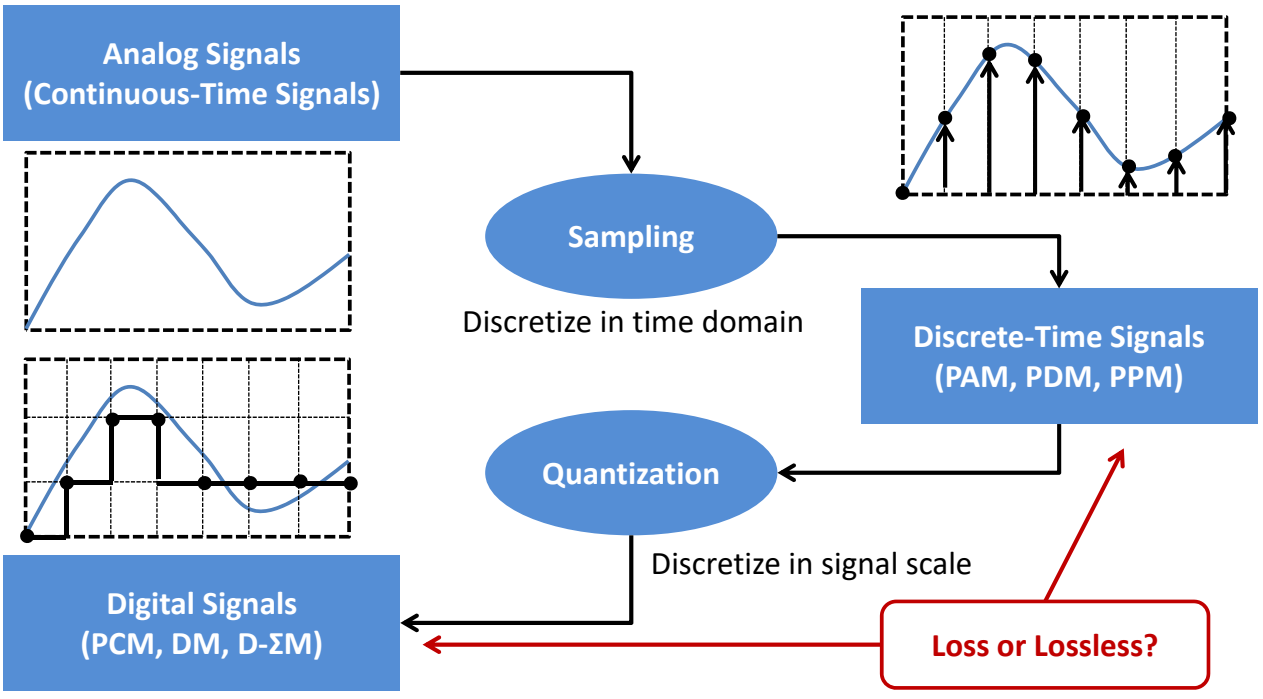
# Outline

- Why do we need digital communications?
- Semi-digital communication of analog signals
  - Sampling: digitalization in time domain
  - Analog pulse modulation schemes: PAM, PDM, PPM
- Generation, detection and analysis of PPM
- Digital communication of analog signals
  - Quantization: digitalization in signal scale
  - Quantization noise
  - Digital modulation schemes: PCM, DM

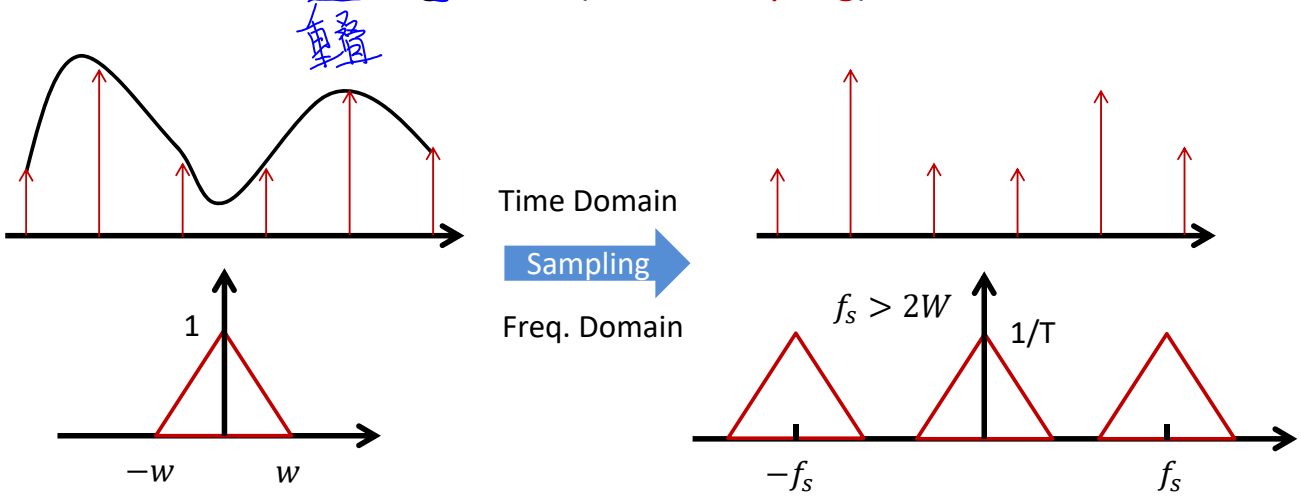


# From Analog to Digital



# Recap: Sampling

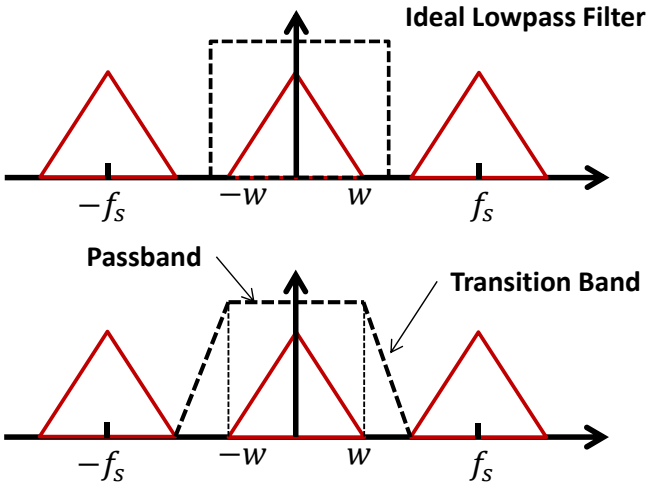
- Sampling: discretize the analog signal in time domain
- Nyquist Rate: the sampling frequency should be larger than twice of the signal bandwidth
  - Otherwise, aliasing occurs (undersampling)






