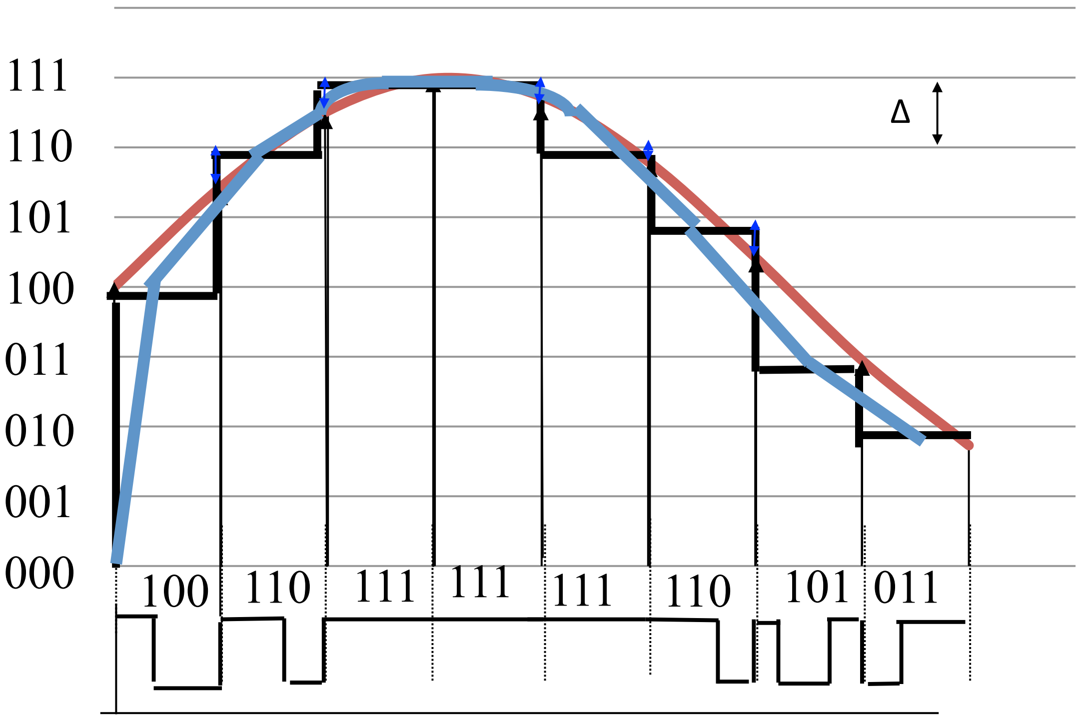
Basic Electronics

Lecture 3

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 ↕ Δ



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

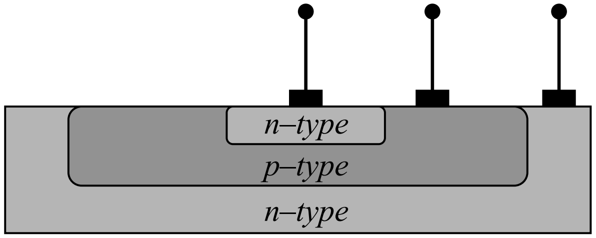
- System Design
  - Initial Development
    - Ideas from Customer Needs
    - Develop Specs from Customer Needs
    - Invent Possible Solutions to meet the Specs
    - Design System Block Diagrams of the Preferred Solution
  - Development of Prototypes
    - Based on the Preferred Solution, a preliminary 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

