Pulse Modulation (2B)

Young Won Lim
9/22/13

Please send corrections (or suggestions) to youngwlim@hotmail.com.

This document was produced by using OpenOffice and Octave.

Pulse Modulation Schemes

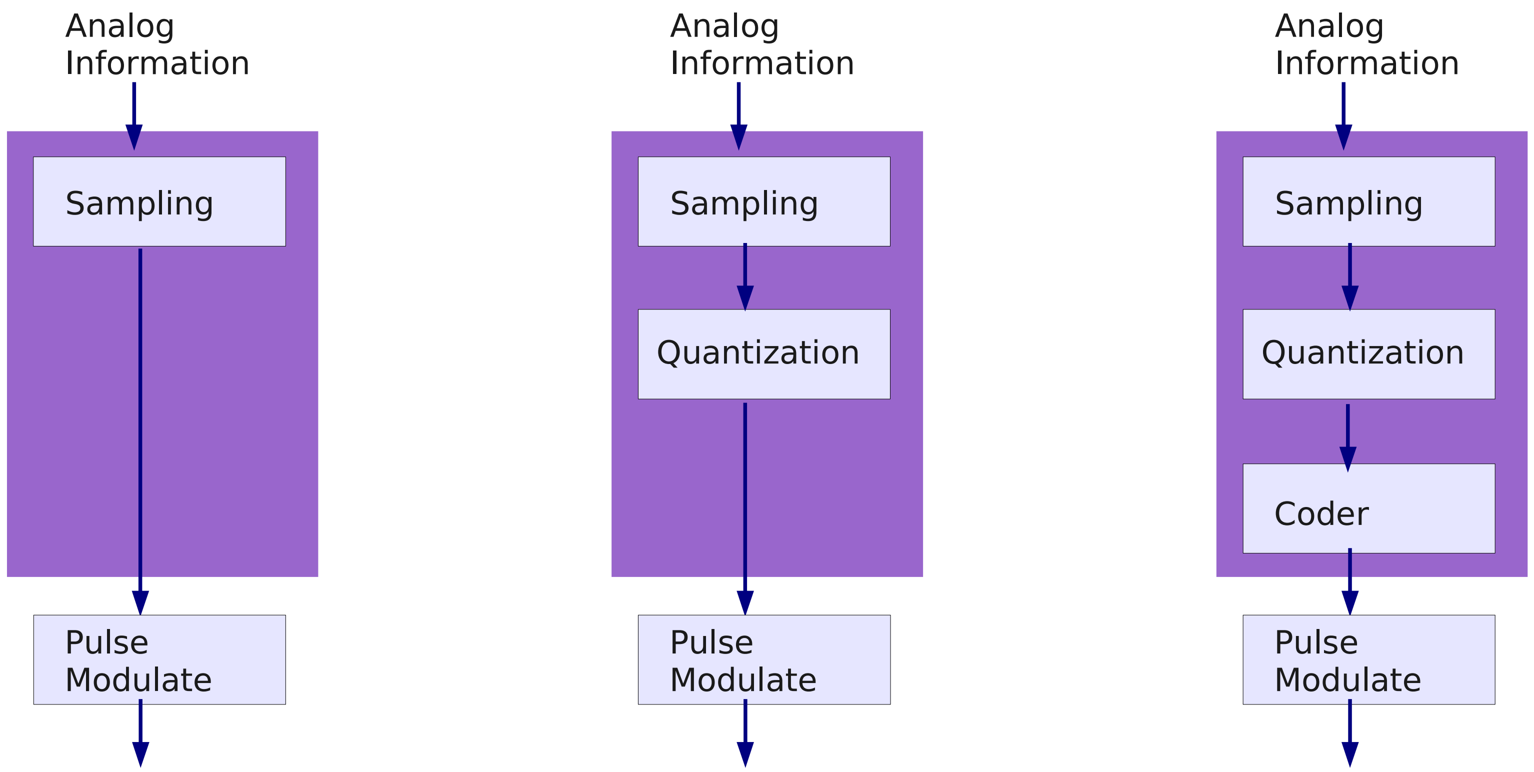
- **PAM (Pulse Amplitude Modulation)**
- **PDM (Pulse Duration Modulation)**
- **PPM (Pulse Position Modulation)**
- **PCM (Pulse Code Modulation)**
- **DM (Delta Modulation)**
- **DPCM (Differential Pulse Code Modulation)**

