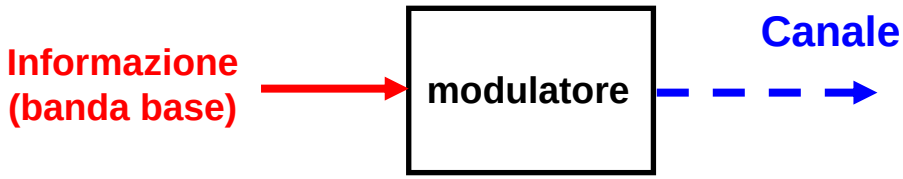
Università degli Studi di Firenze

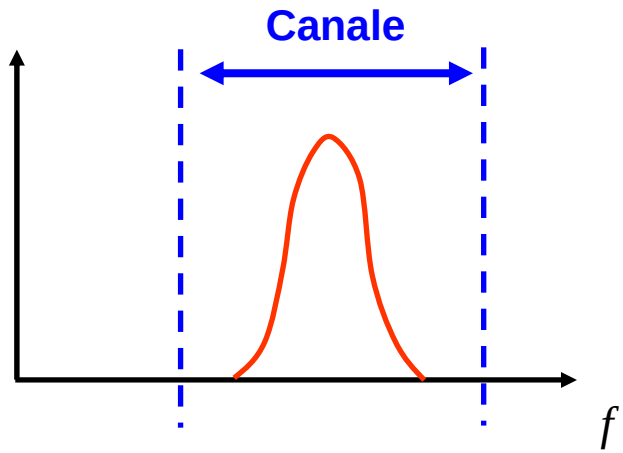
Facoltà d' Ingegneria
Dipartimento di Elettronica e Telecomunicazioni

Modulazioni digitali

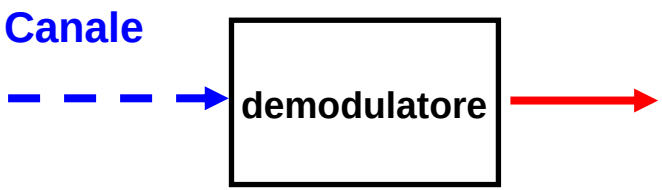
Massimiliano Pieraccini

Modulazione

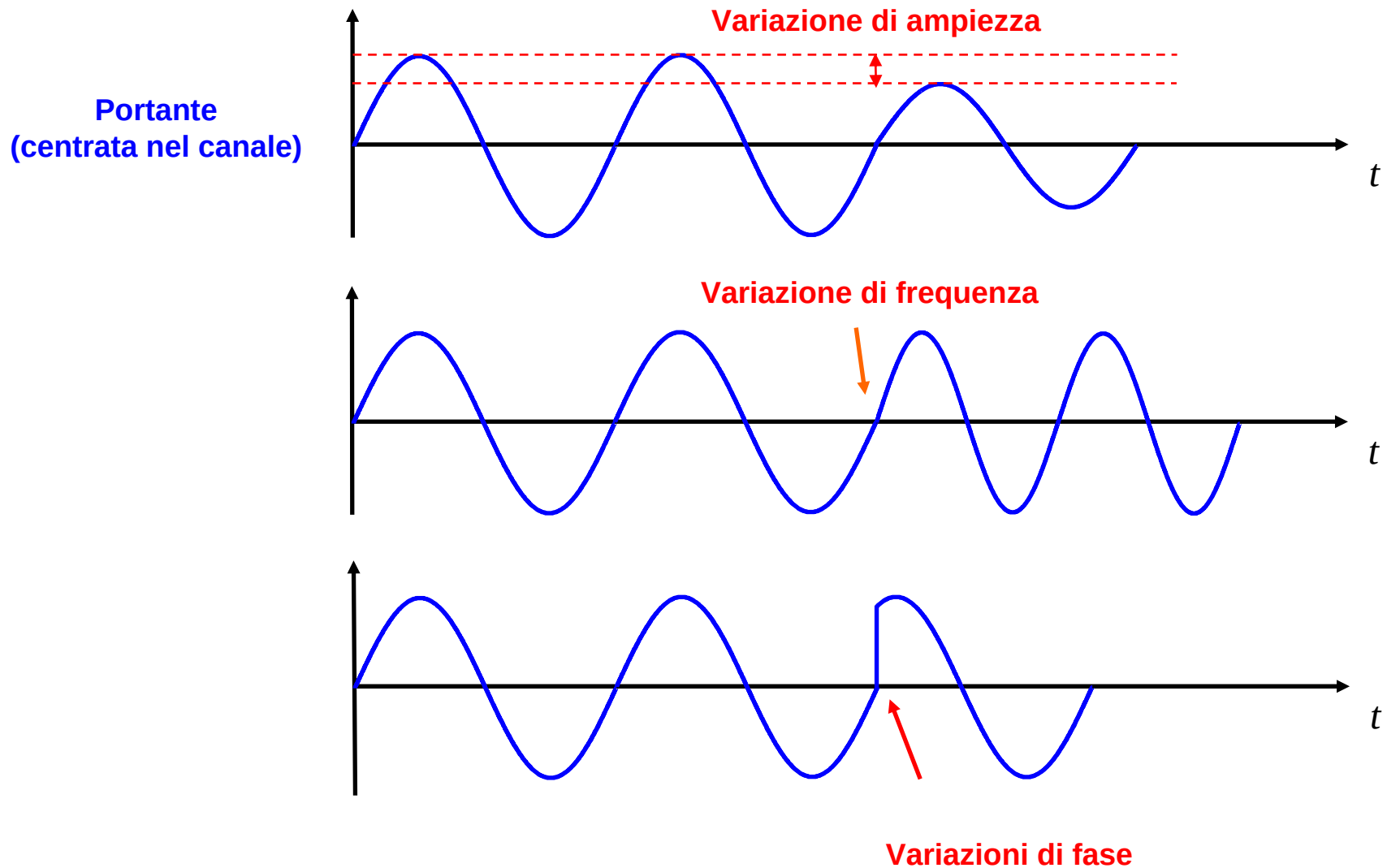




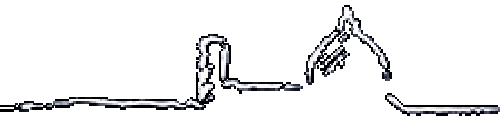
Informazione allocata in frequenza



Tipi di modulazione



Tipi di modulazione



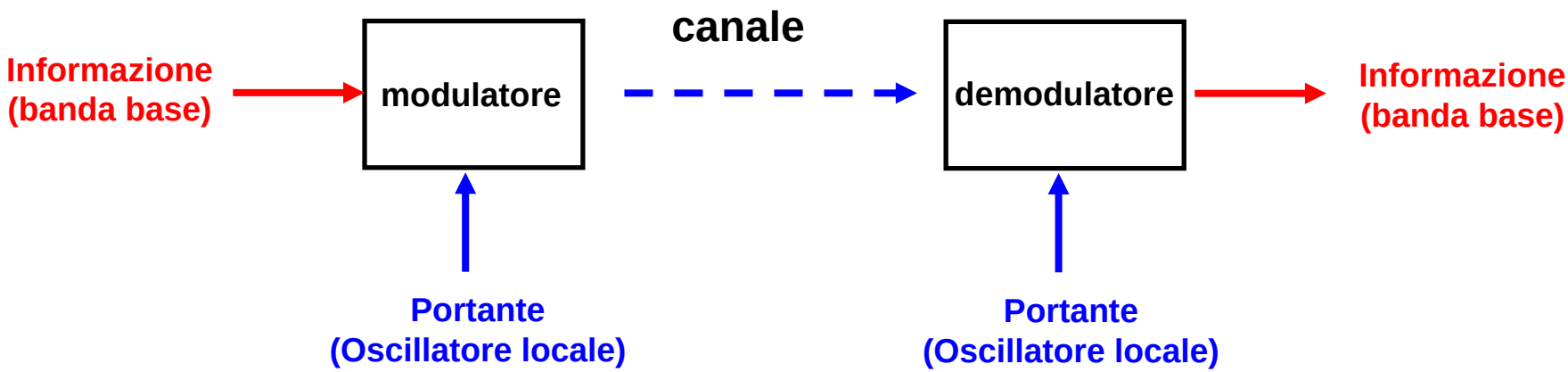
Variazioni continue → **Modulazioni analogiche**

Variazioni discrete → **Modulazioni digitali**

A ogni valore discreto corrisponde un simbolo

“Rigenerazione del segnale”