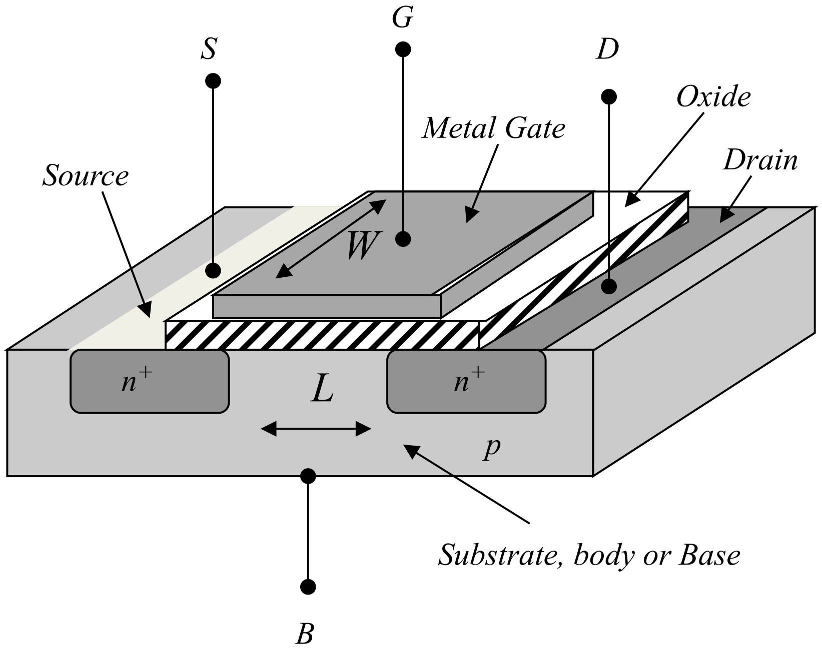
- Circuit Design
  - Develop a Circuit Configuration
  - Select Component Values
  - Estimate Performance
  - Construct Prototype
  - Test
  - Document

