Principles of Communications
ECS 332

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7. Pulse Modulation, ISI, and Pulse Shaping

Office Hours:
BKD, 6th floor of Sirindhralai building
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Friday 14:00-15:30

Principles of Communications
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7.1 Analog Pulse Modulation

ASCII in MATLAB

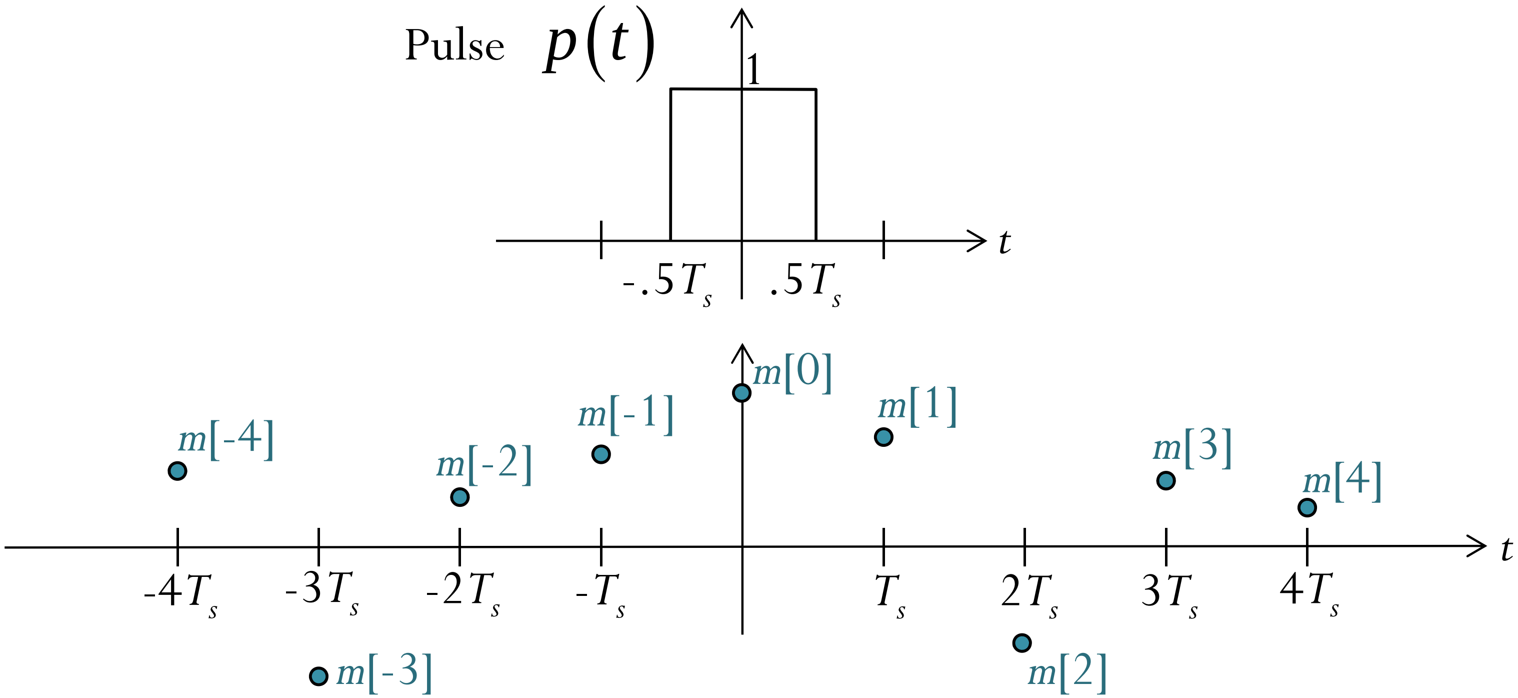
```
>> str='I love SIIT';
>> real(str)

ans =

    73    32   108   111   118   101    32    83    73    73    84

>> dec2base(str,2)

ans =

1001001
0100000
1101100
1101111
1110110
1100101
0100000
1010011
1001001
1001001
1010100
```

text string

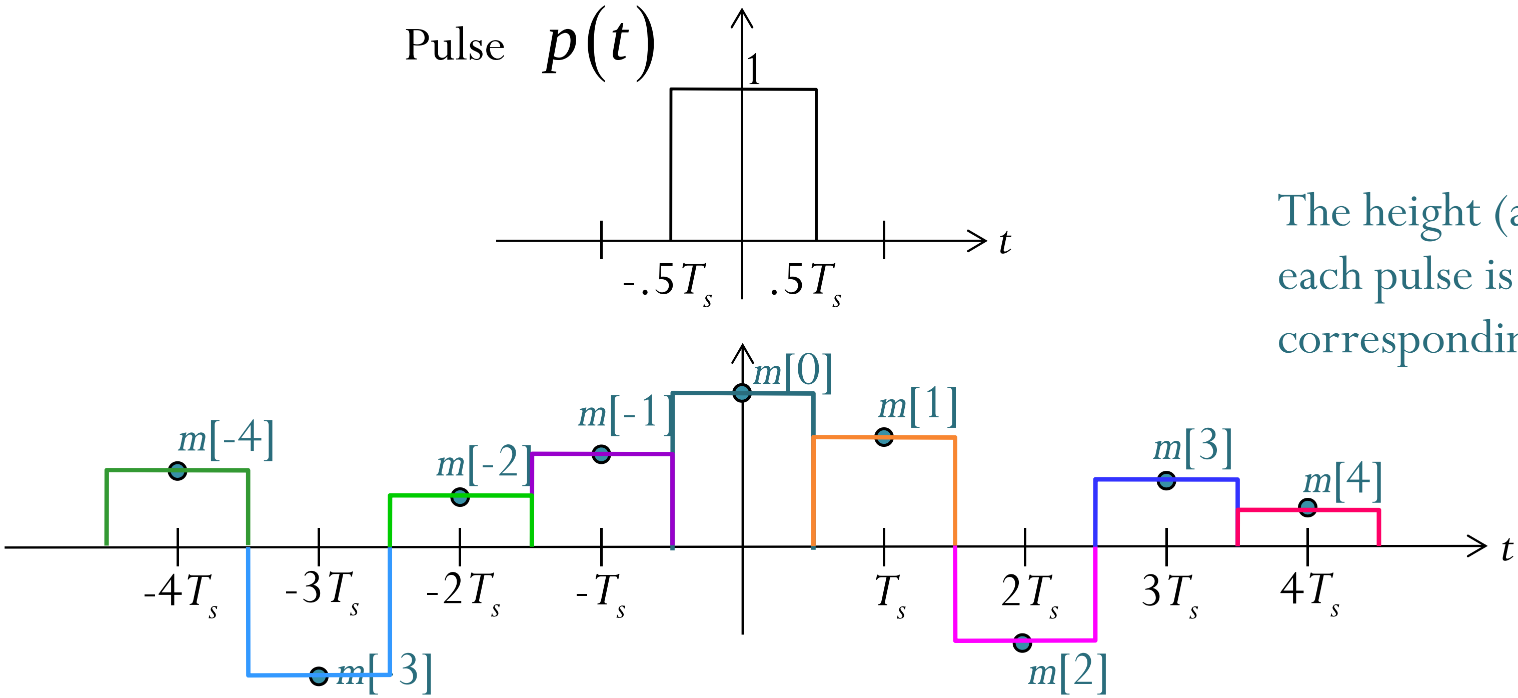
(decimal) ASCII representation of the text string

binary (base 2) representation of the decimal numbers

PAM: Example 7.11 (Figure 56)