Modulazione digitali



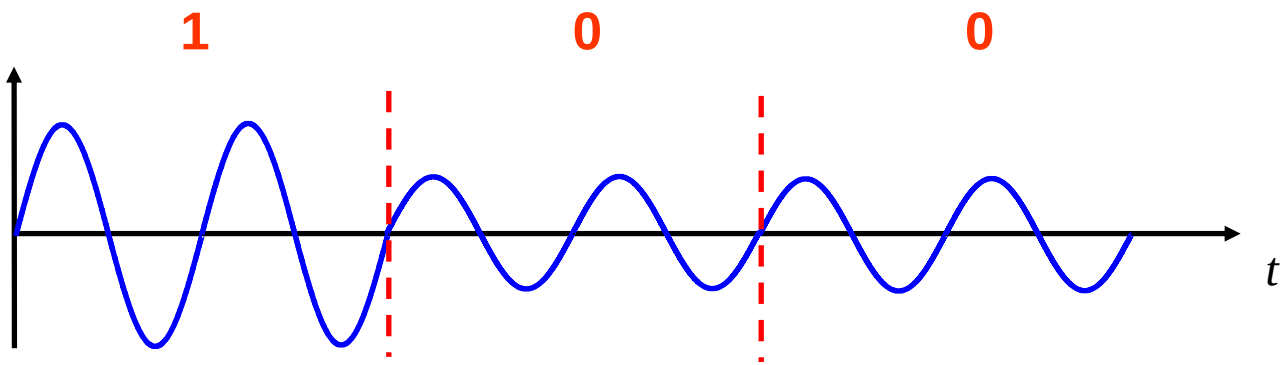
bit rate: numero di bit al secondo

baud: numero di simboli al secondo

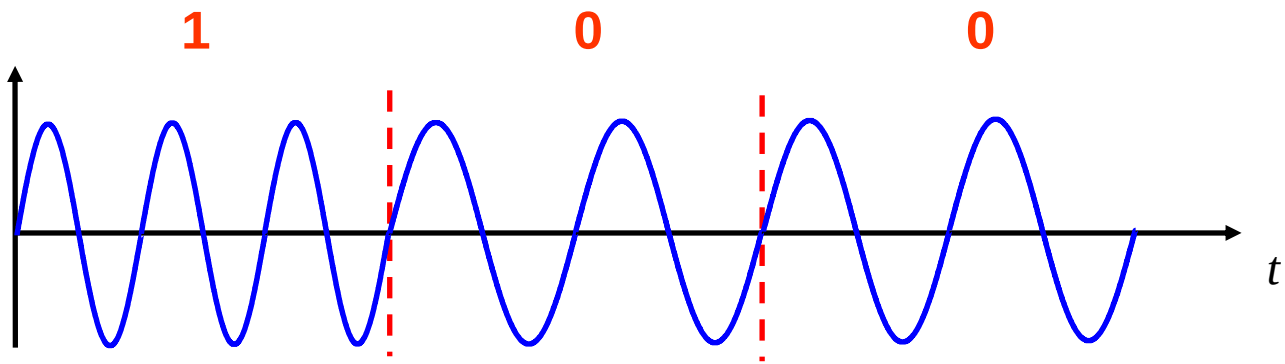
M numero di stati del simbolo

Capacità: $f_b = B\log_2(M)$ $B = \text{bandabase}$

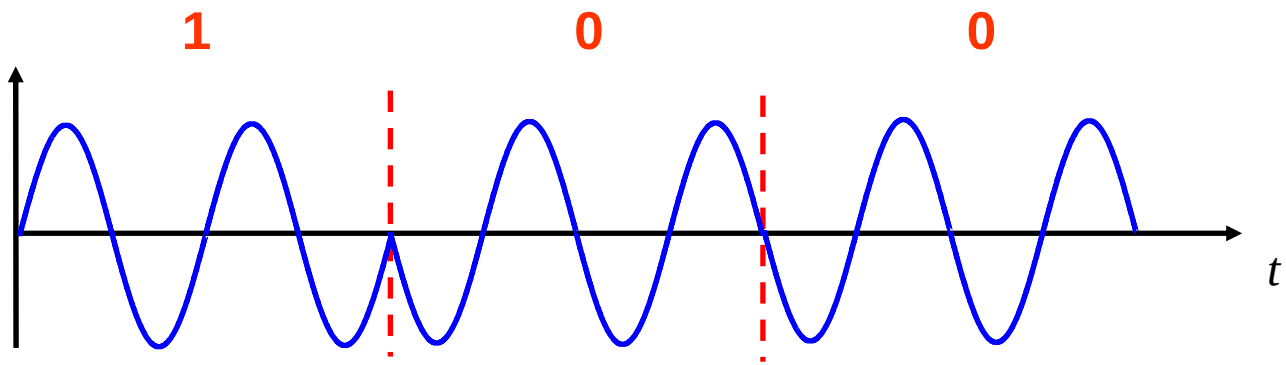
ASK (Amplitude Shift Keying)



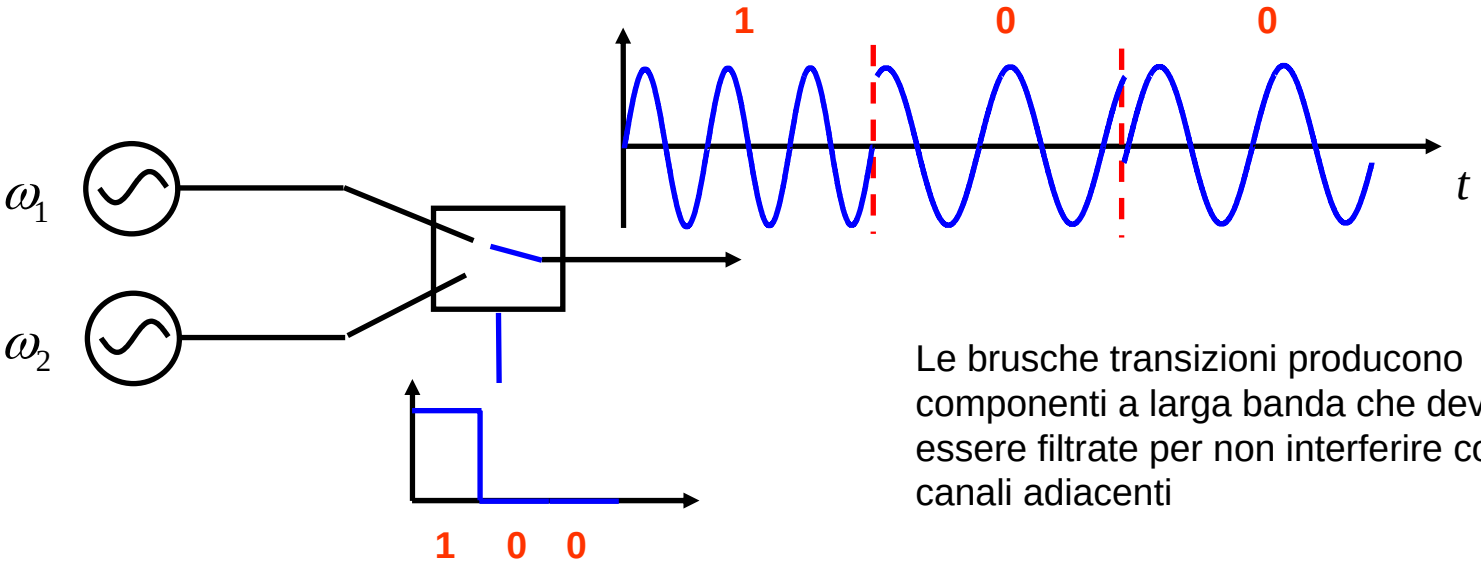
FSK (Frequency Shift Keying)



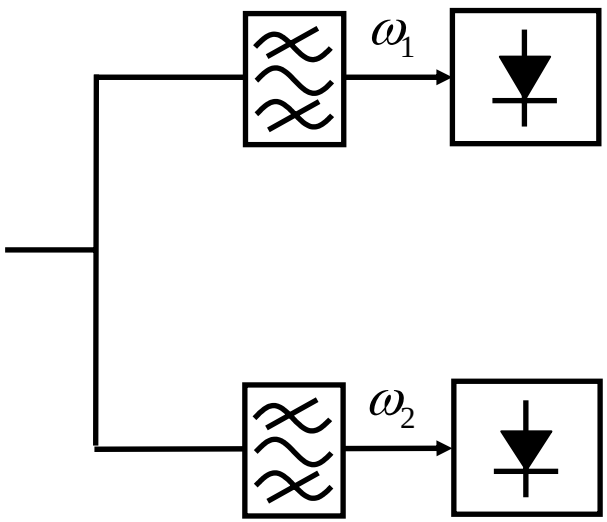
PSK (Phase Shift Keying)



