Pulse Amplitude Modulation (PAM)

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From Analog to Digital…

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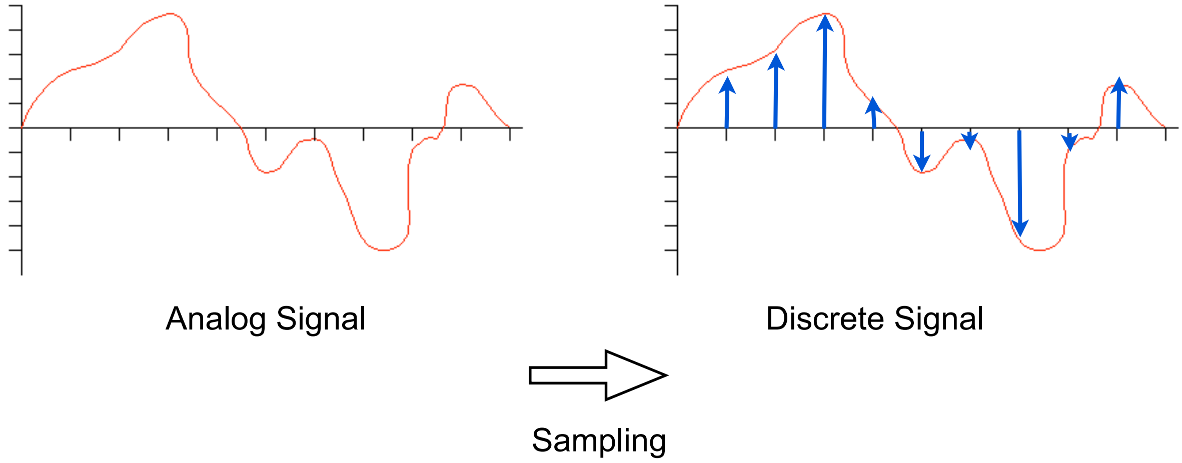
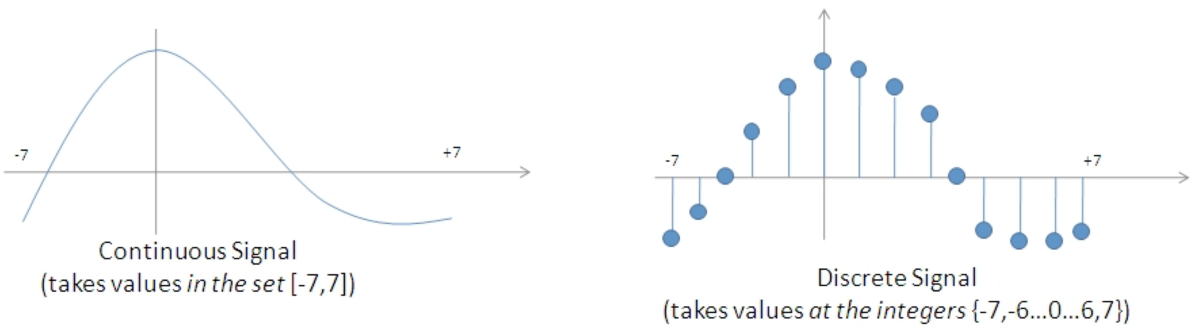


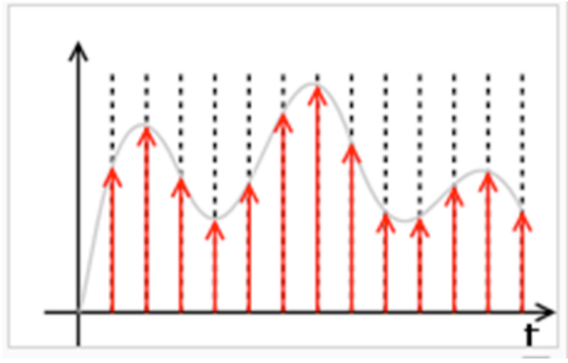
Sampling

- Convert continuous signals to discrete signals

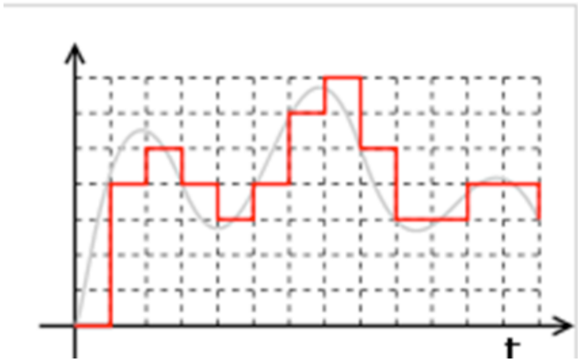


In order to make digital signals, we need …

Quantization



Sampling → Discrete Signal



Quantization → Digital Signal

Pulse Modulations

- Message signals → Modulated signals

- Amplitude → Pulse Amplitude Modulation
- Width → Pulse Width Modulation
- Position → Pulse Position Modulation

