Sistemas de Comunicaciones

Tema 3: Transmisión de Señales

Grado en Ingeniería de Sistemas de Telecomunicación

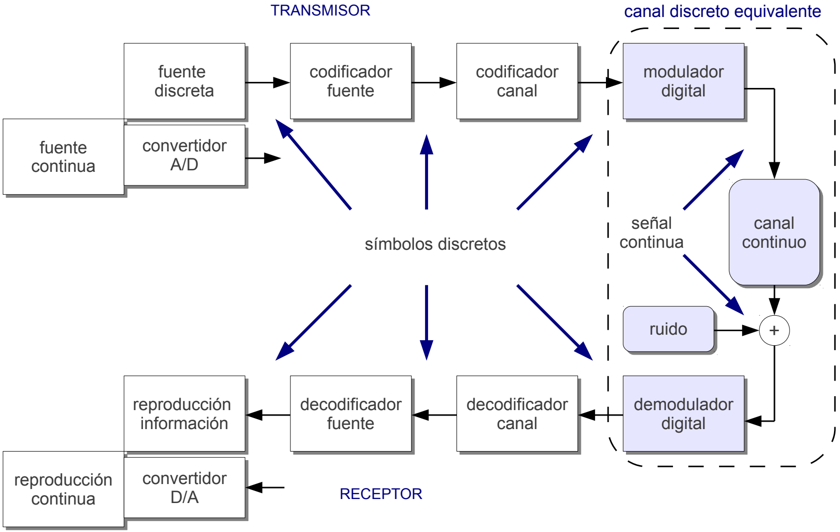
Departamento de Ingeniería de Comunicaciones
Universidad de Málaga

Curso 2012/2013

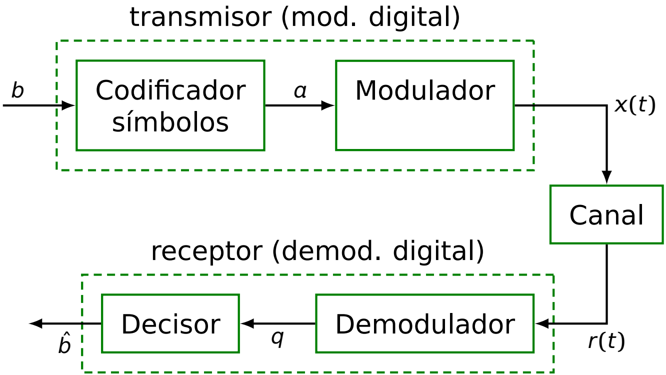
3.4 Transmisión Digital

Modelo sistema
Señales PAM
Señales digitales paso banda
Revisión sistema de comunicaciones digitales

3.4 Transmisión Digital
sistema de comunicaciones digitales



3.4 Transmisión Digital
Modelo sistema



- b: **bits** (o símbolos) $\{b_i\}$ con $i = 0, 1, \ldots, M - 1$
- $M = 2^k$: tamaño de la modulación digital con $k \in \mathbb{N}$
- a: **símbolos** de la constelación transmitida (y q de la recibida)
- $x(t), r(t)$: señales transmitida y recibida

3.4 Transmisión Digital
Modelo sistema

$M = 2$: modulación binaria $M > 2$: modulación M-aria

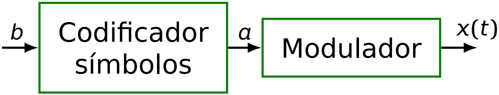
consideraciones

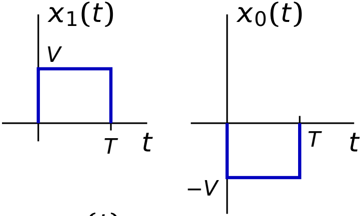
- símbolos equiprobables: $P\{b = b_i\} = P(b_i) = 1/M \quad \forall i$
- transmisión de símbolos independientes: $b_i \rightarrow a_i \rightarrow x_i(t)$, sistema sin memoria
- $x_i(t)$ de energía finita y limitada a $0 \leq t \leq T$
- T: período de símbolo
- modelo de canal: AWGN, $r(t) = x(t) + n(t)$

probabilidad de error de símbolo: $P_e = P\{\hat{b} \neq b\}$

`ejemplo`: **señales PAM** (Pulse Amplitude Modulation), información en la amplitud de los pulsos

