# EEE 360 Communications Systems I

Lecture Presentation 9

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☞ **Baseband Pulse and Digital Signaling:** *Sections 3.1 - 3.2 of the textbook.*

In this chapter, we will be discussing:

- ➢ How to convert analog waveforms into digital. e.g. PCM
- ➢ Investigate the spectrum of digital signals
- ➢ Filtering and ISI
- ➢ Data multiplexing. e.g. TDM

## ☞ Pulse Amplitude Modulation (PAM)

- ➢ convert an analog signal into a pulse-type signal
- ➢ the amplitude of the pulse denotes the analog information

Analog-to-PAM conversion is the first step in converting an analog signal into a Pulse Code Modulation (PCM) digital signal.

Using the Sampling theorem we can represent the analog information using pulses.

The pulse rate required for PAM is $f_s \geq 2B$ where $B$ is the highest frequency in the analog waveform and $2B$ is the Nyquist rate.

There are two types of PAM:

- ➢ Natural Sampling (Gating)
- ➢ Instantaneous Sampling (leads to flat-top pulse)

## ☞ Natural Sampling (Gating)

If $w(t)$ is an analog waveform bandlimited to $B$ hertz, the PAM signal that uses natural sampling (gating) is

$$w_s(t) = w(t)s(t) \tag{1}$$

where

$$s(t) = \sum_{k=-\infty}^{\infty} \Pi\left(\frac{t - kT_s}{\tau}\right) \tag{2}$$

is a rectangular wave switching waveform and $f_s = 1/T_s \geq 2B$. The spectrum for a naturally sampled PAM signal is

$$W_s(f) = \mathcal{F}[w_s(t)] = d \sum_{n=-\infty}^{\infty} \frac{\sin \pi n d}{\pi n d} W(f - n f_s) \tag{3}$$

where $f_s = 1/T_s$, $\omega_s = 2\pi f_s$, the duty cycle of $s(t)$ is $d = \tau/T_s$ and $W(f) = \mathcal{F}[w(t)]$ is the spectrum of the original unsampled waveform. *Look at figures 3.1 and 3.3 in the textbook*.

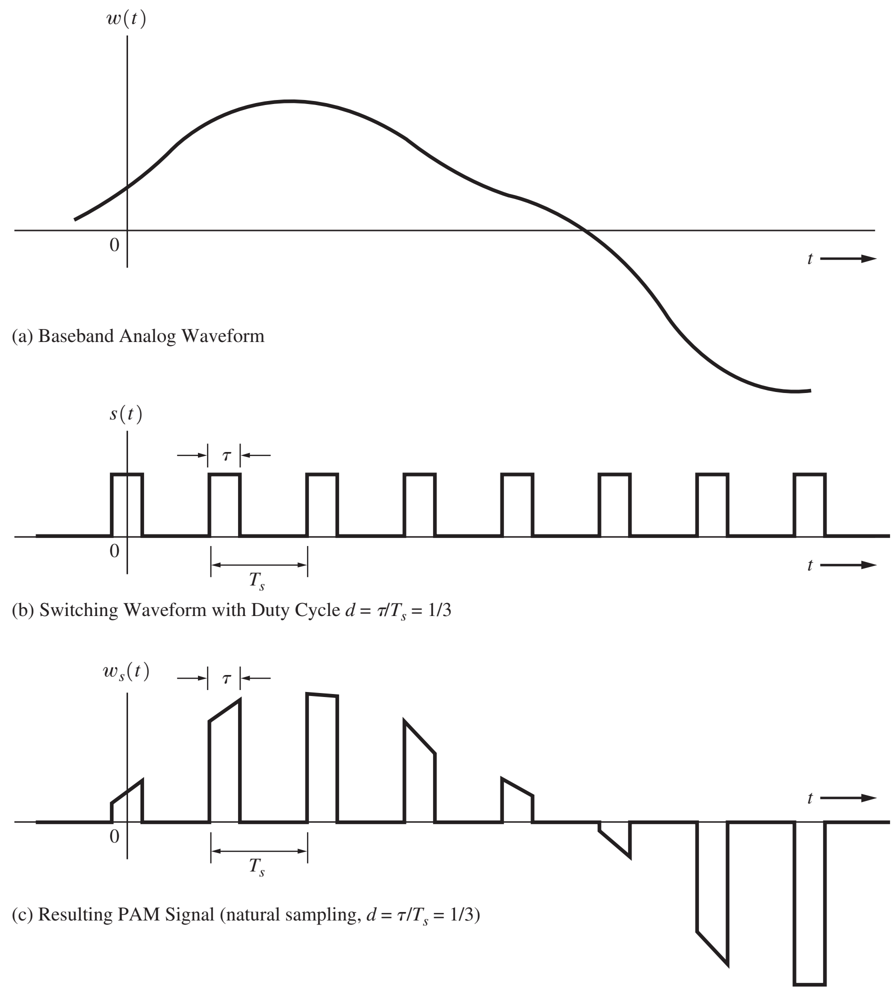
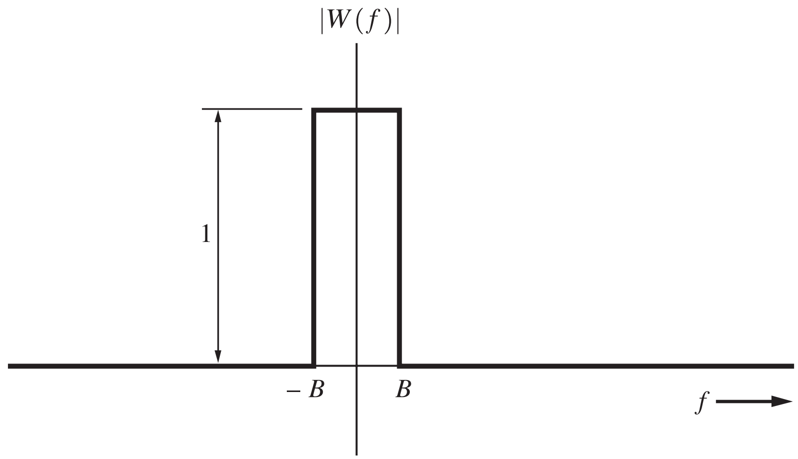
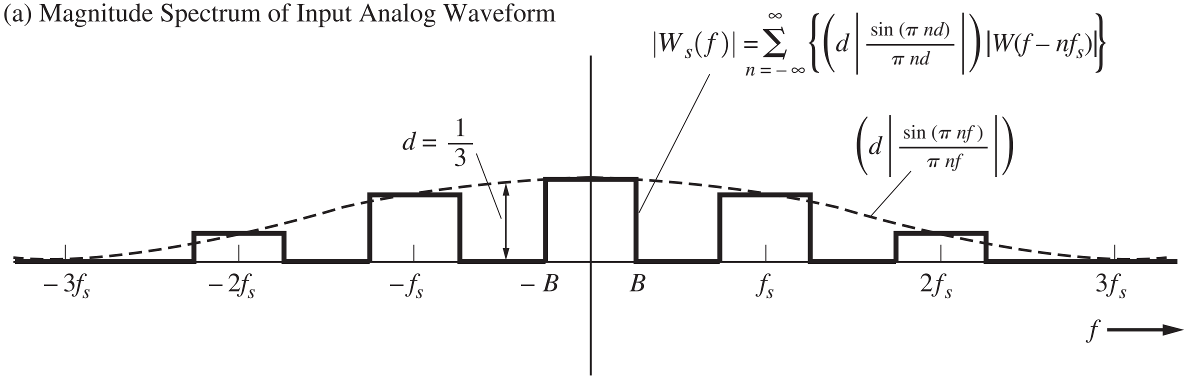