PAM, PDM, PPM: Analog Pulse Modulation

PCM, DM, DPCM: Digital Pulse Modulation

all these are discrete-time signal processing

Pulse Modulation



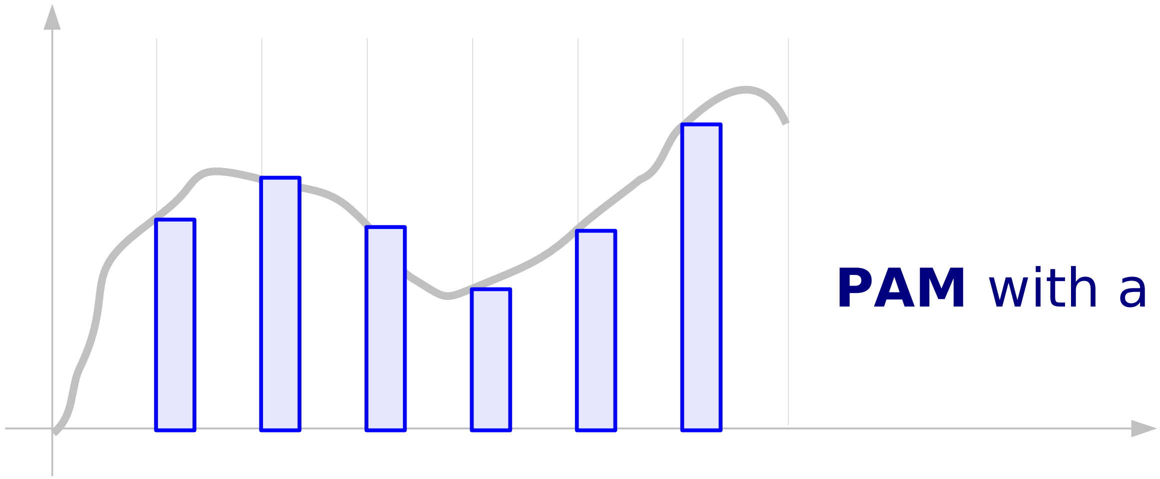
PAM
PDM
PPM

M-ary PAM

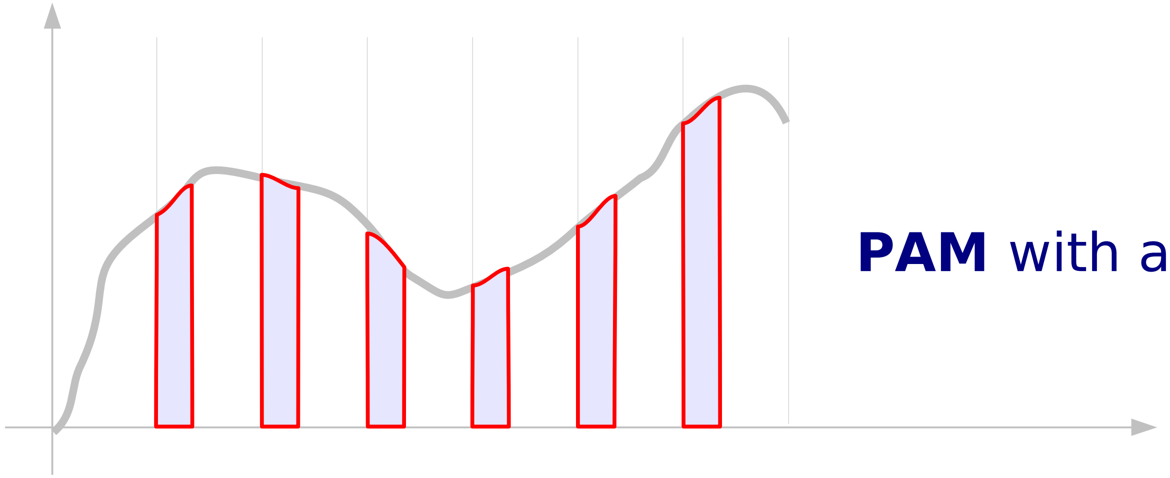
PCM
DM
DPCM

Analog Pulse Modulation

PAM (Pulse Amplitude Modulation)

