BME 301

6-Signals and Systems

What are Signals?

- A Signal is a term used to denote the information carrying property being transmitted to or from an entity such as a device, instrument, or physiological source
- Examples:
  - Radio and Television Signals
  - Telecommunications and Computer Signals
  - Biomedical Engineering Signals

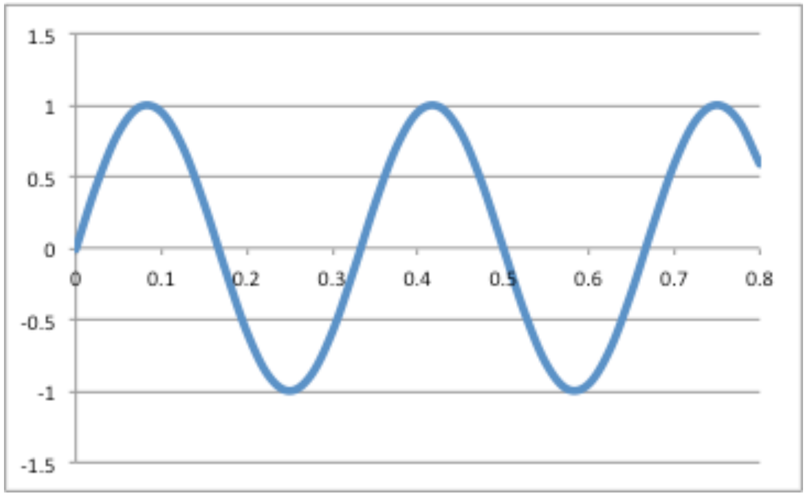
What is a System?

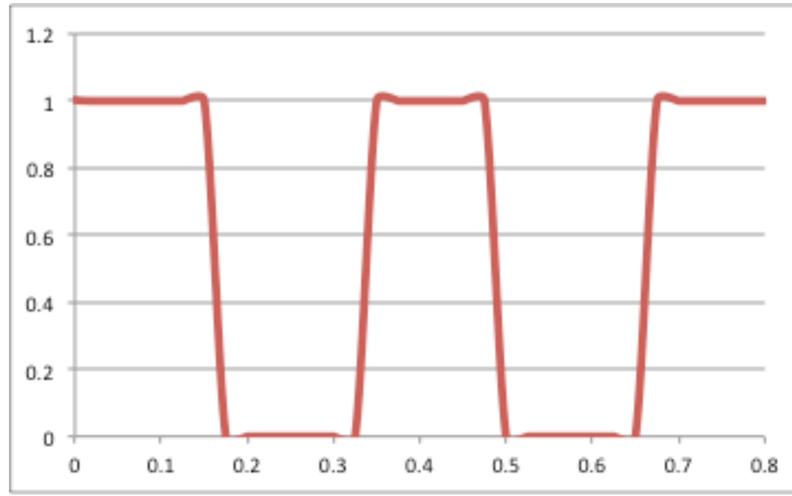
- A System is a term used to denote an entity that processes or operates on Signal(s) to transform one signal to another
  - Manipulate
  - Change
  - Record
  - Transmit
- A System has inputs and outputs
- Examples
  - Amplifiers, Radios, Televisions
  - Telephone, Modem, Computer
  - Oscilloscopes, ECG, EEG, EMG

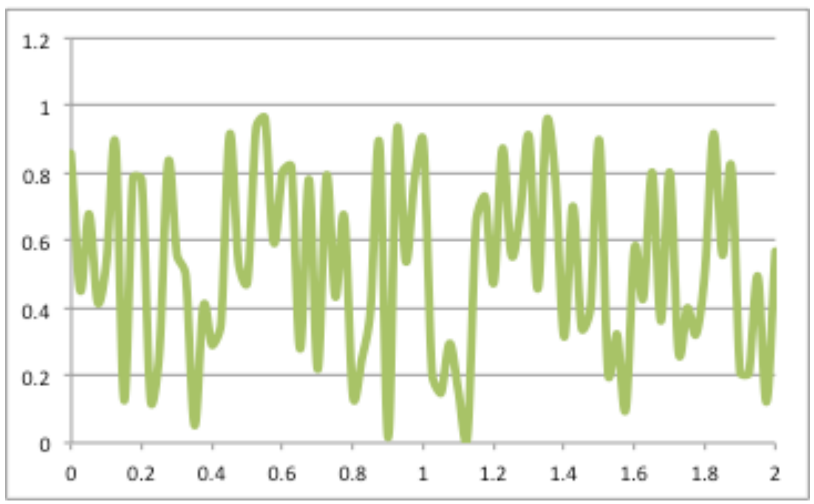
How do we describe Signals?

- Signals are associated with an independent variable(s): e.g., time, single or multivariate spatial coordinate
  - Most instrumentation signals have time as their independent variable
  - A digital photograph or image has spatial coordinates as its independent variables
- We can also represent a Signal by a waveform
- Signal Independent Variables can be either Continuous (also called Analog) or Discrete

Continuous-Time Signals

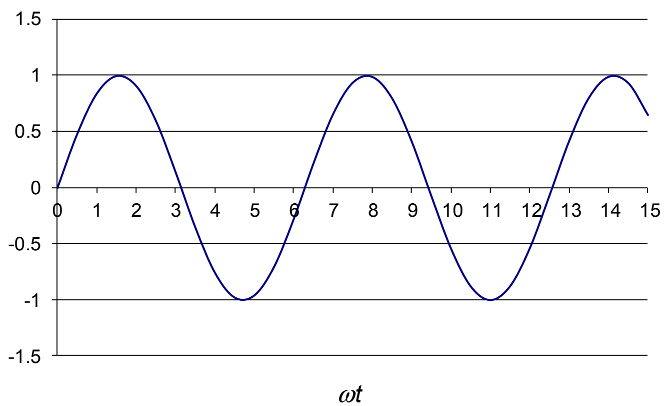






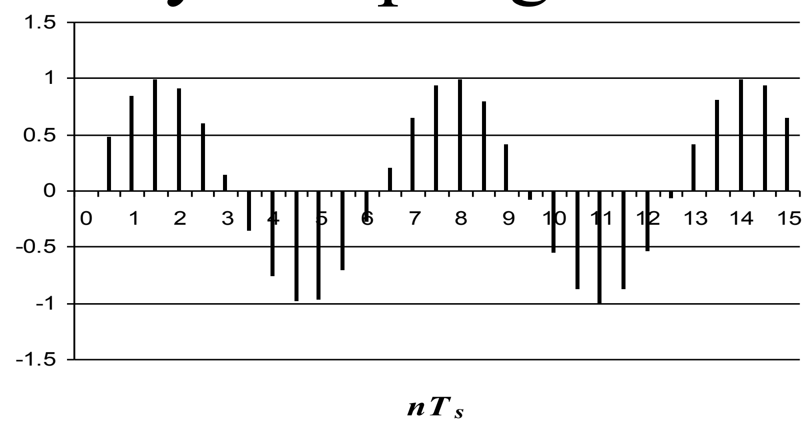
Discrete-Time Signals

A Discrete-Time Signal can be obtained from a Continuous-Time signal by Sampling.