# Recap: Reconstruction

- Reconstruction filter: a lowpass filter to recover the original signal from the sampled version



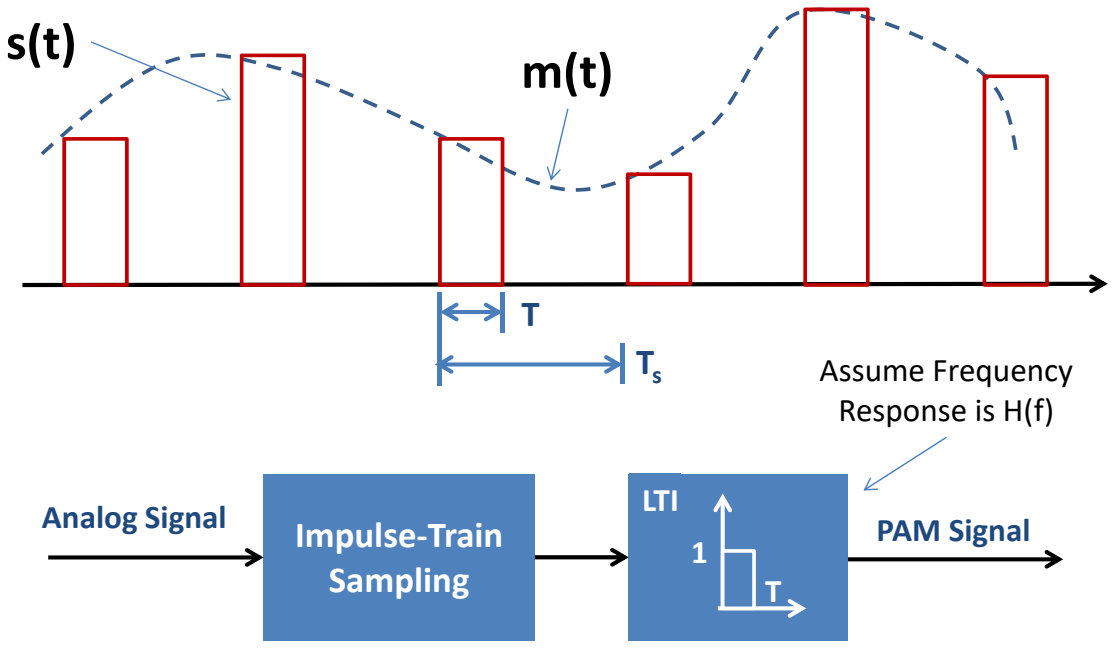
# Analog Pulse Modulation

- Sampled signal maintains all the information of original signal (Sampling Freq. > Nyquist Rate)
- Instead of whole analog signal, it is sufficient to deliver the sampled signal values
- Analog pulse modulation: Use analog pulses to represent the sampled signal values
- Schemes:
  - Pulse Amplitude Modulation (PAM)
  - Pulse Duration Modulation (PDM)
  - Pulse Position Modulation (PPM)