3.4 Transmisión Digital
Modulación 2PAM



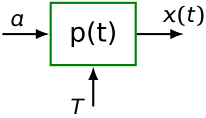


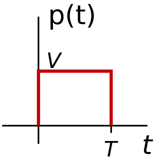
$b = \{0, 1\}$

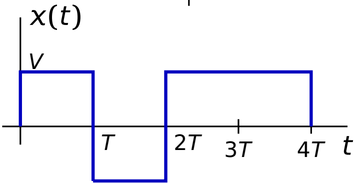
$a = \{-1, +1\}$

$x_i(t) = a_i p(t)$

Modulador





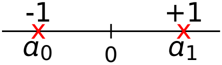


b_i	1	0	1	1
a_i	+1	-1	+1	+1

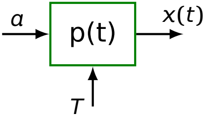
$x(t) = \sum_i a_i p(t - iT)$

$E_1 = E_2 = V^2 T$

Constelación



3.4 Transmisión Digital
Modulación 4-PAM

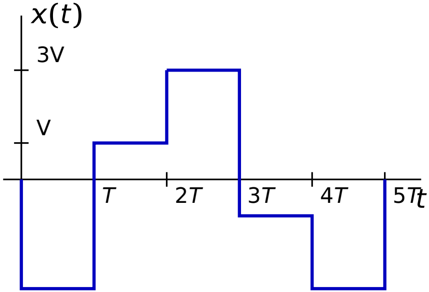


$b = \{00, 01, 10, 11\}$

$a = \{-3, -1, +1, +3\}$

$x(t) = \sum_i a_i p(t - iT)$

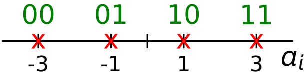
$T = 2T_b$

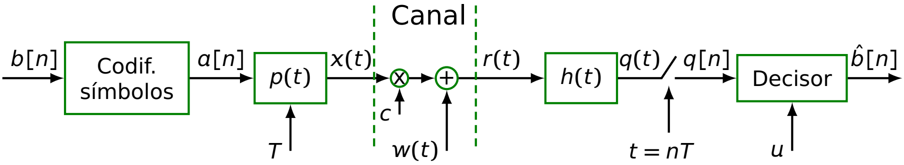


b_i	00	10	11	01	00
a_i	-3	+1	+3	-1	-3

En general: $T = (log_2 M)T_b$

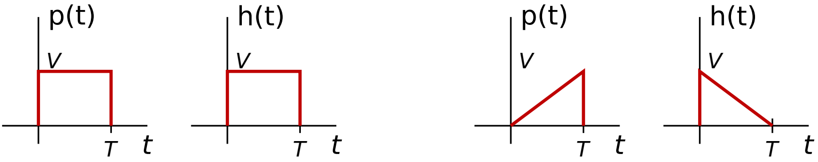
Ej: 1024PAM → 10 bits/símbolo

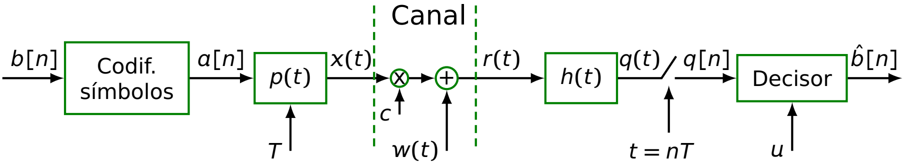




$h(t) = p(T - t)$ "Filtro adaptado", maximiza SNR de q

Ejemplos:

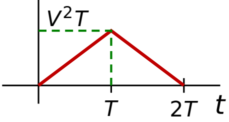




Si no hay ruido ($w(t) = 0$) y considerando $c = 1$

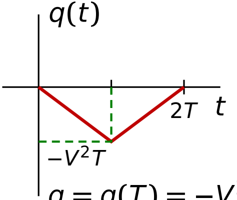
Si $x(t) = p(t)$

$q(t) = R_p(t - T)$



$q = q(T) = V^2 T = E_p$

Si $x(t) = -p(t)$



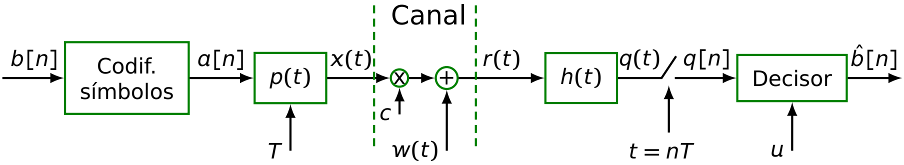
$q = q(T) = -V^2 T = -E_p$

$$q = \pm E_p$$

$$\hat{b} = \begin{cases} 1 \text{ si } q > u \\ 0 \text{ si } q < u \end{cases}$$

$$u = 0$$

3.4 Transmisión Digital
Sistema 2PAM con AWGN



Considerando ruido

$w(t)$ es AWGN con $S_W(f) = \dfrac{N_0}{2}$ (estacionario y con media nula)