Continuous-Time Signal

$$x(t) = \sin(\omega\ t)$$



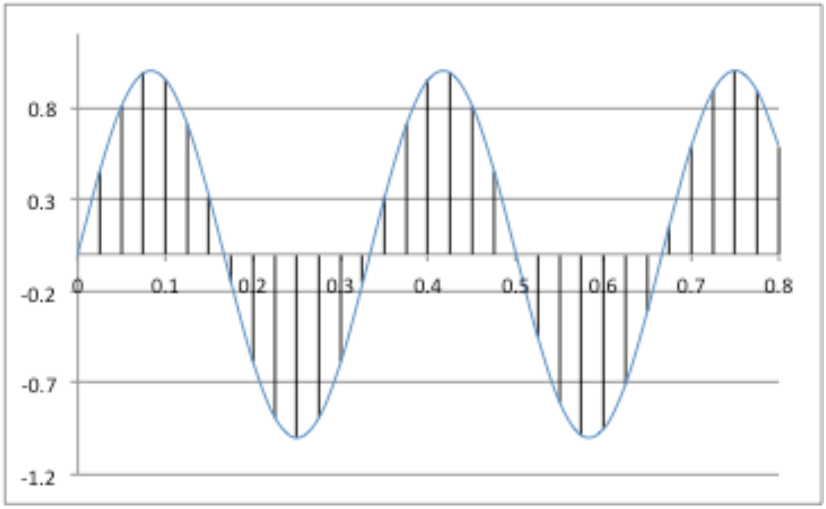
Discrete-Time Signal

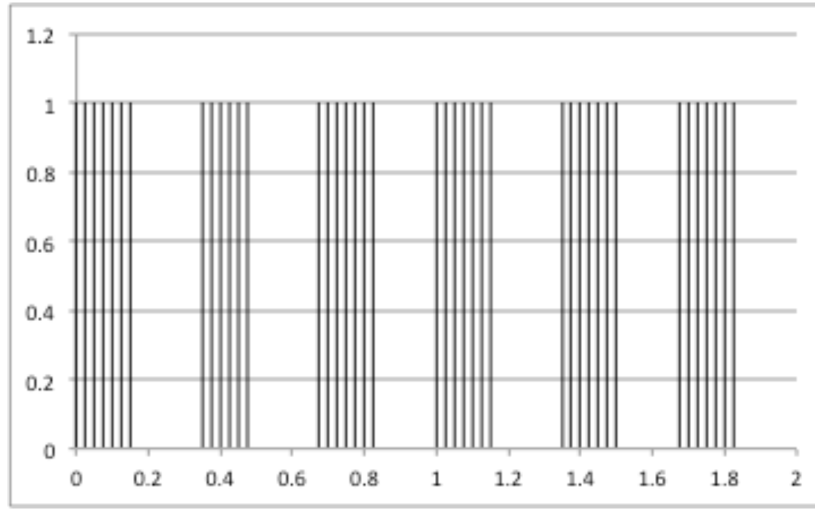
$$x(t \Rightarrow nT_s) \Rightarrow\ x(nT_s) = x[n] = \sin\ (\omega nT_s)$$

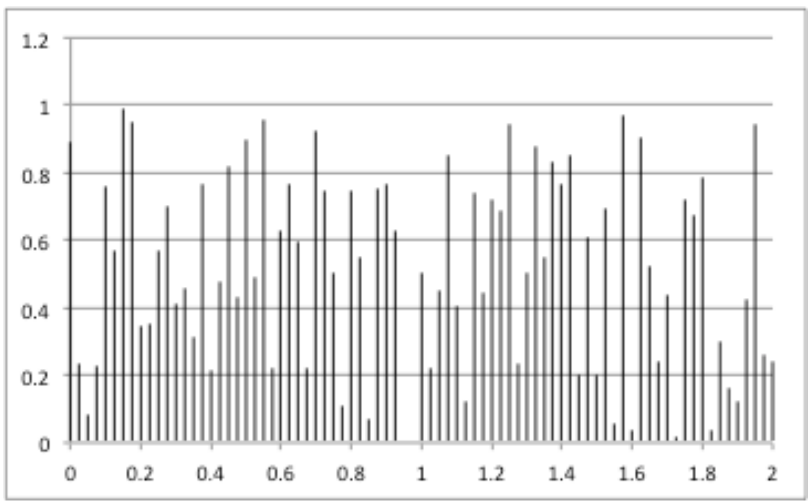
where n is an integer: $N_1 < n < N_2$

and T_s is the sampling period

Discrete Time Signals





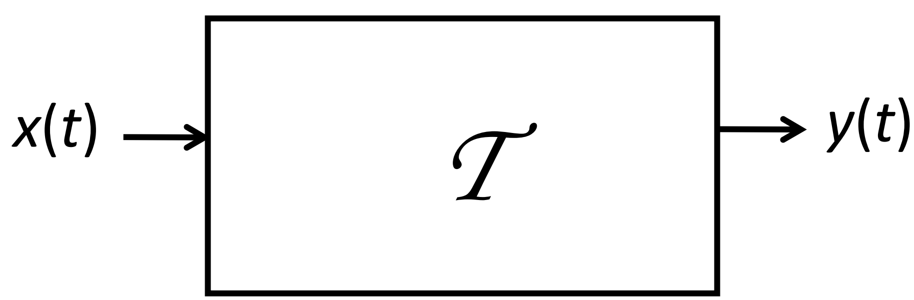


Representation of a System

- How do represent a system mathematically?
  - Since a system transforms a signal into another we write:

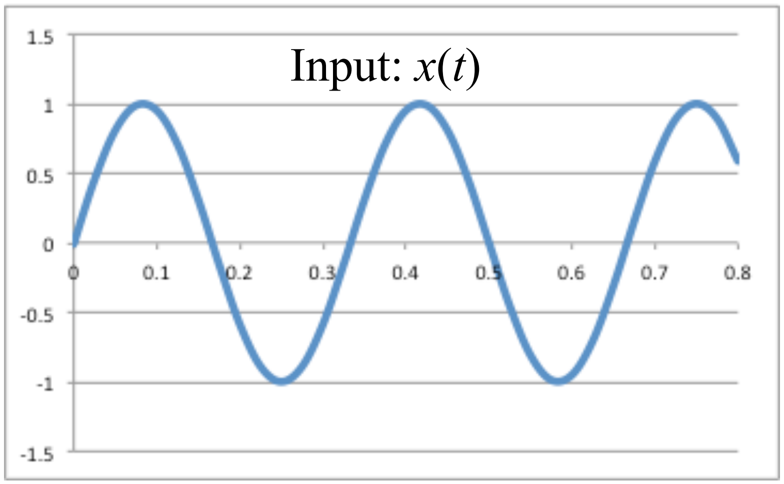
$$y(t)=\mathcal{T}\{x(t)\}$$

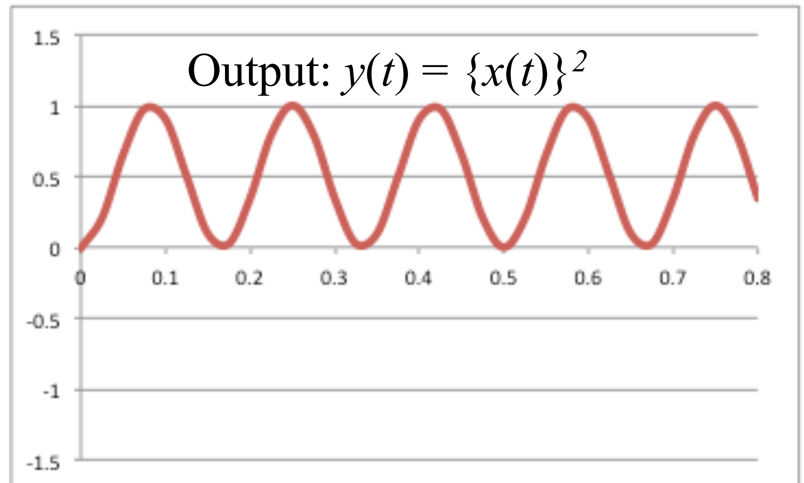
  - where $\mathcal{T}$ is an operator to symbolize a system,
  - $x(t)$ is the signal that goes into the system: input signal
  - And $y(t)$ is transformed signal or output signal
- We can also represent it by a flow diagram



