ELC 5396: Digital Communications

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Signaling over Band-Limited Channels

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- Band-limited channels induce intersymbol interference.
- Design signal waveform, in order to reduce the intersymbol interference to zero.

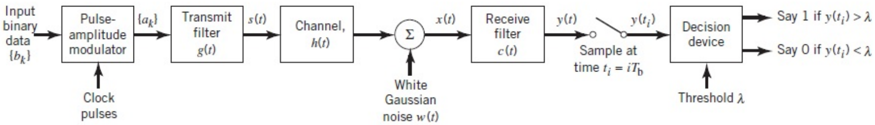
Error Rate Due to Channel Noise in a Matched-Filter Receiver

BPSK:
Symbol 1 is represented by a pulse $g(t)$ and symbol 0 is represented by $-g(t)$.

The energy contained in $g(t)$ is equal to E_b.

$$P_e = Q\left(\sqrt{\frac{2E_b}{N_0}}\right)$$

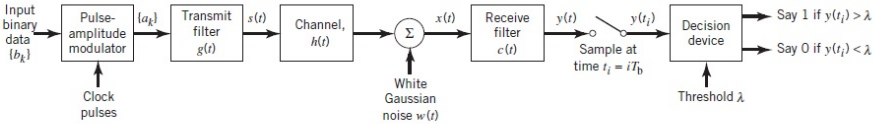
Intersymbol Interference (ISI)



Baseband binary data transmission

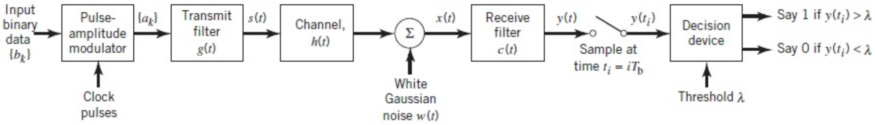
$$
\begin{aligned}
a_k &= \pm 1 \\
s(t) &= \sum_k a_k g(t - kT_b) \\
y(t) &= \sum_k a_k p(t - kT_b) \\
p(t) &= g(t) \otimes h(t) \otimes c(t) \\
P(f) &= G(f)H(f)C(f)
\end{aligned}
$$

Signal Design for Zero ISI



$$
\begin{aligned}
y(iT_b) &= \sum_{k=-\infty}^{\infty} a_k p[(i-k)T_b] \\
&= a_i + \sum_{k=-\infty, k\neq i}^{\infty} a_k p[(i-k)T_b]
\end{aligned}
$$

Signal Design for Zero ISI



Nyquist pulse:
(Nyquist's criterion for distortionless binary baseband data transmission)

$$p[(i-k)T_b] = \begin{cases} 1 & , \quad i = k \\ 0 & , \quad i \neq k \end{cases}$$

$$\sum_{n=-\infty}^{\infty} P(f - nR_b) = T_b$$

where $R_b = 1/T_b$.

Ideal Nyquist Pulse

The simplest waveform to specify the frequency function $P(f)$ is

$$P(f) = \begin{cases} \frac{1}{2W}, & -W \leq f \leq W \\ 0, & |f| > W \end{cases} = \frac{1}{2W} rect\left(\frac{f}{2W}\right)$$

where $W = \frac{1}{2T_b} = \frac{R_b}{2}$. $R_b = 2W$ is the Nyquist rate.

$$p(t) = \frac{\sin(2\pi Wt)}{2\pi Wt} = \mathrm{sinc}(2Wt)$$

Ideal Nyquist Pulse

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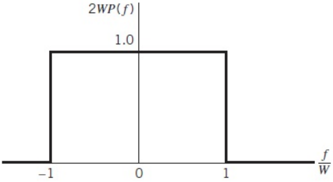
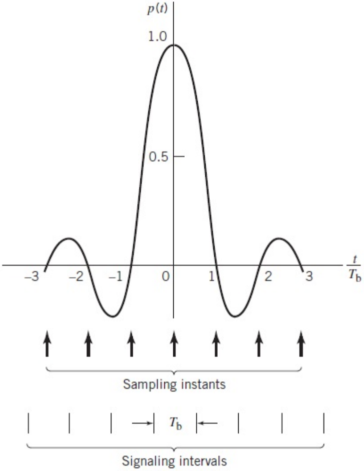