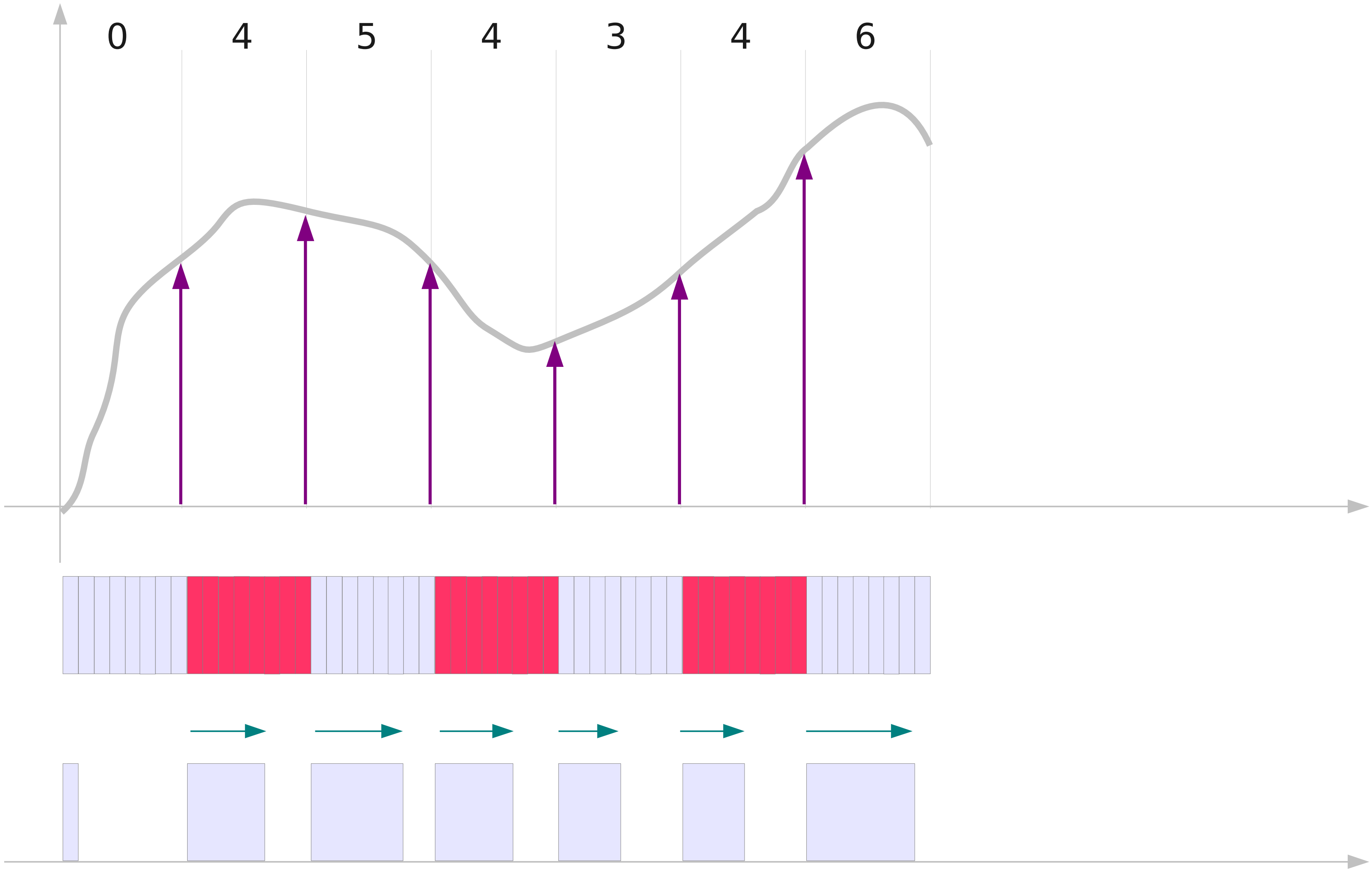


PAM with a flat-top sampling

