Università degli Studi di Firenze

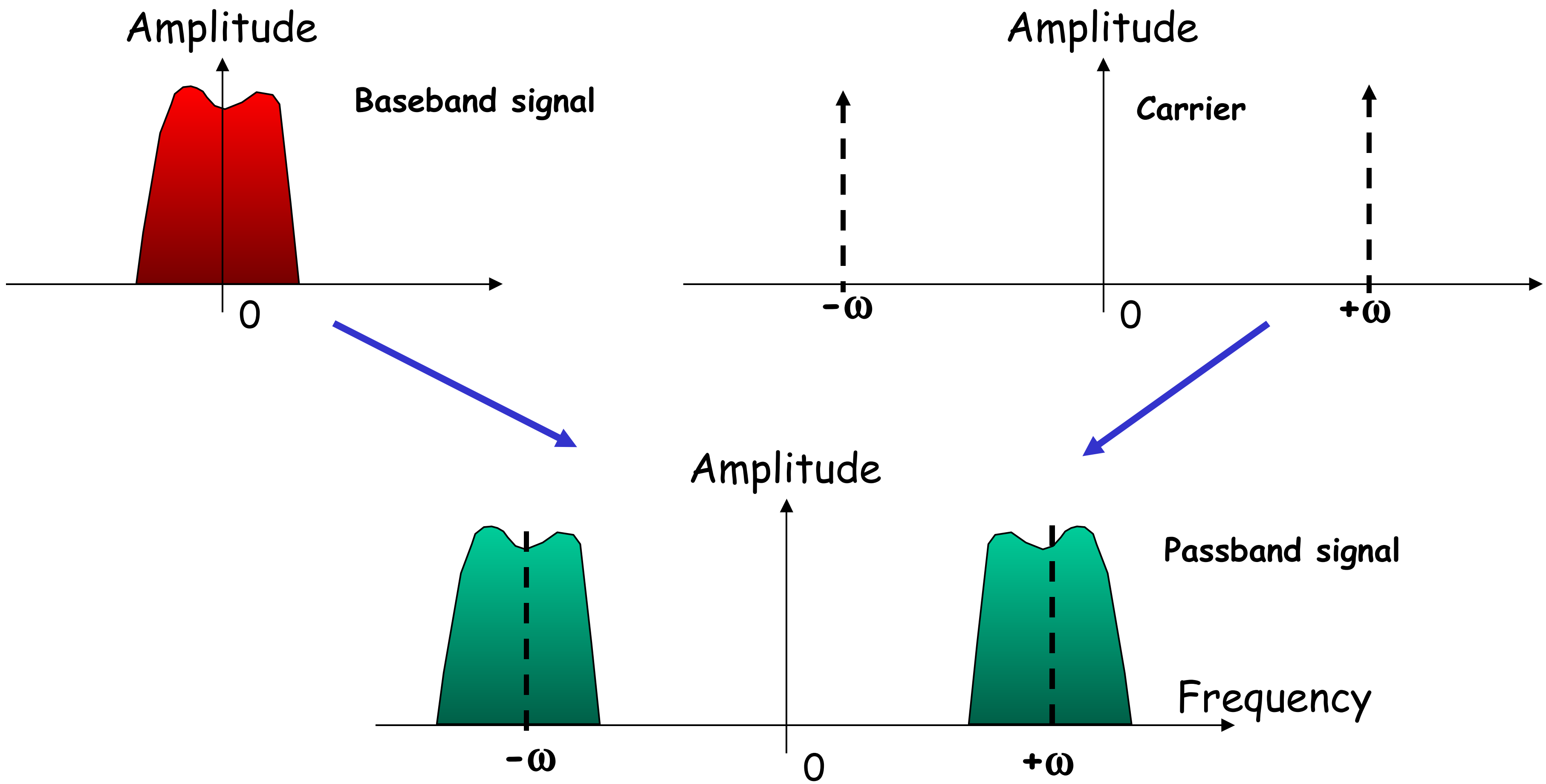
Dipartimento di Elettronica e telecomunicazioni

Iacopo Magrini, iacopo.magrini@unifi.it

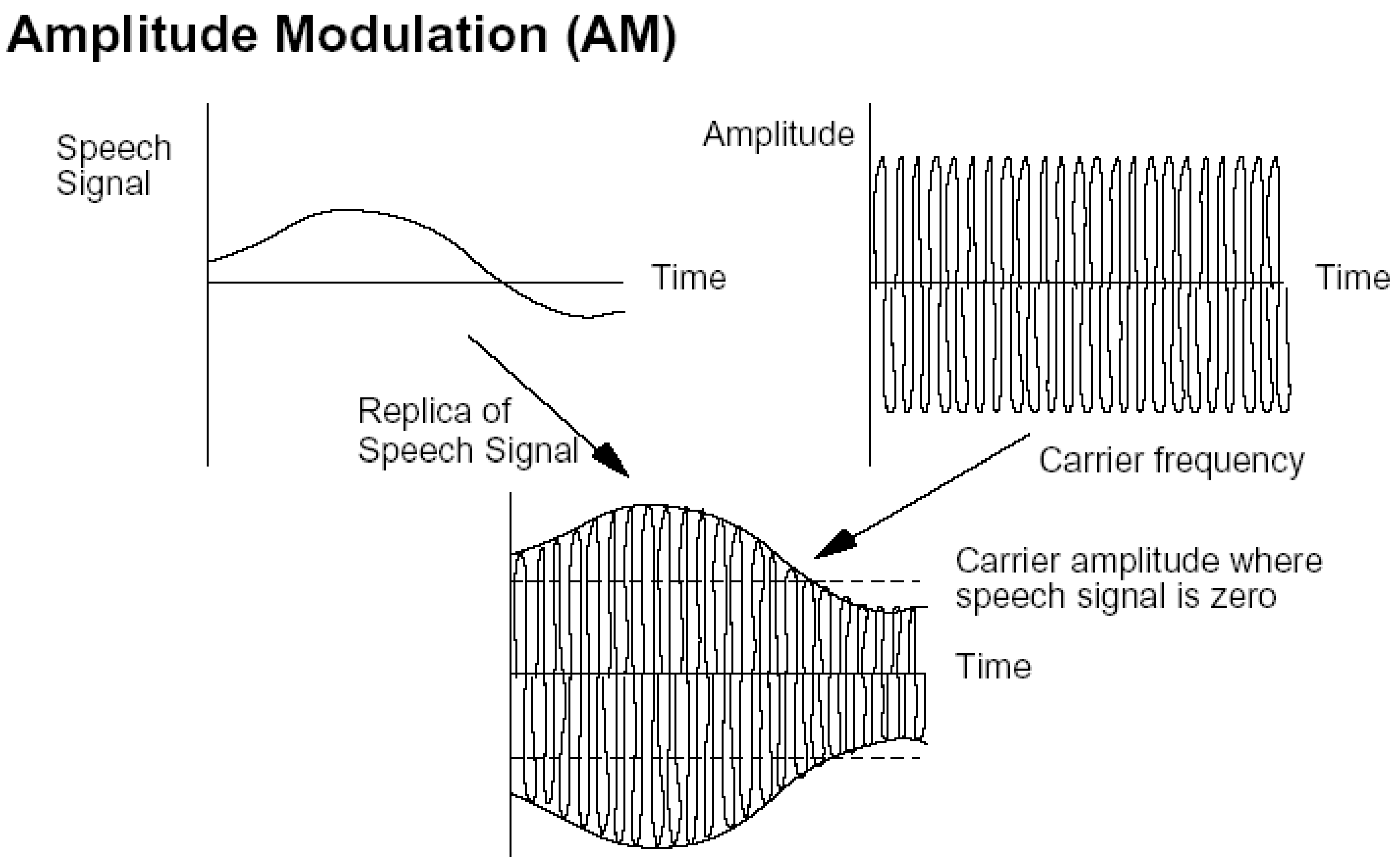
Appunti del corso "Circuiti a Microonde"