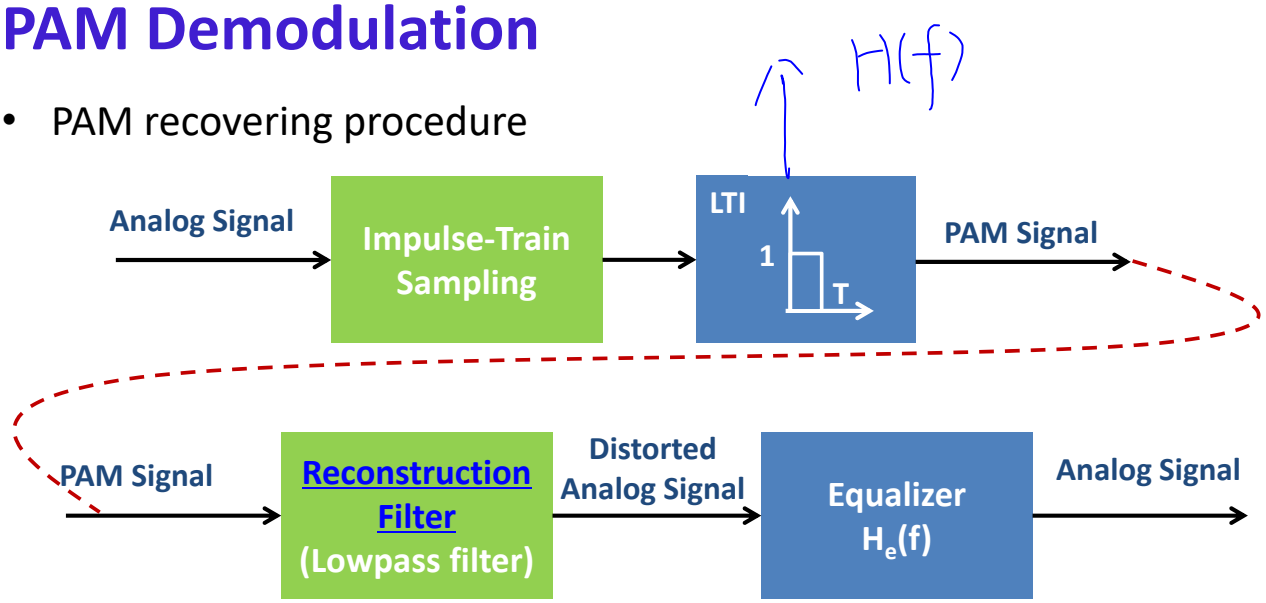
# Pulse Amplitude Modulation

- PAM: sampled signal value is represented by the amplitude of pulses



# PAM Demodulation

- PAM recovering procedure



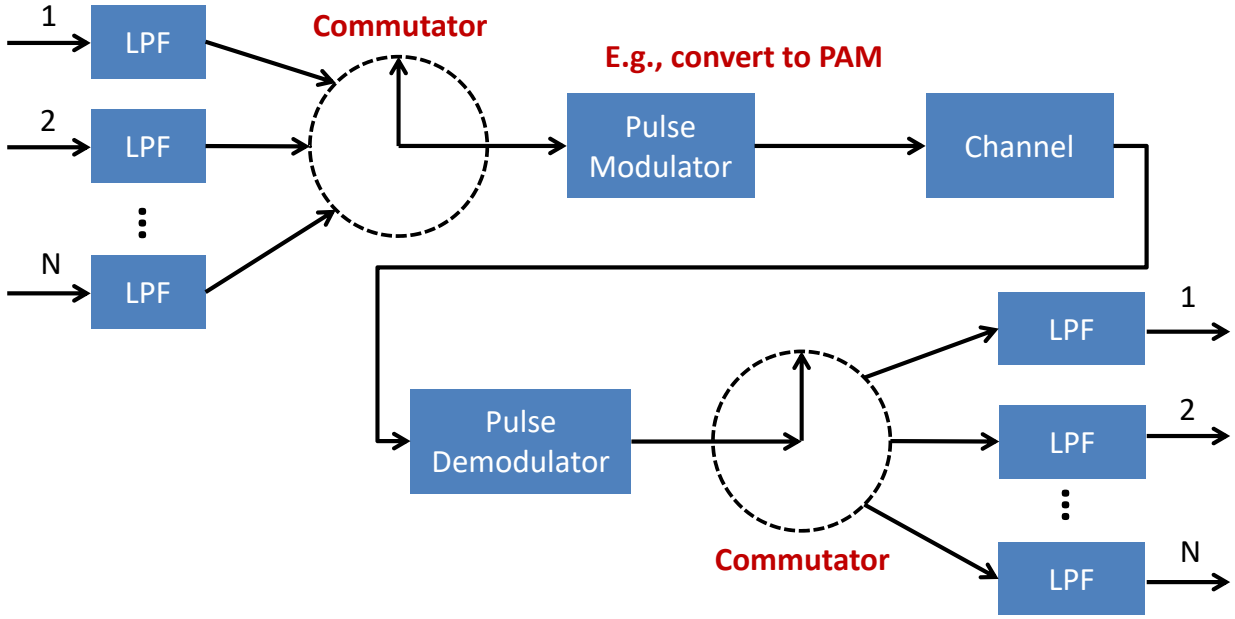

- Within the bandwidth of analog signal, the frequency response of the equalizer $H_e(f)$ should satisfy