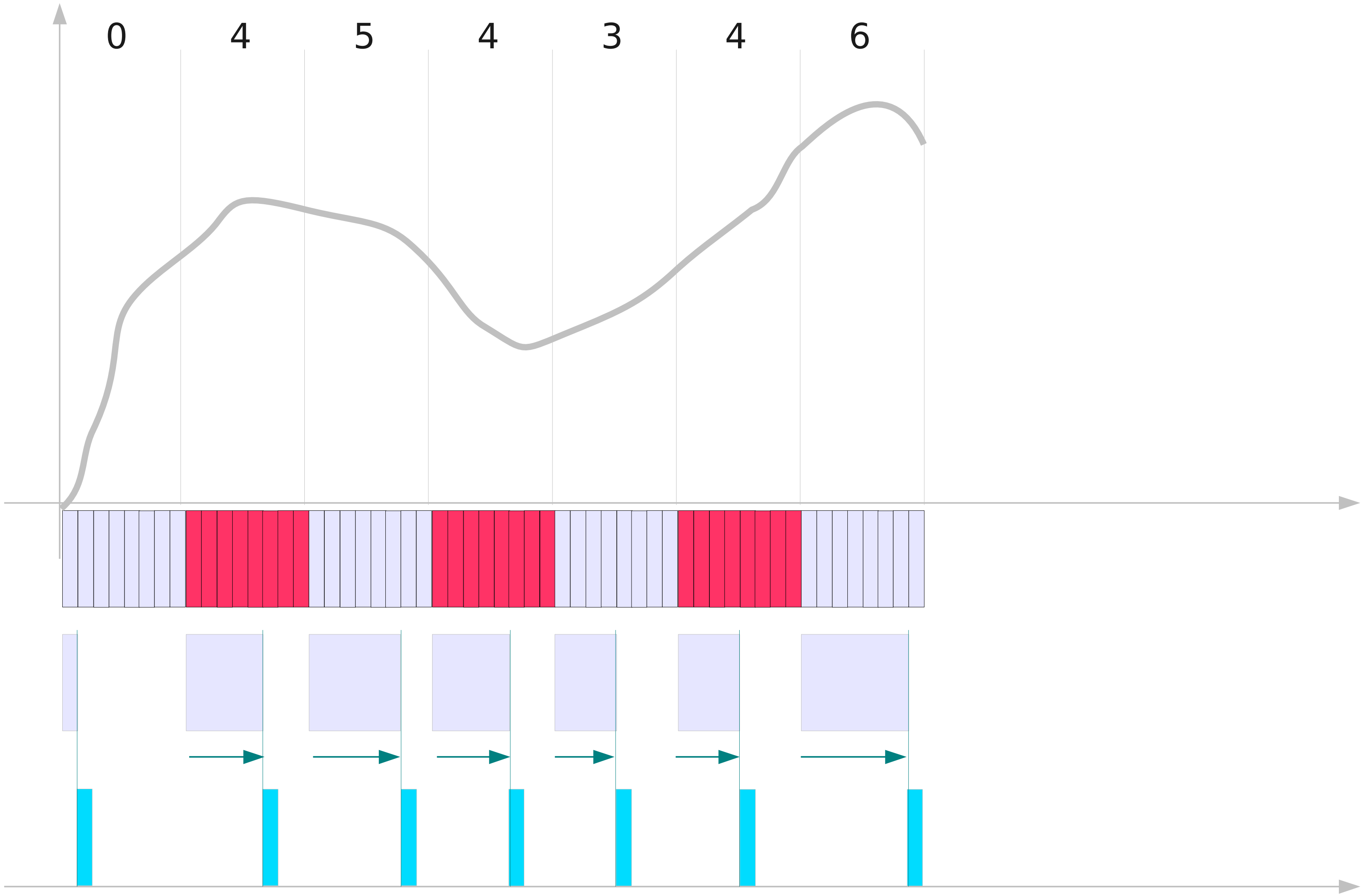


PAM with a natural sampling