Integrated Circuits

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

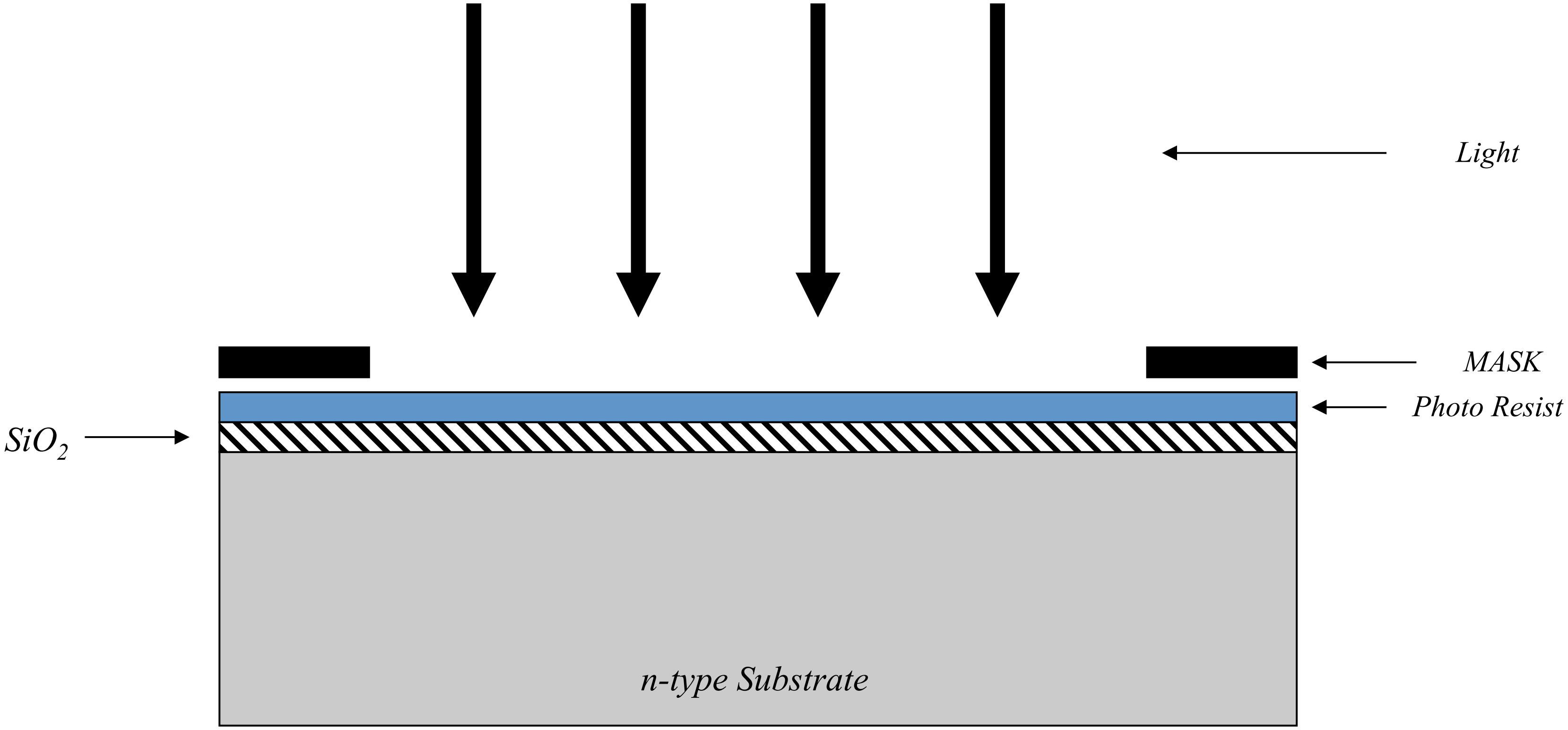


Metal Oxide Semiconductor Field Effect Transistor MOSFET (NMOS) Enhancement Mode

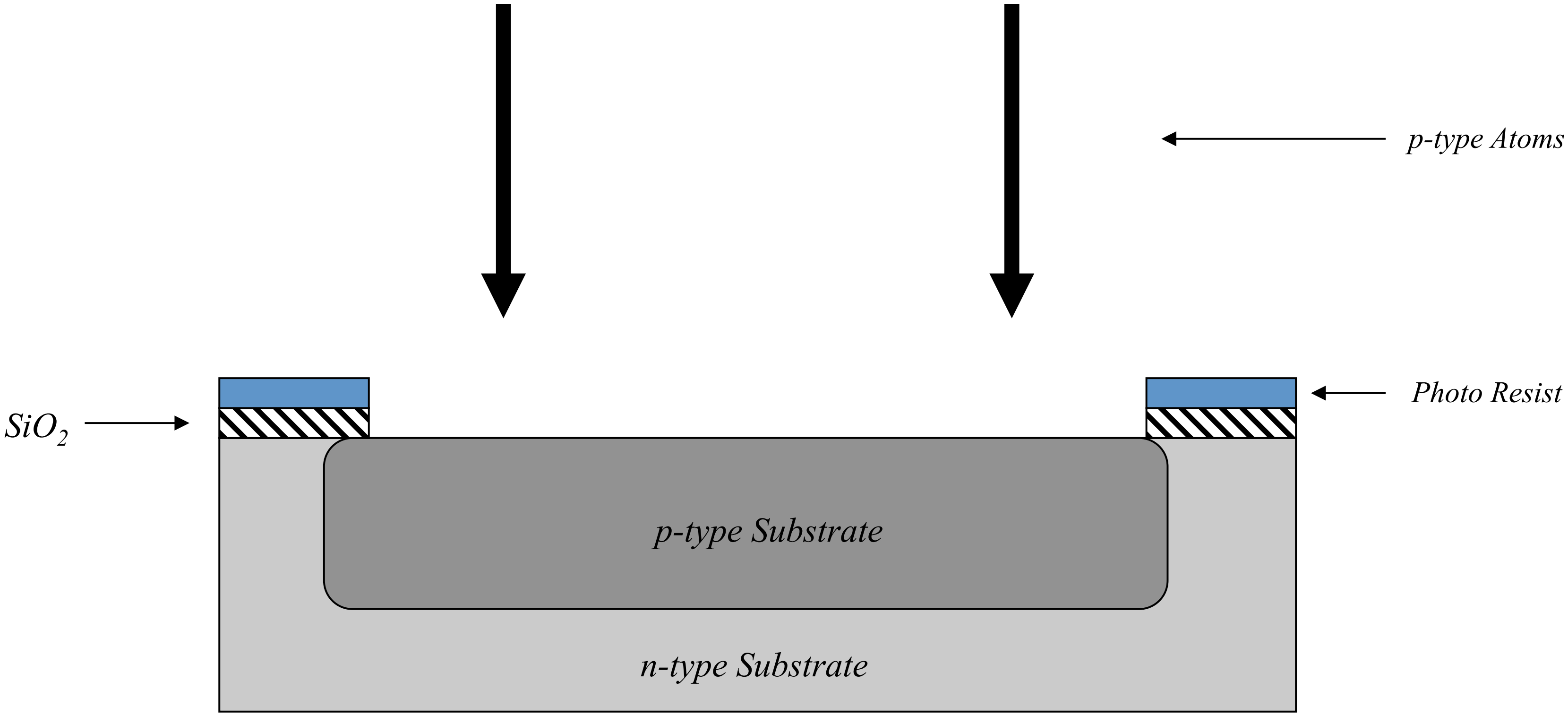


- Consists of Four terminals
  - Drain which is *n*-doped material
  - Source also *n*-doped material
  - Base which is *p*-doped material
  - Gate is a metal and is insulated from the Drain, Source and Base by a thin layer of silicon dioxide ~ .05-.1mm thick
- Basically, an electric current flowing 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.)