Example of a Continuous-Time System

- A squarer system: $y(t)=\{x(t)\}^2$
  - The output equals the square of the input.
  - This is the result of putting the sine wave into the squarer





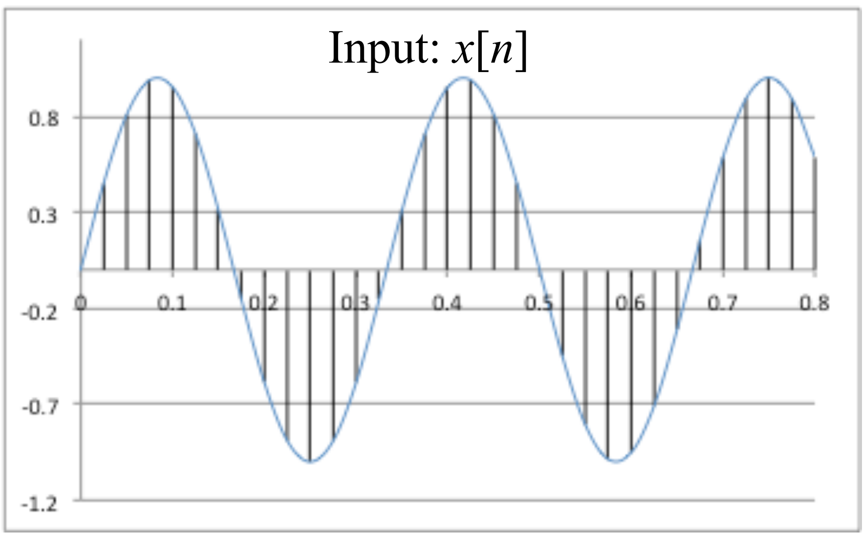
- This is an example of a continuous-time system
- We might be able to build this using an electronic circuit

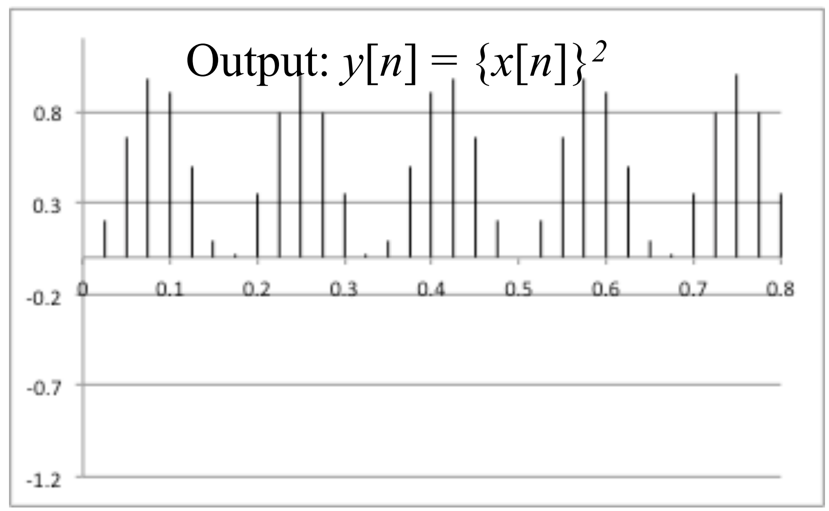
Discrete Time Systems

- If we put a discrete-time signal into a system the output may be a discrete-time signal
- This is called a Discrete-time system.

$$y[n]=\mathcal{T}\{x[n]\}$$

- Using our squarer example: $y[n]=\{x[n]\}^2$





Mixed Systems

- Continuous-to-Discrete systems

$$y[n] = \mathcal{T}\{x(t)\}$$

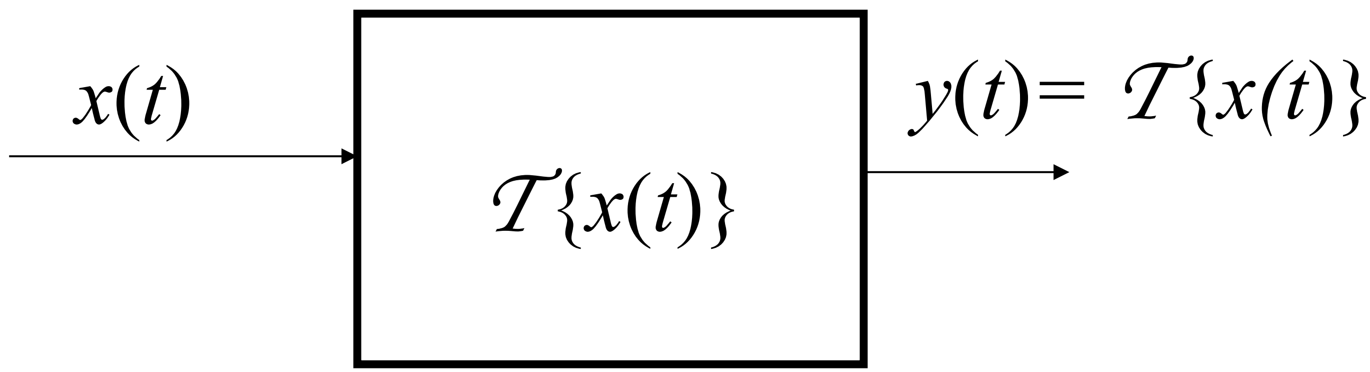
  - Example: a sampler: $y[n]=x(nT_s)$
    - This is also called a A-to-D converter

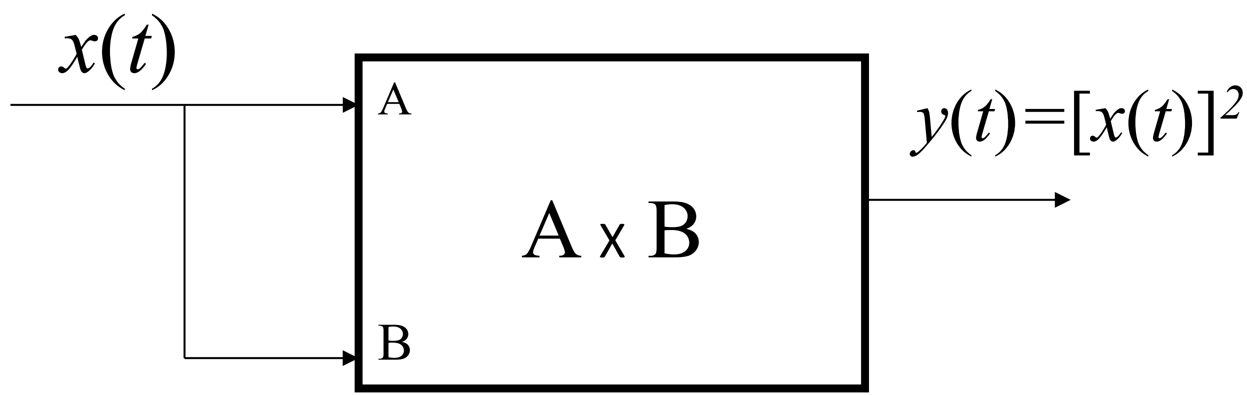
- Discrete-to-Continuous systems

$$y(t) = \mathcal{T}\{x[n]\}$$

  - Example: An D-to-A converter
    - The opposite of a sampler
    - Takes the samples a recreates the Continuous Signal