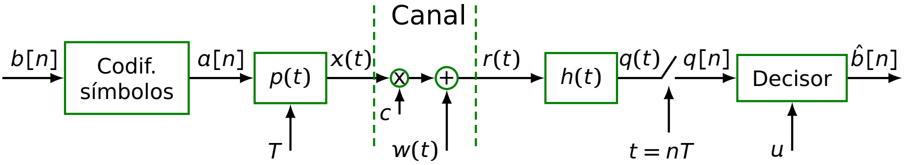
$n(t) = w(t) * h(t)$

$n = n(T) \sim N(0, \sigma_N^2)$

$\sigma_N^2 = P_N = \dfrac{N_0}{2} \int |H(f)|^2 \, df = \dfrac{N_0}{2} \int |P(f)|^2 \, df = \dfrac{N_0}{2} E_p$

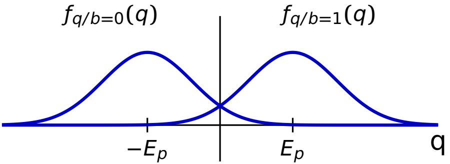
$q = \pm E_p + n$

3.4 Transmisión Digital
Sistema 2PAM con AWGN



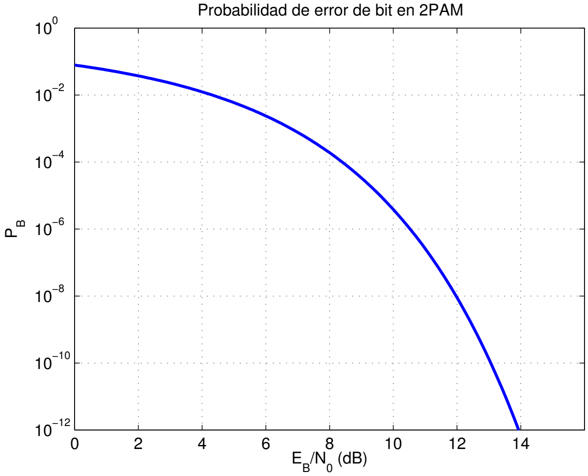
$$q = \pm E_p + n \qquad n \sim N(0, \frac{N_0}{2} E_p)$$

$$P(e/b=0) = \int_0^\infty f_{q/b=0}(q)dq = Q\left[\frac{E_p}{\sqrt{\frac{N_0}{2}E_p}}\right] = Q\left[\sqrt{\frac{2E_p}{N_0}}\right] = P(e/b=1)$$

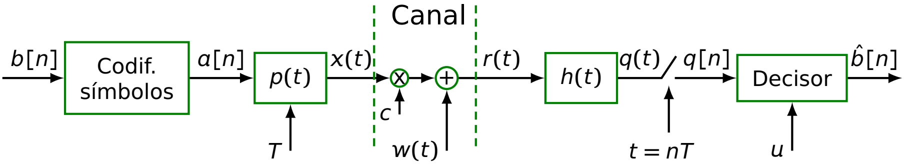


$$\boxed{P_b = Q\left[\sqrt{\frac{2E_b}{N_0}}\right]} \qquad E_b = E_p$$

3.4 Transmisión Digital
Sistema 2PAM con AWGN

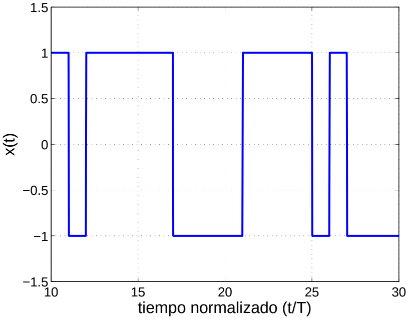


Probabilidad de error para señales 2PAM antipodales.