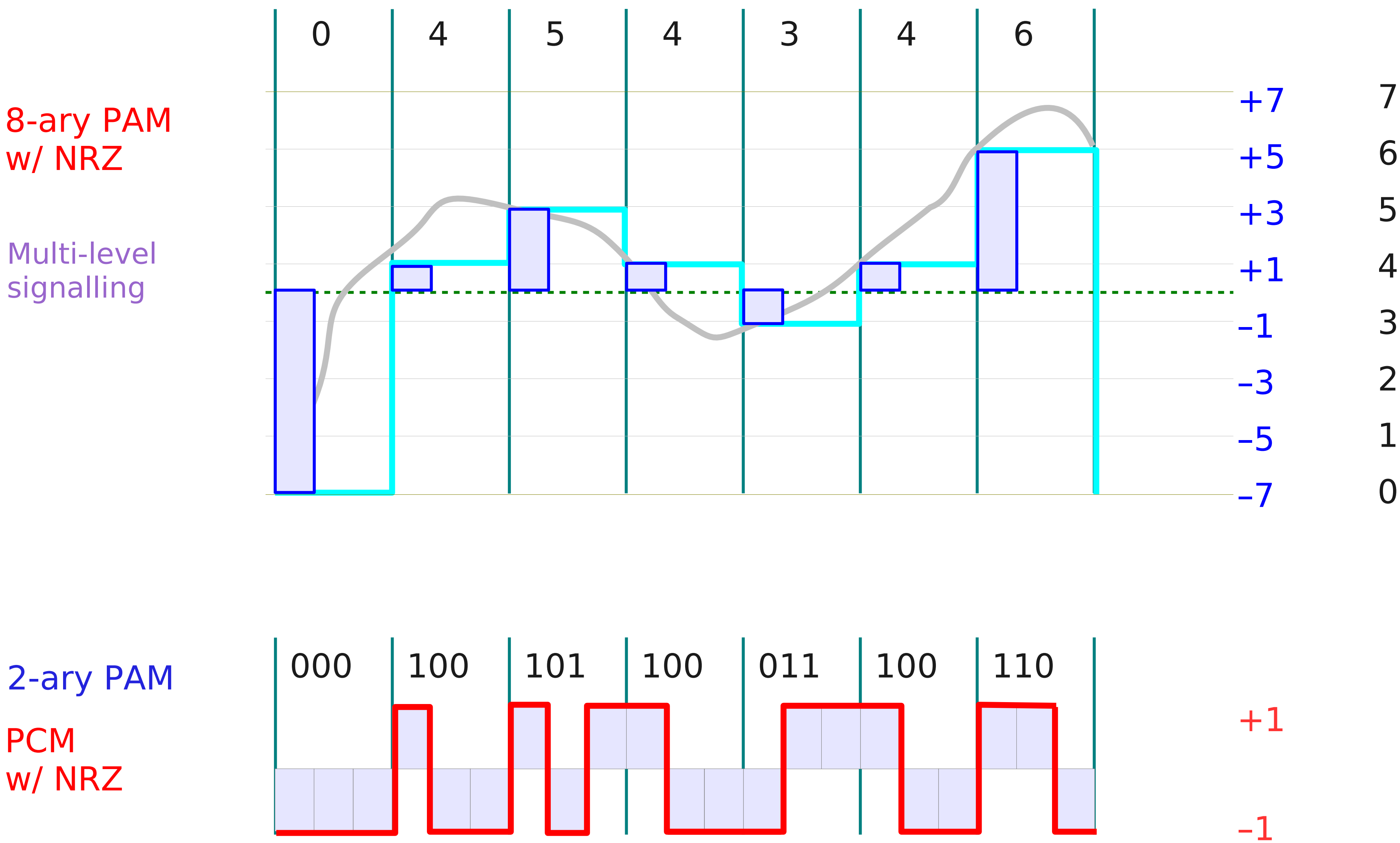
PDM (Pulse Duration Modulation)