$$|H_e(f)| = \frac{1}{|H(f)|} = \frac{\pi f}{\sin(\pi f T)}$$



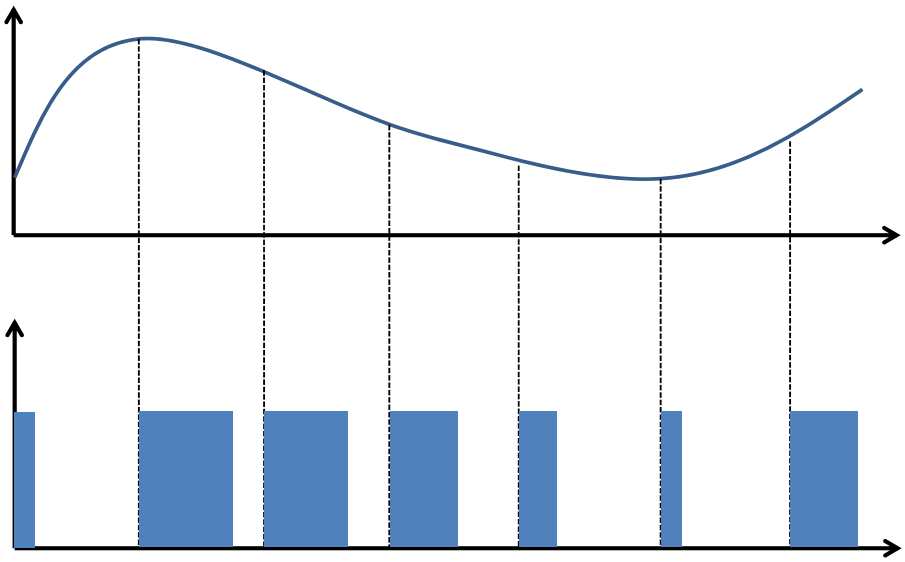
# Time-Frequency Tradeoff

- Larger bandwidth vs. Stronger capability of time-division multiplexing



# Pulse Duration Modulation

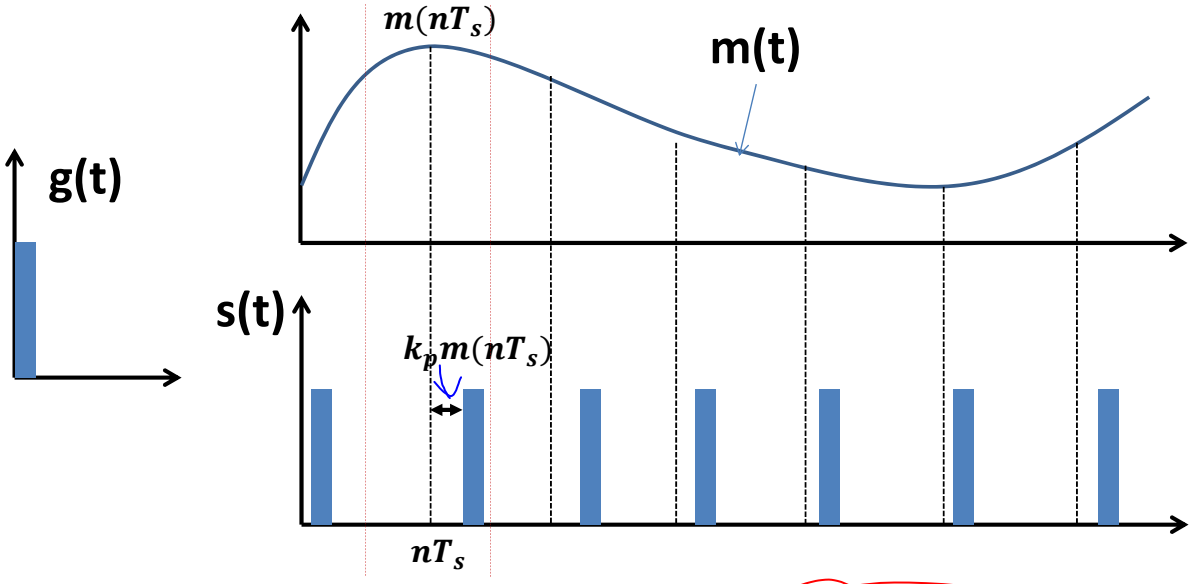
- PDM: sampled signal value is represented by the duration of pulses





# Pulse Position Modulation

- PPM: use the position of pulses to represent to the sampled signal




$$s(t) = \sum_{n=-\infty}^{\infty} g(t - nT_s - k_p m(nT_s))$$

$$k_p |m(t)|_{max} < \frac{T_s}{2}$$

# Discussion

- Is PAM, PDM or PPM better for wireless or wired communications? Why?
- Wired communications
- But they can be made wirelessly.
- Are they digital signals or analog signals?
- In previous examples, they are analog
- But they can deliver digital signals

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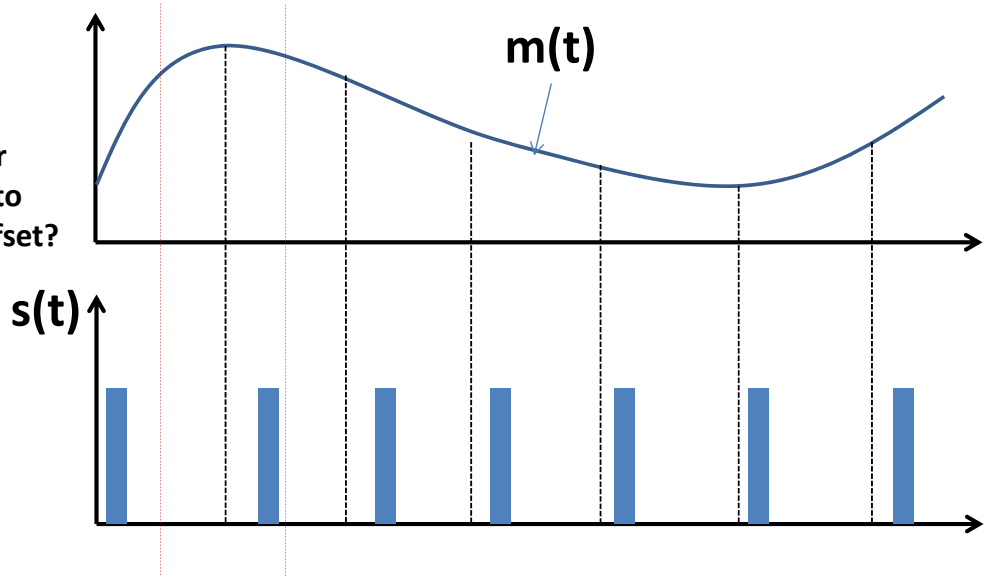
- Generation, detection and analysis of PPM

- Digital communication of analog signals
  - Quantization: digitalization in signal scale
  - Quantization noise
  - Digital modulation schemes: PCM, DM

# PPM Generation

How to transfer the amplitude to the position offset?