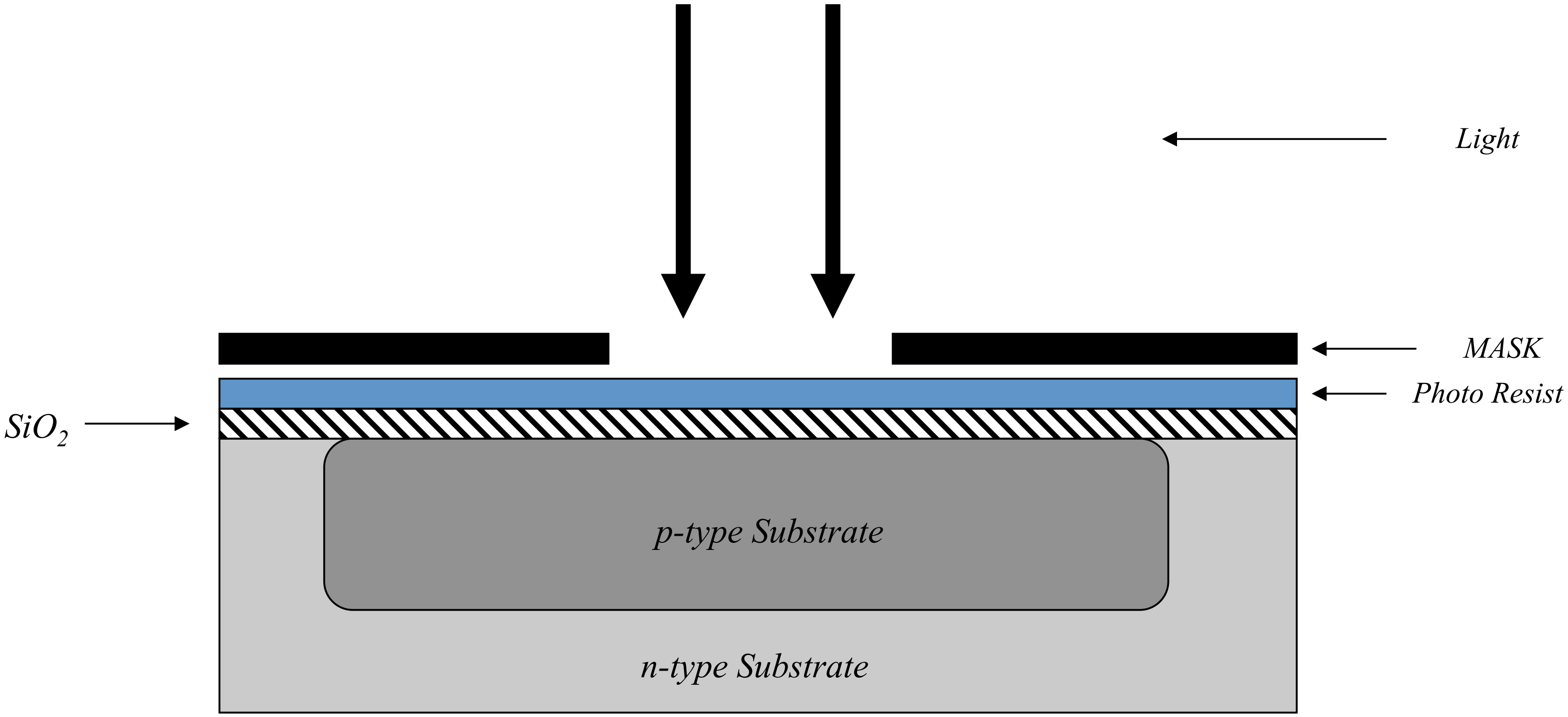
IC Fabrication



IC Fabrication



IC Fabrication