FSK

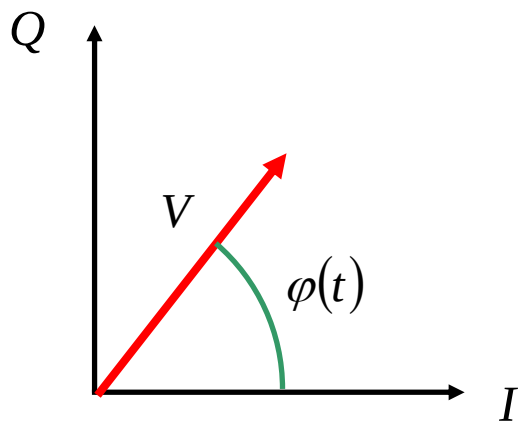


Le brusche transizioni producono componenti a larga banda che devono essere filtrate per non interferire con i canali adiacenti

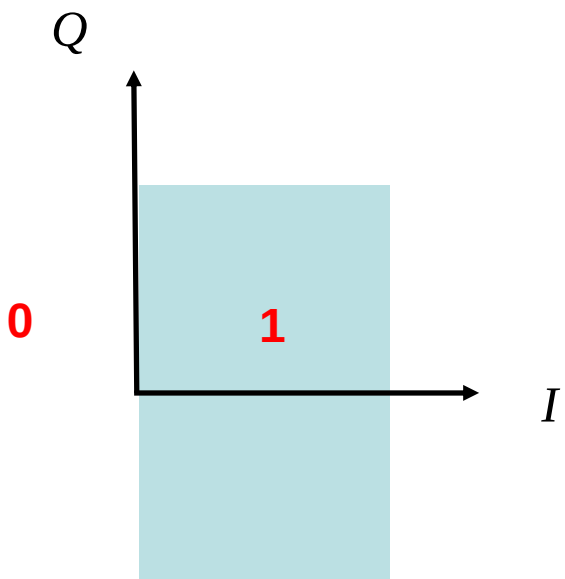


Modulazione IQ

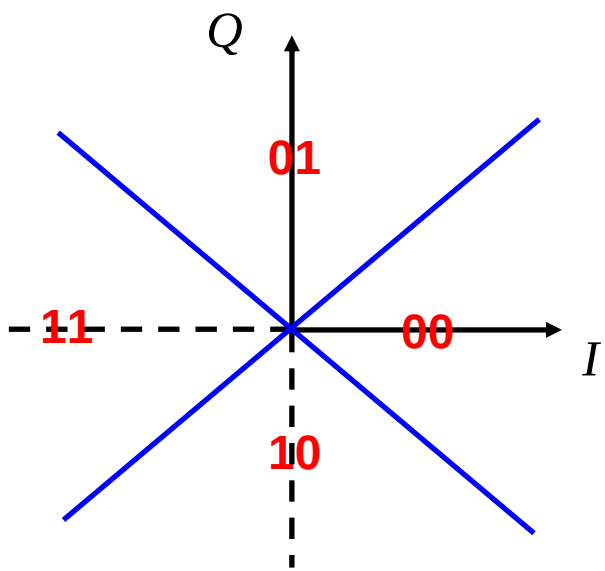
$$v = V\cos(\omega t + \varphi(t))$$



B-PSK

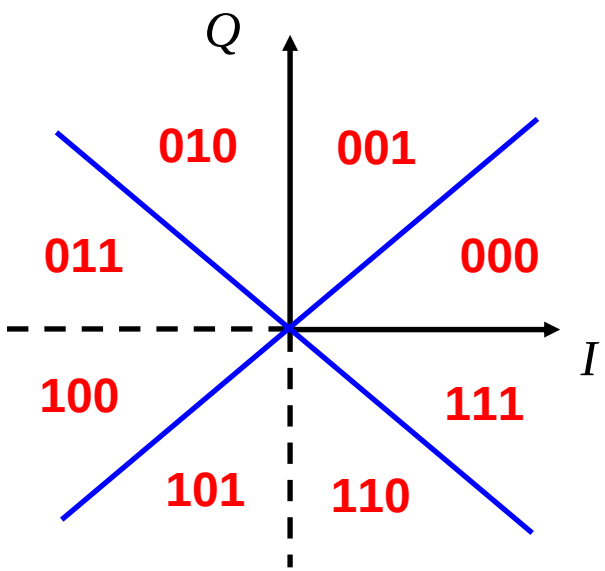


Q-PSK 2bit



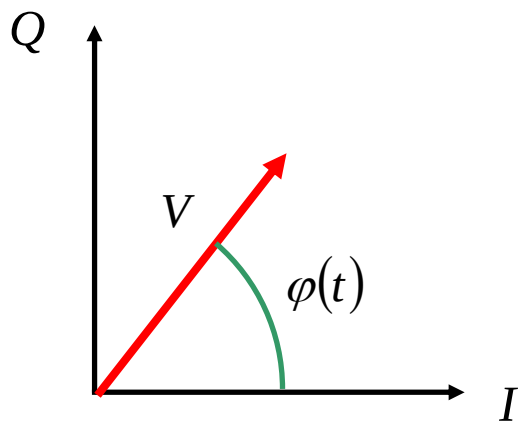
Modulazione IQ

Q-PSK 3bit

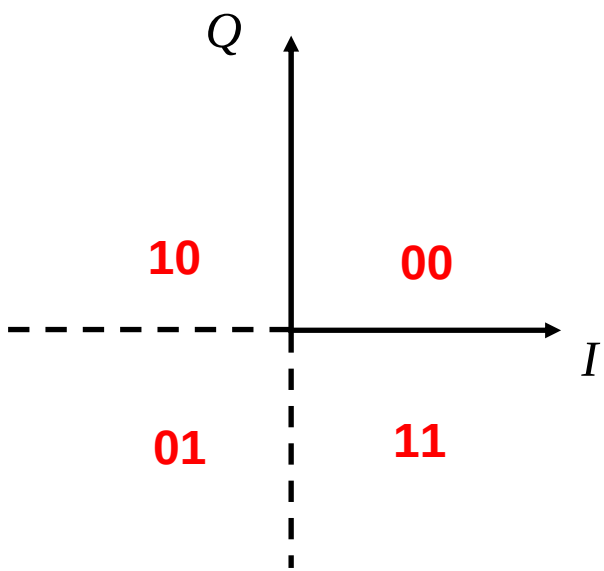


Modulazione IQ

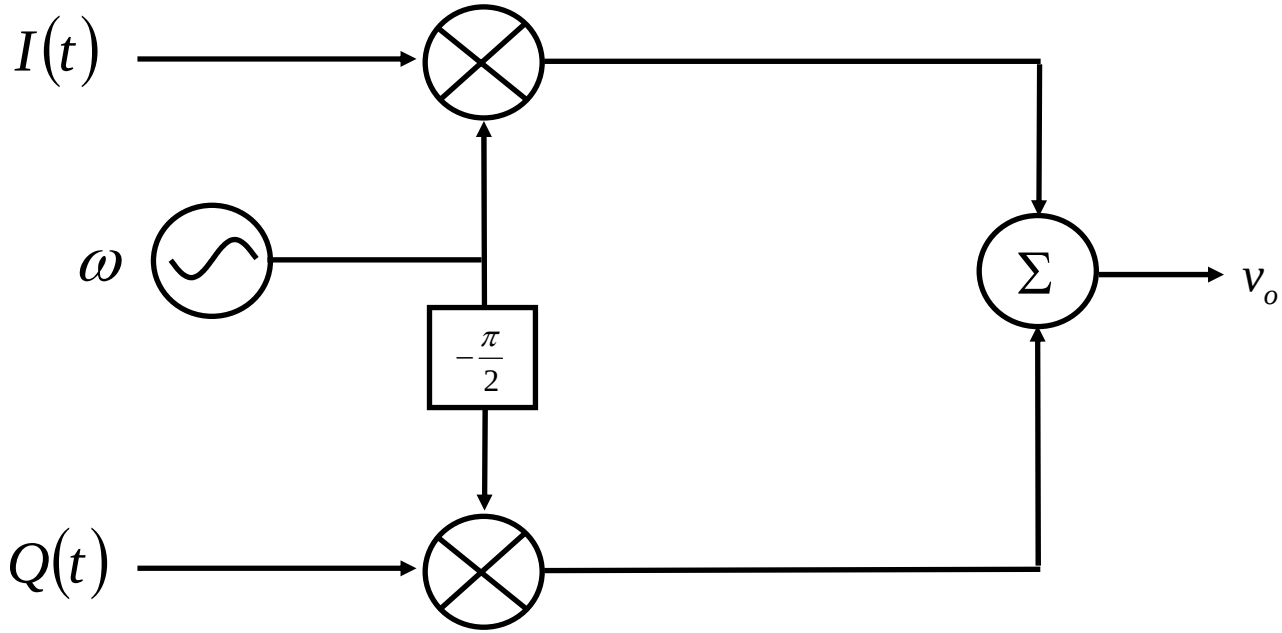
$$v = V\cos(\omega t + \varphi(t))$$



QAM



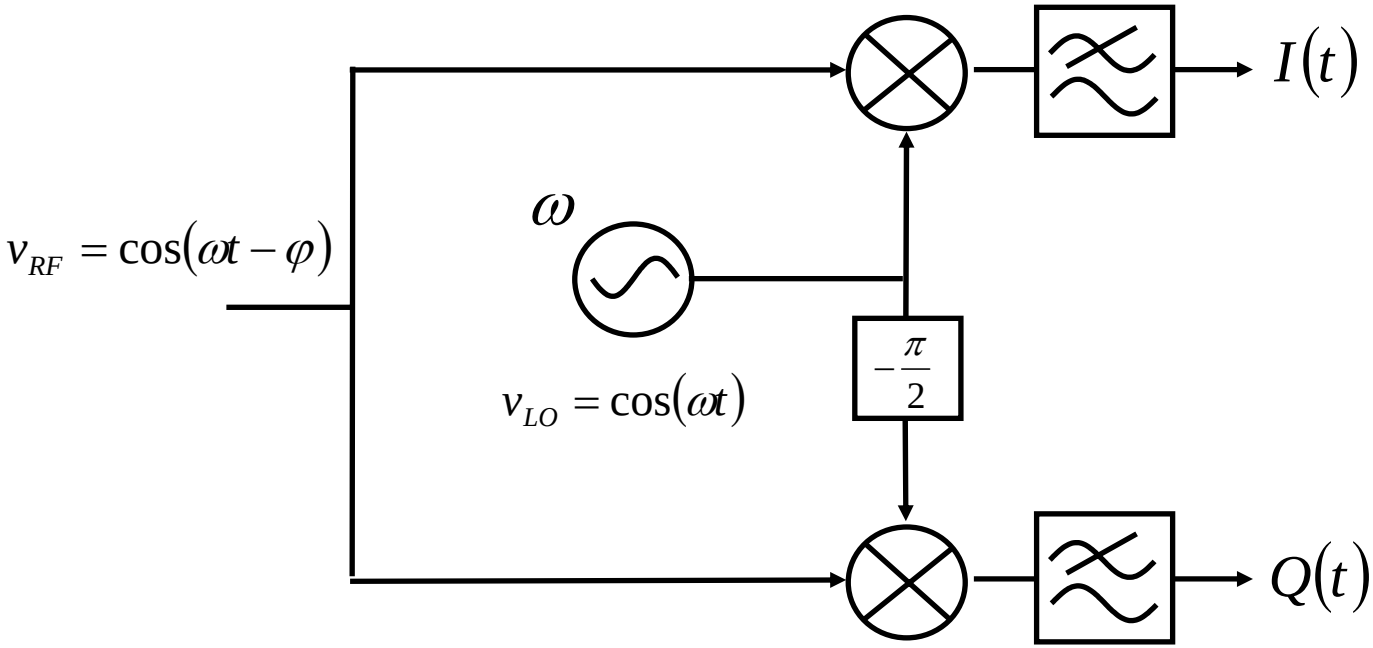
Modulatore IQ



$$v_o = I\cos(\omega t) + Q\sin(\omega t) = \sqrt{I^2 + Q^2}\cos\left(\omega t - \tan^{-1}\left(\frac{Q}{I}\right)\right)$$

φ

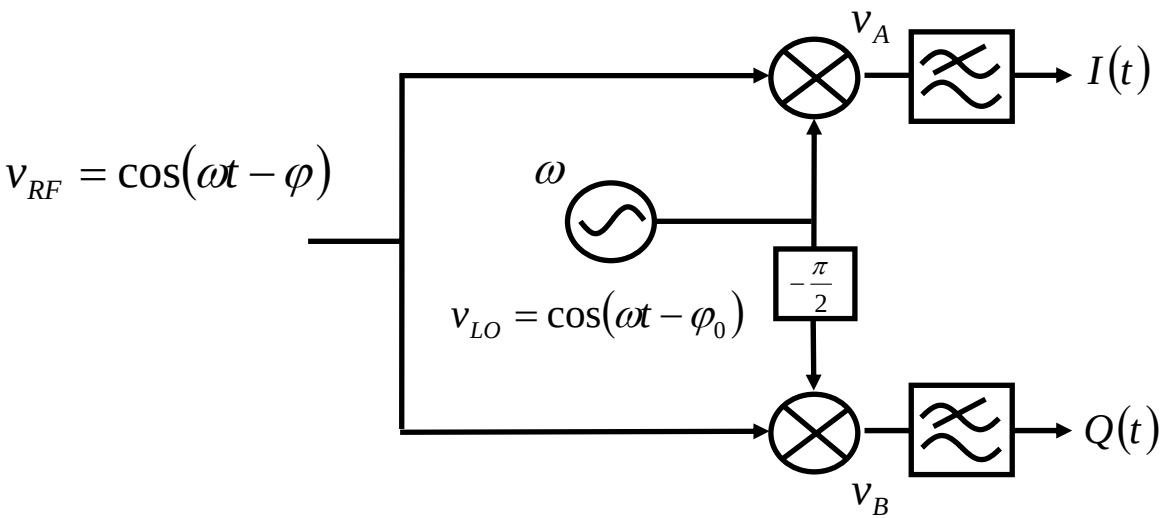
Demodulatore IQ