The Modulation

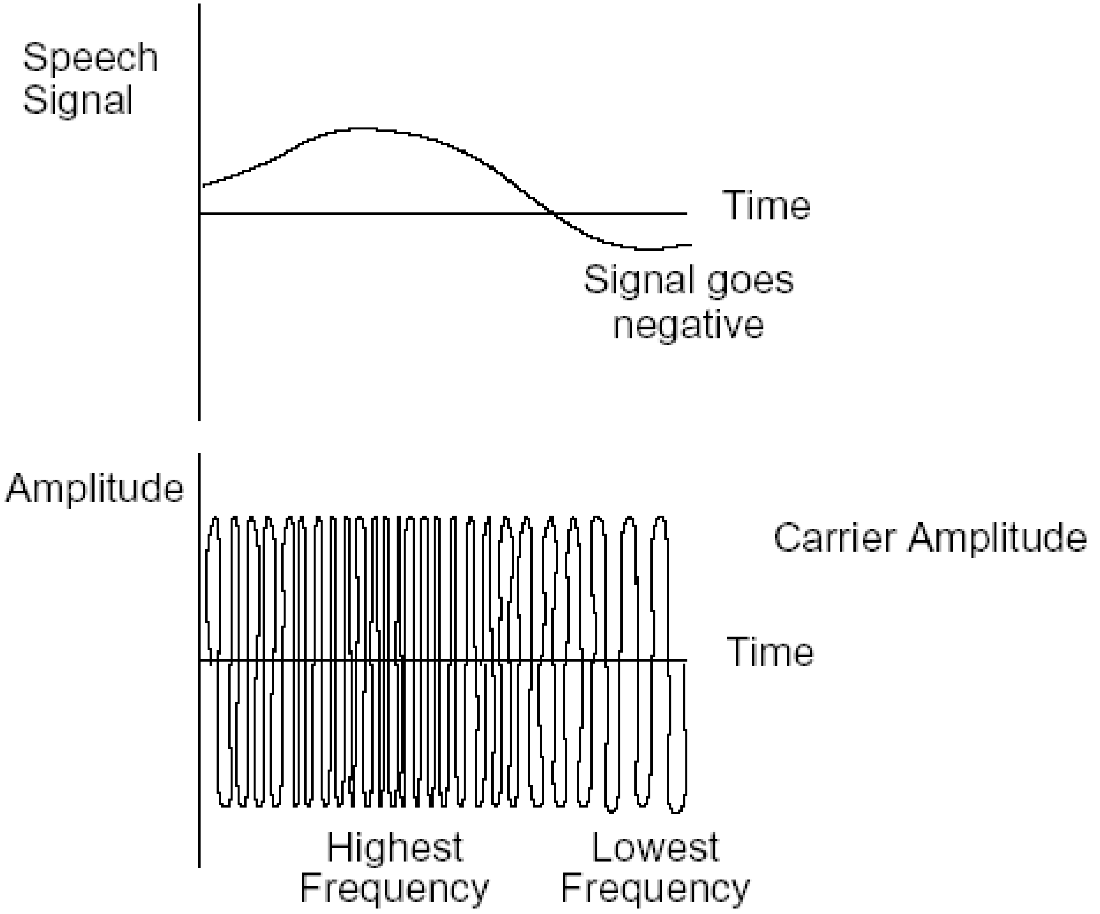
The target is to link the "information" to a carrier



AM Modulation



FM Modulation



Digital Modulation

Analog Mod.		Digital Mod.(binary)
AM	→	ASK
PM		PSK
FM		FSK

Baseband → → Passband

$$x_{BB}(t) = \sum_n b_n p(t - nT_b)$$

$$x_s(t) = i(t)\cos(\omega_c t) - q(t)\sin(\omega_c t)$$

Metrics for Digital modulations

- Signal quality → BER=wrong bits/tot.bits
- Spectral efficiency → Spectrum width
- Power efficiency → PA requirements

Digital modulation techniques

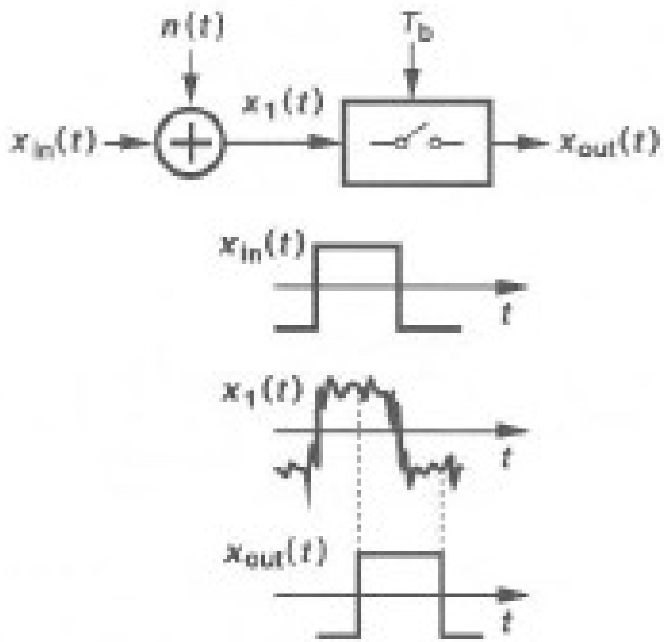
Coherent	Noncoherent
Phase shift keying (PSK)	FSK
Frequency shift keying (FSK)	ASK
Amplitude shift keying (ASK)	Differential PSK (DPSK)
Continuous phase modulation (CPM)	CPM
Hybrids	Hybrids

Coherent (aka synchronous) detection: process received signal with a local carrier of same frequency and phase