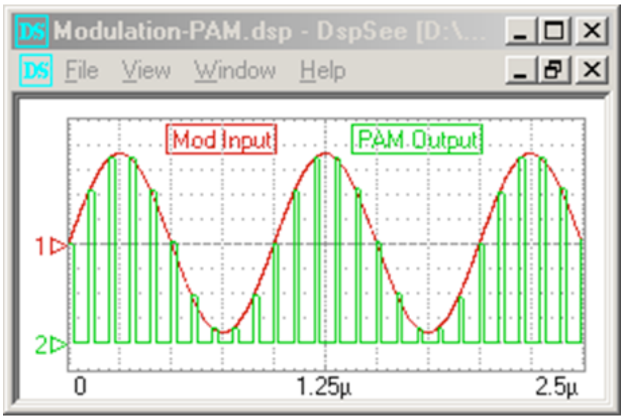
Pulse Time Modulation

- Question: PAM is Continuous/Discrete/Digital Signal?
- Answer: Discrete Signal

Definition of PAM

- **Pulse Amplitude Modulation (PAM)** is a form of signal modulation where the message information is encoded in the amplitude of a series of signal pulses.

- Example:



  – Observations: Width and Position of pulses are kept constant!

Advantages of PAM

- Very simple transmitter - because…
  – act of sampling signals at regular intervals produces PAM.
- Hence, receiver can also be simple (CAUTION).
- PAM is also used to generate other pulse modulations.
- As long as amplitude at the pulse intervals is preserved, no distortion will be introduced (CAUTION).

Disadvantages of PAM

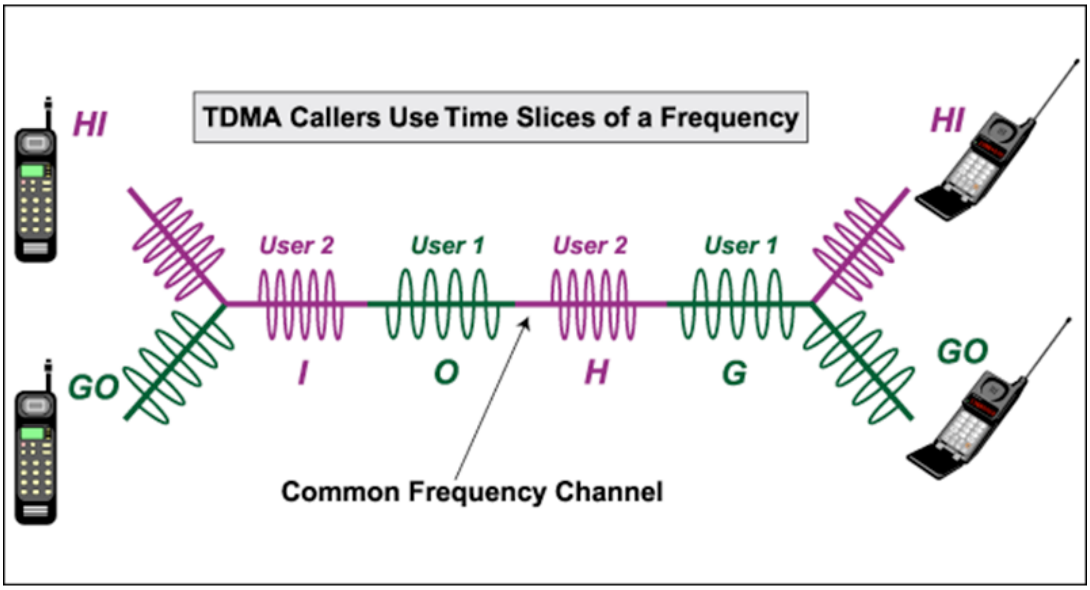
- Circuit implementation may be complex
  - For digital processing, needs "bitstream" → Analog-to-Digital Converter (ADC)
  - Unlike PPM, PWM, PCM
- There is generally "loss" in transmission → received pulse streams are distorted in terms of amplitude → received information is distorted!
- Low efficiency, small operating range, etc.