$$v_A = \cos(\omega t - \varphi)\cos(\omega t) = \frac{1}{2}(\cos(2\omega t - \varphi) + \cos(-\varphi)) \longrightarrow I = \frac{1}{2}\cos(\varphi)$$

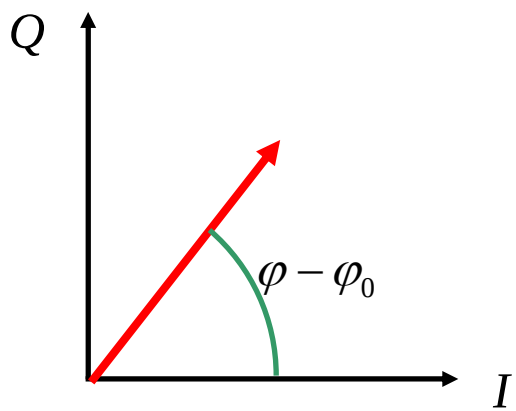
$$v_B = \cos(\omega t - \varphi)\sin(\omega t) = \frac{1}{2}(\sin(2\omega t - \varphi) - \sin(-\varphi)) \longrightarrow Q = \frac{1}{2}\sin(\varphi)$$

Il problema della coerenza del LO del RX

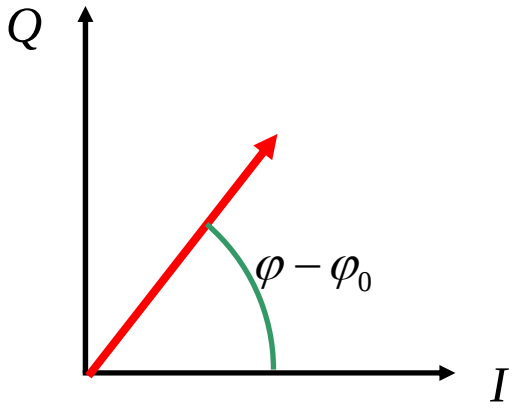


$$v_A = \cos(\omega t - \varphi)\cos(\omega t - \varphi_0) = \frac{1}{2}\left(\cos(2\omega t - \varphi - \varphi_0) + \cos(-\varphi + \varphi_0)\right) \rightarrow I = \frac{1}{2}\cos(-\varphi + \varphi_0) = \frac{1}{2}\cos(\varphi - \varphi_0)$$

$$v_B = \cos(\omega t - \varphi)\sin(\omega t - \varphi_0) = \frac{1}{2}\left(\sin(2\omega t - \varphi - \varphi_0) - \sin(-\varphi + \varphi_0)\right) \rightarrow Q = -\frac{1}{2}\sin(-\varphi + \varphi_0) = \frac{1}{2}\sin(\varphi - \varphi_0)$$



