

Signal Characteristics

Analog Signals

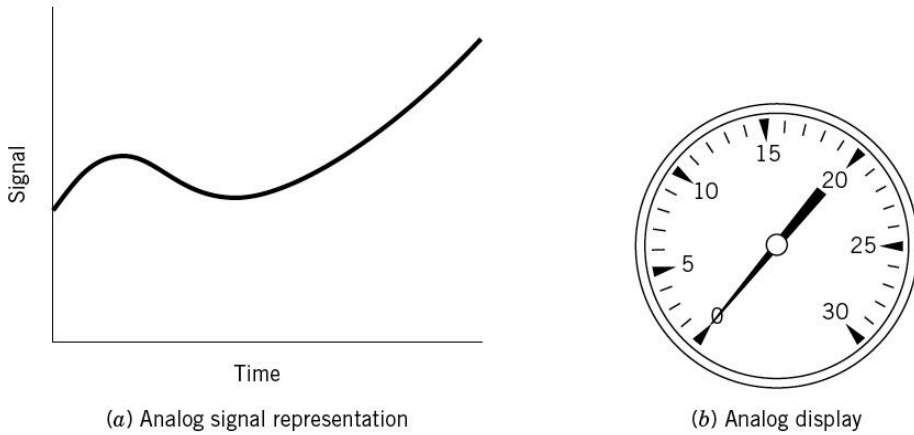


Figure 2.2 Analog signal concepts.

Analog signals are always continuous (there are no time gaps). The signal is of infinite resolution.

Discrete Time Signals

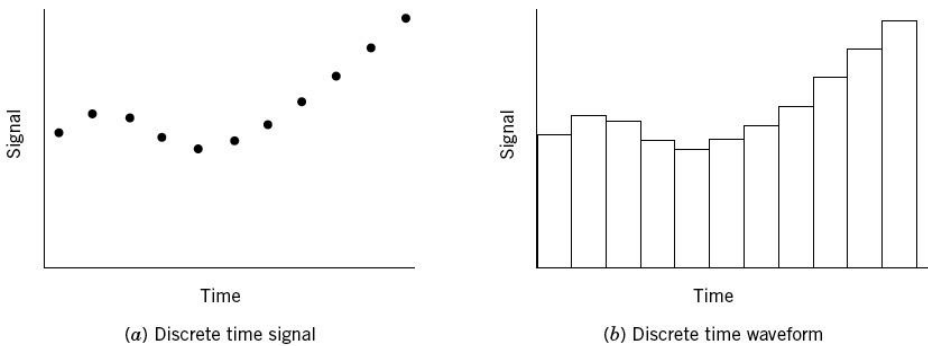
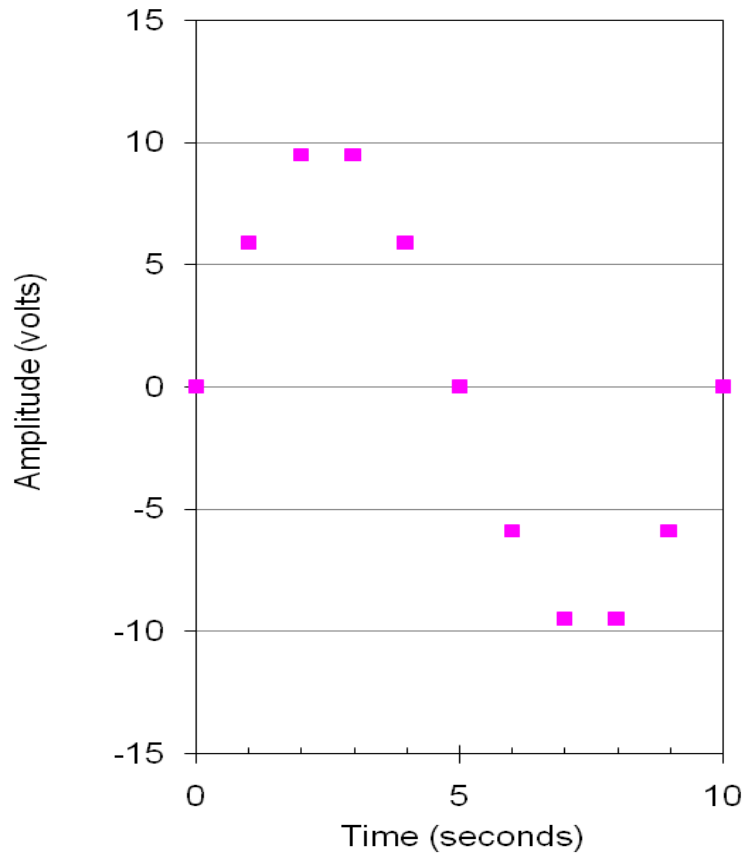


Figure 2.3 Discrete time signal concepts.