Graphical Representations of a System

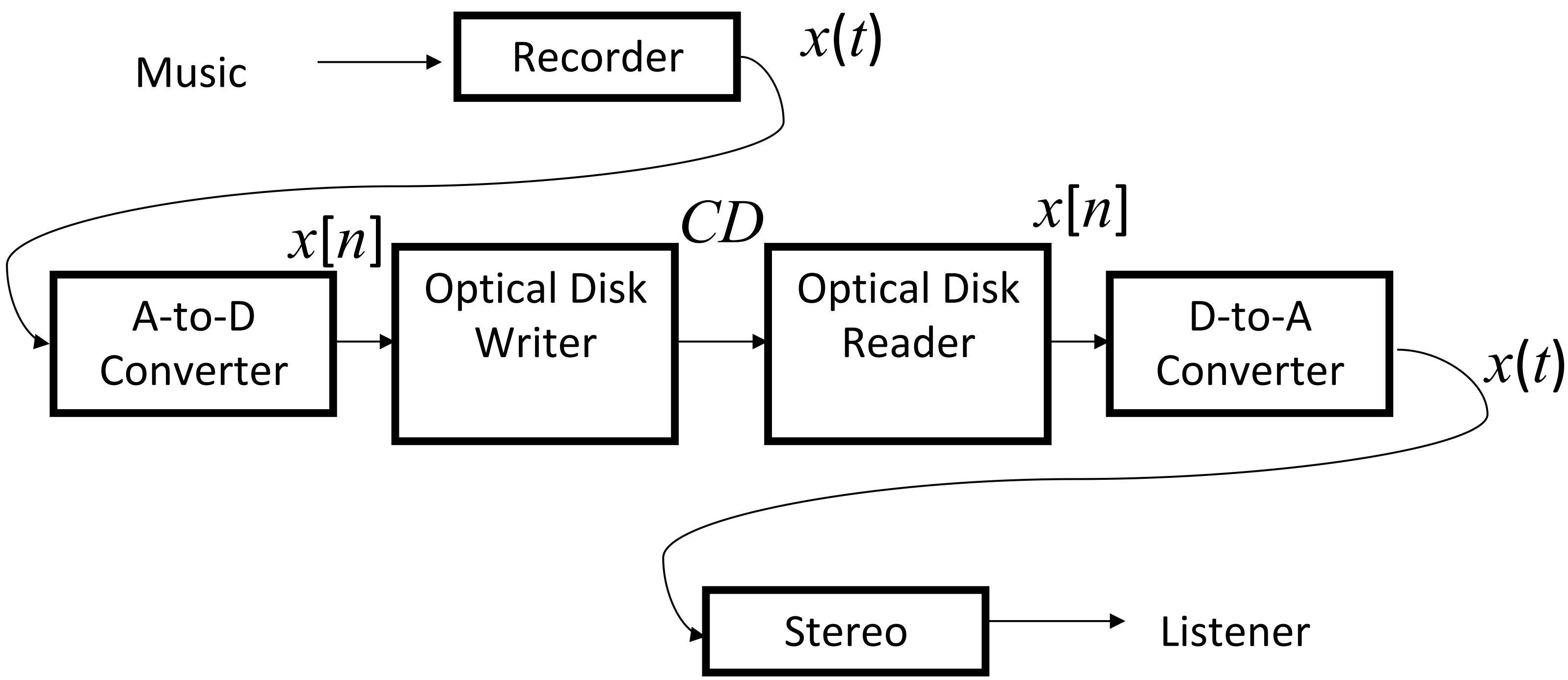




Our Squarer Example

An Example

- Example: A music CD



Sampling

- We can obtain a discrete-time signal by sampling a continuous-time signal at equally spaced time instants, $t_n = nT_s$

$$x[n] = x(nT_s) \quad -\infty < n < \infty$$

- The individual values $x[n]$ are called the samples of the continuous time signal, $x(t)$.
- The fixed time interval between samples, T_s, is also expressed in terms of a sampling rate f_s (in samples per second) such that:

$$f_s = 1/\, T_s \text{ samples/sec.}$$

Continuous-to-Discrete Conversion

- By using a Continuous-to-Discrete (C-to-D) converter, we can take continuous-time signals and form a discrete-time signal.
- There are devices called Analog-to-Digital converters (A-to-D)
- The books chooses to distinguish an C-to-D converter from an A-to-D converter by defining a C-to-D as an ideal device while A-to-D converters are practical devices where real world problems are evident.
  - Problems in sampling the amplitudes accurately
  - Problems in sampling at the proper times

Shannon's Sampling Theorem

- How frequently do we need to sample?
- The solution: Shannon's Sampling Theorem: A continuous-time signal $x(t)$ with frequencies no higher than $f_{\max}$ can be reconstructed exactly from its samples $x[n] = x(nT_s)$, if the samples are taken a rate $f_s = 1 / T_s$ that is greater than $2 f_{\max}$.
- Note that the minimum sampling rate, $2 f_{\max}$, is called the Nyquist rate.

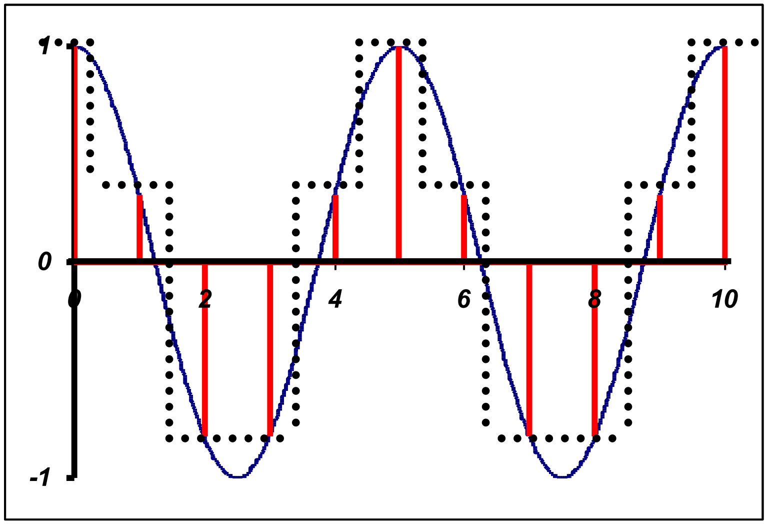
Sampling

- If we sample at the Nyquist rate or higher we can always recover the original continuous signal.
- This is the ideal case practical cases present errors
  - You need a special filter to recover the original signal; practical filter designs only approach the ideal case.
  - Approximation methods are used.
  - You need to know the highest frequency; but most of the time you don’t know it.