Il problema della coerenza del LO del RX



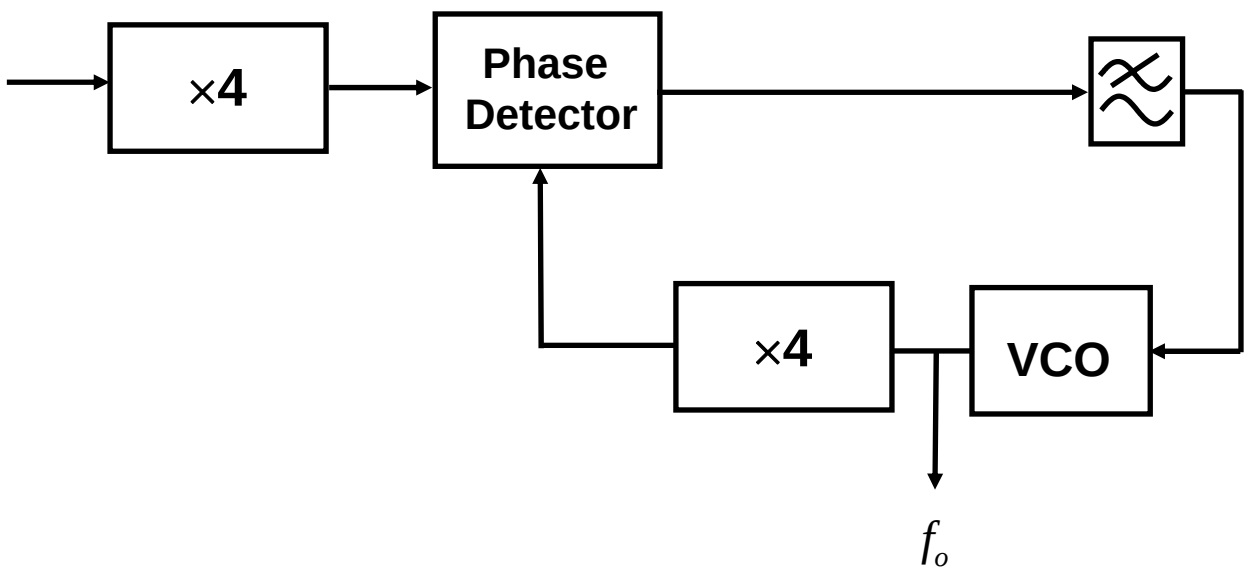
1) Ricostruzione della portante

2) D-PSK (Differential –PSK)

Ricostruzione della portante

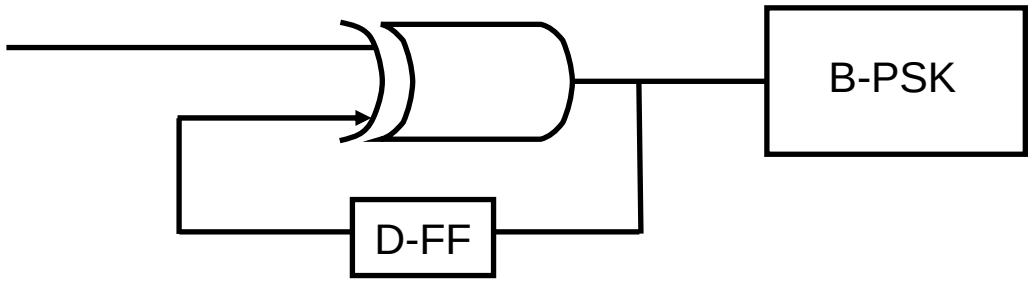
Q-PSK 2bit $s(t) = A\cos(\omega_0 t + \varphi)$ $\varphi = \frac{\pi}{4}, \frac{3}{4}\pi, -\frac{\pi}{4}, -\frac{3}{4}\pi$

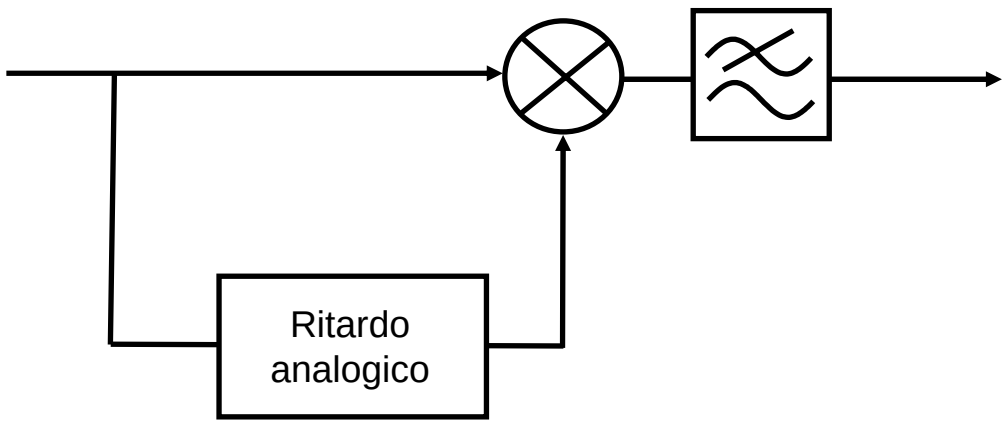
×4 $s(t) = A\cos(4\omega_0 t + 4\varphi)$ $4\varphi = \pi, 3\pi, -\pi, 3\pi = \pi$