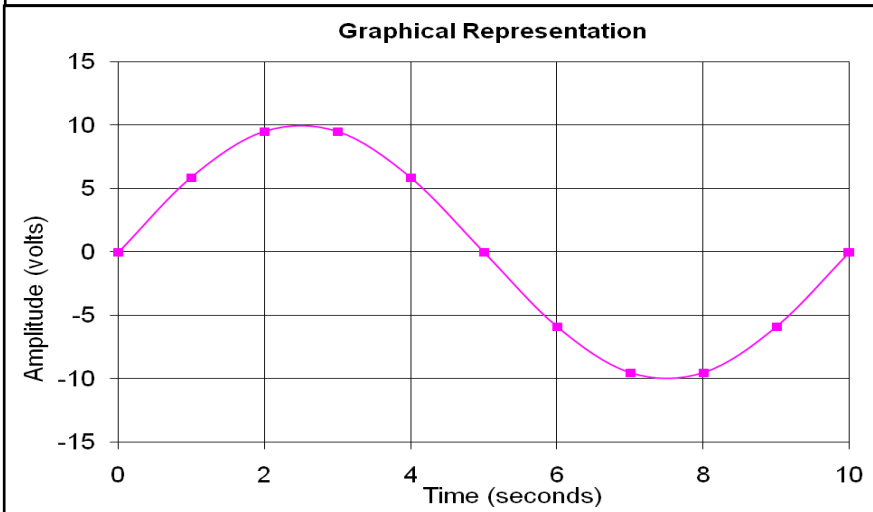
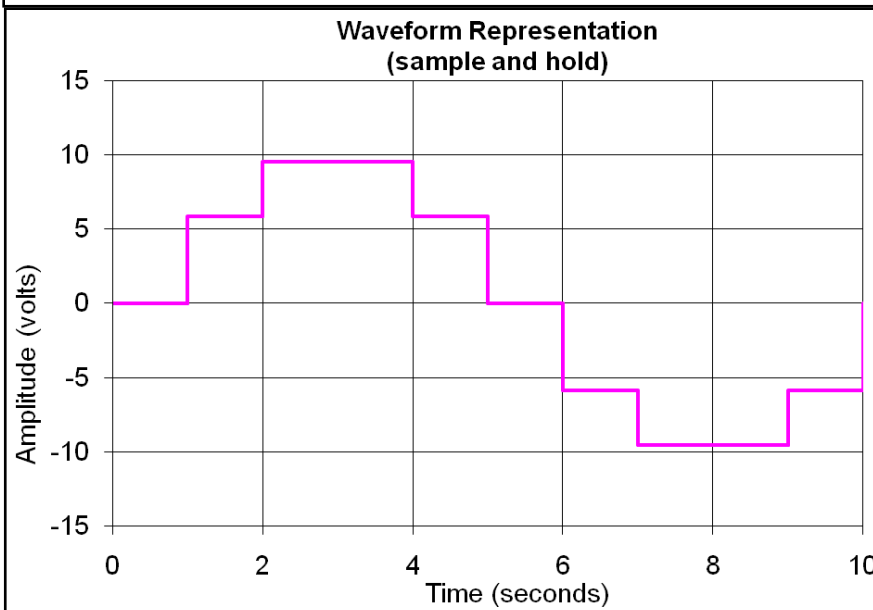
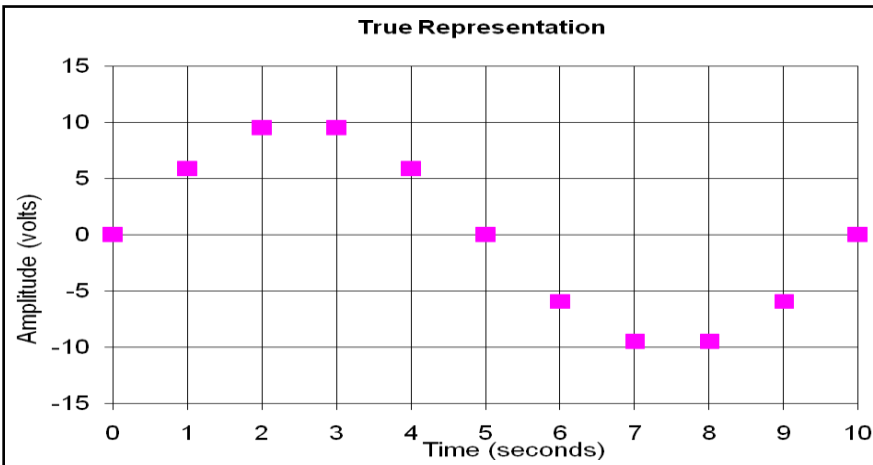
Discrete Time Signals only provide information about the signal magnitude at infinitesimally short points in time. Information about what the signal does between the available points is not known!