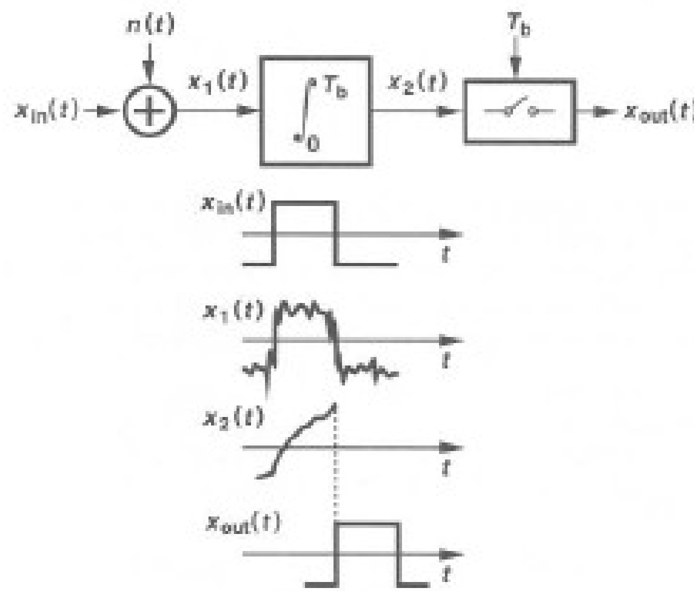
Noncoherent (aka envelope) detection: requires no reference wave

Digital Modulation Detection

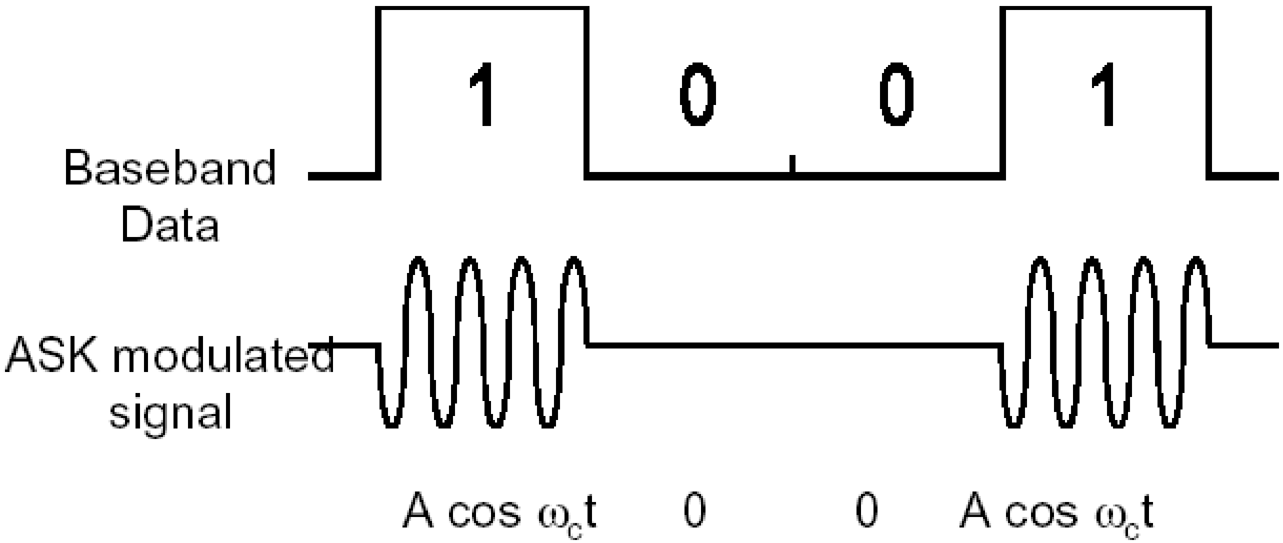
(1) Sampling the peak value



(2) Sampling the peak value after integration

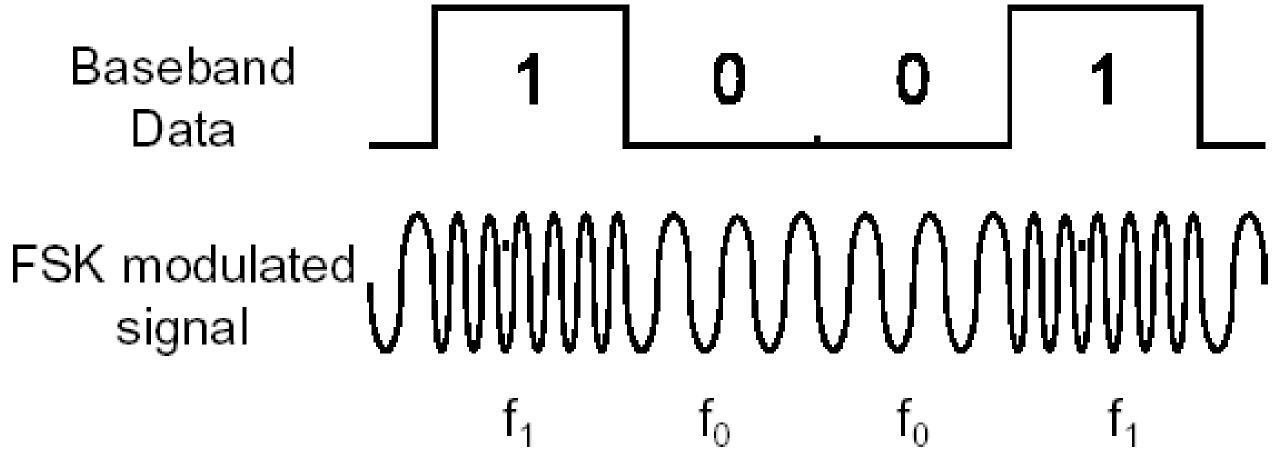


ASK Modulation



- Pulse shaping can be employed to remove spectral spreading.
- ASK demonstrates poor performance, as it is heavily affected by noise and interference.

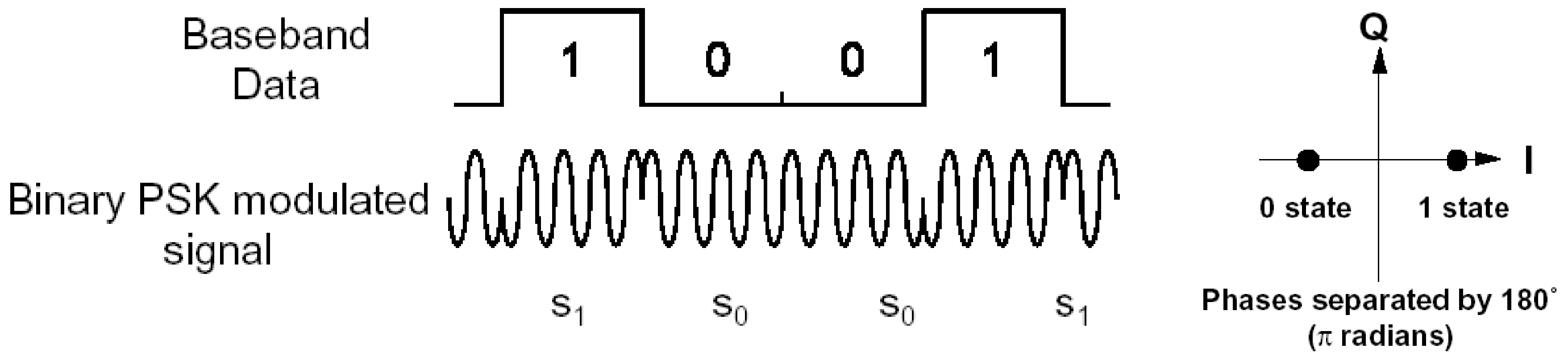
FSK Modulation



where $f_0 = A\cos(\omega_c - \Delta\omega)t$ and $f_1 = A\cos(\omega_c + \Delta\omega)t$

- Bandwidth occupancy of FSK is dependant on the spacing of the two symbols. A frequency spacing of 0.5 times the symbol period is typically used.
- FSK can be expanded to a M-ary scheme, employing multiple frequencies as different states.