Why Digital Communications?

- Several advantages:
  - Easier signal processing → errors caused by random processes can be detected and corrected → robust to noise
  - Sampled instead of continuously monitored → finite number of data
  - Much simpler multiplexing of multiple digital signals than continuous signals

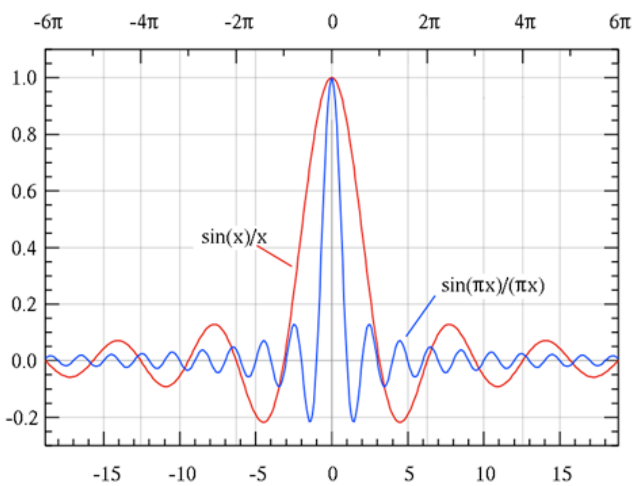
Multiplexing

- **Definition:** multiplexing (also known as muxing) is a process, where multiple analog message signals or digital data streams are combined into one signal over a shared medium.



One More Property

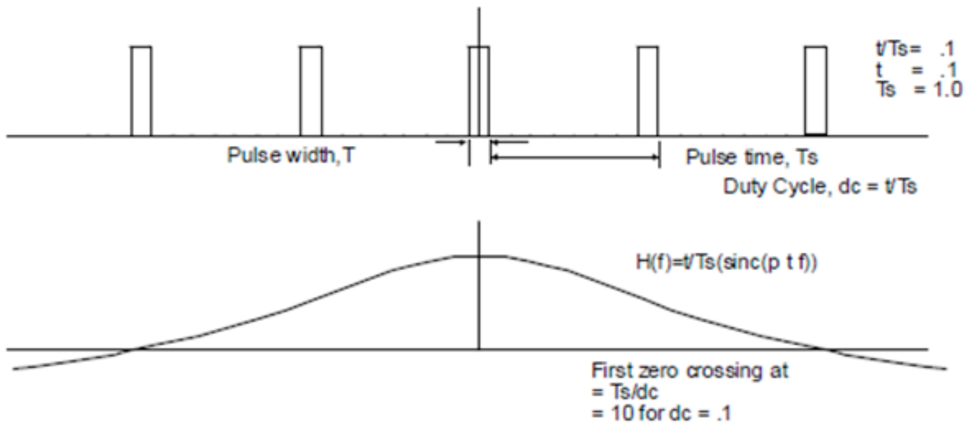
- Fourier transform of rectangular function: Sinc Function



- Impulse is in practice a collection of “rectangular functions”...

Non-ideal Sampling

- Ideal sampling: impulse train
  - In frequency domain: still impulse train
- In practice: non-ideal sampling
  - Pulses with finite widths
  - No longer impulse train in frequency domain



Revisit: Sampling and Recovery

- Ideal Sampling (with impulse trains)
  - Sampled message:

$$\begin{aligned} x_s(t) &= \mathrm{comb}_T\{x(t)\} \\ &= x(t)p_T(t) \\ &= x(t)\sum_{k=-\infty}^{\infty}\delta(t-kT) \\ &= \sum_{k=-\infty}^{\infty} x(kT)\delta(t-kT) \end{aligned}$$

  - Fourier transform of sampled message:

$$\begin{aligned} X_s(f) &= \frac{1}{T}\mathrm{rep}_{\frac{1}{T}}\{X(f)\} \\ &= \frac{1}{T}X(f) * p_{\frac{1}{T}}(f) \\ &= \frac{1}{T}X(f) * \sum_{k=-\infty}^{\infty}\delta\left(f-\frac{k}{T}\right) \\ &= \frac{1}{T}\boxed{\sum_{k=-\infty}^{\infty} X\left(f-\frac{k}{T}\right)} \end{aligned}$$