Table 1

r	Discrete data
0	0.0
1	5.9
2	9.5
3	9.5
4	5.9
5	0.0
6	-5.9
7	-9.5
8	-9.5
9	-5.9
10	0.0



Sampling: The process of obtaining discrete realizations (values) from a continuous variable at finite time intervals. The discrete values in the table on the left are plotted on the right. Be sure to resist the temptation to assume values between the realizations. A common misconception is to draw a line between the points. It should also be noted that the sampling process produced data with only 2 significant figures. It has a finite resolution.



Signal Characteristics: Definitions

Magnitude - generally refers to the maximum value of a signal. The Signal plotted above has a magnitude of 9.5 volts.

Range – is minimum to maximum value of a signal. The signal plotted above has a range of -9.5 to +9.5 volts.

Amplitude - indicative of signal fluctuations relative to the mean. The signal plotted above has an amplitude of 9.5 volts.

Dynamic - signal is time varying.

Static - signal does not change over the time period of interest.

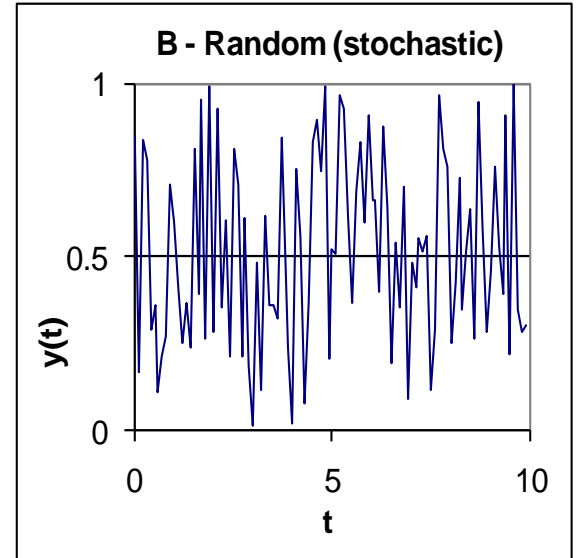
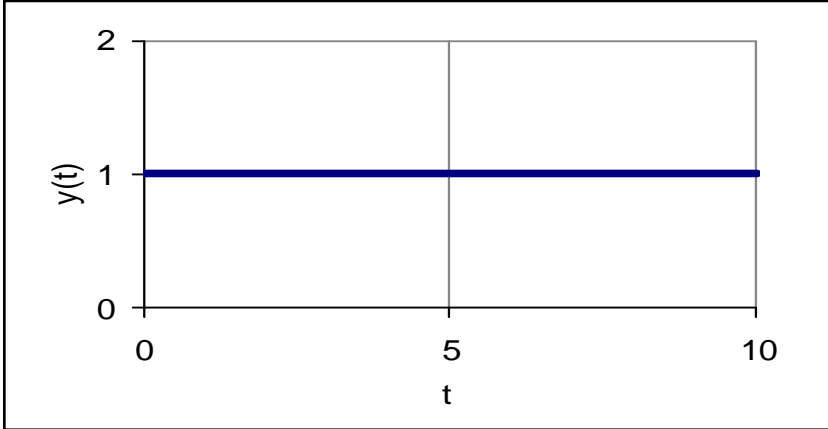
Deterministic - signal can be described by an equation (other than a Fourier series or integral approximation). The signal above is deterministic because the equation $y(t) = 10 \sin(\pi/5 t)$ describes the waveform.