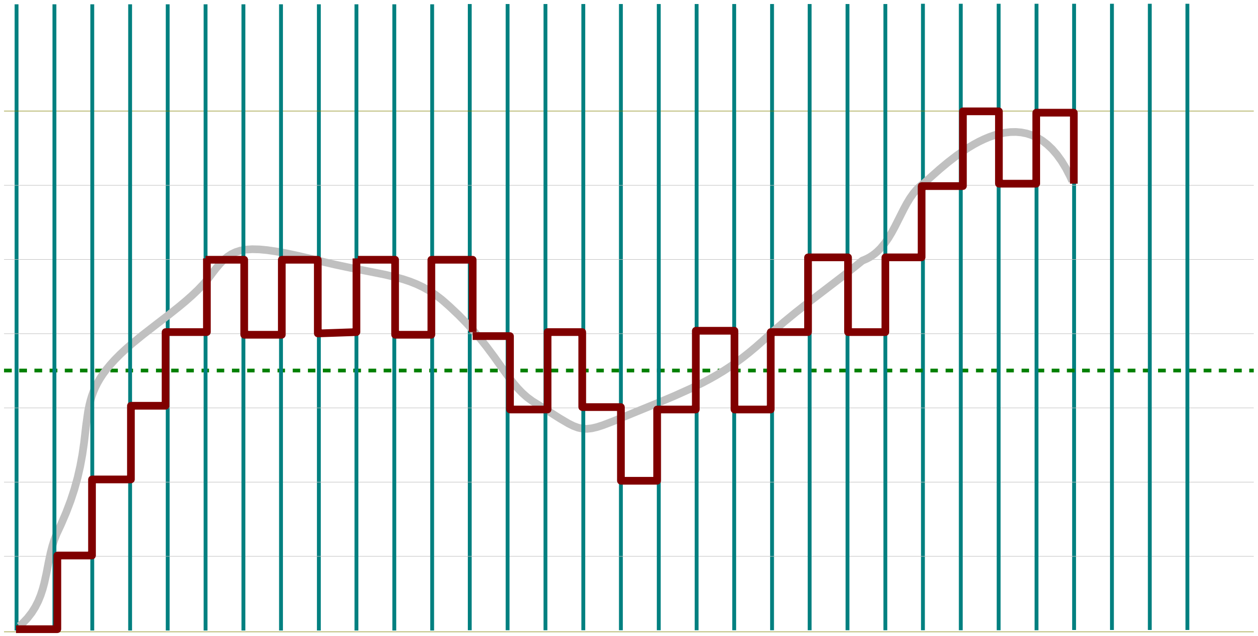
PPM (Pulse Position Modulation)



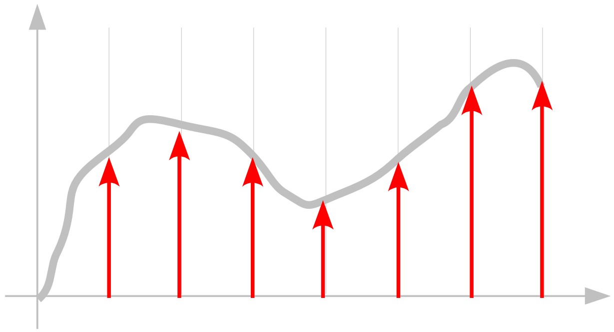
8-ary PAM vs PCM



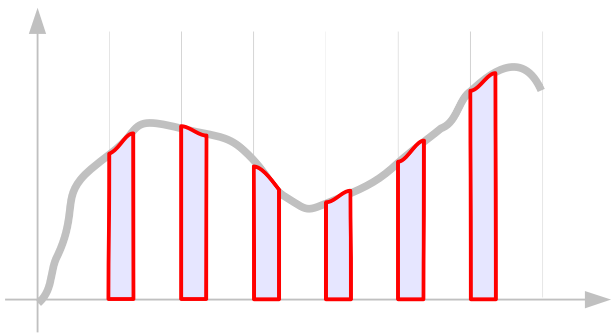
DM (Delta Modulation)