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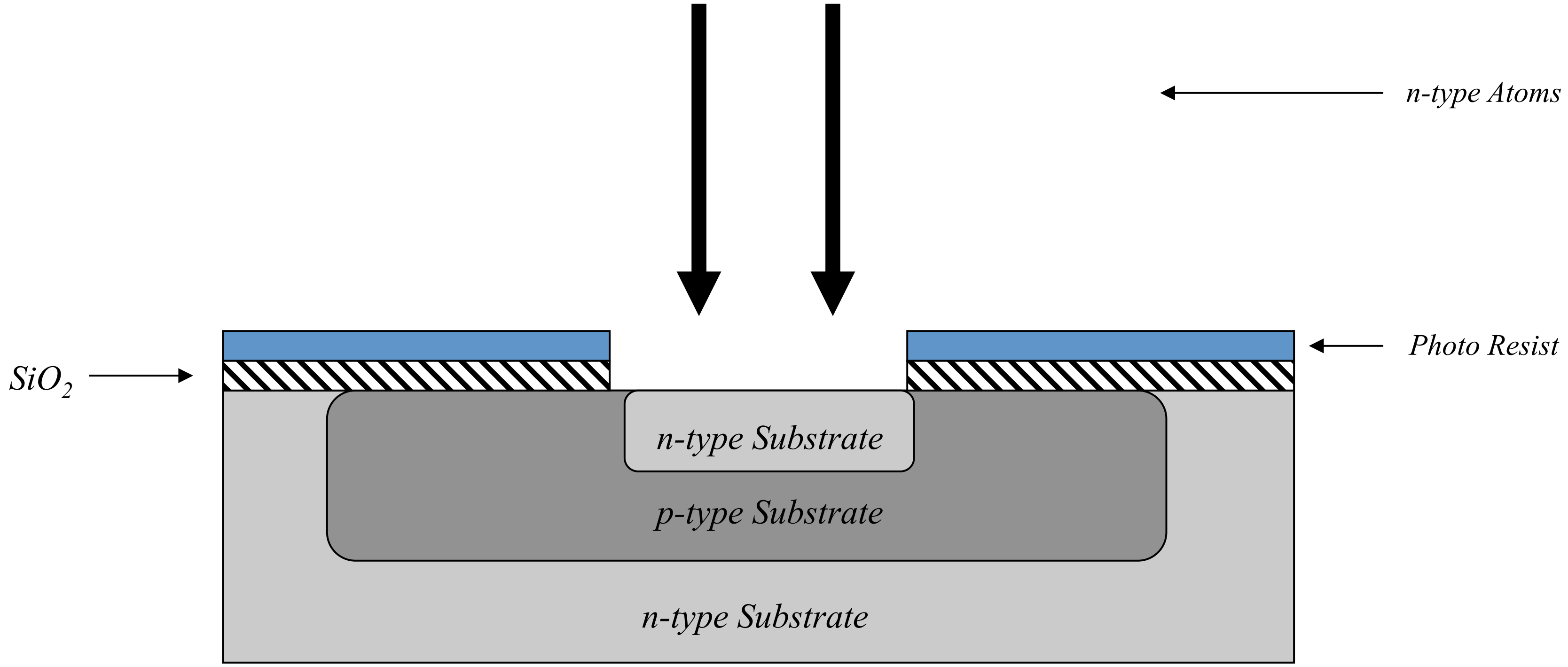
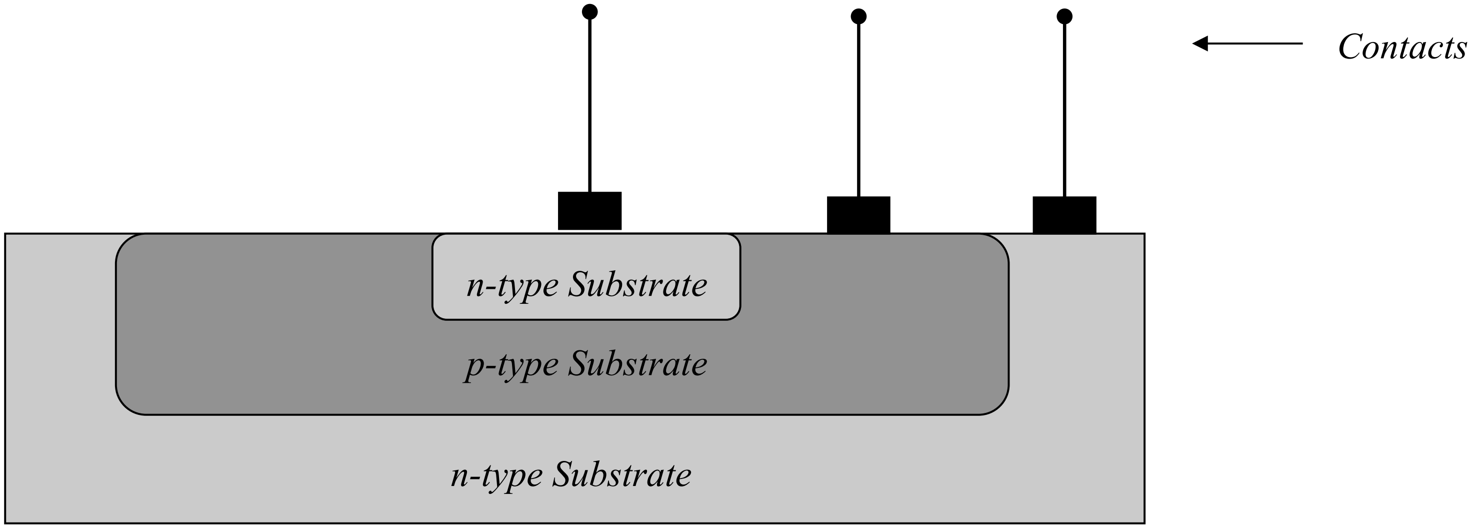