PSK Modulation

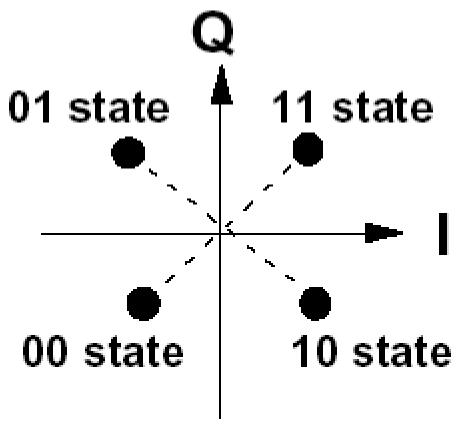


where $s_0 = -A \cos \omega_c t$ and $s_1 = A \cos \omega_c t$

- Binary Phase Shift Keying (BPSK) demonstrates better performance than ASK and FSK.
- PSK can be expanded to a M-ary scheme, employing multiple phases and amplitudes as different states.
- Filtering can be employed to avoid spectral spreading.

QPSK Modulation (I)

- Quadrature Phase Shift Keying (QPSK)
  - Multilevel modulation technique: 2 bits per symbol
  - More spectrally efficient, more complex receiver



Phase of carrier:
$\pi/4$, $3\pi/4$, $5\pi/4$, $7\pi/4$

2x bandwidth efficiency of BPSK

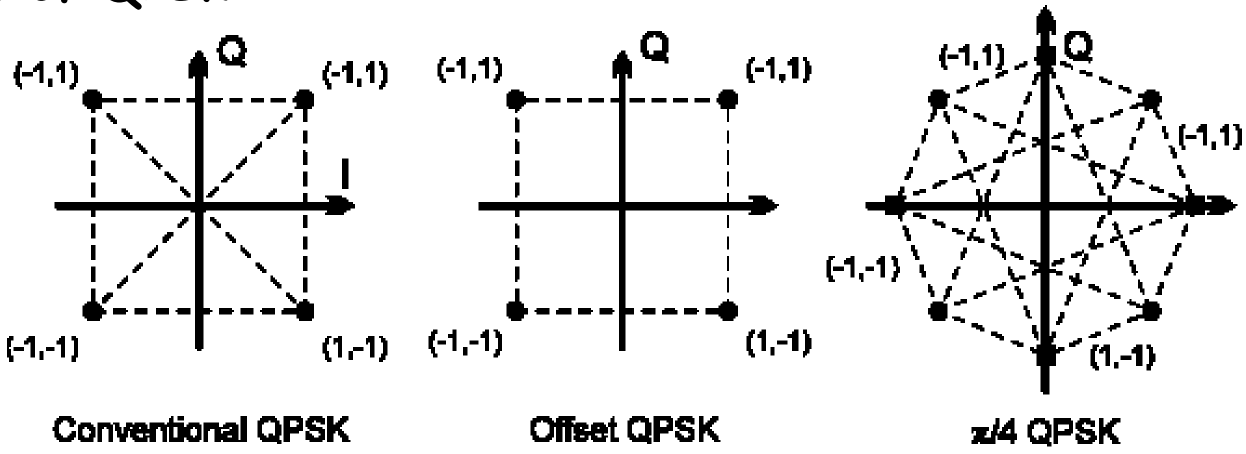
Output waveform is sum of modulated ± Cosine and ±Sine wave

Symbol rate=

(bit rate)/(n° bit x symbol)

QPSK Modulation (II)

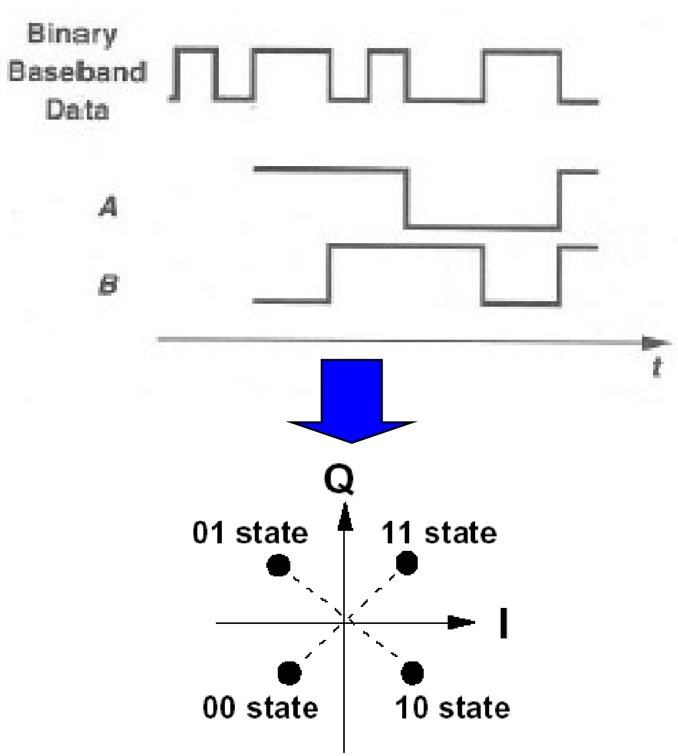
Types of QPSK

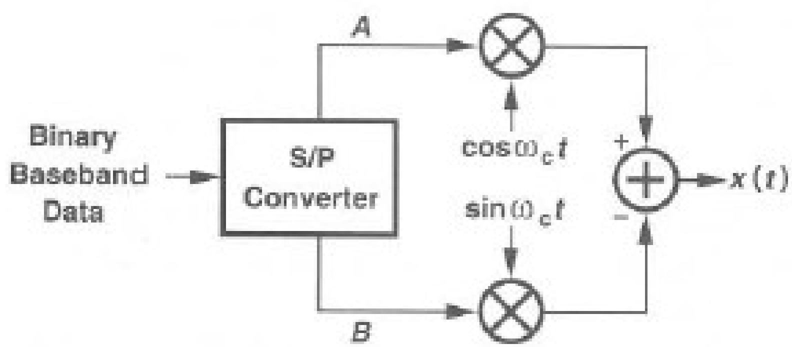


- Conventional QPSK has transitions through zero (ie. 180º phase transition). Highly linear amplifier required.
- In Offset QPSK, the transitions on the I and Q channels are staggered. Phase transitions are therefore limited to 90º.
- In π/4-QPSK the set of constellation points are toggled each symbol, so transitions through zero cannot occur. This scheme produces the lowest envelope variations.
- All QPSK schemes require linear power amplifiers.