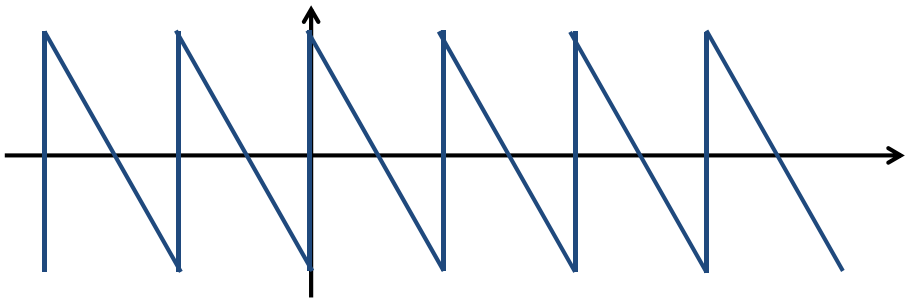

$$s(t) = \sum_{n=-\infty}^{\infty} g(t - nT_s - k_p m(nT_s))$$

$$k_p |m(t)|_{max} < \frac{T_s}{2}$$



# Sawtooth Wave

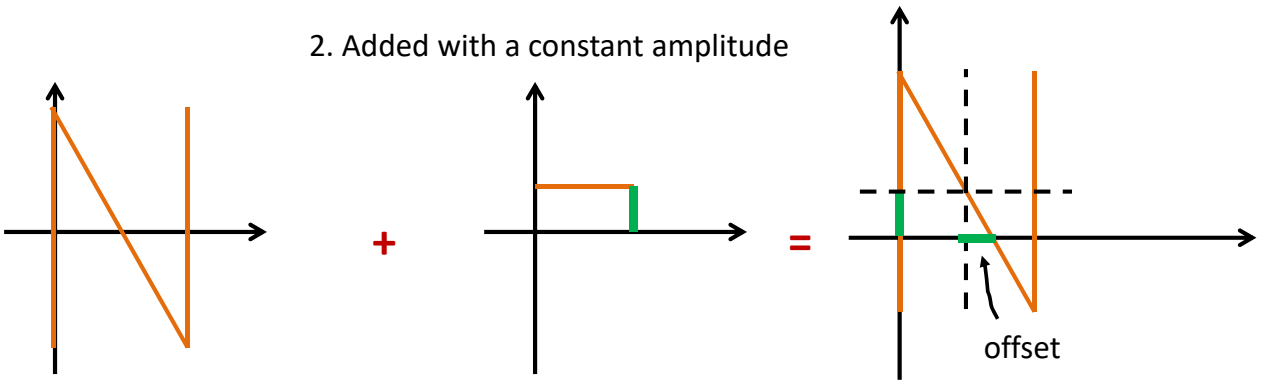
**Idea:** sawtooth wave can transfer the amplitude information to the x-axis position