Differential Phase Shift Keying

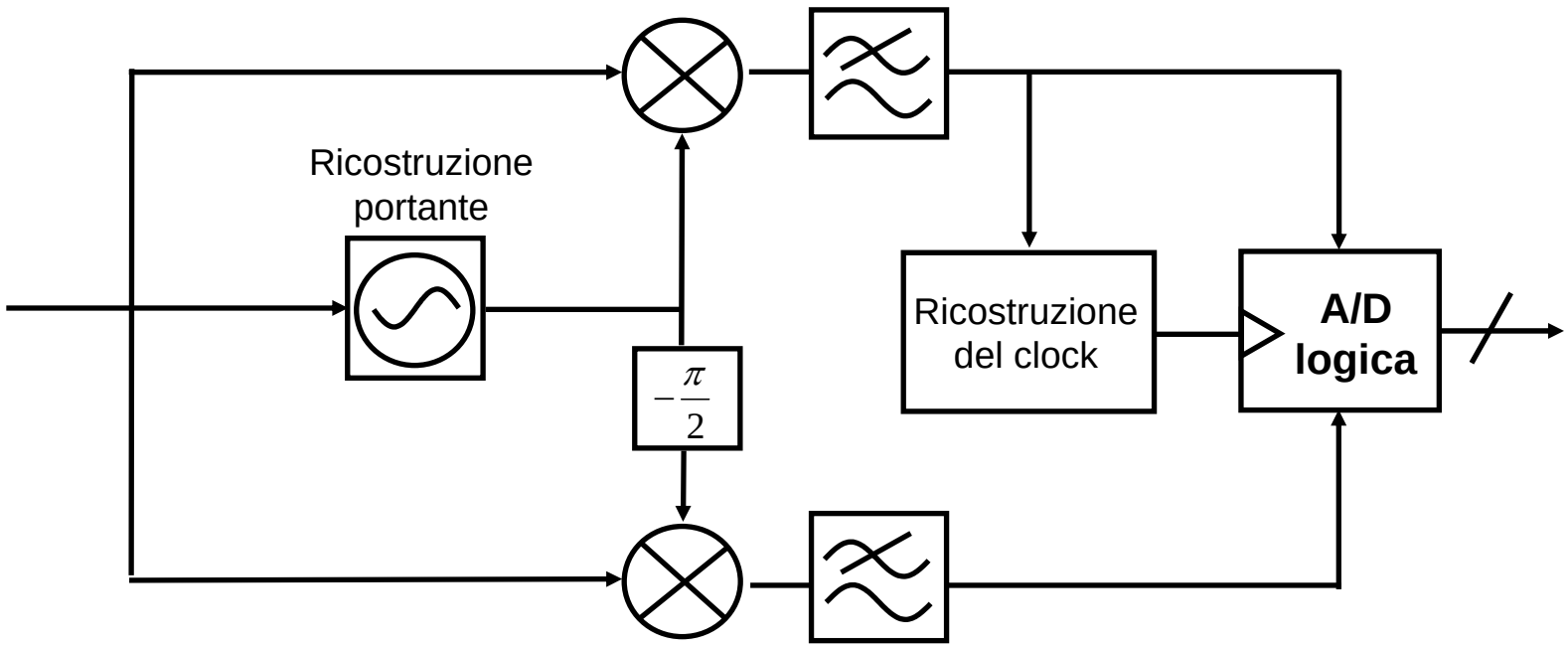
B-PSK



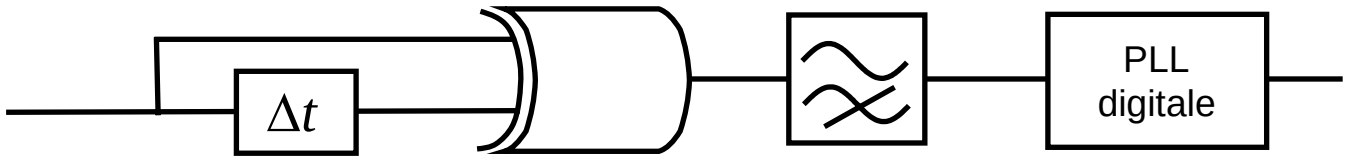


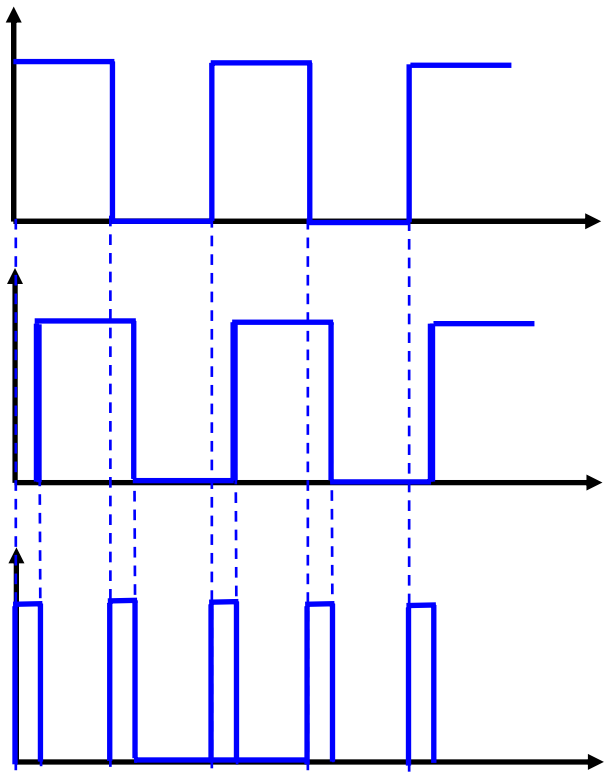
Il SNR è inferiore di 3dB

Demodulatore IQ



Ricostruzione del clock

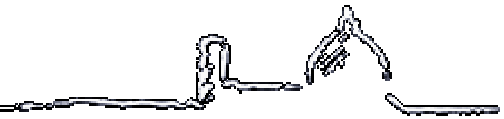




0 1 0 1 0 1 Massima frequenza

0 1 0 0 0 1 Componenti a più bassa frequenza

Ricostruzione del clock



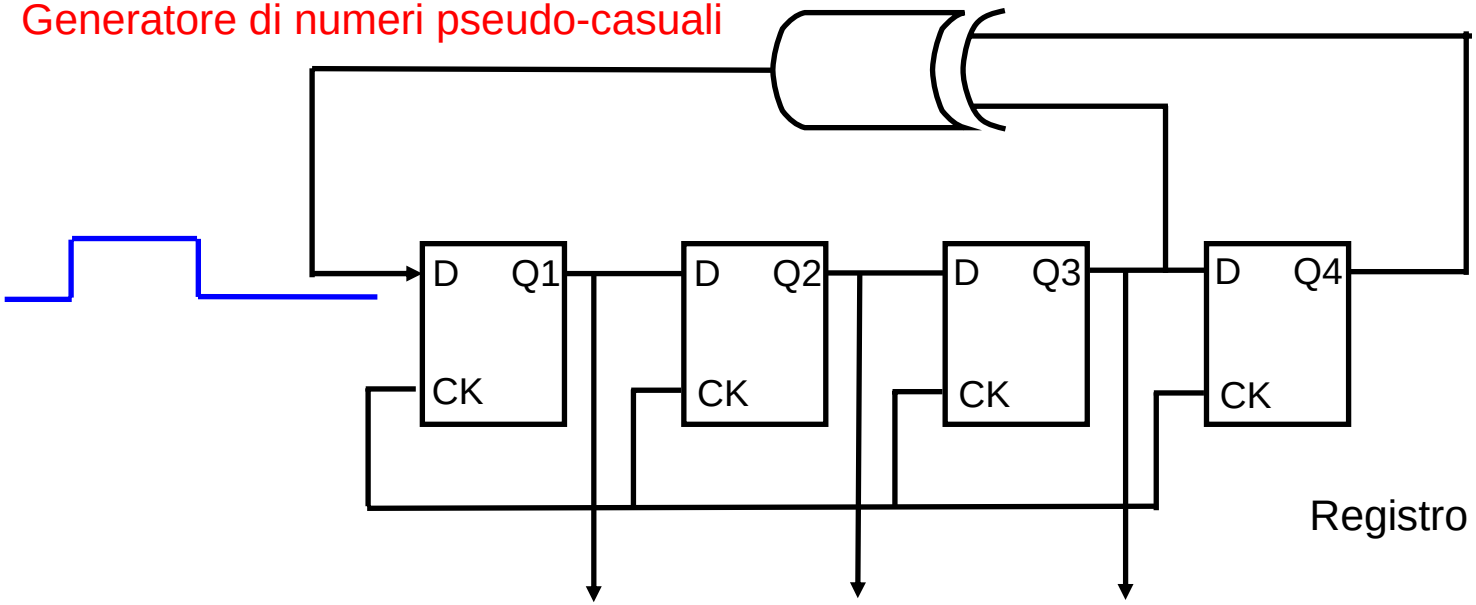
Bit stuffer

Ogni 5 simboli uguali, il sesto è diverso.
Il ricevitore ignora il valore del sesto simbolo se i precedenti 5 sono uguali

Ricostruzione del clock

Bit scrambling

Generatore di numeri pseudo-casuali



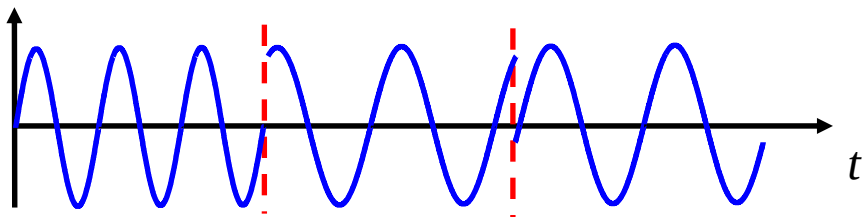
Registro a scorrimento

MLS (Maximum Lenght Sequence) = $2^N - 1$

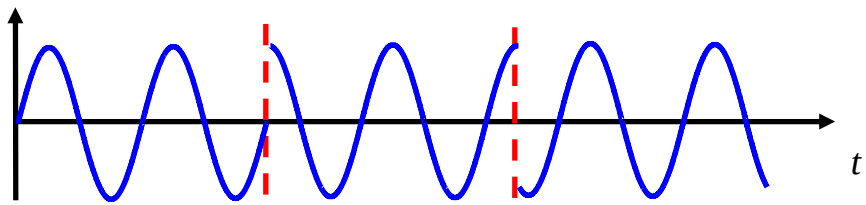
Nota: la funzione logica della rete di reazione dipende dal numero di bit