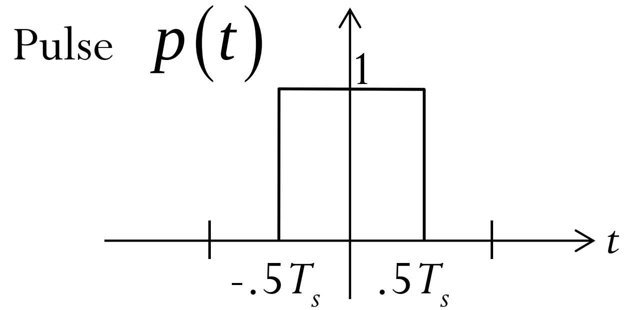


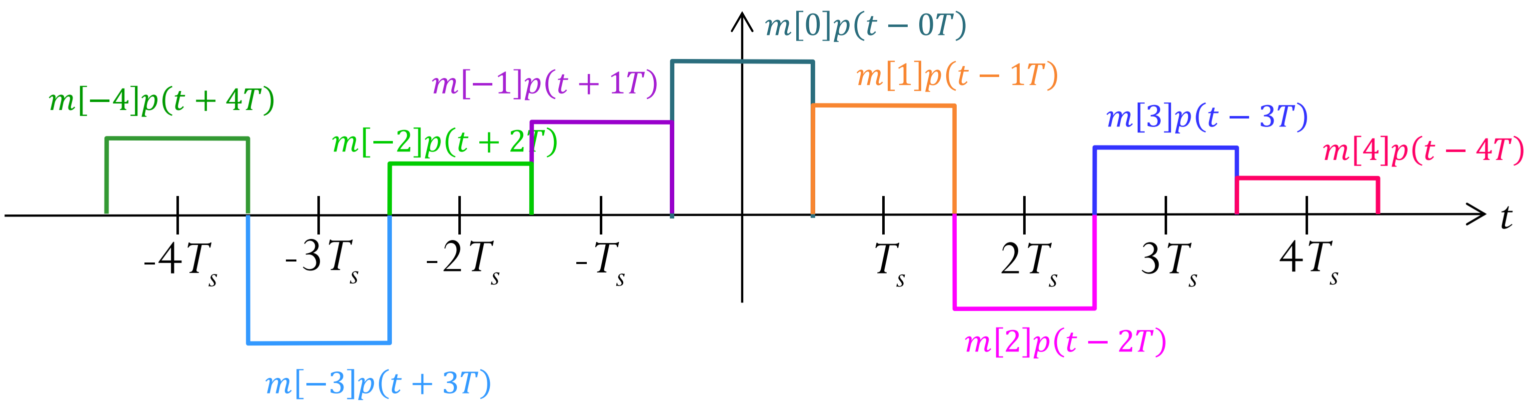
PAM: Example 7.11 (Figure 56)



The height (amplitude) of each pulse is scaled by the corresponding $m[n]$

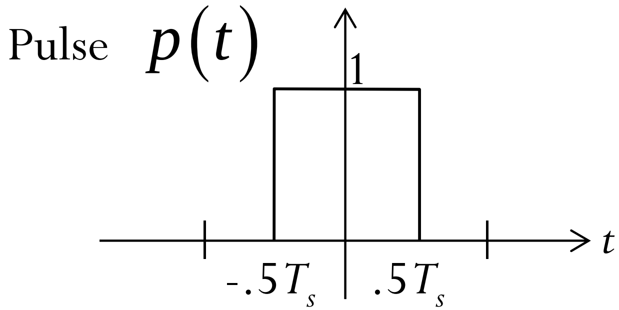
PAM: Example 7.11 (Figure 56)

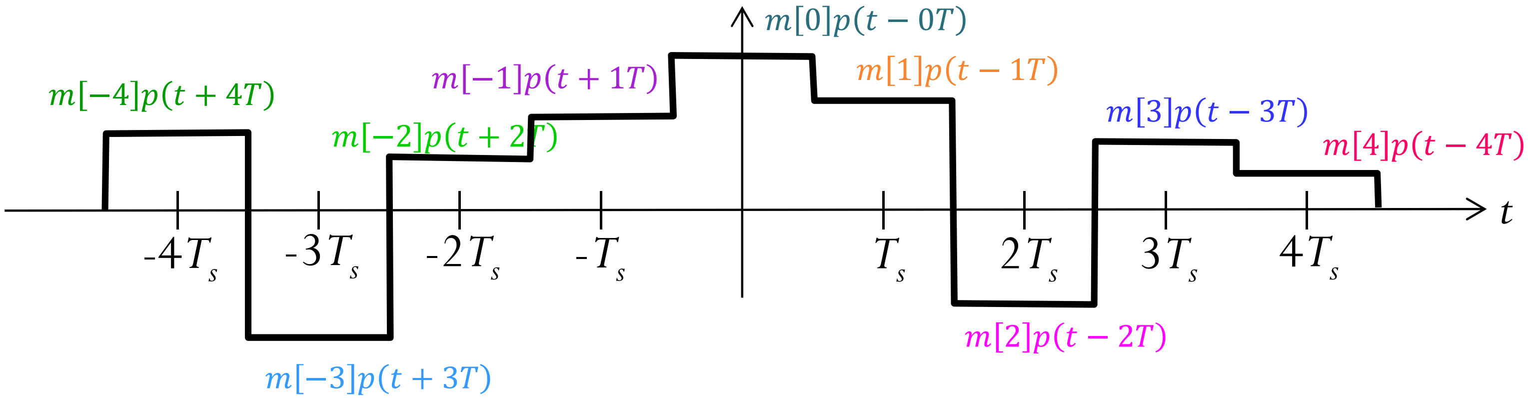




$$x_{\text{PAM}}(t)=\sum_{n=-\infty}^{\infty} m[n]\,p(t-nT)$$

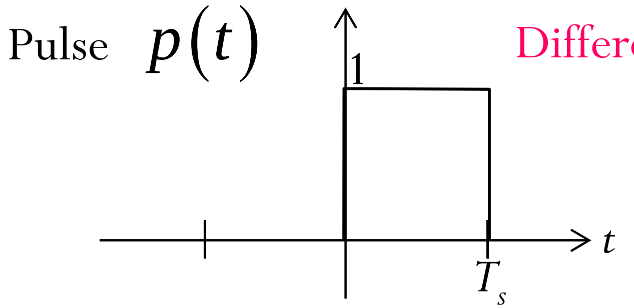
PAM: Example 7.11 (Figure 56)