Repetition of X(f)

Revisit: Sampling and Recovery

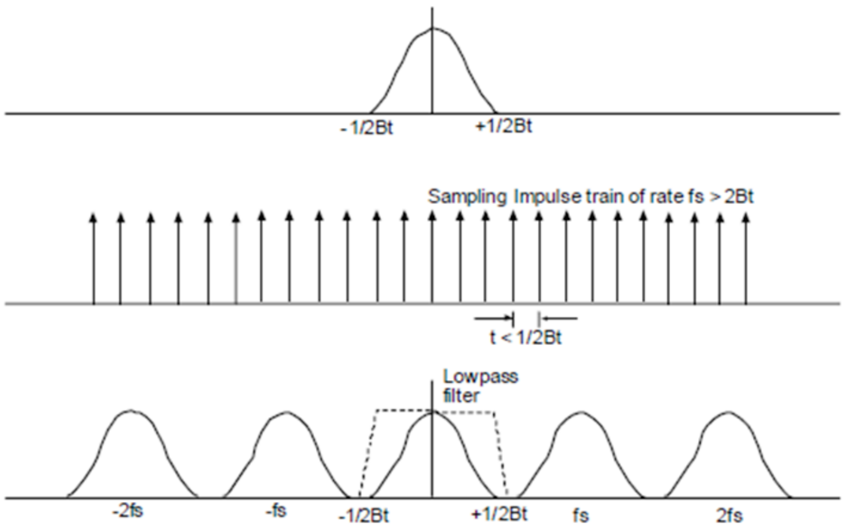
$$X(f)$$

$$*$$

$$\sum_{k=-\infty}^{\infty} \delta\left(f - \frac{k}{T}\right)$$

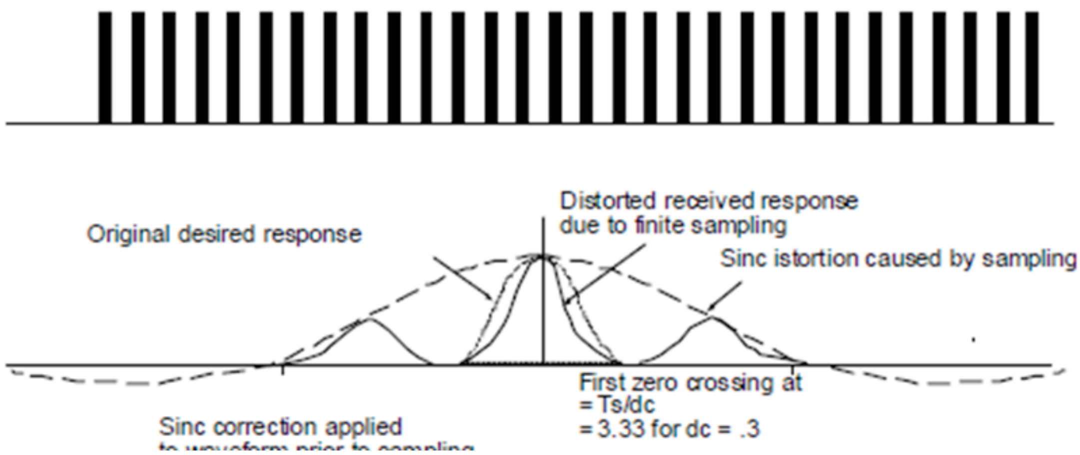
$$=$$

$$\frac{1}{T}\sum_{k=-\infty}^{\infty} X\left(f - \frac{k}{T}\right)$$

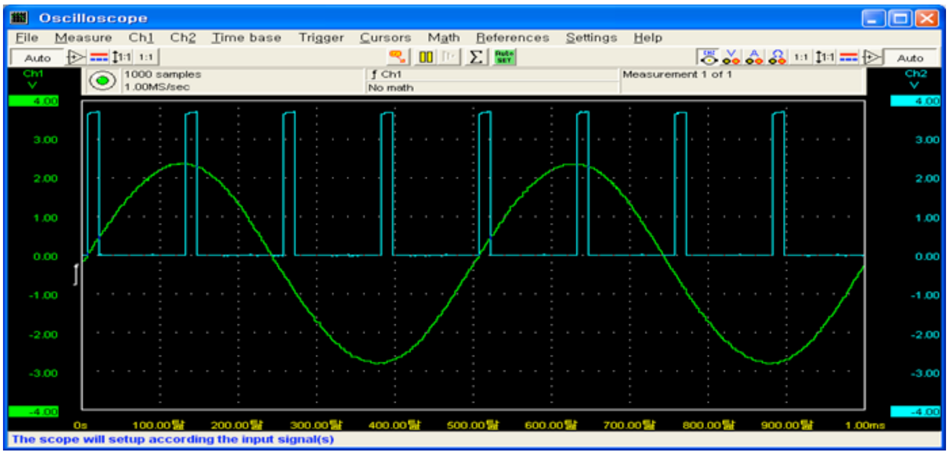


Revisit: Sampling and Recovery

- Non-ideal Sampling

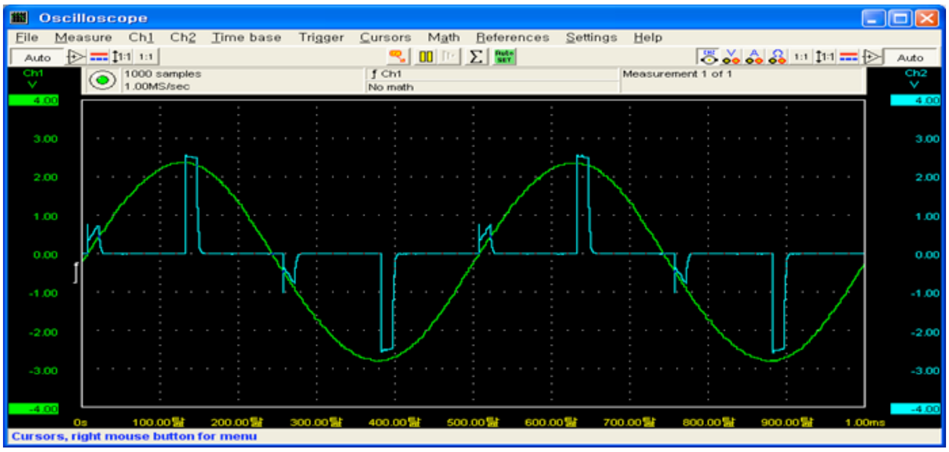