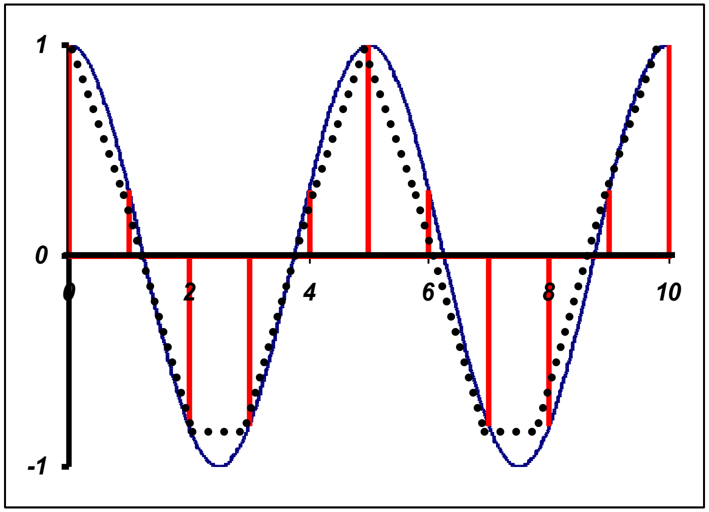
Discrete-to-Continuous Conversion

- An D-to-C converter uses the samples to reconstruct the continuous-time signal by interpolation.
- There are various interpolation algorithms which may be used:
  - Zero-Order Hold
  - Linear
  - Cubic Spline

Interpolation



Zero-Order Hold



Linear

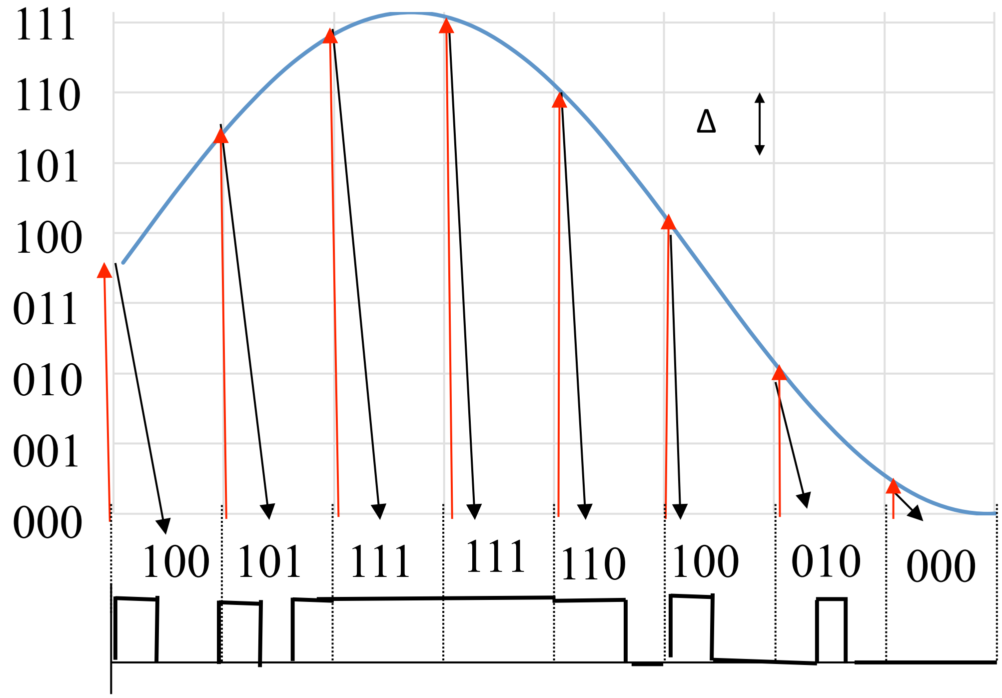
- Oversampling always improves the reconstruction
- Best reconstruction is Low Pass Filter or what the text calls: Ideal Bandlimited Interpolation

Non-sinusoidal Signals

- Sampling and reconstruction processes for any continuous-time signal is the same
  - Shannon's Sampling theorem
  - Nyquist Rate $f_s \geq 2f_{max}$ to eliminate aliasing
  - Oversampling to improve interpolation
  - Ideal (low pass filter) Bandlimited interpolation

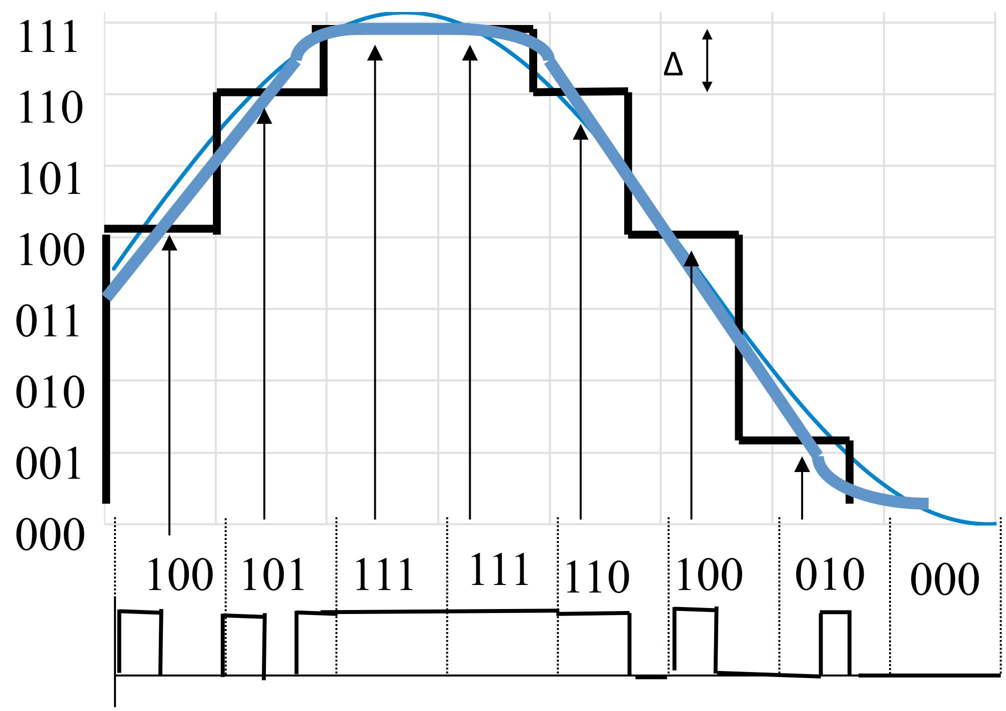
Conversion from Analog to Digital

- This an example of sampling with levels
- There are 3 bits per sample
- The zones are Δ units wide



Digital to Analog Reconstruction

- This an example of the reconstruction of the original signal from the coded samples
- This line ▬ is the staircase approximation of the samples from the codes
- This line ▬ is the approximation as a result of the applying a low pass filter to the staircase approximation
- Note the quantization error/noise



Analog vs Digital

- Noise
  - Analog signals are prone to noise
  - Noise is less damaging to Digital signals since we know what values the digital signal takes on
- Circuitry
  - Digital signals can be easily processed by electronic circuits or Integrated Circuits – ICs
  - Analog signals require filters and other elements to assure that the signal is not distorted
- Transmission
  - More digital information can be transmitted than analog information over the same transmission lines.