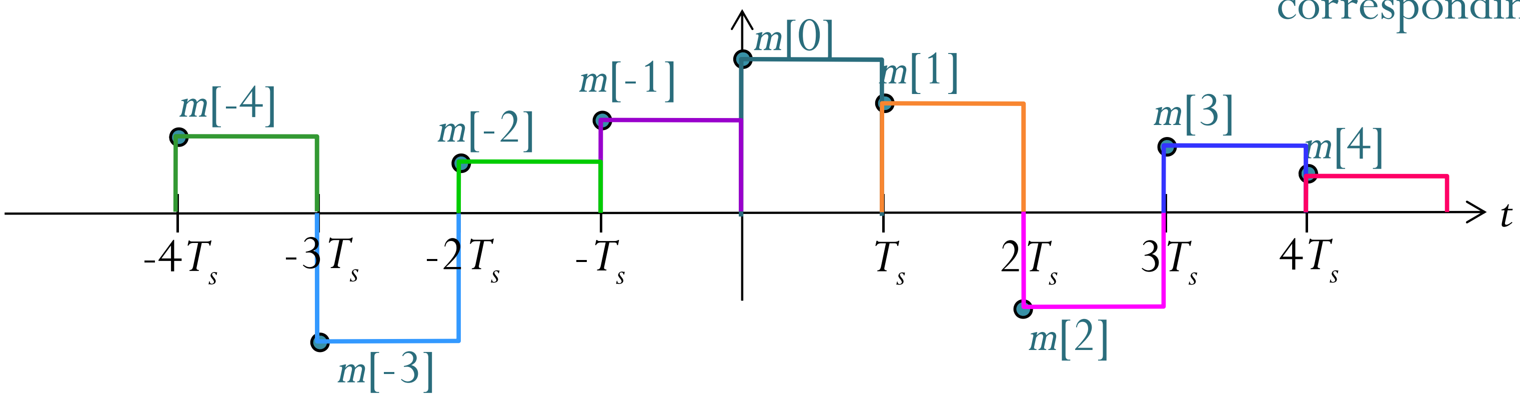
$$x_{\text{PAM}}(t) = \sum_{n=-\infty}^{\infty} m[n]\,p(t-nT)$$

PAM: Example 7.12 (Figure 57)



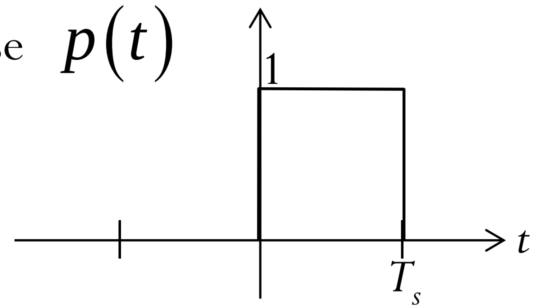
Different pulse is used here.

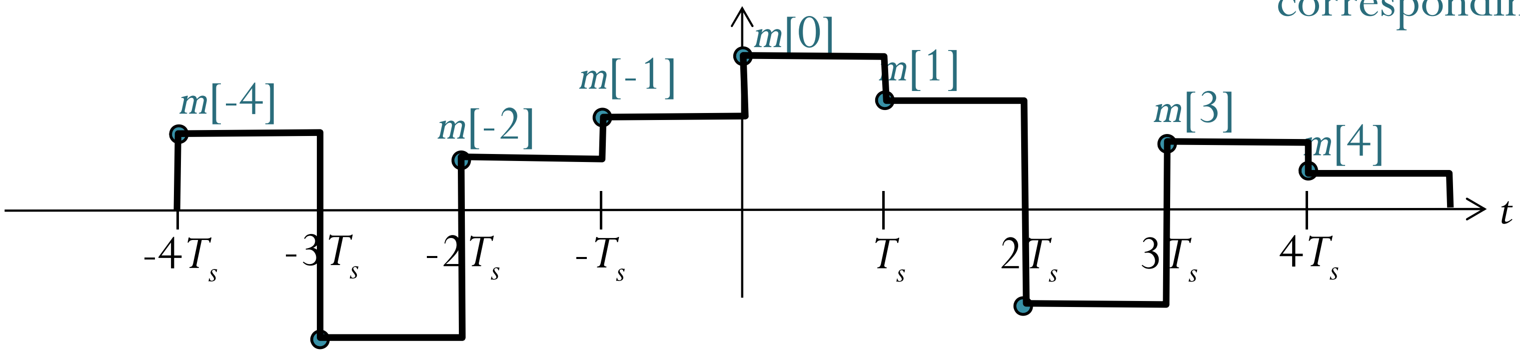
The height (amplitude) of each pulse is scaled by the corresponding $m[n]$



PAM: Example 7.12 (Figure 57)