Illustrative Results



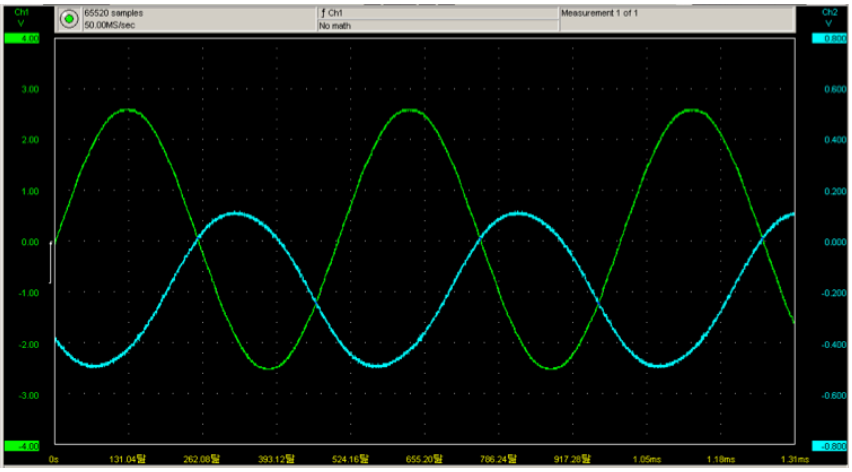
- Message signal and pulse trains

Illustrative Results



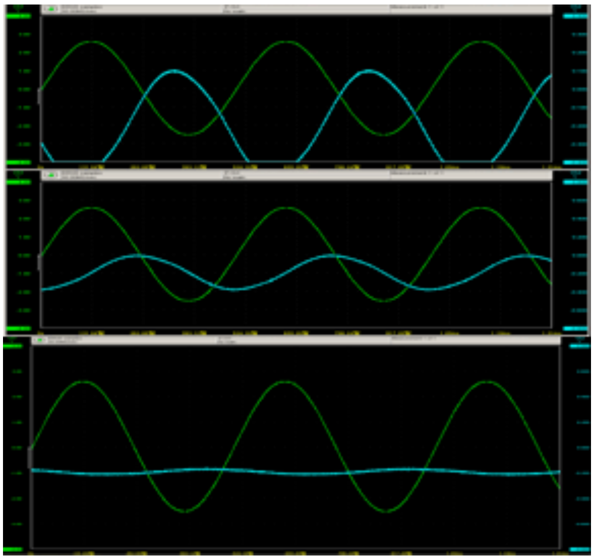
- Sampled message: PAM signal

Illustrative Results



- Well demodulated if sampling rate is higher than Nyquist rates

Illustrative Results



- Not well demodulate - sample rate is less than Nyquist rates
- Observe that the recovered signals keep fluctuating - Think about the reason why...