QPSK Modulation (III)

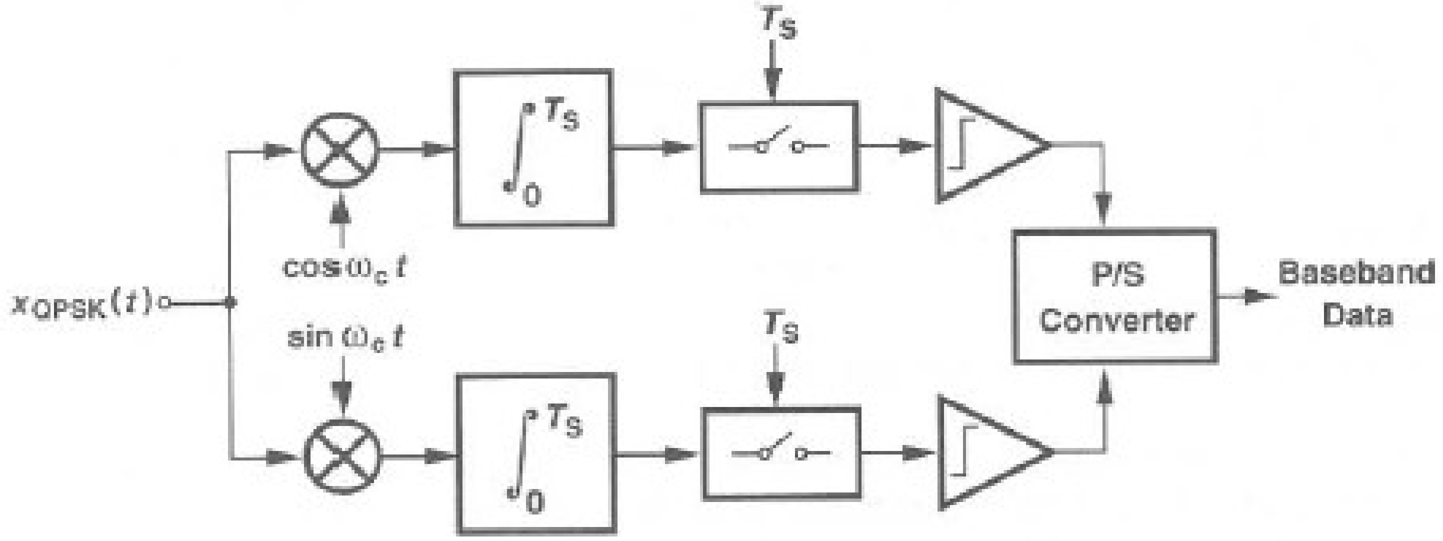
QPSK modulator





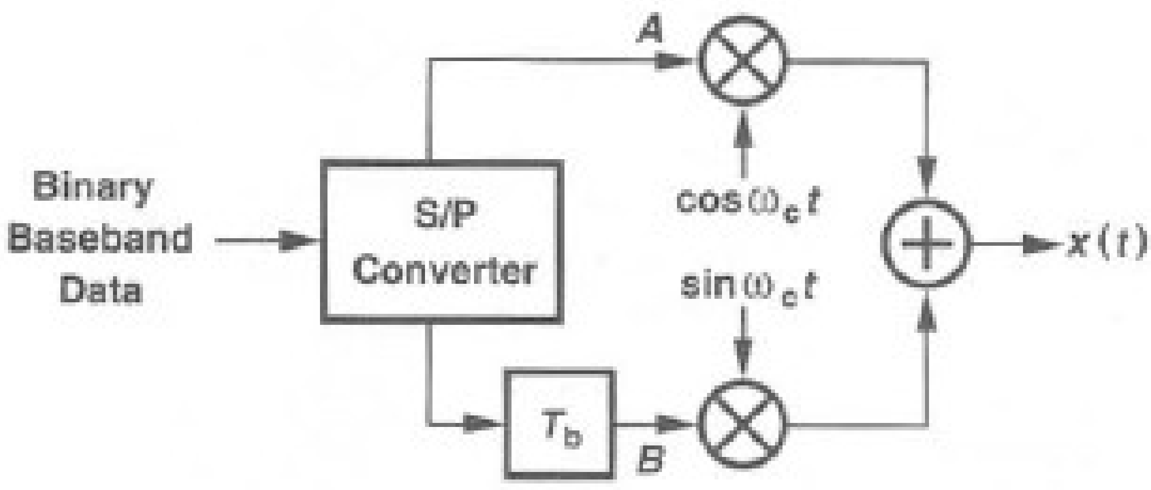
QPSK Modulation (IV)

QPSK demodulator (coherent)



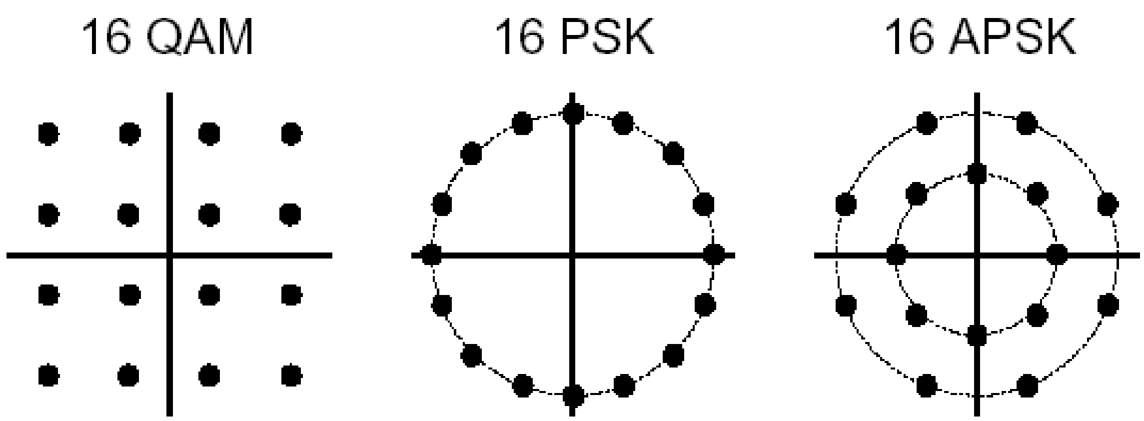
QPSK Modulation (V)