Non-deterministic - describes a signal which has no discernible pattern of repetition and cannot be described by a simple equation. Turbulence is a typical non-deterministic signal.

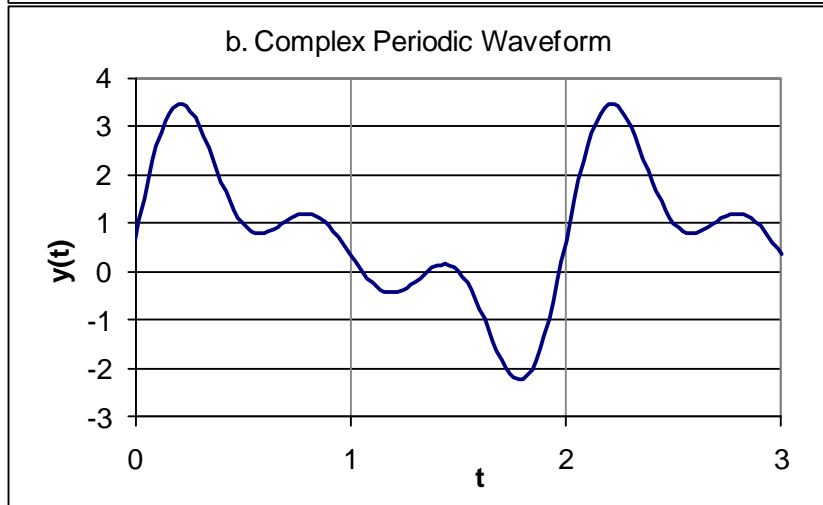
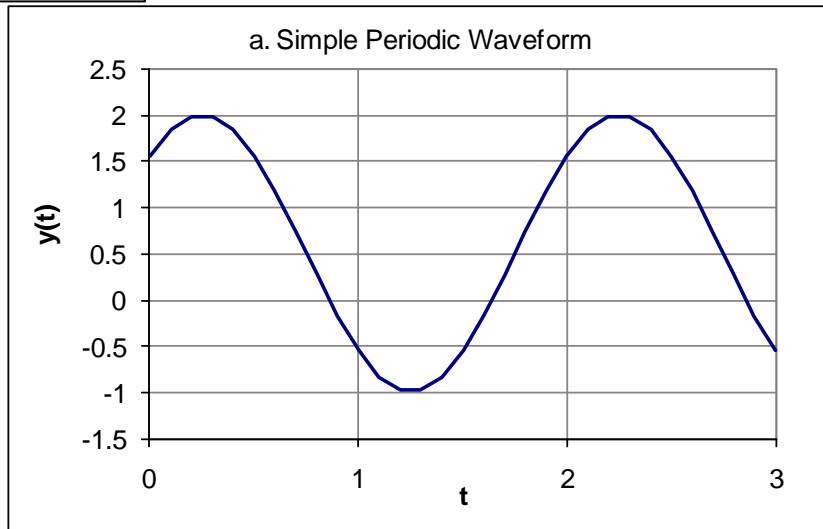
Classification of Waveform

A - Deterministic

1. Static



2. Dynamic



Signal Analysis

Average or Mean Value

Provides a measure of the static portion of a signal over a period of time.

$$\bar{y} \equiv \frac{\int_{t_1}^{t_2} y(t) dt}{\int_{t_1}^{t_2} dt}$$

This is often referred to as the DC component or DC offset. DC is an acronym for Direct Current. A battery typically supplies a constant DC voltage.

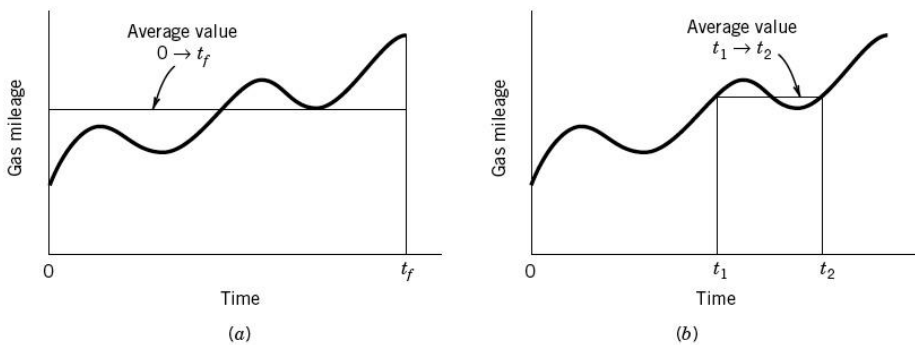


Figure 2.7 Effect of time period on mean value for a nondeterministic signal.