Pulse Time Modulation (PTM)

- additional slides

Pulse Modulations

- Message signals → Modulated signals
- Amplitude → Pulse Amplitude Modulation
- Width → Pulse Width Modulation
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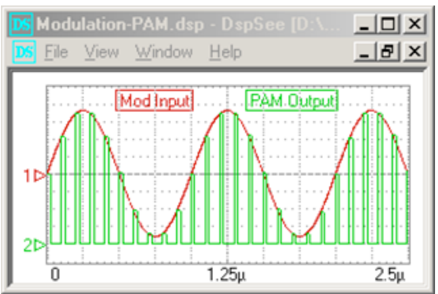
Pulse Time Modulation

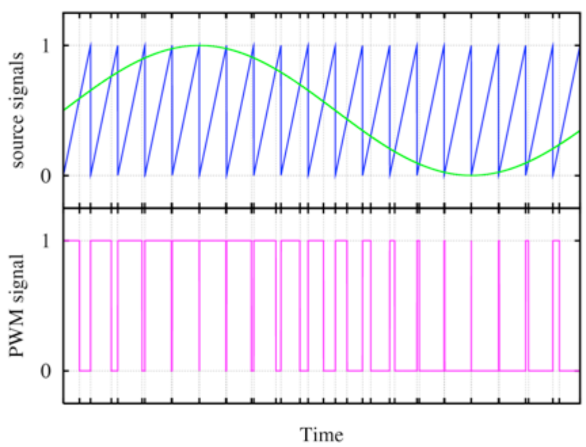


- Q: What if we play with timing (e.g., width or position) of pulses?

Pulse Time Modulation (PTM)

- Time characteristics of pulses
- Examples:
  – Pulse Width Modulation (PWM) = Pulse Duration Modulation (PDM)
  – Pulse Position Modulation (PPM)
  – Pulse Frequency Modulation (PFM)
- We may be interested in
  – PWM: Time duration of pulses
  – PPM: Time occurrence of pulses

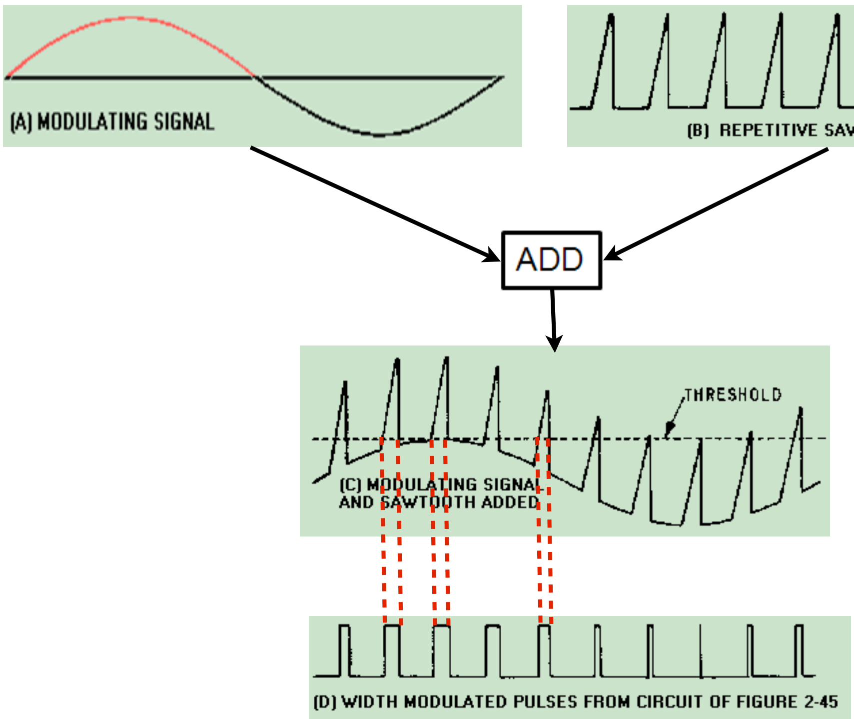
Example: PWM



PWM Illustration

- Observations:
  – Width (or duration) of pulses is VARYING
  – Amplitudes of pulses are CONSTANT
  – Noise Robustness: PWM > PAM