Pulse $p(t)$

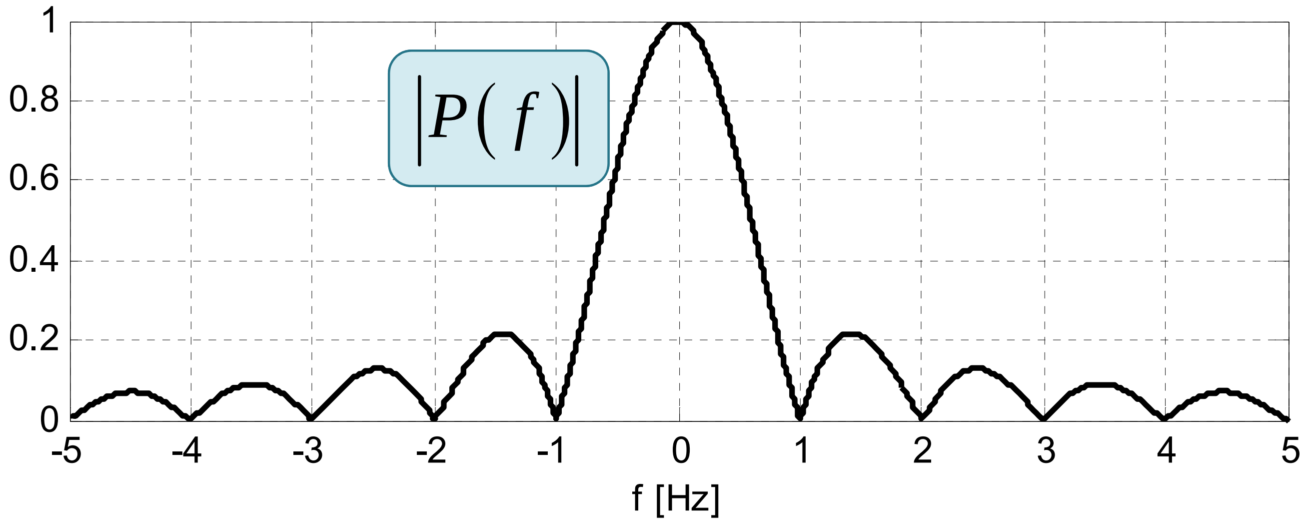


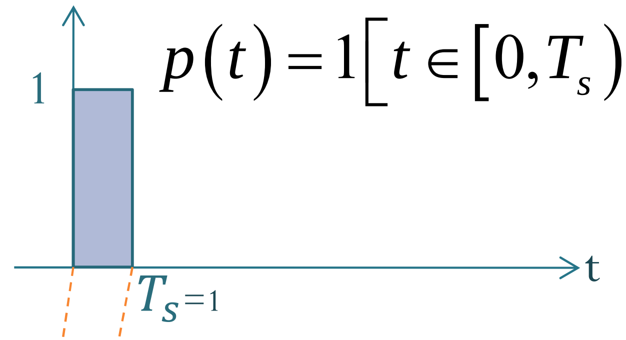


The height (amplitude) of each pulse is scaled by the corresponding $m[n]$

$$x_{\text{PAM}}(t) = \sum_{n=-\infty}^{\infty} m[n]\, p(t - nT)$$

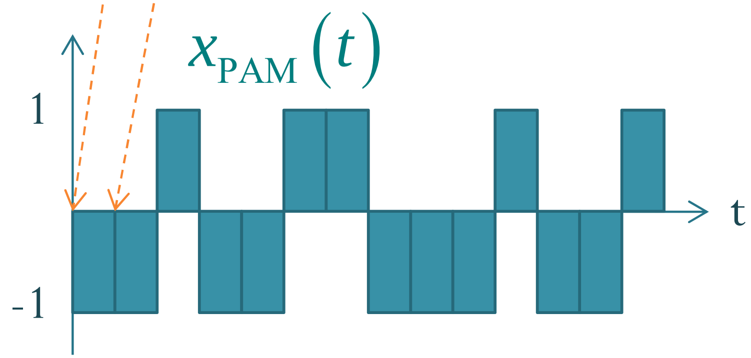
Review: Spectrum of PAM signal





$$p(t) = 1\left[t \in [0, T_s)\right]$$

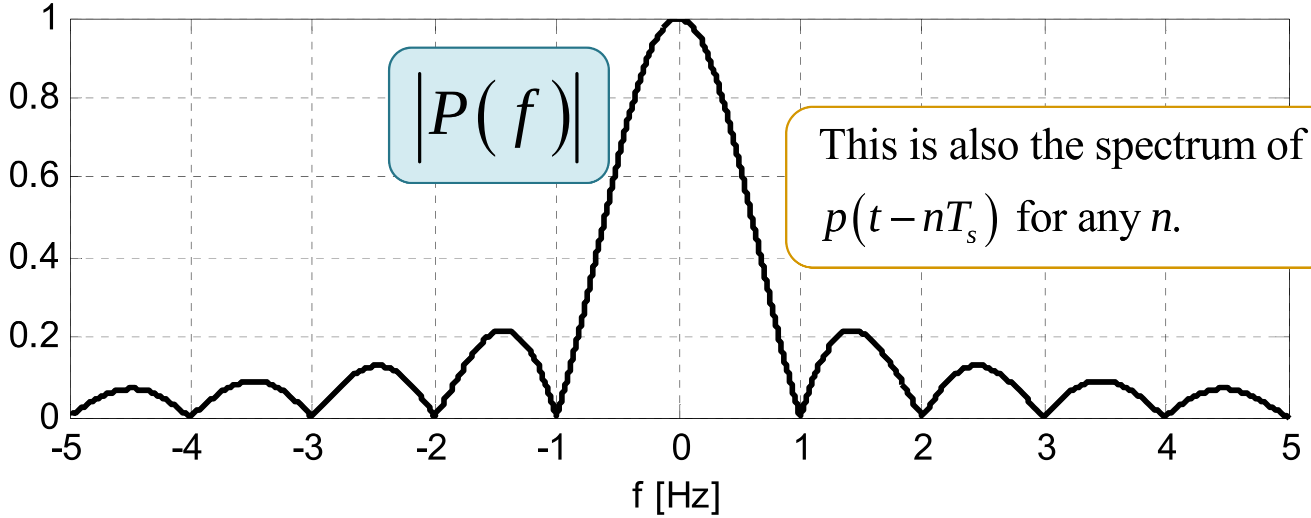
m= [-1,-1,1,-1,-1,1,1,-1,-1,-1,1,-1,-1,1,-1,1,1,-1,-1,-1,-1,1,-1,-1,-1,-1,-1,1,-1,1]



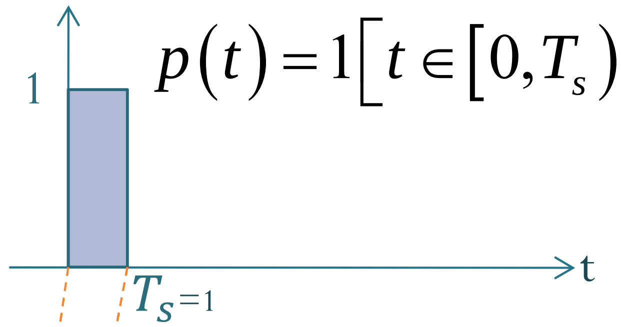
$$x_{\text{PAM}}(t) = \sum_n m[n]\, p(t - nT_s)$$

Can you sketch the spectrum of $x_{\text{PAM}}(t)$?

$X_{\mathrm{PAM}}(f)$ (2/4)

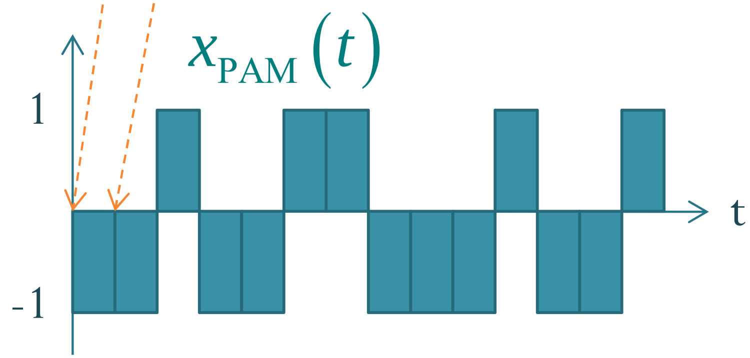


This is also the spectrum of $p(t-nT_s)$ for any n.



$$p(t)=1[t\in[0,T_s)]$$

m= [-1,-1,1,-1,-1,1,1,-1,-1,-1,1,-1,-1,1,-1,1,1,-1,-1,-1,-1,1,-1,-1,-1,-1,-1,1,-1,1]



$$x_{\mathrm{PAM}}(t)=\sum_n m[n]\,p(t-nT_s)$$

Does this mean $|X_{\mathrm{PAM}}(f)|$ will simply be a sum of $|P(f)|$ and therefore its shape will be similar to $|P(f)|$?