Il problema delle brusche variazioni di fase

FSK

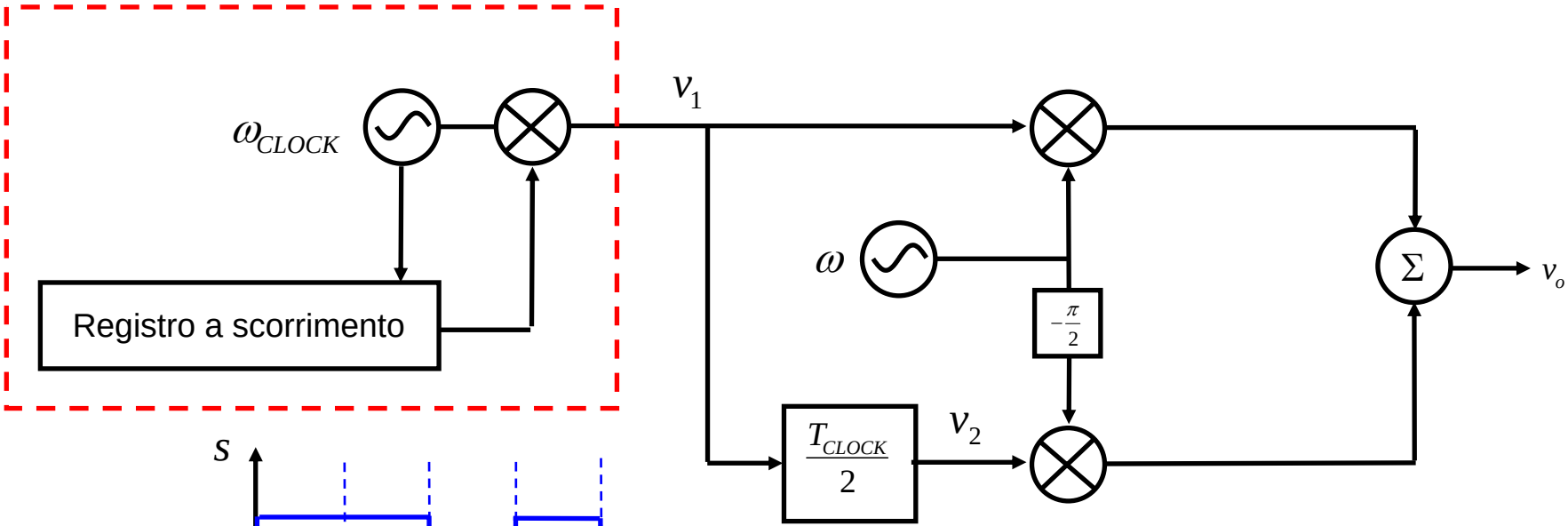


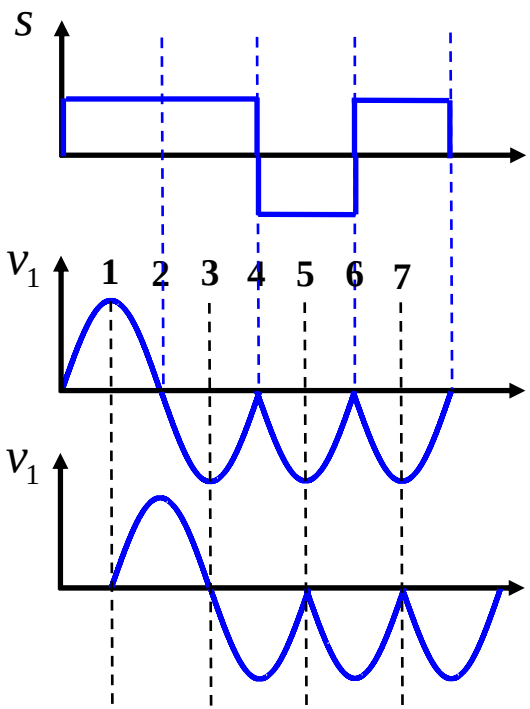
PSK

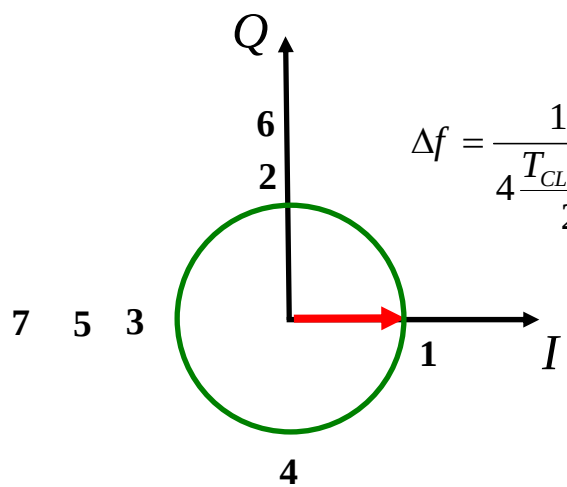


Le brusche transizioni producono componenti a larga banda che devono essere filtrate per non interferire con i canali adiacenti