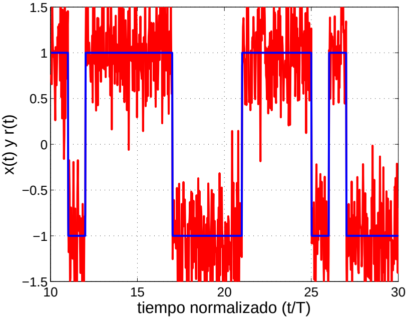
Canal
b[n]
Codif.
símbolos
a[n]
p(t)
x(t)
T
c
w(t)
r(t)
h(t)
q(t)
q[n]
t = nT
Decisor
u
b̂[n]

$x(t)$



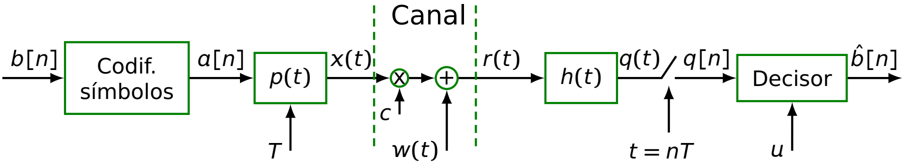
x(t)
tiempo normalizado (t/T)

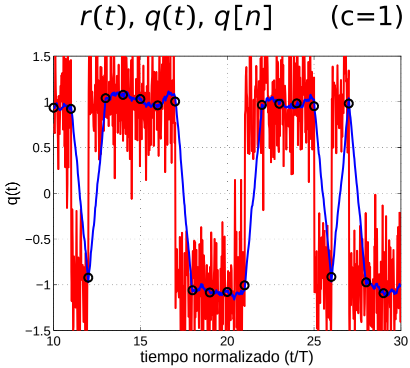
$x(t)$ y $r(t)$ (c=1)

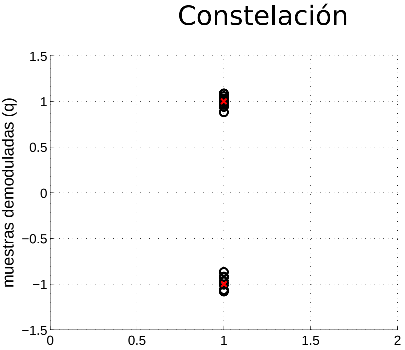


x(t) y r(t)
tiempo normalizado (t/T)

3.4 Transmisión Digital
Sistema 2PAM con AWGN





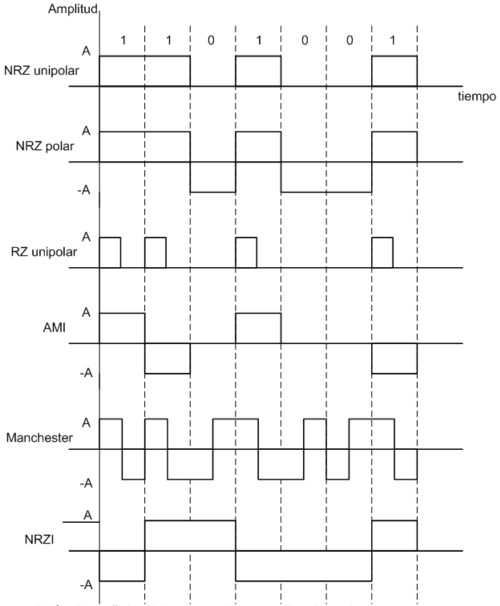


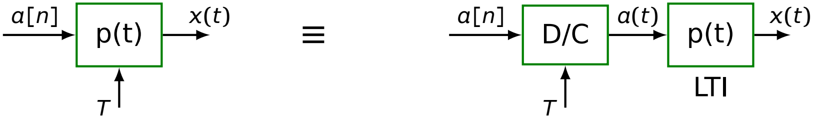
Formas de onda 2PAM

(Códigos de línea)

Prop. buscadas:

- Ausencia DC
- Muchas transiciones para sincronización
- Detección errores





Se puede demostrar:

$$S_X(f) = \frac{1}{T} S_A(f') \Big|_{f'=\frac{f}{fm}} |P(f)|^2$$

$$|P(f)|^2 = S_p(f) \quad \text{DEE de } p(t)$$

Asumiendo:

- Símbolos binarios independientes

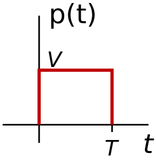
- $a[n]$ es un proceso estacionario discreto en tiempo y amplitud

$$a[n] \in \{+A, -A\} \Rightarrow R_A[n] = A^2 \delta[n] \Rightarrow S_A(f') = A^2$$

$$S_X(f) = \frac{A^2}{T} |P(f)|^2$$

3.4 Transmisión Digital
DEP 2PAM

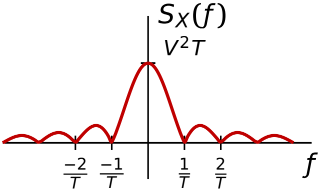
Ejemplo: Señal 2PAM antipodal (NRZ polar)

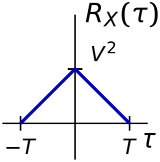


$$|P(f)| = V\ T\ sinc(fT)$$

$$A = 1$$

$$S_X(f) = \frac{1}{T} V^2 T^2 sinc^2(fT) = V^2 T sinc^2(fT)$$





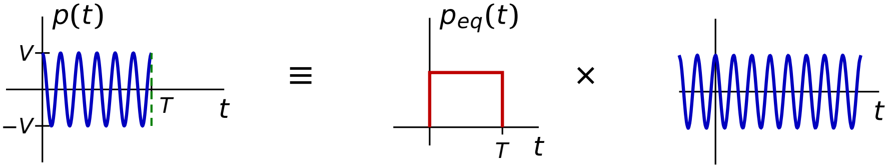
$$P_X = R_X(0) = V^2$$

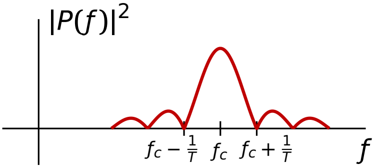
$$E_{x_i} = V^2 T$$

$$P_X = \frac{E_{X_i}}{T} = V^2$$

$p(t) = V cos(\omega_c t + \phi) \qquad 0 \leq t \leq T$

habitualmente $f_c = \dfrac{k}{T} \gg \dfrac{1}{T}$





$$B_T = 2B = \frac{2}{T}$$

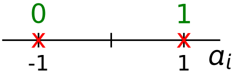
3.4 Transmisión Digital
Señales digitales paso banda: ASK

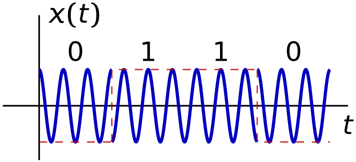
ASK (*Amplitude-Shift Keying*) ≡ PAM modulada en DBL

$x_i(t) = a_i V cos(\omega_c t)$

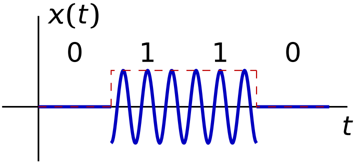
BASK (*Binary* ASK)

si $a_i = \{-1, +1\}$





OOK (*On-Off keying*) ≡ ASK con equivalente paso bajo NRZ Unipolar

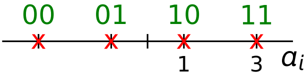


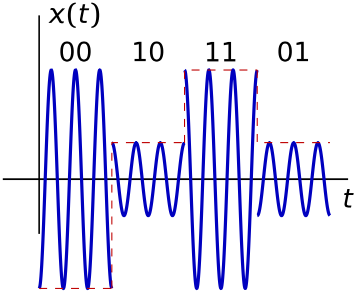
ASK (*Amplitude-Shift Keying*) ≡ PAM modulada en DBL

$x_i(t) = a_i V cos(\omega_c t)$

4-ASK

si $a_i = \{-3, -1, +1, +3\}$



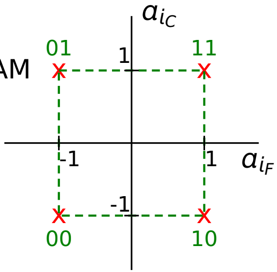


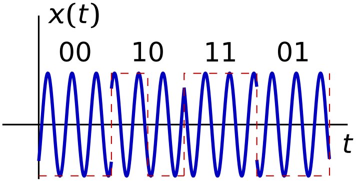
En general **M-ASK**

QAM *Quadrature Amplitud Modulation*

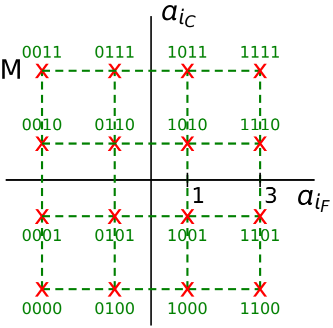
$$x_i(t) = a_{i_F} V cos(\omega_c t + \phi) - a_{i_C} V sen(\omega_c t + \phi)$$