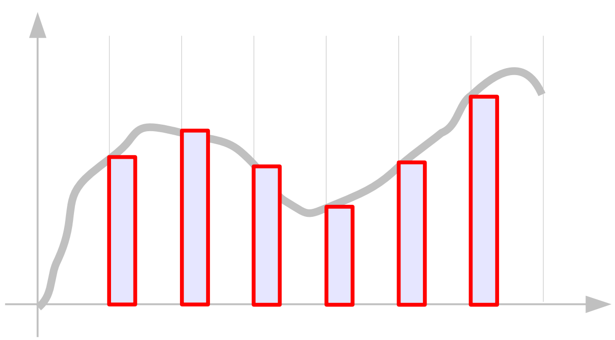
Types of Sampling



impulse sampling



natural sampling



flat-top sampling

Impulse Sampling

Impulse train

$$x_\delta(t) = \sum_{n=-\infty}^{+\infty} \delta(t - nT_s) \quad \Longleftrightarrow \quad X_\delta(f) = \frac{1}{T_s}\sum_{n=-\infty}^{+\infty} \delta(f - nf_s)$$

Shifting property

$$x(t)\delta(t-t_0) = x(t_0)\delta(t-t_0)$$

$$x_s(t) = x(t)x_\delta(t) \quad \Longleftrightarrow \quad X_s(f) = X(f) * X_\delta(f)$$

$$= \sum_{n=-\infty}^{+\infty} x(t)\delta(t - nT_s) \qquad = X(f) * \left[\frac{1}{T_s}\sum_{n=-\infty}^{+\infty} \delta(f-nf_s)\right]$$

$$= \sum_{n=-\infty}^{+\infty} x(nT_s)\delta(t - nT_s) \qquad = \frac{1}{T_s}\sum_{n=-\infty}^{+\infty} X(f-nf_s)$$

Natural Sampling

Pulse train

$$x_p(t) = \sum_{n=-\infty}^{+\infty} c_n e^{j2\pi n f_s t} \quad \Longleftrightarrow \quad c_n = \frac{1}{T_s} sinc\left(\frac{nT}{T_s}\right)$$

$$x_s(t) = x(t) x_p(t) \quad \Longleftrightarrow \quad X_s(f) = X(f) * X_p(f)$$

$$= x(t) \sum_{n=-\infty}^{+\infty} c_n e^{j2\pi f_s t}$$

$$= \sum_{n=-\infty}^{+\infty} c_n \left[x(t) e^{j2\pi f_s t}\right] \quad \Longleftrightarrow \quad = \sum_{n=-\infty}^{+\infty} c_n X(f - n f_s)$$

Sample and Hold

Sampled Pulse train

$$x_p(t) = \sum_{n=-\infty}^{+\infty} c_n e^{j2\pi n f_s t} \quad \Longleftrightarrow \quad c_n = \frac{1}{T_s} sinc\left(\frac{nT}{T_s}\right)$$

$$x_s(t) = p(t) * [x(t) x_\delta(t)] \quad \Longleftrightarrow \quad X_s(f) = P(f)\,[X(f) * X_\delta(f)]$$

$$= p(t) * \left[x(t) \sum_{n=-\infty}^{+\infty} \delta(t - nT_s) \right] \quad \Longleftrightarrow \quad = P(f) \left[X(f) * \left[\frac{1}{T_s} \sum_{n=-\infty}^{+\infty} \delta(f - nf_s) \right] \right]$$

$$= P(f) \left[\frac{1}{T_s} \sum_{n=-\infty}^{+\infty} X(f - nf_s) \right]$$

Sampling Theorem

Uniform Sampling Theorem

A band-limited signal having no spectral components above f_m Hz
can be determined uniquely
by values sampled at *uniform intervals* of T_s seconds

$$T_s \le \frac{1}{2 f_m} \qquad f_s = \frac{1}{T_s} \qquad f_s \ge 2 f_m$$

Upper limit of T_s

Lower limit of f_s

Nyquist Criterion

Nyquist Rate $f_s = 2 f_m$

References

[1] http://en.wikipedia.org/
[2] http://planetmath.org/
[3] B. Sklar, “Digital Communications: Fundamentals and Applications”
[4] S. Haykin, M Moher, “Introduction to Analog and Digital Communications”, 2ed