Figure 1: Natural PAM (Couch, 2001)




(a) Magnitude Spectrum of Input Analog Waveform




(b) Magnitude Spectrum of PAM (natural sampling) with $d = 1/3$ and $f_s = 4$ B

Figure 2: Spectrum of natural PAM (Couch, 2001)

It should be noted that the bandwidth of the PAM signal is much wider than the bandwidth of the original signal.

☞ **Instantaneous Sampling (Flat-top PAM)**

This is a generalization of the impulse train sampling. If an analog waveform $w(t)$ is bandlimited to $B$ hertz, the instantaneous sampled PAM signal is given by

$$w_s(t) = \sum_{k=-\infty}^{\infty} w(kT_s)h(t - kT_s) \tag{4}$$

where $h(t)$ denotes the sampling pulse shape and is given by

$$h(t) = \Pi\left(\frac{t}{\tau}\right)\begin{cases} 1, & |t| < \tau/2 \\ 0, & |t| > \tau/2 \end{cases} \tag{5}$$

where $\tau \leq T_s = 1/f_s$ and $f_s \geq 2B$.

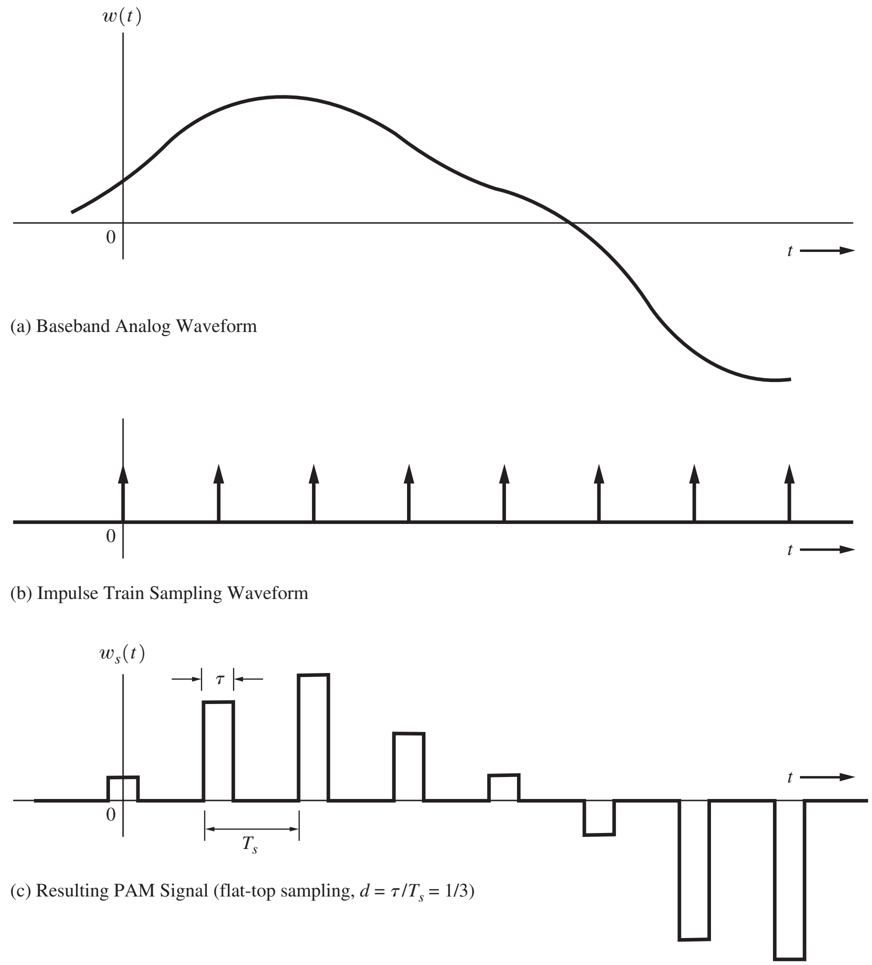


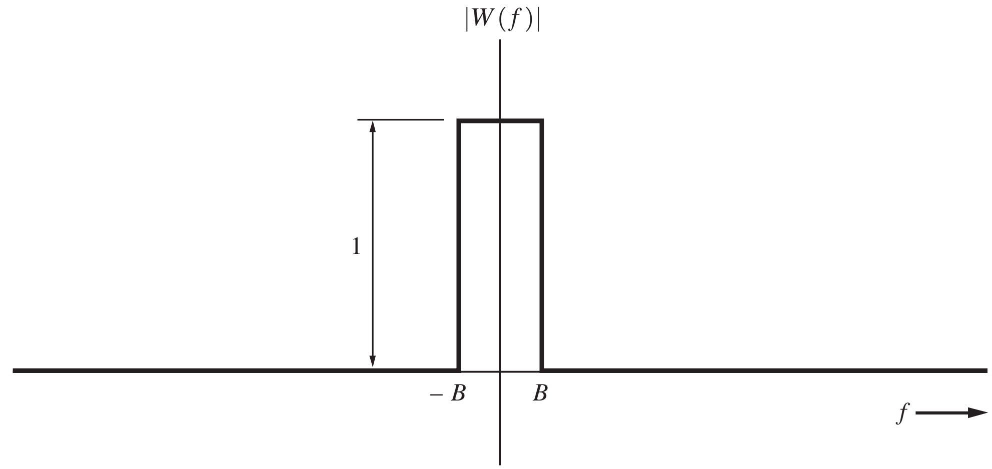

Figure 3: flat-top PAM (Couch, 2001)

The spectrum for a flat-top PAM signal is

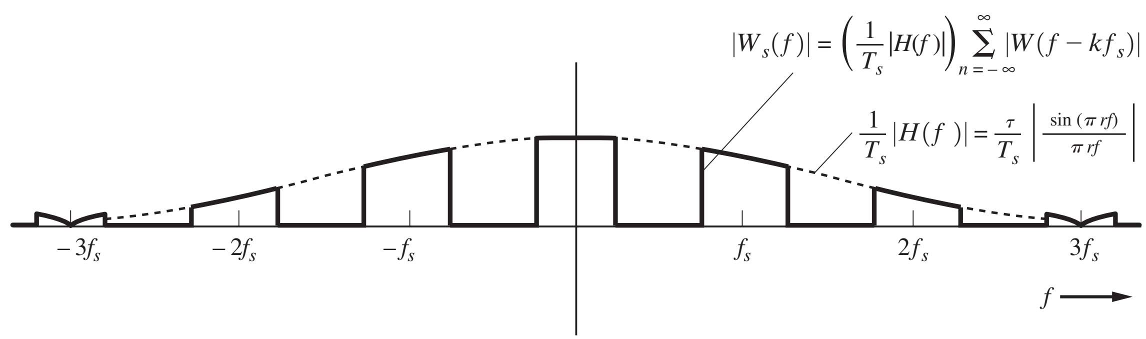
$$W_s(f) = \frac{1}{T_s} H(f) \sum_{k=-\infty}^{\infty} W(f - kf_s) \tag{6}$$

where

$$H(f) = \mathcal{F}[h(t)] = \tau \left( \frac{\sin \pi\tau f}{\pi\tau f} \right) \tag{7}$$




(a) Magnitude Spectrum of Input Analog Waveform




(b) Magnitude Spectrum of PAM (flat-top sampling), $\tau/T_s = 1/3$ and $f_s = 4B$

Figure 4: Spectrum of flat-top PAM (Couch, 2001)