PWM Generation



PWM and Duty Cycle

- Duty Duty cycle:
  - amount of time in period that pulse is high
- PWM is function of duty cycle

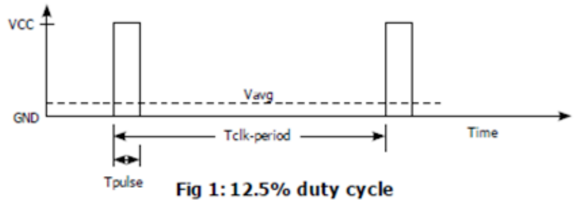


Fig 1: 12.5% duty cycle

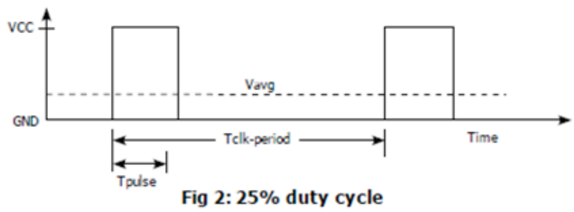


Fig 2: 25% duty cycle

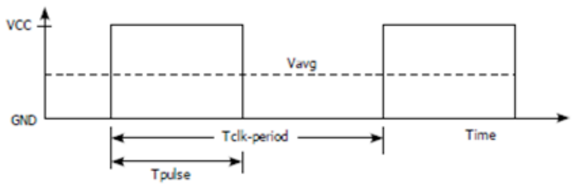
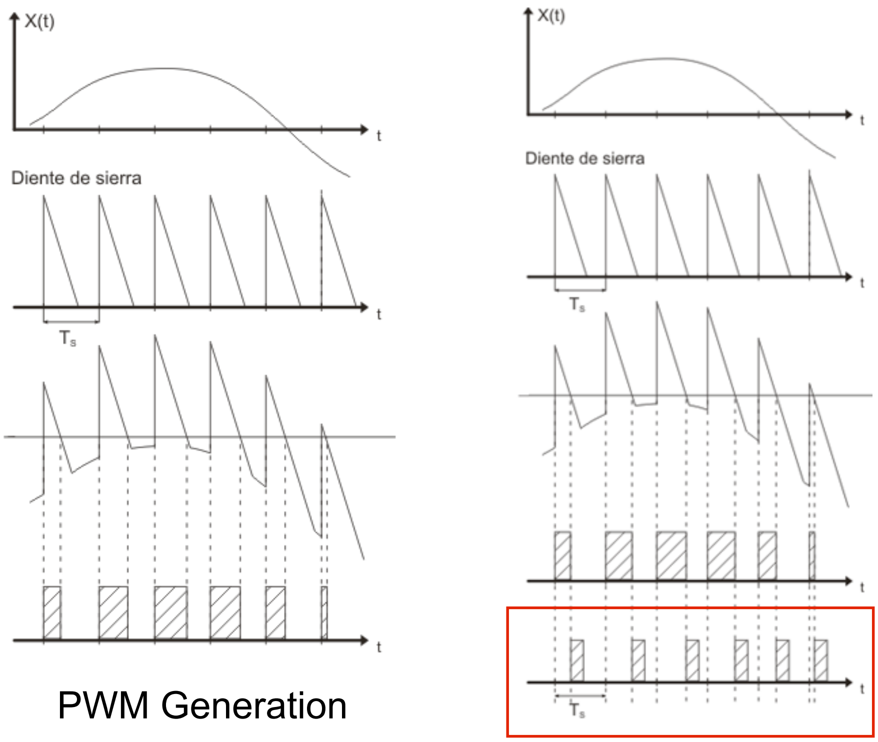


Fig 3: 50% duty cycle

PPM



PWM Generation

PPM Generation

Properties of PPM

- Characteristics:
  - Positions of pulses are varying
  - Amplitudes of pulses are constant
- Advantages
  - Non-coherent detection: no need for PLL (phase-locked loop)
- Disadvantages
  - Sensitivity to multipath interference
  - Require synchronization – to find starting point