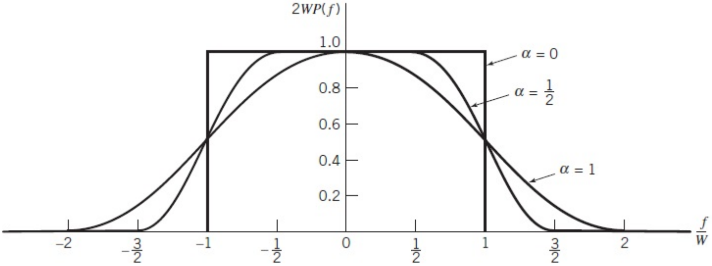
Raised-Cosine

$$P(f) + P(f - 2W) + P(f + 2W) = \frac{1}{2W}, \;\; -W \le f \le W$$

The raised-cosine spectrum satisfies the above

$$P(f) = \begin{cases} \frac{1}{2W} & 0 \le |f| < f_1 \\ \frac{1}{4W}\{1 + \cos[\frac{\pi}{2W\alpha}(|f| - f_1)]\} & f_1 \le |f| < 2W - f_1 \\ 0 & |f| \ge 2W - f_1 \end{cases}$$

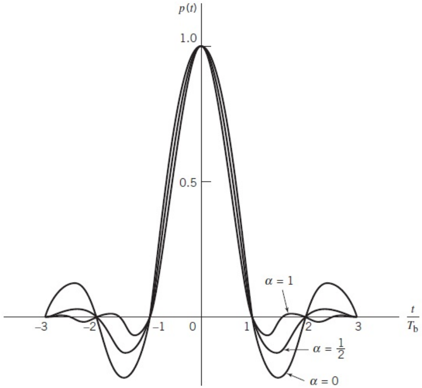
Raised-Cosine



Roll-off factor: $\alpha = 1 - f_1/W$.

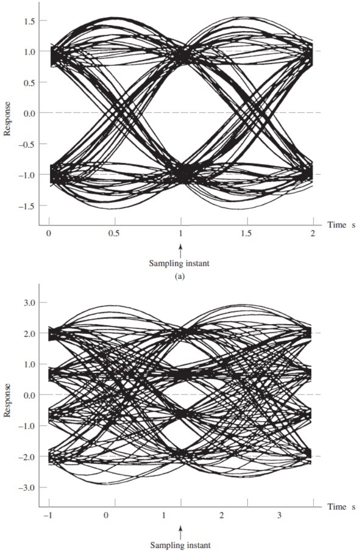
Transmission bandwidth: $B_T = 2W - f_1 = W(1 + \alpha)$.

Raised-Cosine



$$p(t) = \text{sinc}(2Wt)\frac{\cos(2\pi\alpha Wt)}{1 - 16\alpha^2 W^2 t^2}$$

Post-Processing Techniques: The Eye Pattern



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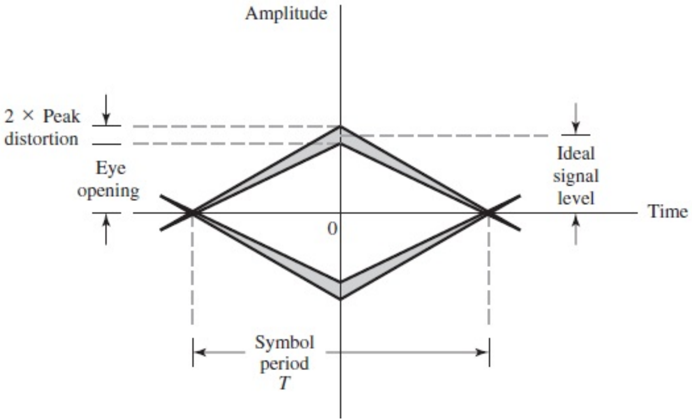

Adaptive Equalization