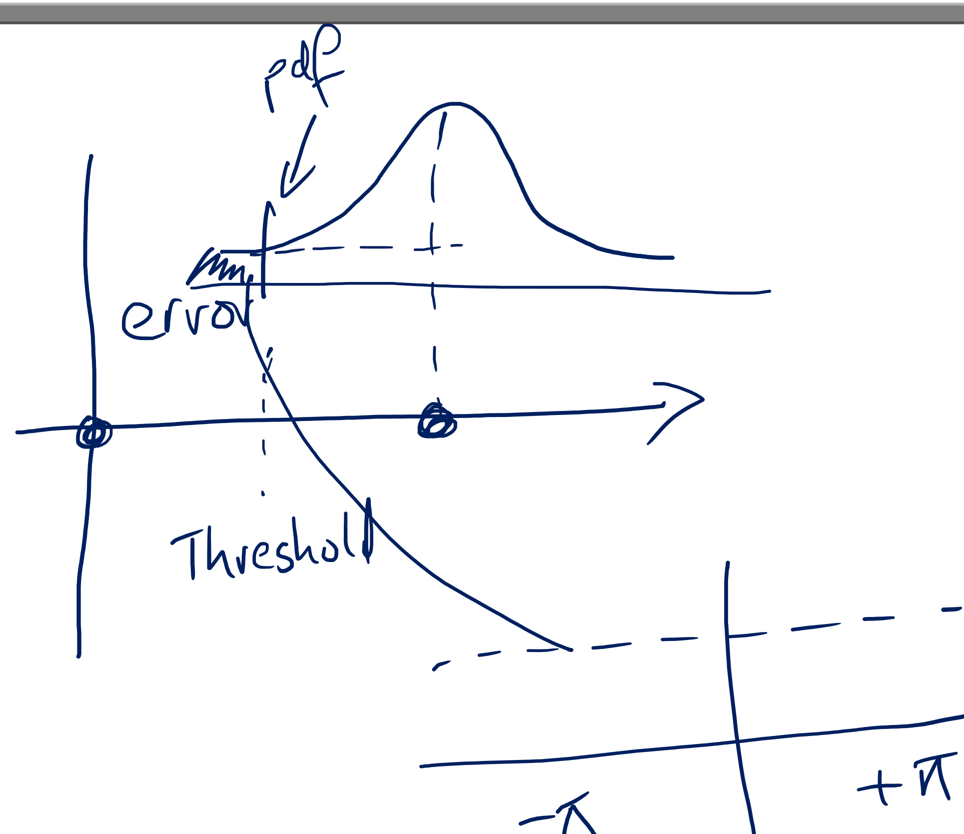


AWGN in Non Coherent Detection of ASK





zero mean



Amplitude is Gaussian
phase is uniform random 0 to 2π
exists in both in-phase & quadrature

Diode will detect both inphase & quadrature noise with respect to the carrier

Non-Coherent Detection of ASK (2)

- The simplicity of this approach is often outweighed by the inability of a non-coherent detector to extract signal from noise.
- A coherent detector can do this and can achieve a lower Bit Error Rate (BER) over the same channel, with the same S/N ratio.

E_b/N_0

Coherent Detection (1)

ASK

- Coherent detection requires the local generation of a replica of the carrier signal. LO
- If a local carrier is available, then the reverse process to modulation can be performed at the receiver. LO
- Essentially the locally generated carrier is multiplied by the incoming signal. Thus:

LO phase offset between Tx & Rx twice carrier frequency

rx signal $A(t)\cos(\omega_c t) \bullet \cos(\omega_c t+\theta) = 0.5A(t)\cos(\theta) + 0.5A(t)\cos(2\omega_c t+\theta)$

DC SUM

- The process results in two output components. One is the baseband message signal (multiplied by a $\cos(\theta)$ term) and the other is the baseband message signal shifted to twice the carrier frequency.