O-QPSK modulator



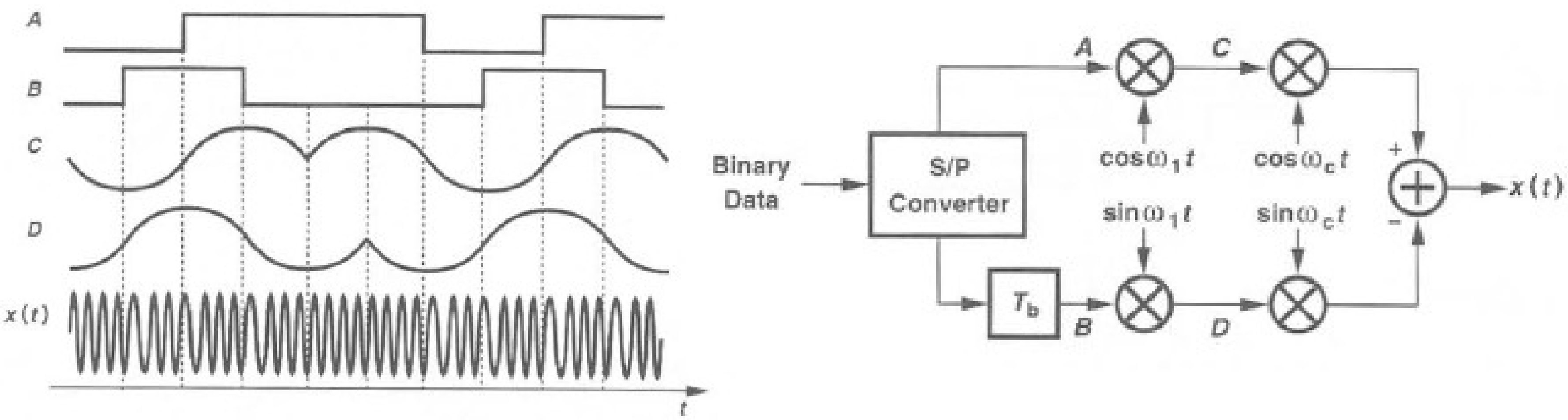
M-ary and QAM Modulations

- Amplitude and phase shift keying can be combined to transmit several bits per symbol (in this case M=4). These modulation schemes are often refered to as *linear*, as they require linear amplification.
- 16QAM has the largest distance between points, but requires very linear amplification. 16PSK has less stringent linearity requirements, but has less spacing between constellation points, and is therefore more affected by noise.
- M-ary schemes are more bandwidth efficient, but more susceptible to noise.



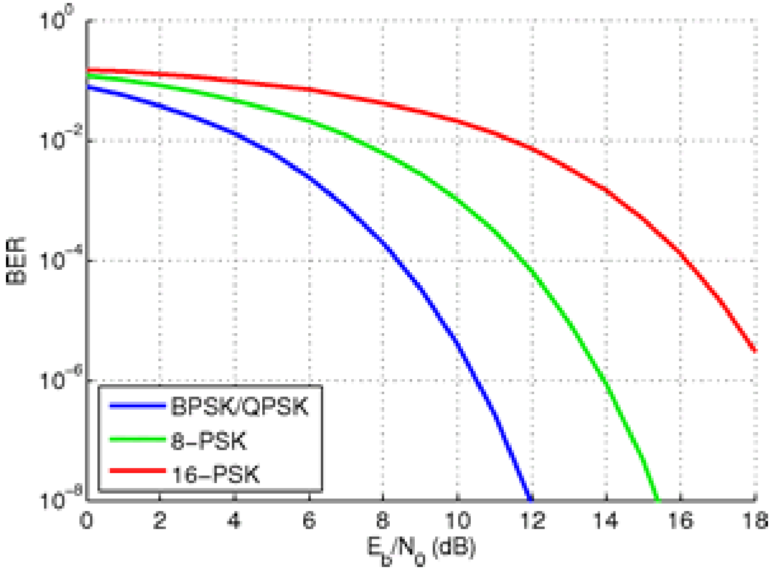
MSK Modulation

MSK modulator

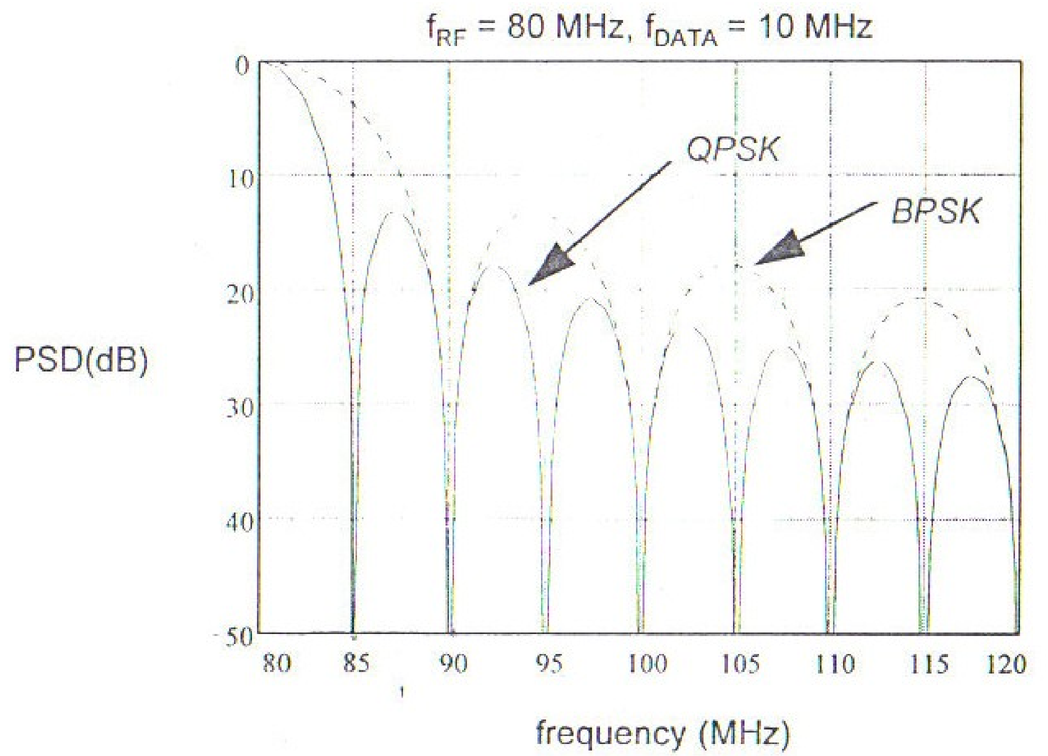


Modulations Performance

Modulation Format	Error free Eb/No
16 PSK	18dB
16 QAM	15dB
8PSK	14.5dB
4PSK	10.1dB
4QAM	10.1dB
BFSK	13dB
BPSK	10.5dB