MSK Minimum Shift Keying





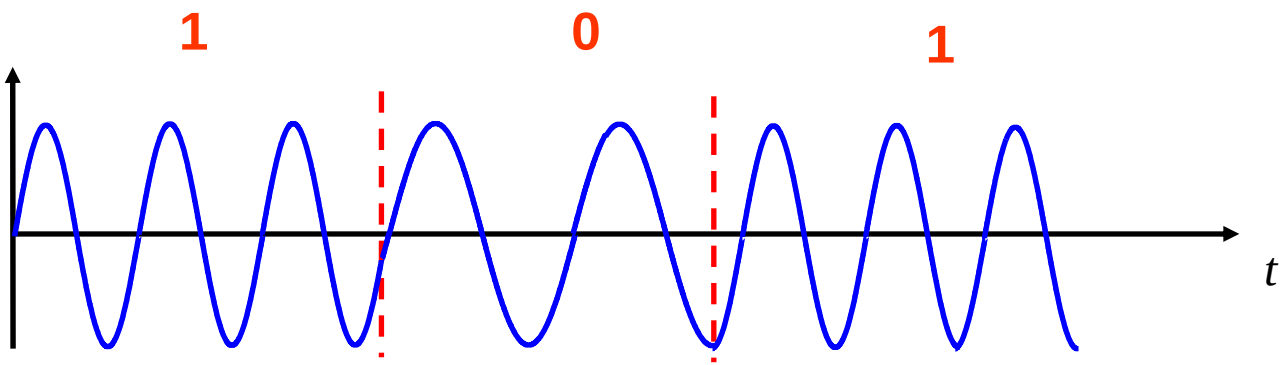


$$\Delta f = \frac{1}{4\frac{T_{CLOCK}}{2}} = \frac{1}{2T_{CLOCK}}$$

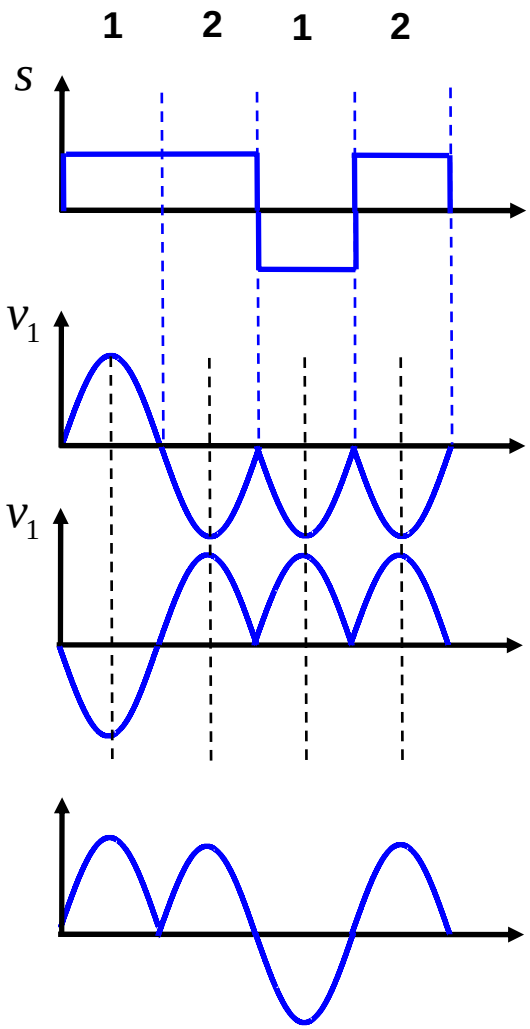
Mantiene la continuità di fase

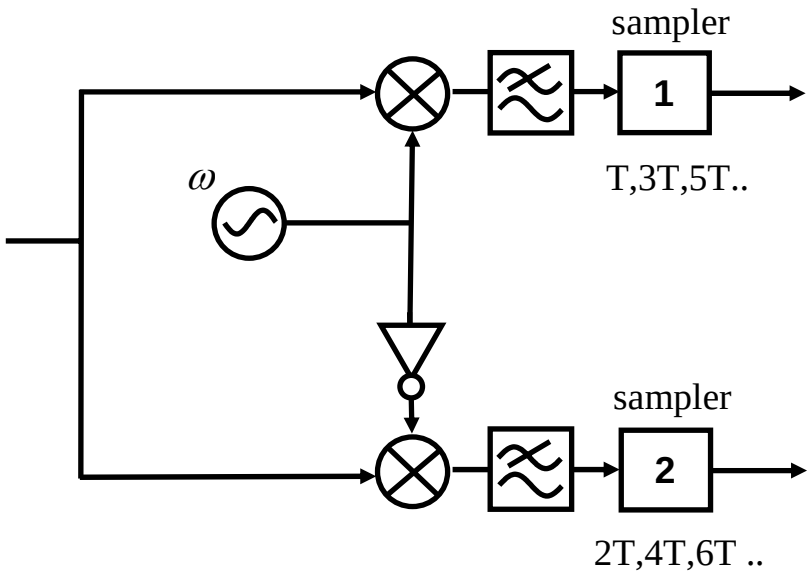
MSK Minimum Shift Keying

Continuità di fase

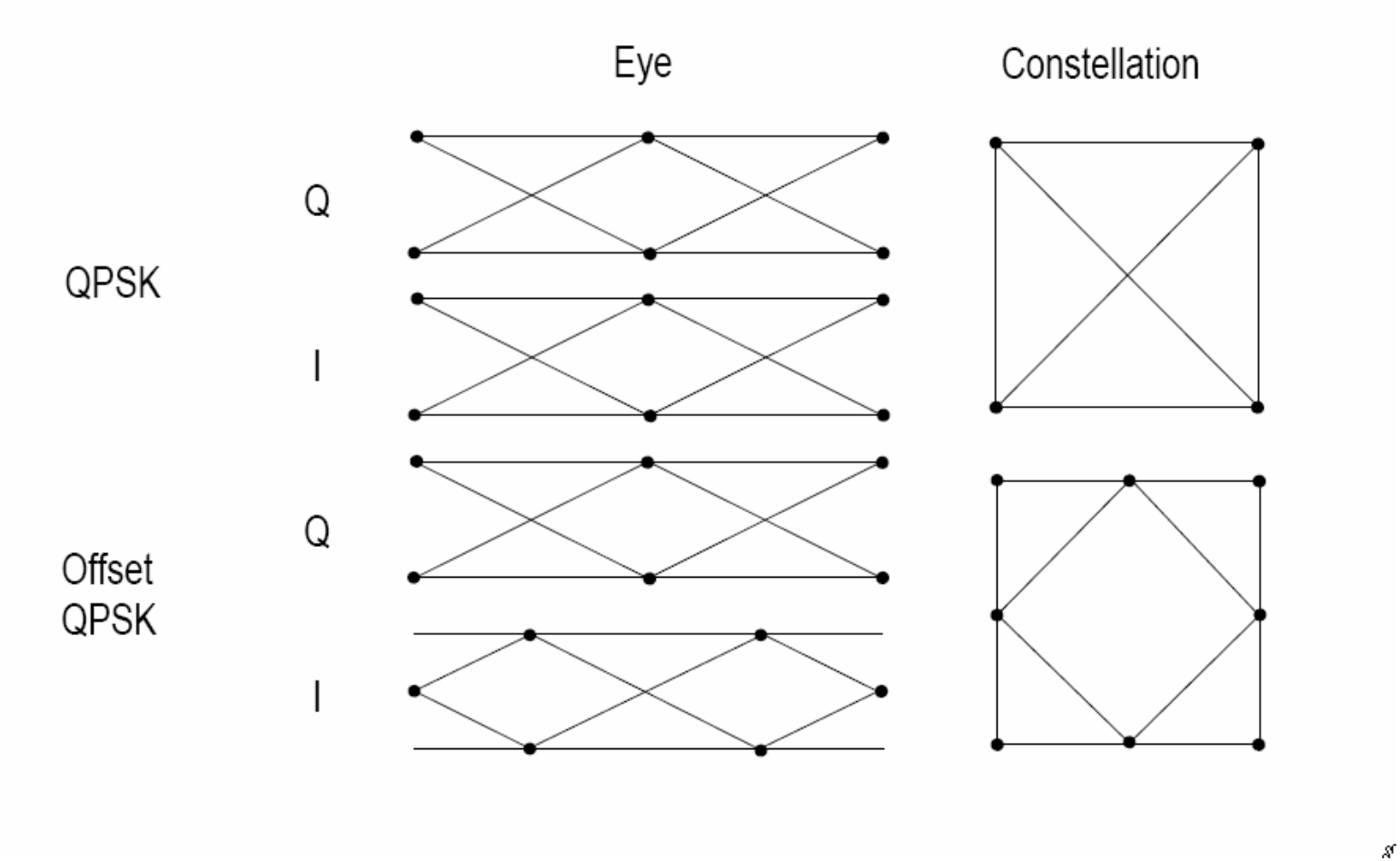


Demodulatore MSK

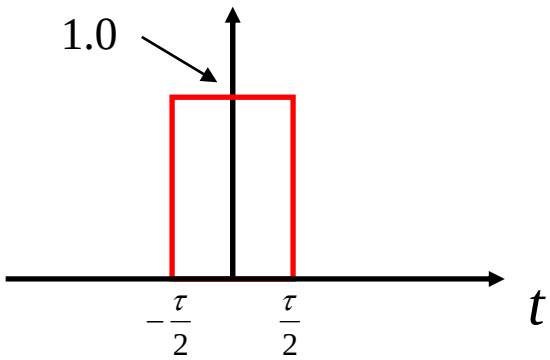


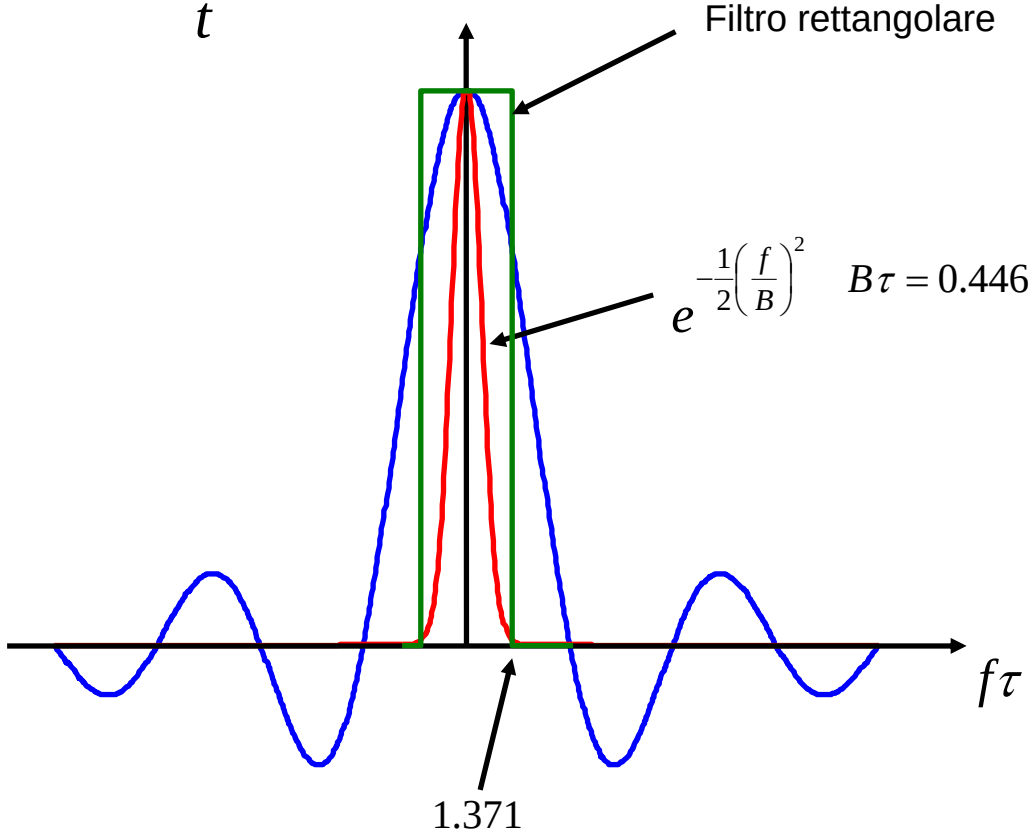


Offset Q- PSK



Filtro gaussiano





Modulation format	Theoretical bandwidth efficiency limits
MSK	1 bit/second/Hz
BPSK	1 bit/second/Hz
QPSK	2 bits/second/Hz
8PSK	3 bits/second/Hz
16 QAM	4 bits/second/Hz
32 QAM	5 bits/second/Hz
64 QAM	6 bits/second/Hz
256 QAM	8 bits/second/Hz

Modulation format	Application
MSK, GMSK	GSM, CDPD
BPSK	Deep space telemetry, cable modems
QPSK, $\pi/4$ DQPSK	Satellite, CDMA, NADC, TETRA, PHS, PDC, LMDS, DVB-S, cable (return path), cable modems, TFTS
OQPSK	CDMA, satellite
FSK, GFSK	DECT, paging, RAM mobile data, AMPS, CT2, ERMES, land mobile, public safety
8PSK	Satellite, aircraft, telemetry pilots for monitoring broadband video systems
16 QAM	Microwave digital radio, modems, DVB-C, DVB-T
32 QAM	Terrestrial microwave, DVB-T
64 QAM	DVB-C, modems, broadband set top boxes, MMDS
256 QAM	Modems, DVB-C (Europe), Digital Video (US)