phase error

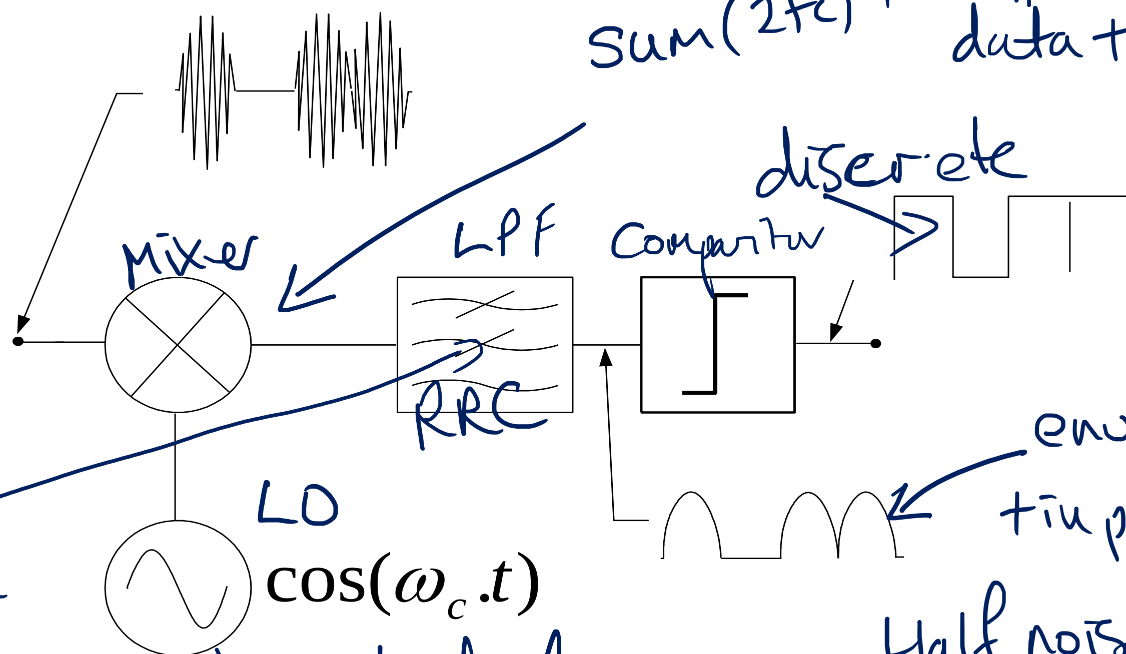
Coherent Detection (3)

ASK (Rx)

Modulated carrier ($\cos \omega_c t$)
+ noise in I+Q

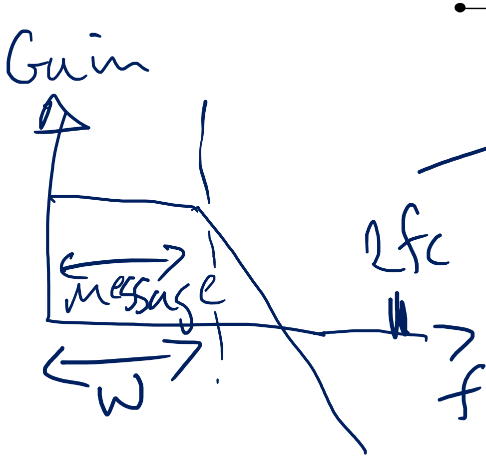
sum ($2f_c$) + difference
data + noise
inphase component

discrete



envelope + in phase noise

phase locked to cos of tx carrier



Half noise power at the output.
3dB better in AWGN than non-coherent ASK

Coherent Detection (2)

- By passing these two products through a low pass filter, the higher frequency component can be removed. Thus only A(t)cos(θ) is left.
  PLL
- θ defines the phase error between the locally generated carrier and the received carrier. Any non-zero value of θ (i.e. any phase error) causes a loss in performance since cos(θ)<1.
- Thus, it is crucial for coherent detection to be able to accurately generate the local carrier signal.
- One way to do this is to use a Phase Lock Loop (PLL).

AWGN and Coherent Detection of ASK

$$\left[A_n \cos\omega_c t + A_n \sin\omega_c t\right] \cdot \cos\omega_c t$$

$$= A_n \cos\omega_c t \cdot \cos\omega_c t + A_n \sin\omega_c t \cdot \cos\omega_c t$$

$$\frac{A_n}{2}\Big[\underbrace{\cos(\omega_c t - \omega_c t)}_{\cos 0 \,=\, 1} + \cos(\underbrace{\omega_c t + \omega_c t}_{2\omega_c t \text{ LPF}}) + \underbrace{\sin(\omega_c t - \omega_c t)}_{\sin 0 \,=\, 0} + \sin(\underbrace{\omega_c t + \omega_c t}_{2\omega_c t \text{ LPF}})\Big]$$

Only detects "in-phase" noise component.

No Quadrature noise after coherent mixer