Important Properties of $\mathcal{F}$

$$\{x * y\}(t) = \int_{-\infty}^{\infty} x(\mu) y(t-\mu) d\mu = \int_{-\infty}^{\infty} x(t-\mu) y(\mu) d\mu$$

Convolution Properties:

$$x * y \overset{\mathcal{F}}{\rightleftharpoons} X \times Y$$

$$x \times y \overset{\mathcal{F}}{\rightleftharpoons} X * Y$$

Note that the magnitude of this is simply $|G(f)|$

Shifting Properties:

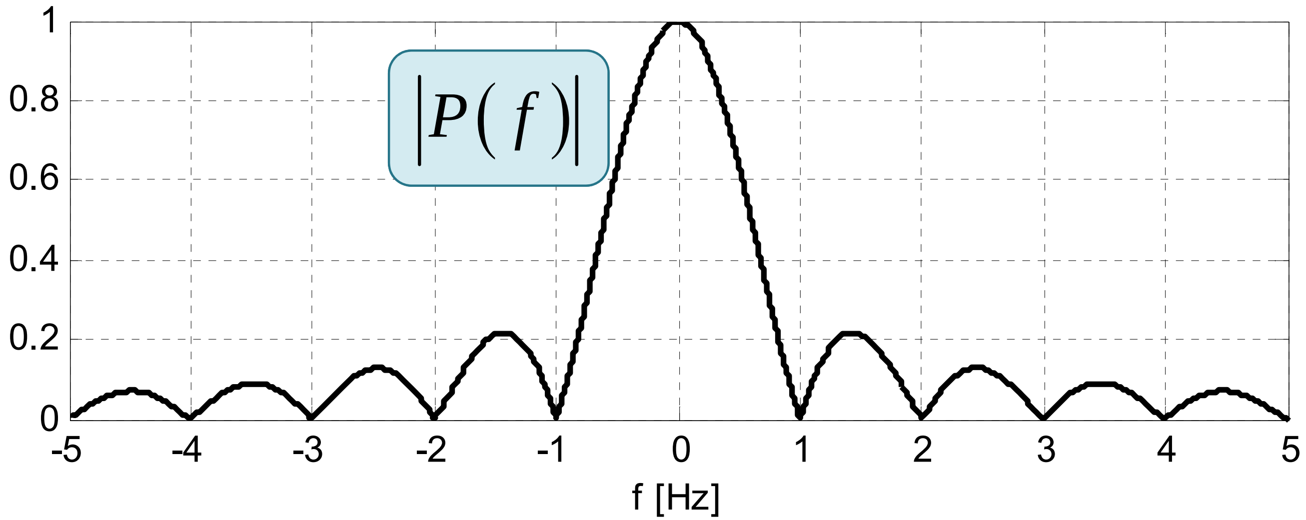
$$g(t - t_0) \overset{\mathcal{F}}{\rightleftharpoons} e^{-j2\pi f t_0} G(f)$$

$$e^{j2\pi f_0 t} g(t) \overset{\mathcal{F}}{\rightleftharpoons} G(f - f_0)$$

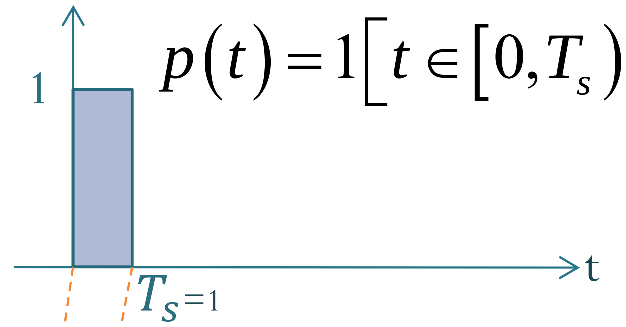
Modulation:

$$g(t)\cos(2\pi f_c t) \overset{\mathcal{F}}{\rightleftharpoons} \frac{1}{2} G(f - f_c) + \frac{1}{2} G(f + f_c)$$

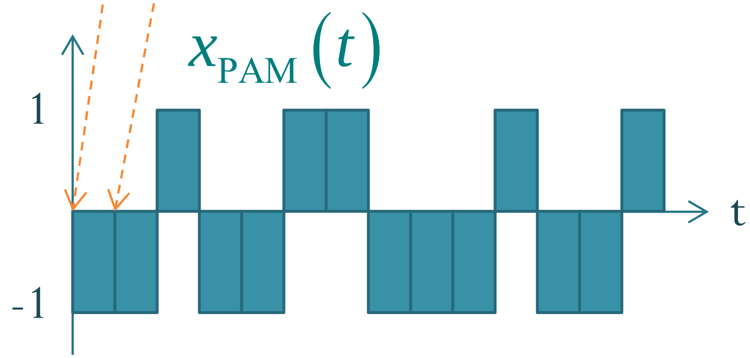
$X_{\mathrm{PAM}}(f)$ (3/4)



$$p(t) = 1\left[t \in [0, T_s)\right]$$



m= [-1,-1,1,-1,-1,1,1,-1,-1,-1,1,-1,-1,1,-1,1,1,-1,-1,-1,-1,1,-1,-1,-1,-1,-1,1,-1,1]



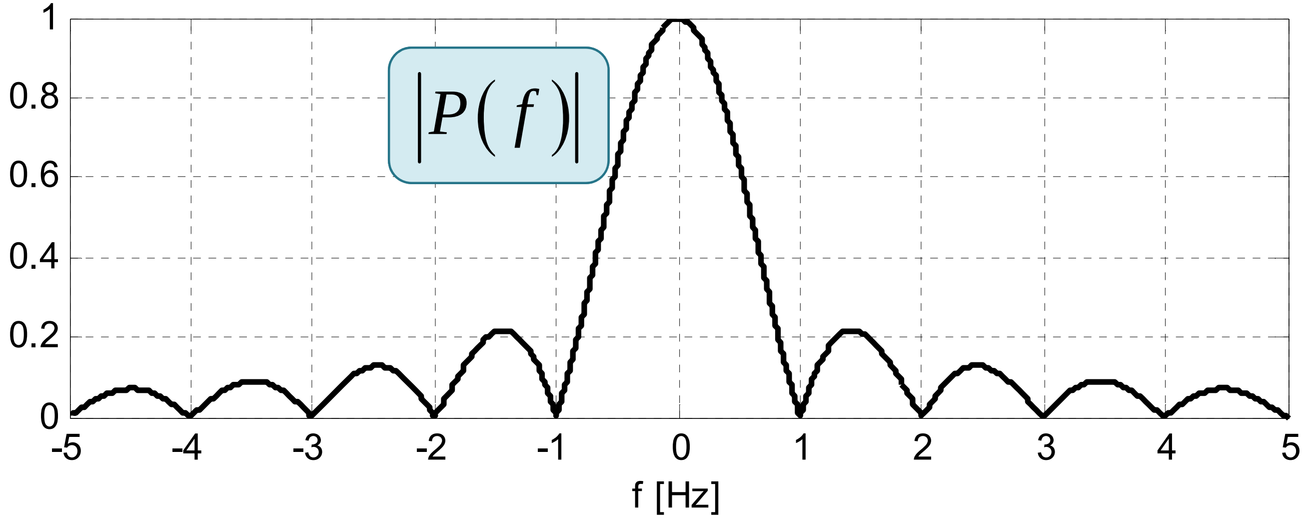
$$x_{\mathrm{PAM}}(t) = \sum_n m[n]\, p(t - nT_s)$$