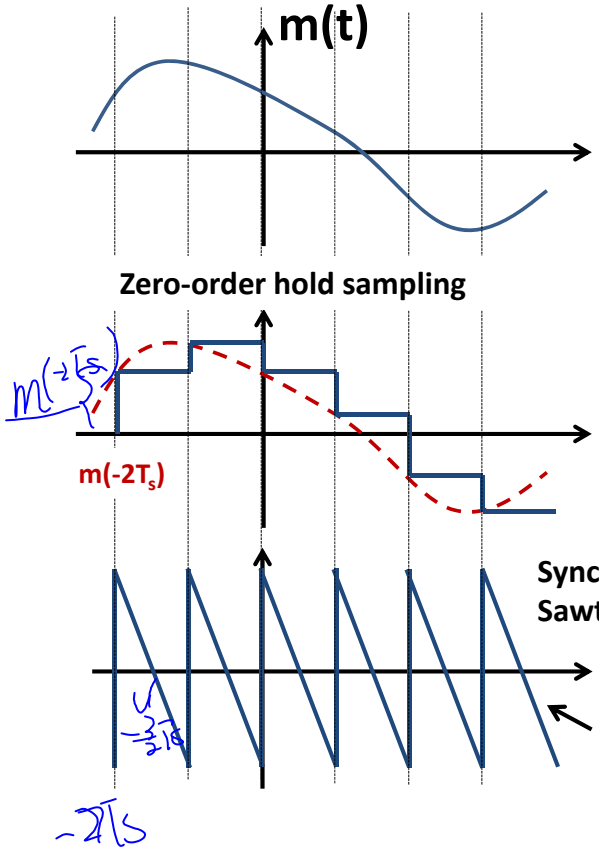
1. Given one period sawtooth wave

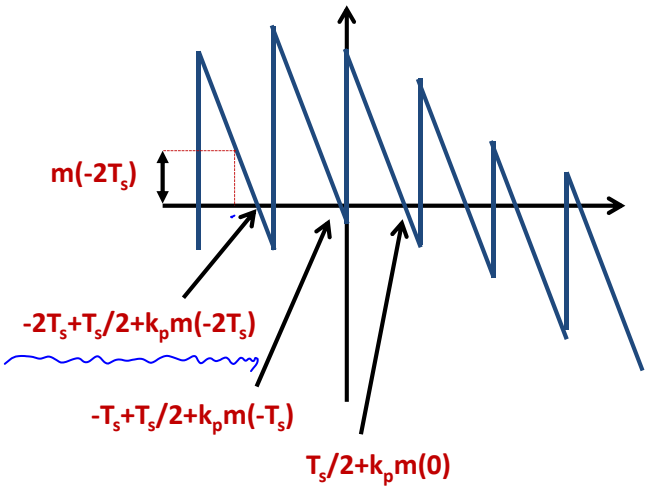
2. Added with a constant amplitude

3. The offset is proportional to the amplitude



# Zero-Order Hold + Sawtooth Wave



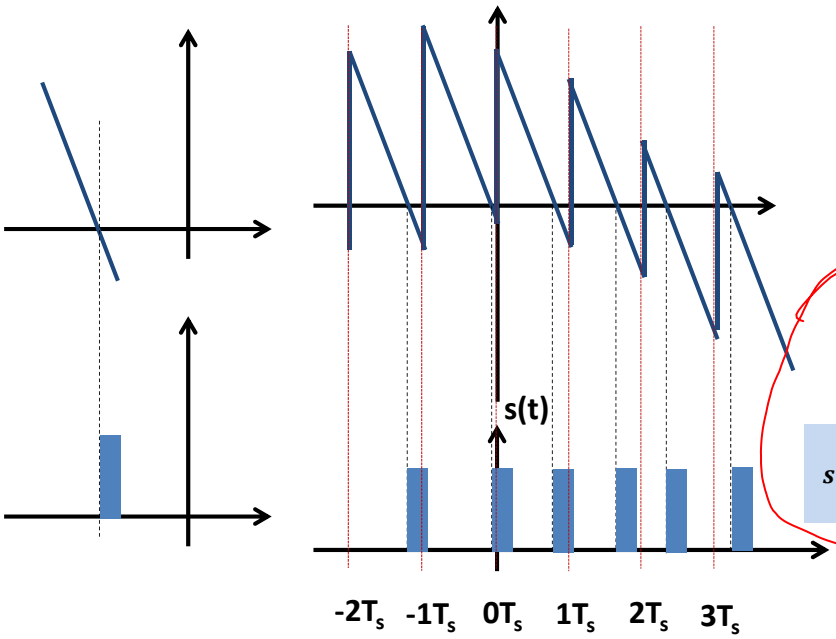

$$nT_s + \frac{T_s}{2} + k_p m(nT_s)$$

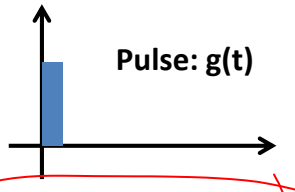
n=…-2,-1, 0, 1, 2,…



# Threshold Detector

**Threshold Detector**: generate a pulse when signal crosses zero in negative-going direction



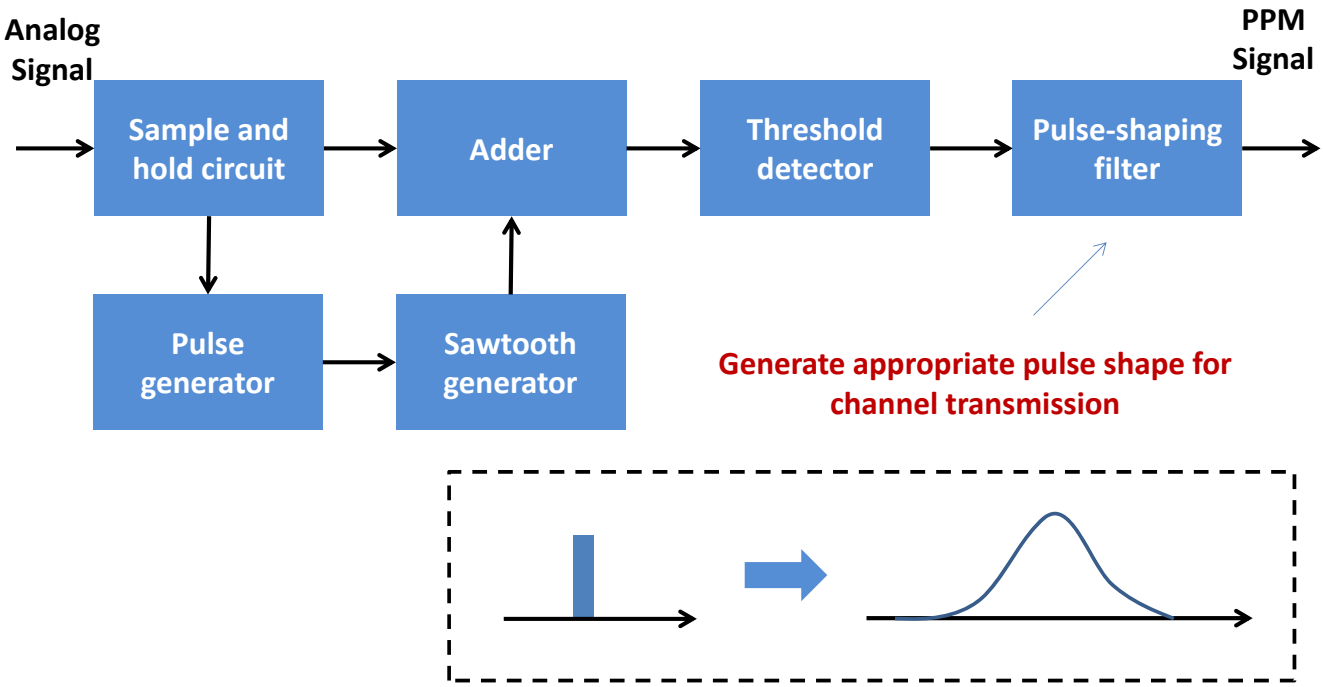

$$nT_s + \frac{T_s}{2} + k_p m(nT_s)$$

n=…-2,-1, 0, 1, 2,…

$$s(t) = \sum_{n=-\infty}^{\infty} g(t - nT_s - \frac{T_s}{2} - k_p m(nT_s))$$

$k_p$ is related to the slope of the sawtooth wave

# Generation Block diagram

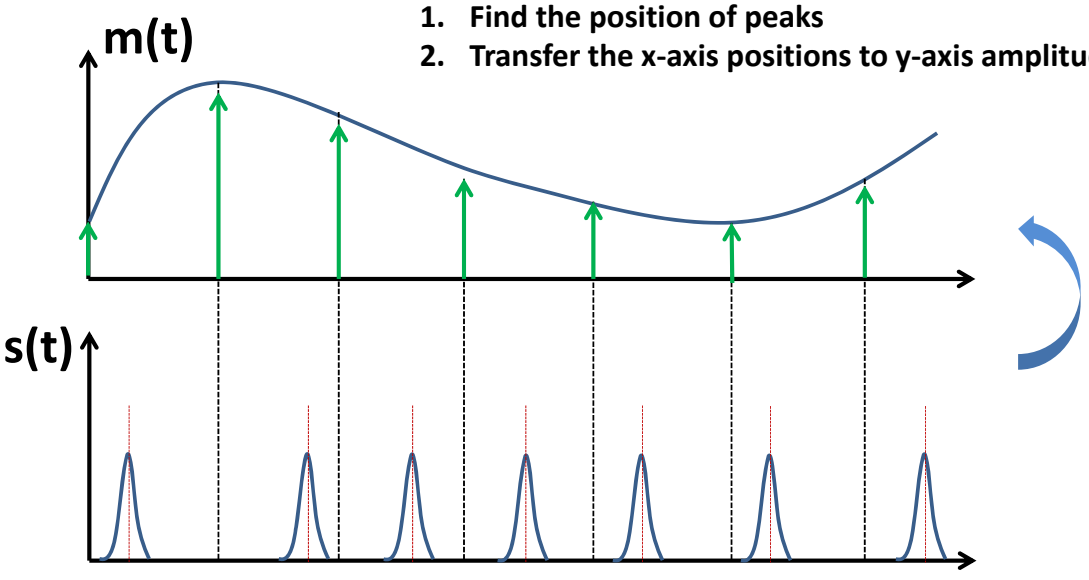