4-QAM





16-QAM

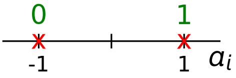


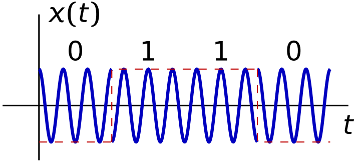
En general **M-QAM**

PSK (*Phase-Shift Keying*)

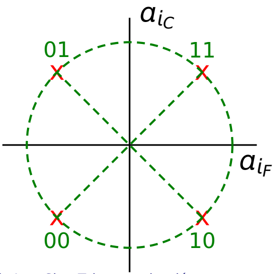
$$x_i(t) = V cos(\omega_c t + \phi_i) = cos(\phi_i) V cos(\omega_c t) - sen(\phi_i) V sen(\omega_c t)$$

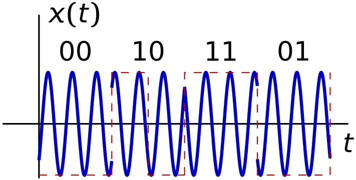
BPSK $\equiv$ BASK si $\phi_i = \{0, \pi\}$





QPSK (*Quadrature* PSK) si $\phi_i = \{\pi/4, 3\pi/4, 5\pi/4, 7\pi/4\}$





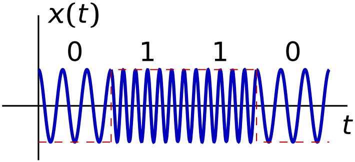
FSK (*Frequency-Shift Keying*)

$x_i(t) = V cos(\omega_i t)$

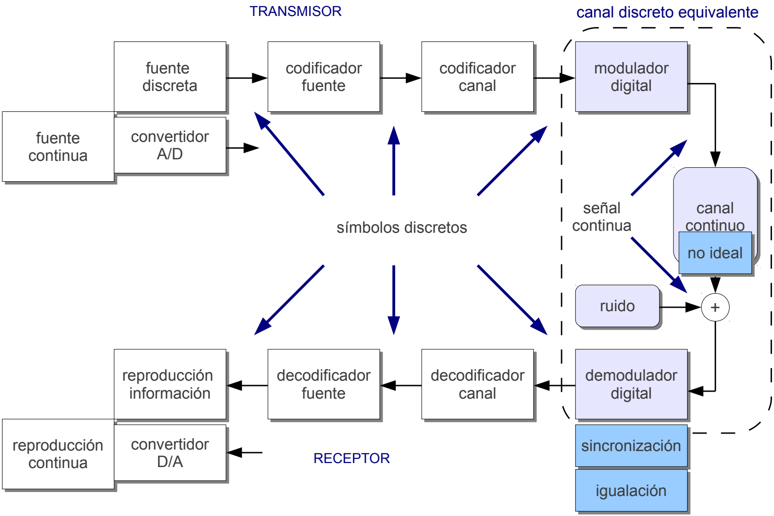
$\omega_i = 2\pi f_i$

BFSK

si $f_i = \{f_c - f_0, f_c + f_0\}$

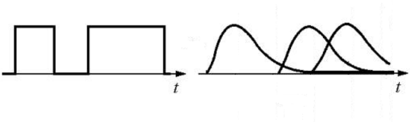


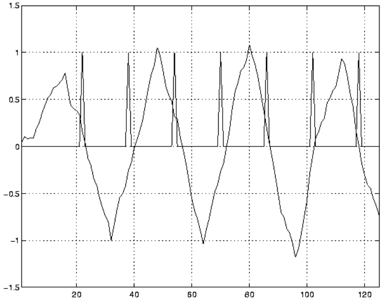
3.4 Transmisión Digital
Revisión sistema de comunicaciones digitales



3.4 Transmisión Digital
Problemas prácticos

- Interferencia entre símbolos, **ISI** (distorsión lineal canal, aumento P_b), **igualación**
- **sincronización** (de portadora, de símbolo, de trama)
- transmisión analógica por SCD (PCM, GSM...)





Ejemplos - símbolos con ISI y sincronización de símbolo.