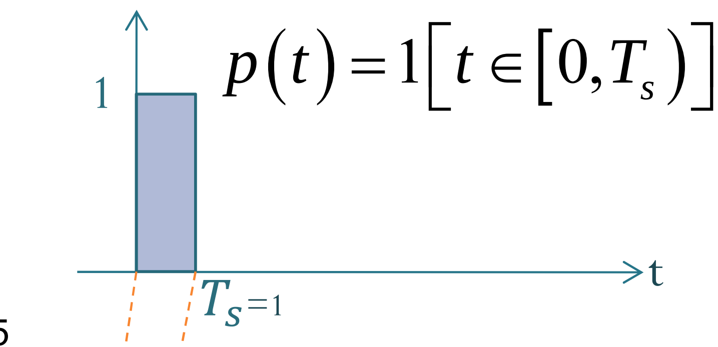
$$\xrightarrow{\mathcal{F}} X_{\mathrm{PAM}}(f) = \sum_n m[n]\, P(f)\, e^{-j2\pi f n T_s}$$

$$= P(f) \sum_n m[n]\, e^{-j2\pi f n T_s}$$

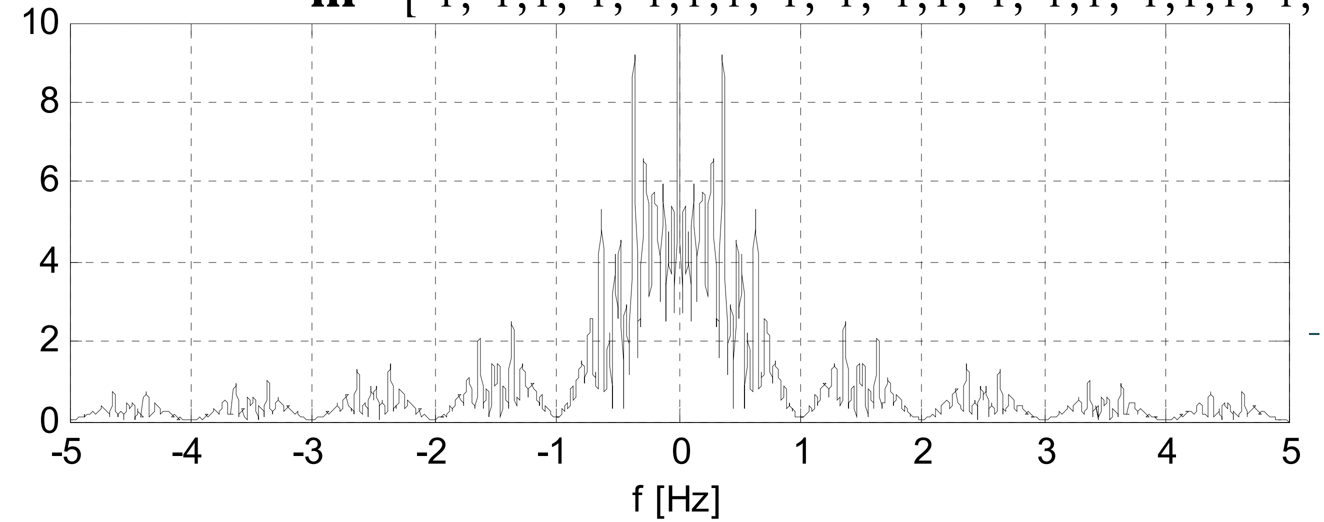
Figure 59

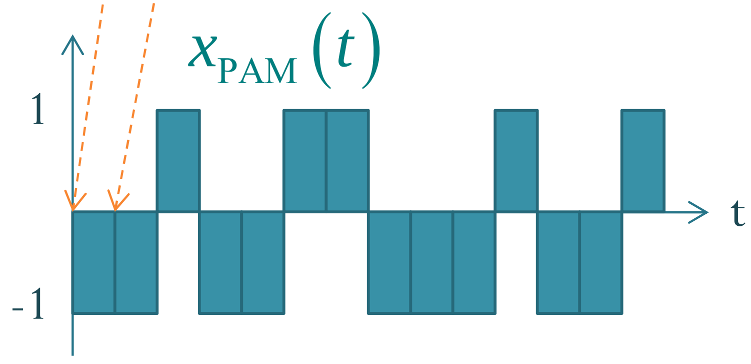
$X_{\mathrm{PAM}}(f)$ (4/4)





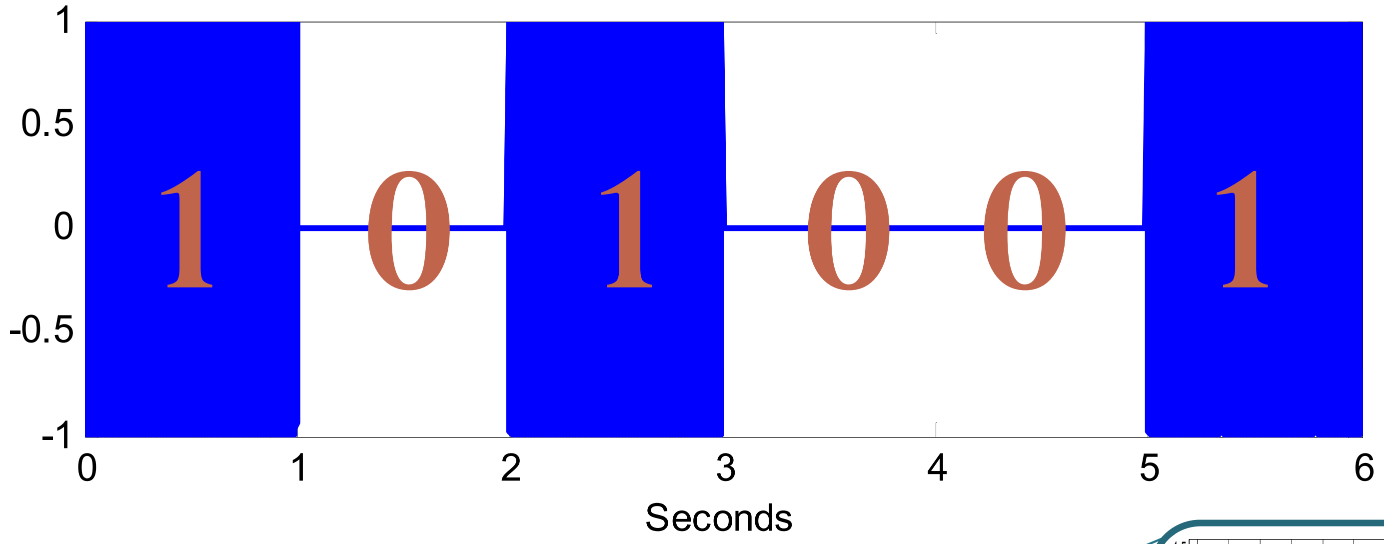
$\mathbf{m} = [-1,-1,1,-1,-1,1,1,-1,-1,-1,1,-1,-1,1,-1,1,1,-1,-1,-1,-1,1,-1,-1,-1,-1,-1,1,-1,1]$