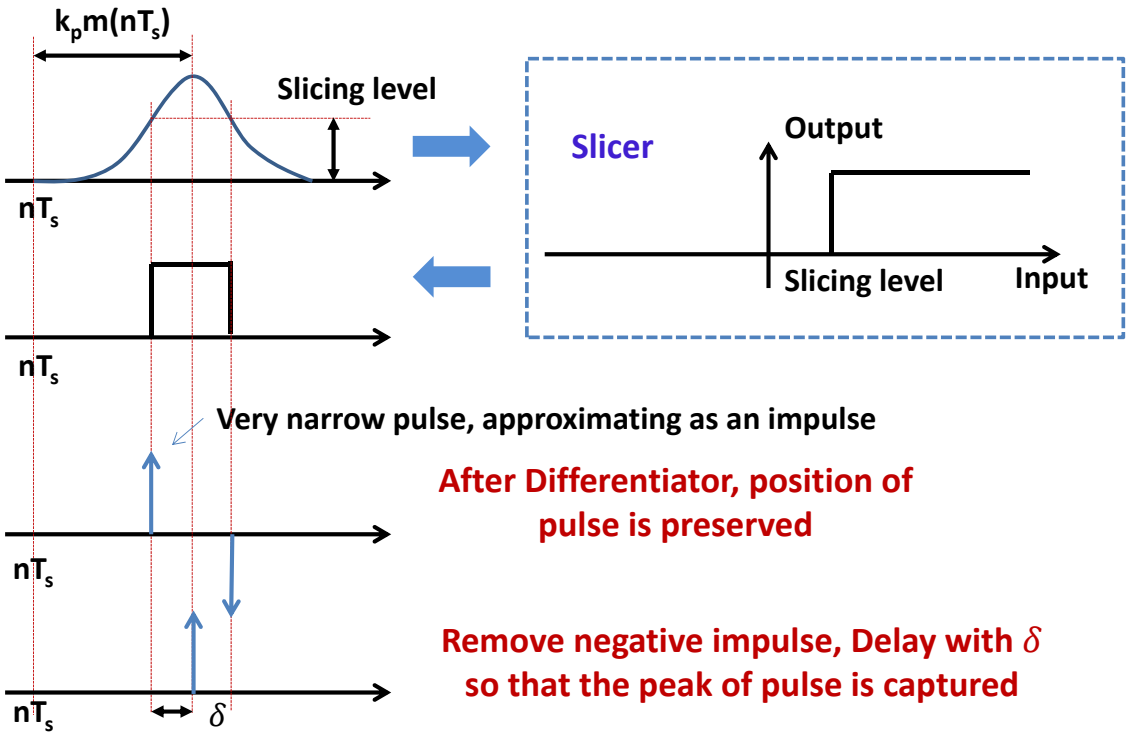

# PPM Signal Detection

How to recover the amplitude information from the pulse position?

1. Find the position of peaks
2. Transfer the x-axis positions to y-axis amplitudes



# Locate Peak Position



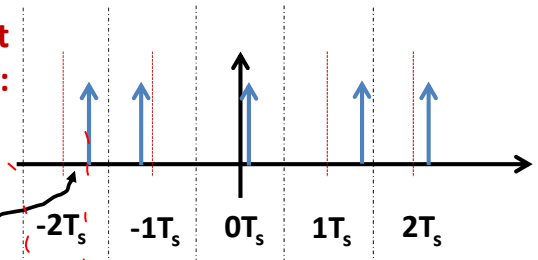

After Differentiator, position of pulse is preserved

Remove negative impulse, Delay with $\delta$ so that the peak of pulse is captured



# Transfer Position to Amplitude

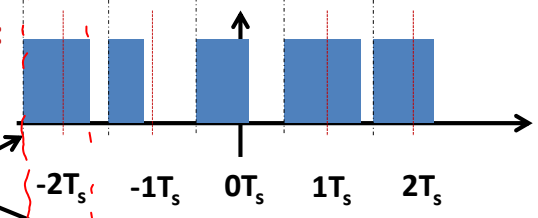
A sequence of impulses, who represent the peak positions of PPM signal:




$k_p m(-2T_s)$

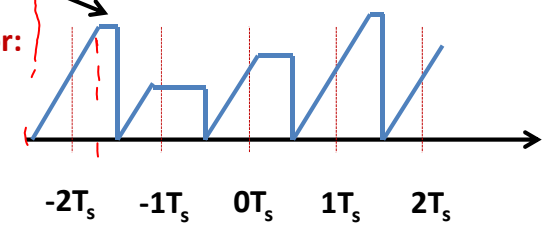
Use the pulse as a switch:

h




$$Area:\ h\left(\frac{T_s}{2} + k_p m(-2T_s)\right)$$

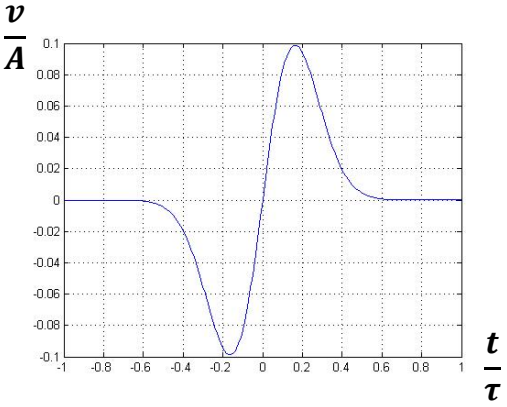
Periodic Integrator:



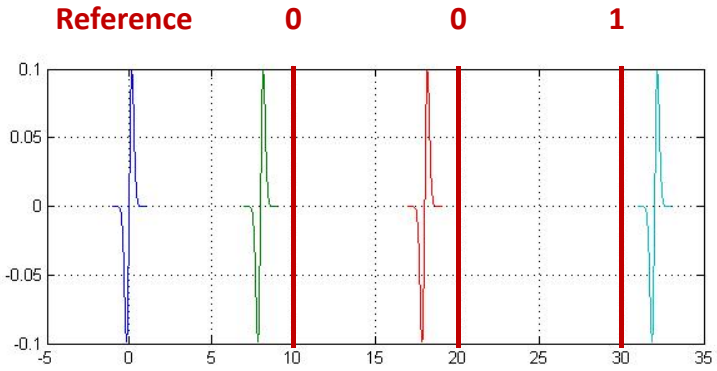

$$m(-2T_s) = \frac{Area - \frac{hT_s}{2}}{hk_p}$$

# Ultra-Wideband (PPM) 超寬帶

- Ultra-wideband (UWB) is a radio technology which may be used at a very low energy level for short-range, high-bandwidth communications using a large portion of the radio spectrum (how?)
- Use Gaussian monocycle as pulse shape




$$v(t) = A\frac{t}{\tau}\, e^{-6\pi\left(\frac{t}{\tau}\right)^2}$$



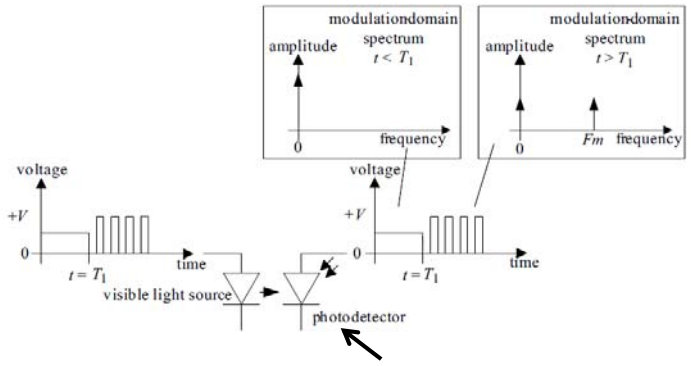

Short pulse can distribute power over large spectrum, leading to low power spectrum density



# Visible Light Communication

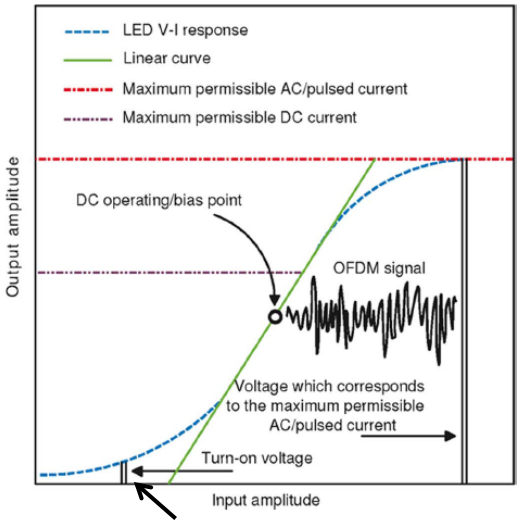
- Light emitting diode (LED) can transfer the electricity to light
- LED output light power is linear with the drive current

**VLC system with LED and photodetector (PD) as the transmitter and receiver, respectively**




**Transfer the light power to electric power**

IEEE Std 802.15.7, *Short-Range Wireless Optical Communication Using Visible Light,* 2011



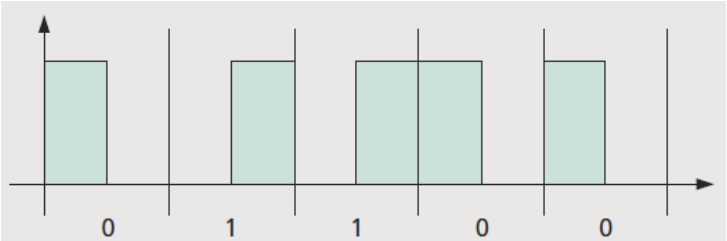

**Above the turn-on voltage, current increases with the voltage**

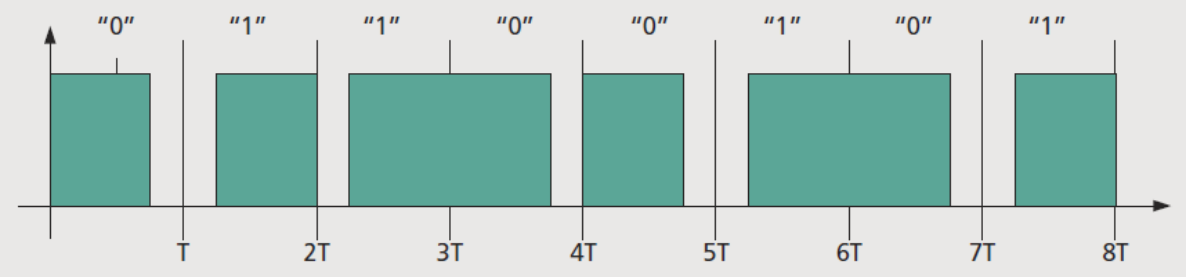
H. Elgala, R. Mesleh, and H. Haas, *An LED Model for Intensity-Modulated Optical Communication Systems,* IEEE Photo. Tech. Lett., 2011

# Visible Light Communication

- Variable pulse position modulation (VPPM) is used as one modulation scheme in IEEE802.15.7

- **Pulse duration can be adjusted according to the requirement of illumination**
- **Pulse position is used to carry binary sequence**




S. Rajagopal, R. D. Roberts, and S. Y. Lim, *IEEE 802.15.7 Visible Light Communication: Modulation Schemes and Dimming Support,* IEEE Comm. Mag., 2012



# Homework #D2

- D2.1

Plot the spectrum of a PAM wave produced from the following modulating signal

$$\boldsymbol{m(t) = A_m \cos(2\pi f_m t)}$$

assuming $f_m = 0.2Hz$, PAM sampling period $T_s = 1s$, and pulse duration $T = 0.45s$.