Design Process

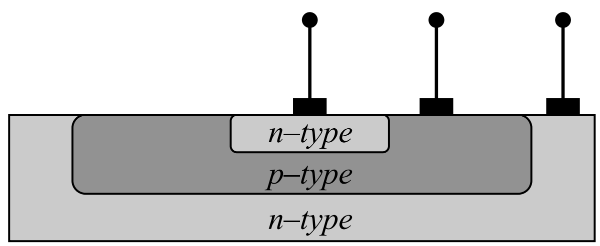
- System Design
  - Initial Development
    - Ideas from Customer Needs
    - Develop Specs from Customer Needs
    - Invent Possible Solutions to meet the Specs
    - Design System Block Diagrams of the Preferred Solution
  - Development of Prototypes
    - Based on the Preferred Solution, a preliminary breadboard circuit design is made and tested
    - If breadboard design meets the Specs, then a prototype circuit is made and tested
    - If the prototype meets the Specs, then Production can begin
  - Production
    - Continual testing against the Spec are made to assure System Quality

Design Process

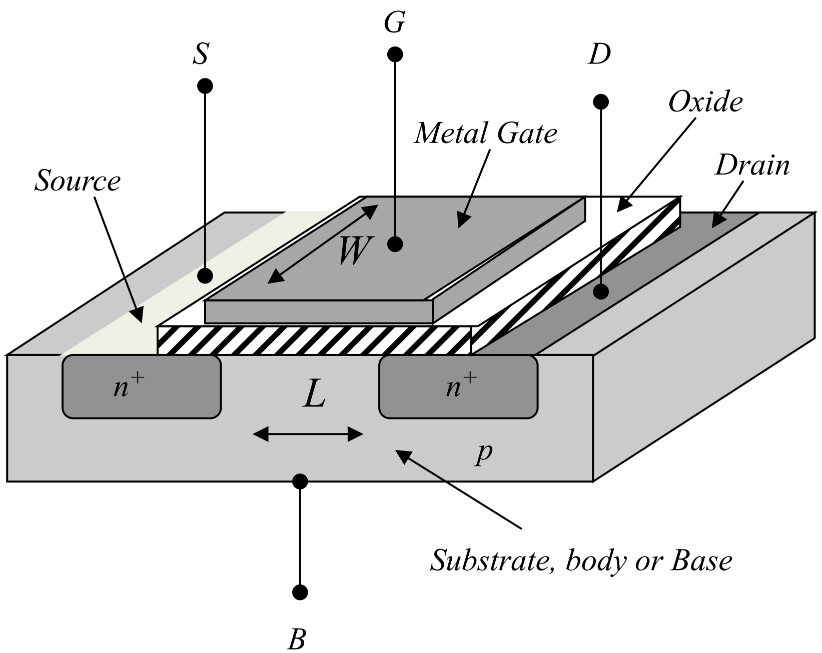
- Circuit Design
  - Develop a Circuit Configuration
  - Select Component Values
  - Estimate Performance
  - Construct Prototype
  - Test
  - Document

Integrated Circuits

- Building many circuits to fit into small packages
- The process to build ICs is based on technologies used to manufacture the transistor