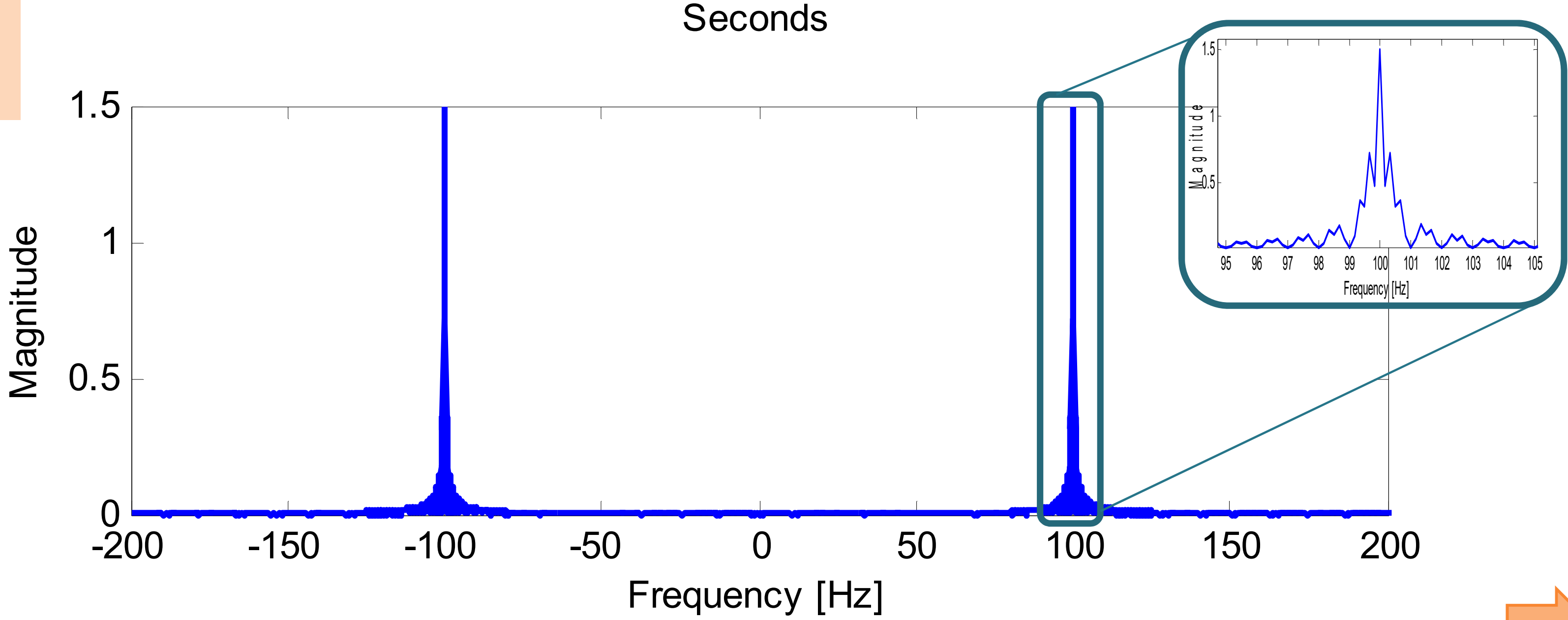


$$x_{\mathrm{PAM}}(t) = \sum_n m[n]\, p(t - nT_s) \xrightarrow{\mathcal{F}} X_{\mathrm{PAM}}(f) = P(f) \sum_n m[n] e^{-j2\pi f n T_s}$$

A revisit to an earlier OOK Example

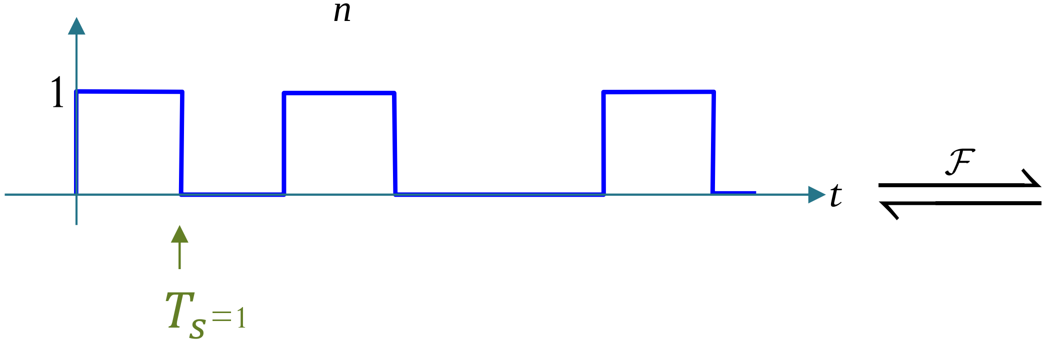


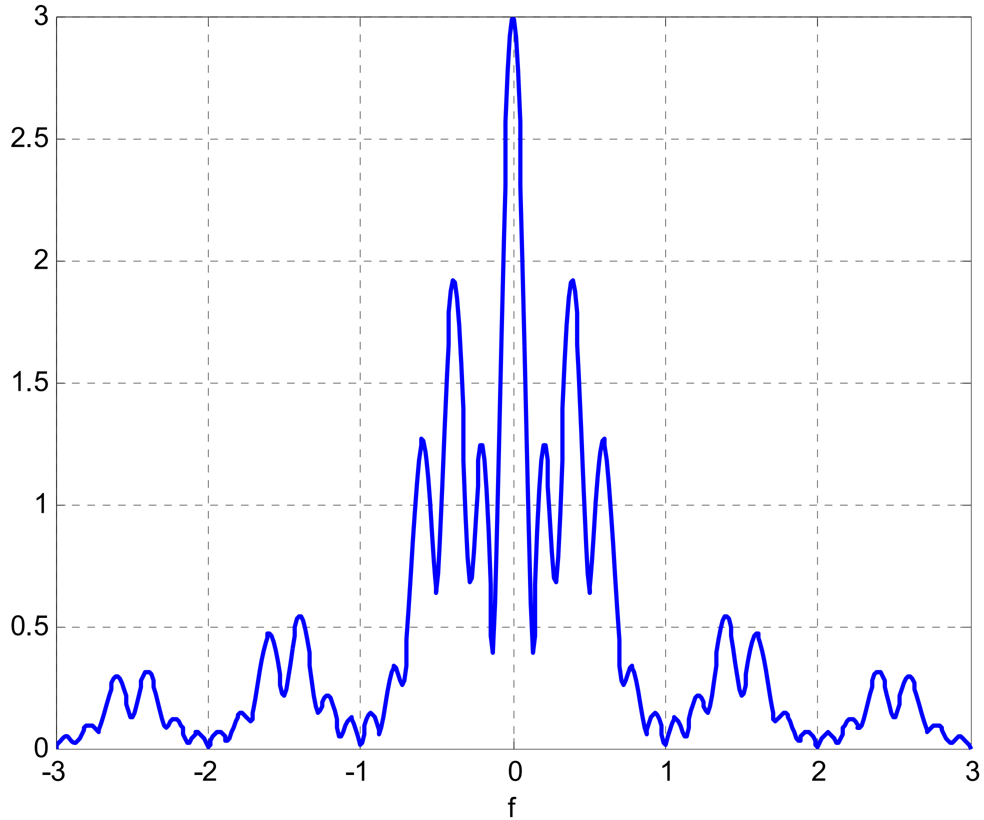
$f_c = 100$ Hz
Bit rate = 1 bps



A revisit to an earlier OOK Example

$$x_{\mathrm{PAM}}(t) = \sum_{n} m[n]\, p(t - nT_s)$$





Nyquist's (first) Criterion for Zero ISI

- Two equivalent definitions for **Nyquist pulse**:
- In the **time domain**,

Symbol "duration"
"interval"