As you can ascertain from the above equation the value of t_1 and t_2 can have a significant effect on the integral. Take time problem 2.3 and to open and manipulate the Excel spreadsheet [Problem 2.3.xls](#) which can be found on the class notes web site.

Fluctuating or AC Component

The dynamic portion of a signal, $y(t)$, is characterized by the various measures of the magnitude and the amount of the fluctuation. AC is an acronym for Alternating Current. One such characterization of the fluctuating component is the *RMS* value, or Root Mean Square.

$$y_{rms} = \sqrt{\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} y^2 dt}$$

The fluctuating portion alone is often characterized by a term called the variance, σ^2 , or the square root of the variance the standard deviation, σ .

$$\sigma^2 = \lim_{T \rightarrow \infty} \frac{1}{T} \int_0^T [y(t) - y']^2 dt$$

Where, y' is the true mean value of the signal, T is the period of time over which the signal is being evaluated and $y(t)$ is the signal.

Mean - average or static portion of a signal over the time of interest. Sometimes called the dc component or the dc offset of the signal [Excel tip: Mean = AVERAGE(numbers...)]. The mean value of the signal plotted above is 0.

RMS - root-mean-square - average value of the square of the signal over the time of interest. [Excel tip: RMS = SQRT(SUMSQ(numbers1 to n)/n)]. The RMS of the signal plotted above is 6.7.

Digital Sampling

Acronyms

ADC – Analog to Digital Converter

DAQ – Data Acquisition system

Glossary

Quantization: The truncation of an analog signal to a finite resolution. The resolution of the data in Table 1 is 2 significant figures. The quantization is therefore 0.1.

Q, ADC Resolution: is called the Quantization step size and is defined as the smallest voltage increment that will cause the digital output to change (a change in the least significant bit of the ADC output value). If the data in Table 1 was produced by an ADC then the resolution would be 0.1 volts.

M, ADC Bits: is the ADC word size in bits. It is referred to as M in this class. A typical PC these days has a word size of either M=32 or 64 bits. A typical ADC word size is M=12 or 16 bits. The ADC in our lab has a word size of 12 bits. It can therefore output numbers from 0 to $(2^{12} - 1) = 4095$.

E_{FSR} – is the Full Scale Range of the ADC in units of potential Energy or in our case voltage. The input voltage range, E_{FSR} , is divided into 2^M equal increments where M is the number of bits in the ADC output word.

Gain: an input signal amplification factor or multiplier. If an input signal is amplified by a factor the effective E_{FSR} is changed. For example if an ADC has a E_{FSR} of 20 volts and an input range from -10 to +10 volts and the input signal is amplified by a gain of 2 then a 5 volt input signal would become a 10 volt signal before entering the ADC. It is multiplied by a gain of 2. The effective input full scale range would be therefore change to -5 to +5 volts.

Uni-polar: an ADC input range which is positive only going from 0 volts to some maximum positive voltage.

Bi-polar: an ADC input range which equally spans 0 volts. The ADC in our lab is bi-polar spanning a range from -10 Volts to +10 Volts.

Using the above definition we can determine that the **quantization step size** without gain is defined as