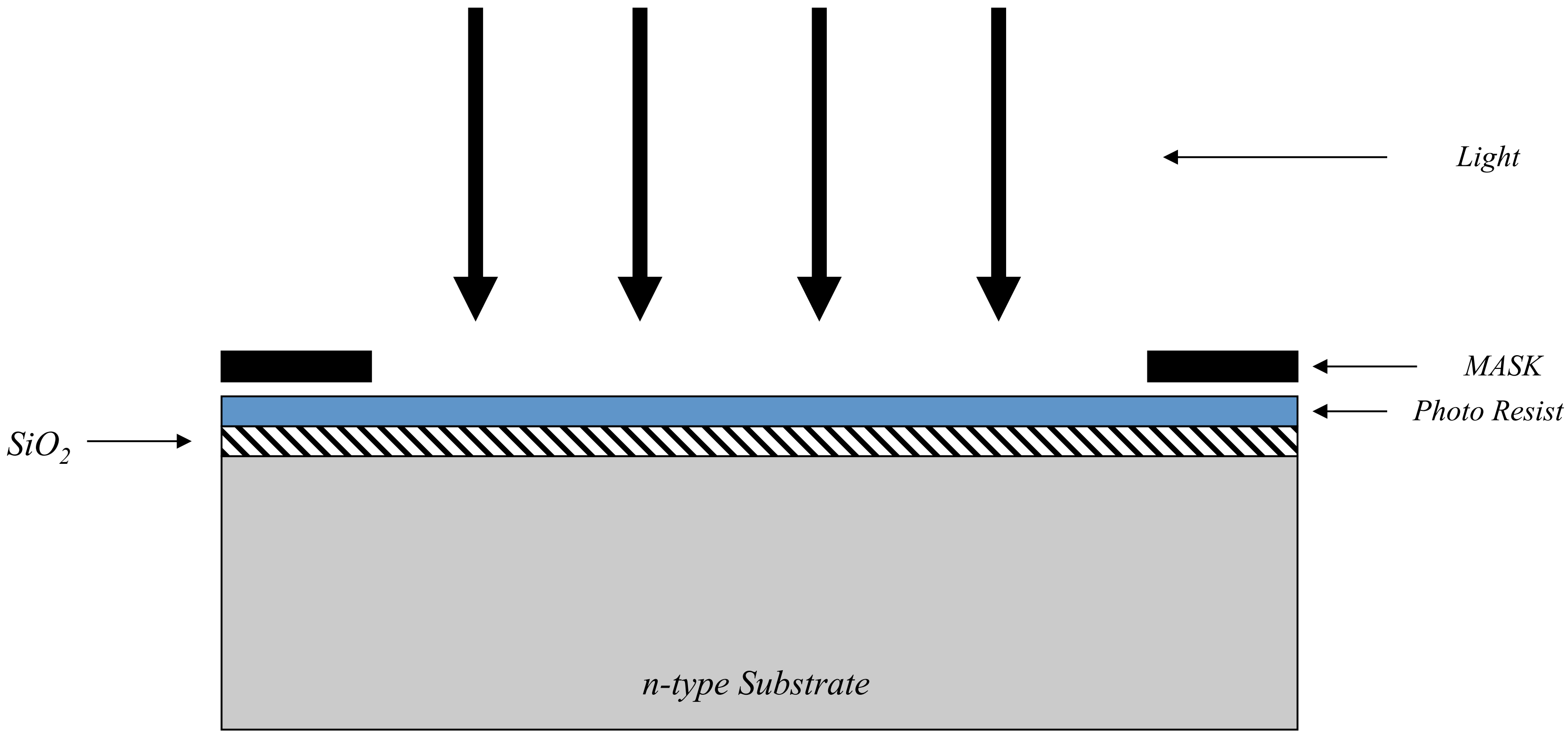


Metal Oxide Semiconductor Field Effect Transistor MOSFET (NMOS) Enhancement Mode

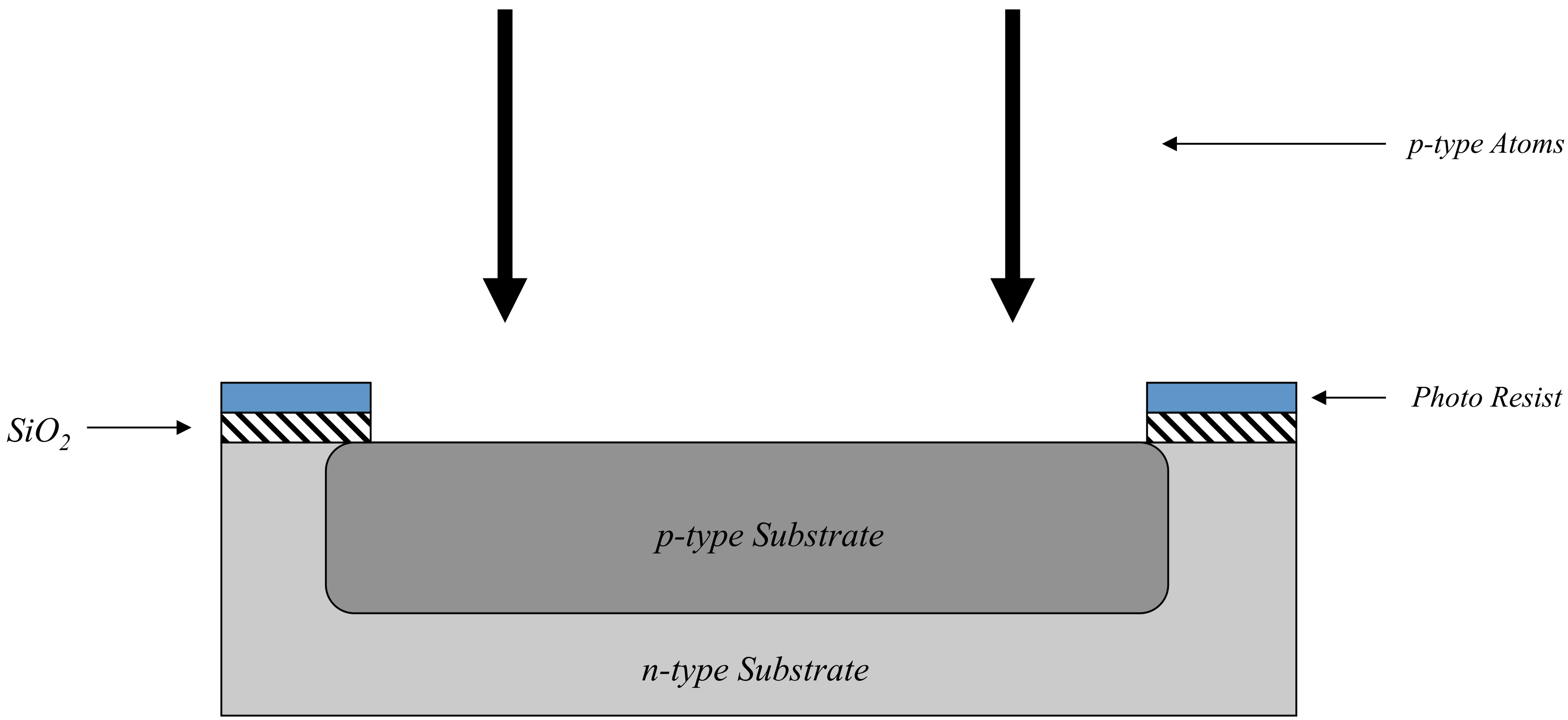


- Consists of Four terminals
  - Drain which is *n*-doped material
  - Source also *n*-doped material
  - Base which is *p*-doped material
  - Gate is a metal and is insulated from the Drain, Source and Base by a thin layer of silicon dioxide ~ .05-.1mm thick
- Basically, an electric current flowing from drain to source, i_D, is controlled by the amount of voltage (electric field) appearing between the gate and base (note that the base and source are usually tied together and therefore, it is referred to as the gate to source voltage or gate voltage), v_{GS}.
- i_D flows through a channel of n-type material which is induced by v_{GS}. The amount of i_D is a function of the thickness of the channel and the voltage between drain and source, v_{DS}
- However, the thickness of channel is controlled by the level of gate voltage. (The width, .5 to 500 mm, and length, .2 to 10 mm, of the channel is shown in the diagram.)