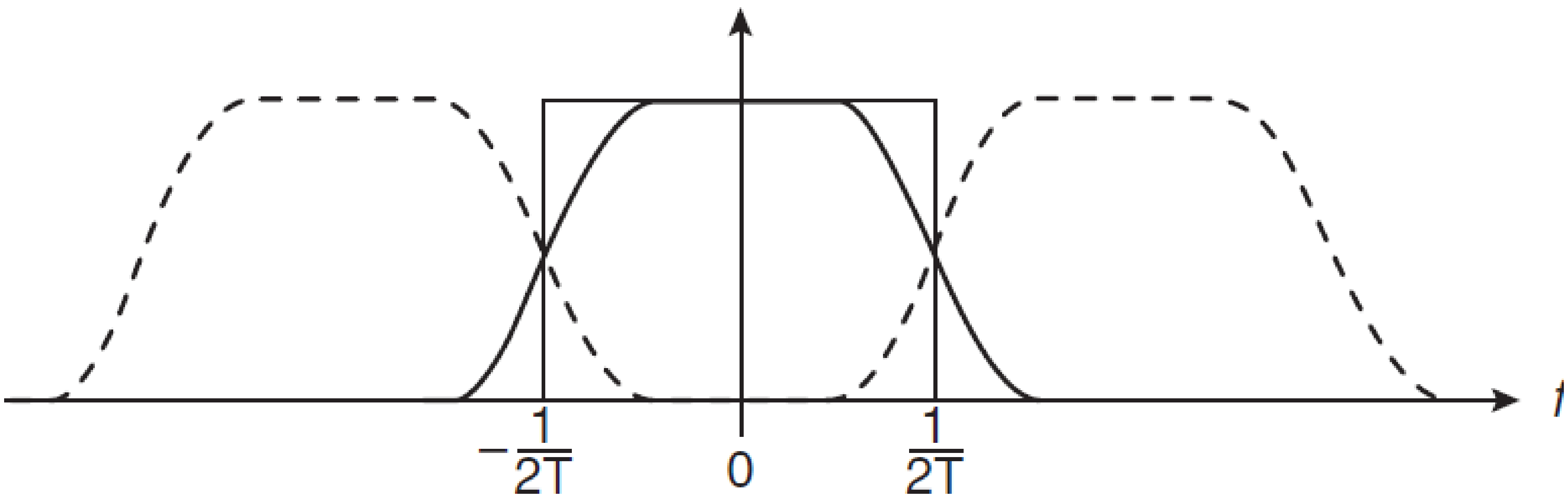
$$p(t) = \begin{cases} 1, & t = T, \\ 0, & t = \pm T, \pm 2T, \pm 3T, \ldots \end{cases}$$

$\frac{1}{T}$ = signaling rate
measured in
[symbols per second]
or
[baud]

- In the **frequency domain**,

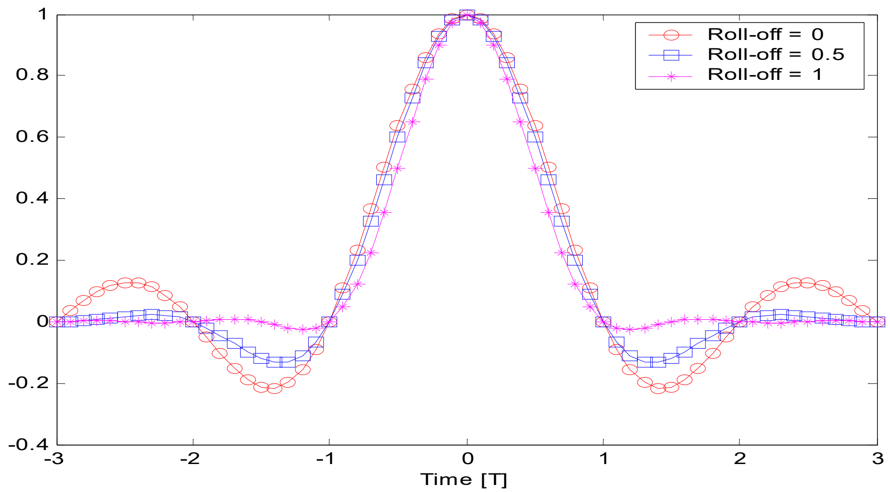
$$\sum_{k=-\infty}^{\infty} P\left(f - \frac{k}{T}\right) \equiv T, \qquad |f| \leq \frac{1}{2T}$$

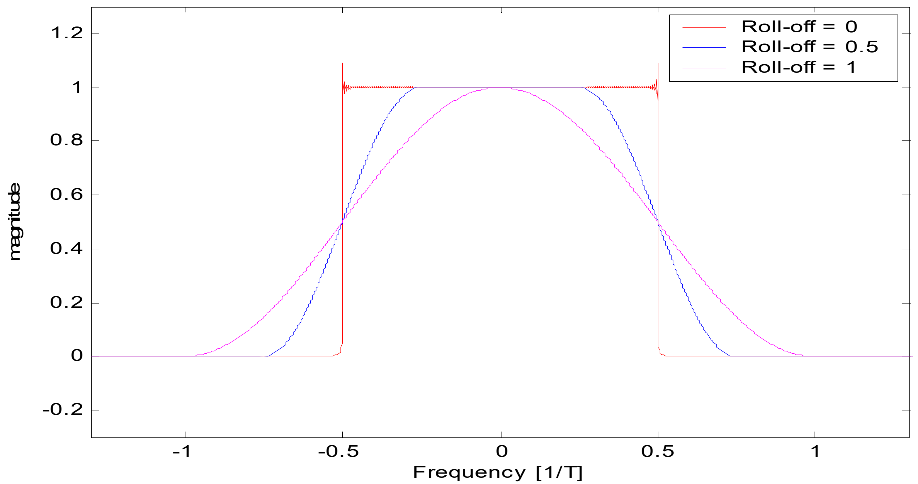
Nyquist criterion



[Blahut, 2008, Fig 2.9]

Raised Cosine Pulses





For fixed nonzero α, the tails decay as $1/t^3$ for large |t|.

Although the pulse tails persist for an infinite time, they are eventually small enough so they can be truncated with only negligible perturbations of the zero crossings.

$$p_{RC}(t;\alpha) = \frac{\cos\frac{\alpha\pi t}{T}}{1-\frac{4\alpha^2 t^2}{T^2}} \operatorname{sinc}\frac{\pi t}{T}$$

$$= \frac{\cos\frac{\alpha\pi t}{T}}{1-\frac{4\alpha^2 t^2}{T^2}} \frac{\sin\frac{\pi t}{T}}{\frac{\pi t}{T}}$$