Band enhancement



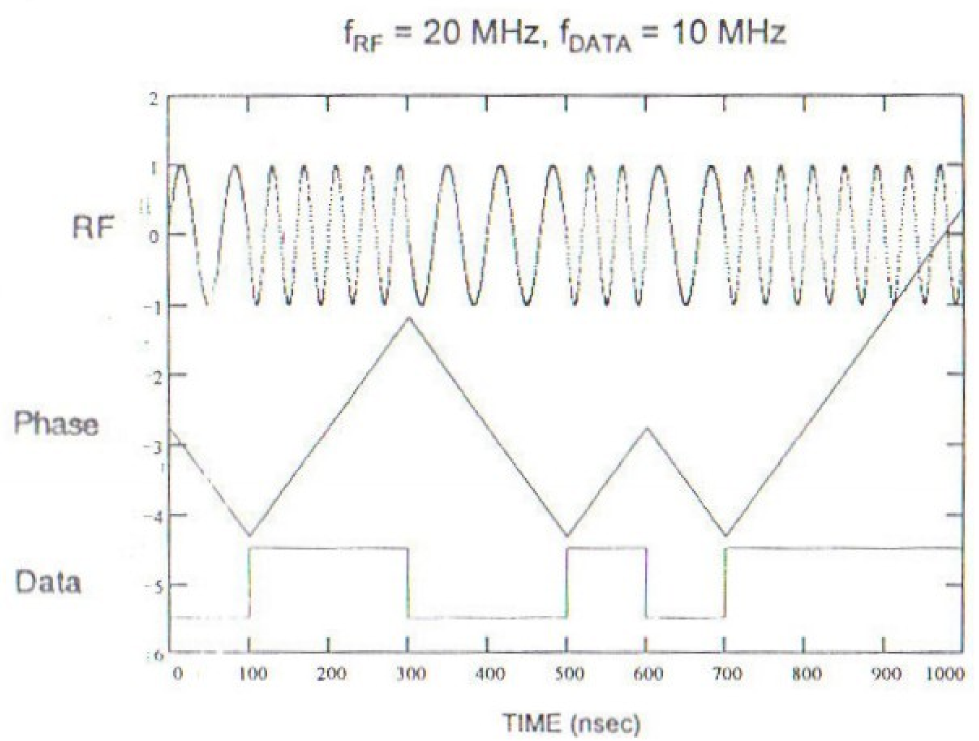
First null= 1/Tsimbol

Symbol rate=

(bit rate)/(n° bit x symbol)

<u>2 bits symbol leads to an half equivalent bit rate</u>

FSK Modulation (I)



K=1,0

$$s(t) = A\cos\cdot\{\,[\omega_c - (-1)^{k}\Delta\omega]t\,\}$$

FSK Modulation (II)

Starting from the previous relation, removing the carrier and filtering we obtain

$s_i(t) = B\cos[-(-1)^k \Delta\omega \cdot t]$ **I component**

$s_q(t) = B\sin[-(-1)^k \Delta\omega \cdot t]$, **Q component**

$$|\tilde{s}(t)| = \sqrt{[s_i(t)]^2 + [s_q(t)]^2} = B \cdot \sqrt{2}$$ **Amplitude**

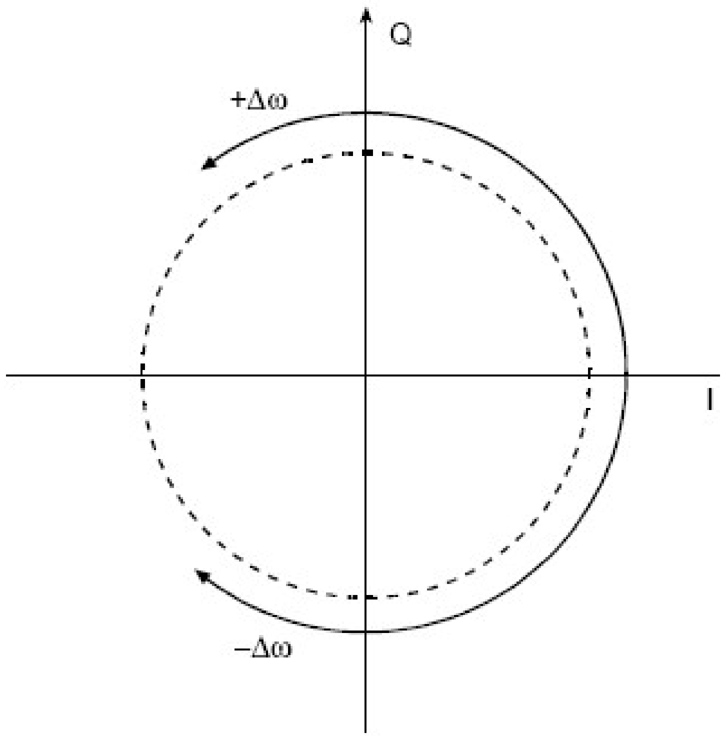
$$\angle\tilde{s}(t) = arctg\frac{s_q(t)}{s_i(t)} = arctg[tg - (-1)^k \Delta\omega \cdot t] = -(-1)^k \Delta\omega \cdot t$$ **Phase**

FSK Modulation (III)

It is possible to describe the baseband signal by means of a phasor

$$\tilde{s}(t) = \sqrt{2}B \cdot e^{j[-(-1)^{k}\Delta\omega \cdot t]}$$

The sign of K settles the rotation



FSK Modulation (IV)

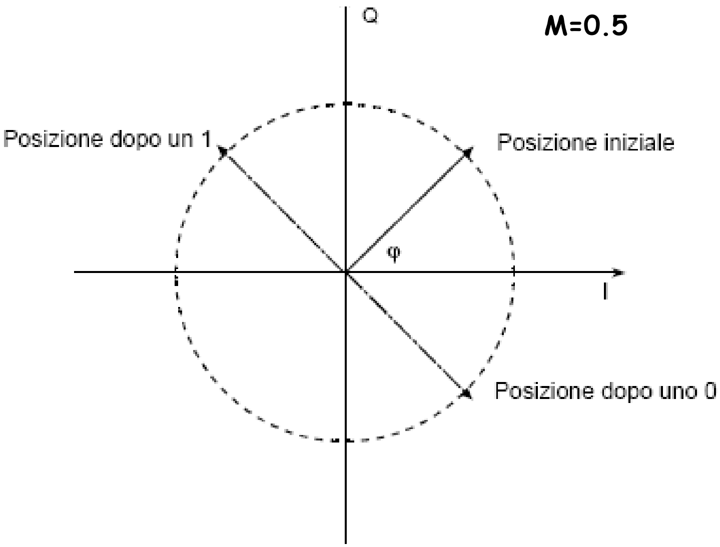
Defining the modulation index and remembering the relation between symbol time and rate frequency we can derive the phase increment during the symbol time

$$m = \frac{1}{\pi} \cdot \frac{\Delta\omega}{f_{rate}}$$

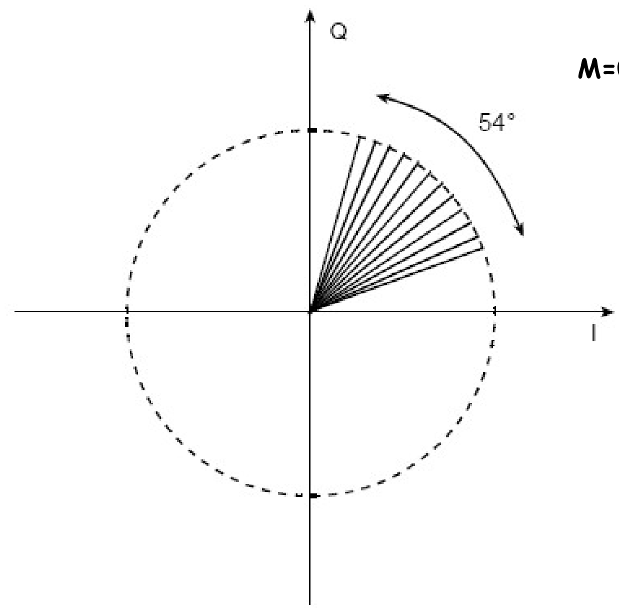
$$T_{simsol} = 1/f_{rate}$$

$$\Delta\angle\tilde{s}(t) = -(-1)^k \frac{\Delta\omega}{f_{rate}} = -(-1)^k m\pi \,.$$