$$Q = E_{FSR} / 2^M$$

If the gain is included the definition becomes

$$Q = E_{FSR} / \text{Gain} / 2^M$$

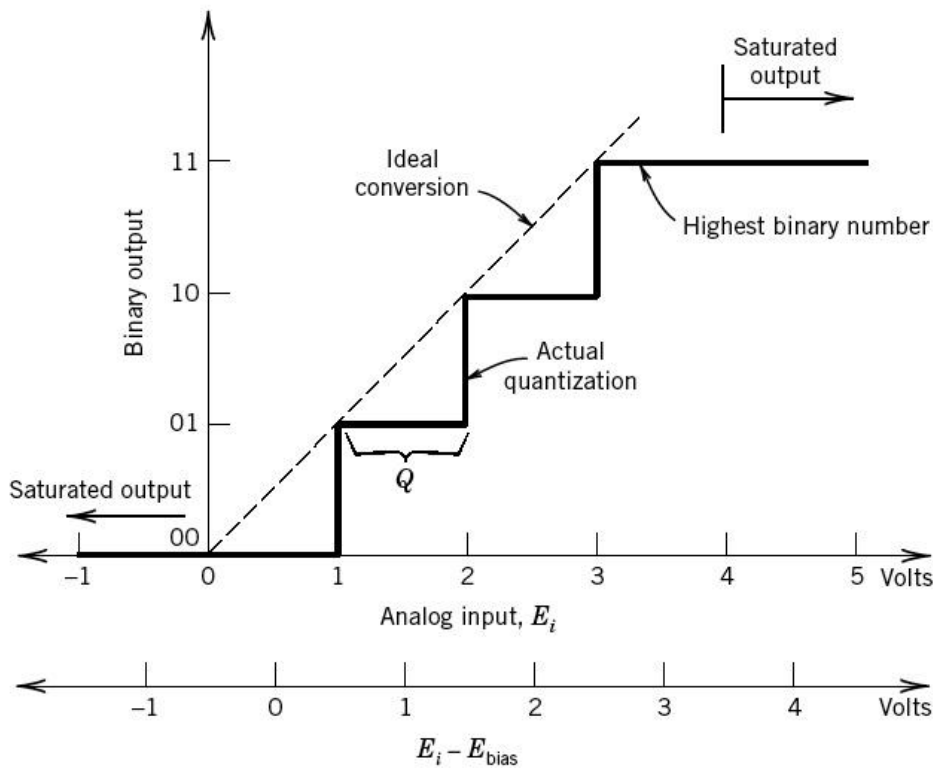


Figure 7.7 Binary quantization and saturation.

Example From above figure 7.7: $E_{FSR} = 4 \text{ V}$, $M = 2$, $\text{Gain} = 1$,

$$Q = 4/2^2 = 1\text{V}$$

Lab ADC Characteristics

12 bit digital output word size, $M = 12$

20 Volt analog input range, $E_{FSR} = 20$ volts

Variable input signal amplification or gain. Available gains of 1, 2, 5, 10, 100 & 200

Lab ADC Example:

$$Q = 20V/Gain/2^{12}$$

For highest available Lab ADC Gain of 200 the quantization step size becomes:

$$Q = 20V/200/4096 = 0.0000244 \text{ V}$$

For the lowest available Lab ADC Gain value of 1 the quantization step size becomes:

$$Q = 20V/1/4096 = 0.00488 \text{ V}$$

Quantization Error

Any time an analog signal (of infinite resolution) is truncated to a binary value of finite resolution an error is introduced. Every digital representation of a number by a computer has a finite resolution. The error introduced by the truncation process may or may not be significant. *It is your job as an engineer to know when the truncation is significant.*

$$\text{Error} = (\text{ADC Output} - \text{True Value})/\text{True Value}$$

Example: From figure 7.7 without shifting of the input signal (upper abscissa) if the input value is 1.5 what is the percent error?

$$\text{Error} = (1 - 1.5)/1.5 = -1/3 \text{ V or } -33\%$$

What is the error for an input signal of 1.99999999 Volts?

e_Q – is the error due to quantization or truncation. In the above example e_Q can range from 0 to 1 volt.

Notice that the lower abscissa is shifted by $\frac{1}{2}$ of Q in Figure 7.7.

Input voltage shifting is used to minimize the error by adding a bias of $Q/2$. This effectively *rounds off* the input value to the nearest ADC binary output value. The maximum error then becomes $\pm \frac{1}{2} Q$. Think of this as a change from truncation to rounding off. The error then becomes

$$e_Q = \pm \frac{1}{2}Q$$

ADC SNR, ADC Signal-to-noise ratio: relates the power of the signal (Ohm's Law E^2/R) to the power of the smallest signal change, Q , that can be detected $E^2/(R2^M)$

The recording industry expresses the ADC SNR in decibels (dB):

$$\text{SNR[dB]} = 20 \log 2^M$$

Homework: Reading: 2.2, 7.1-7.2, Problems: [2.2](#), [2.3](#), [2.8 - 2.10](#), Interact with the Quantization tab of the [ADC Simulation.xls](#) spreadsheet.