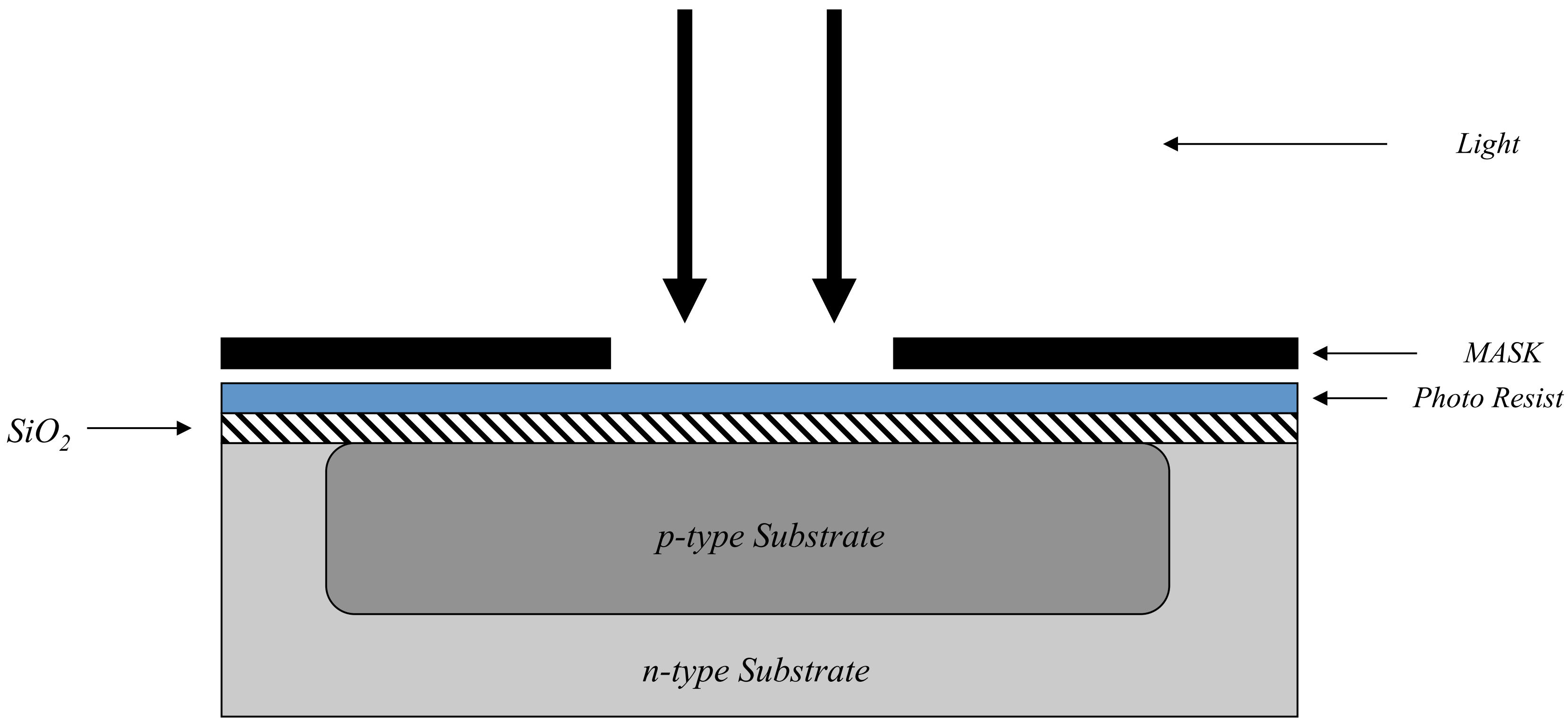
IC Fabrication
Using Photolithography



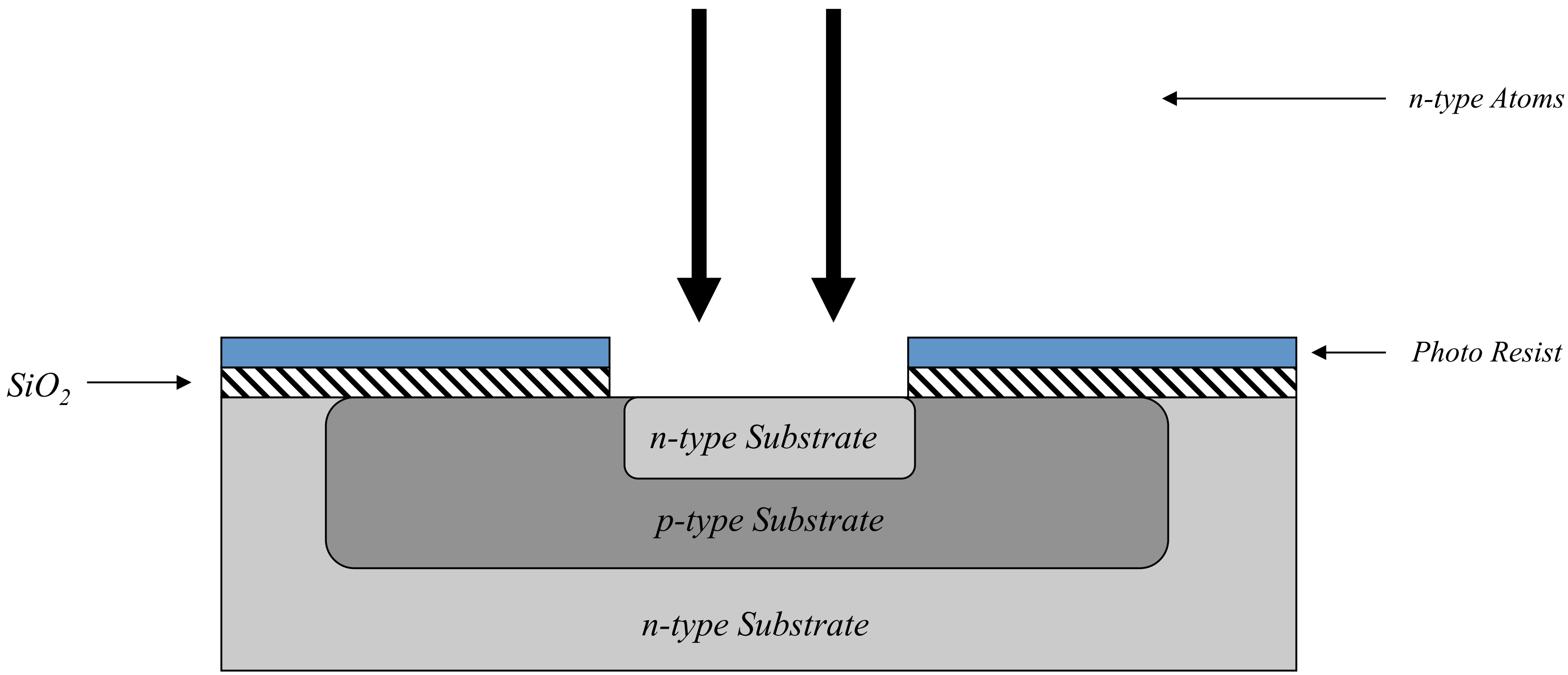
IC Fabrication Using Photolithography



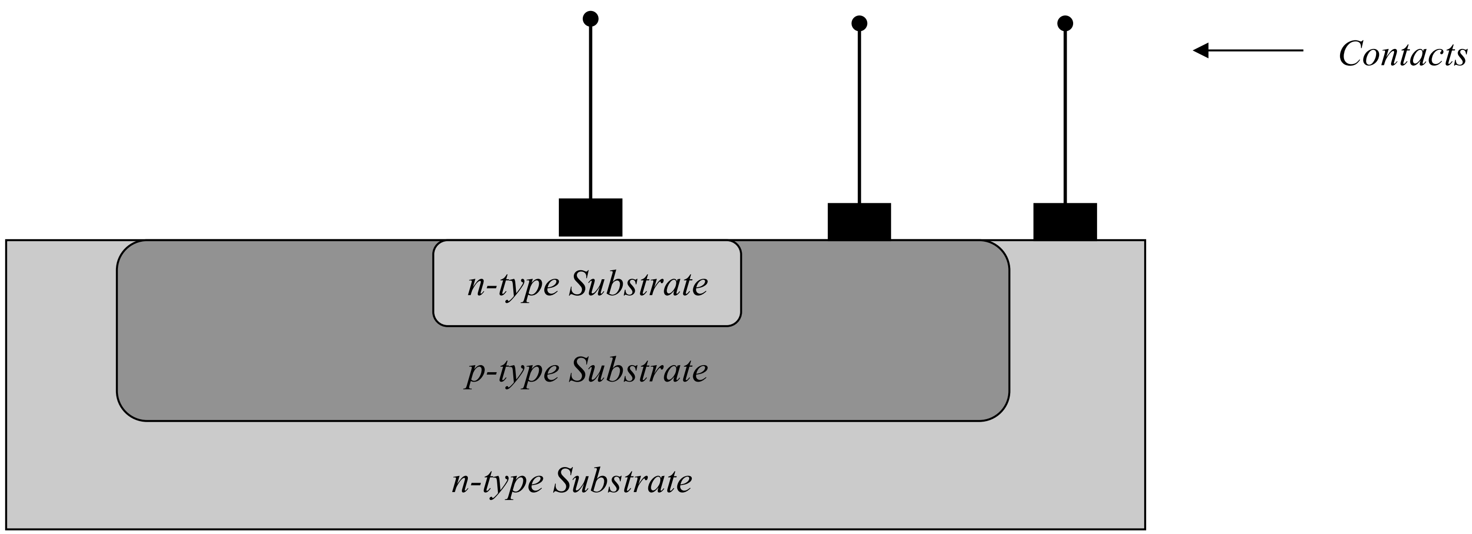
IC Fabrication
Using Photolithography



IC Fabrication Using Photolithography



IC Fabrication Using Photolithography



Homework

1. For the ECG signal following
   a. What is the minimum sampling rate for the following periodic signal?
   b. What would be a good sampling rate to choose to ensure that all of the necessary features were captured?

   Period: 1 sec

   Smallest detail: 0.0005 sec

Homework

2. Describe the benefits of Digital Designs vs Analog Designs.
3. In the Design process what governs the design?
4. What is the purpose of documentation during the design process?
5. HONORS STUDENTS ADD THE FOLLOWING

For the typical human voice spectrum what would be the minimum sampling rate? Assuming data is transmitted using 10bits/sec, how many levels are needed to converted the voice signal from analog to.