M=0.5

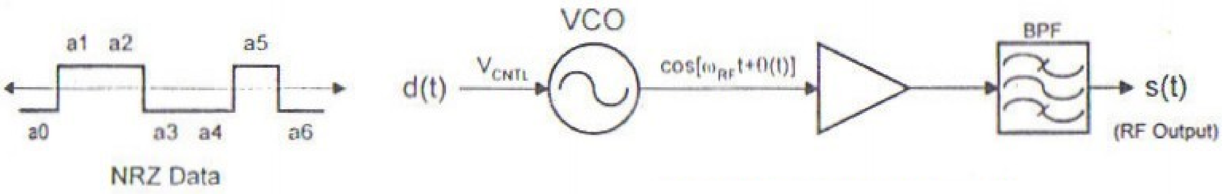


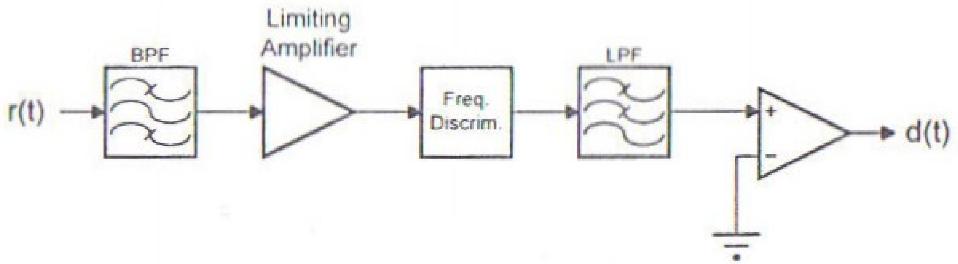
M=0.3



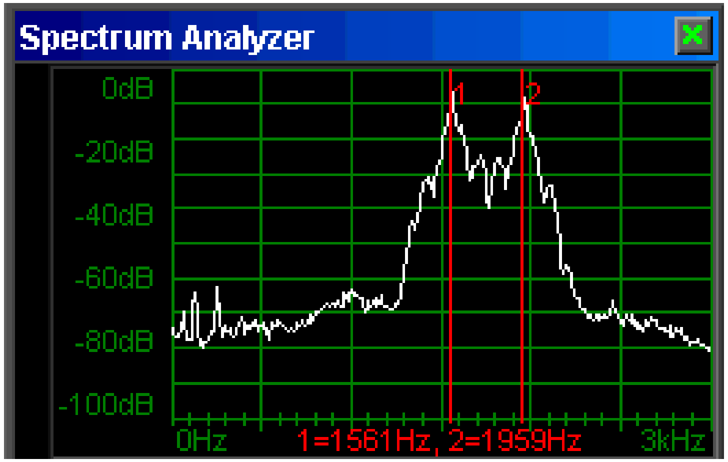
FSK Modulation (V)

Noncoherent TX path (Top) and RX path (bottom) for Binary FSK modulation



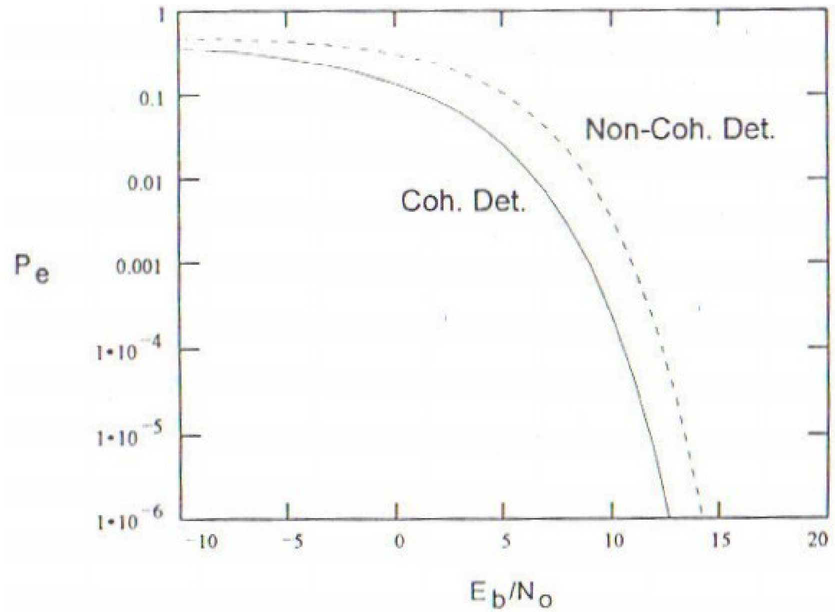


FSK Modulation (VI)



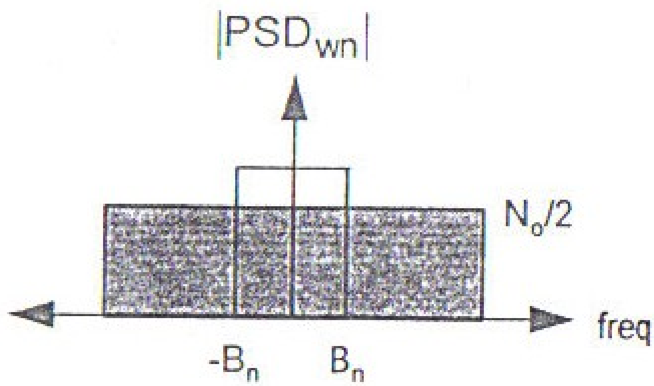
FSK spectrum for low modulation index

Probability error Vs Eb/No



FSK Modulation (VII)

It is possible to derive the relation between Eb/No and SNR



$$N = \left(\frac{N_0}{2}\right) \cdot (2B_n)$$

$$E_b = S \cdot T_b \qquad N_0 = \frac{N}{B_n}$$

$$\frac{E_b}{N_0} = \frac{S \cdot T_b}{N/B_n} = \frac{S}{N} \cdot B_n T_b = \frac{S}{N} \cdot \frac{B_n}{f_b}$$