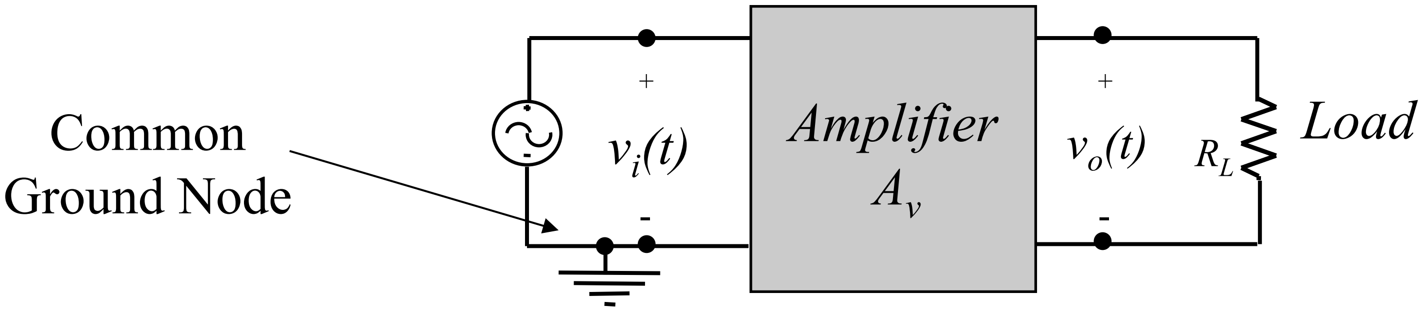
IC Fabrication



Basic Amplifier Types

- An amplifier produces an output signal with the same wave shape as the input signal but usually with a larger amplitude.

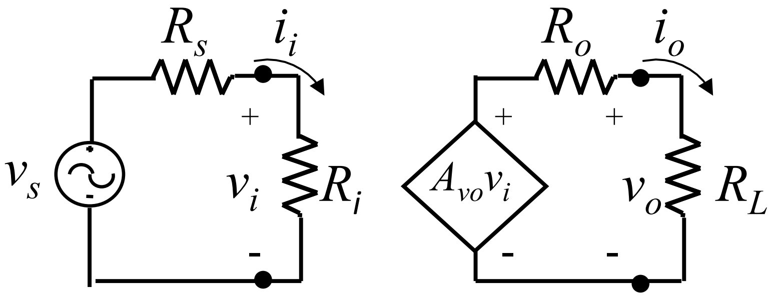
$$v_o(t)=A_v\,v_i(t)$$



- A_v is called the voltage gain and if <0 then the amplifier is inverting; otherwise non-inverting.

Voltage-Amplifier Model

- Parameters:
  - Open Circuit Voltage Gain A_{vo}
  - Input and Output impedance $R_i=v_i / i_i$; $R_o=v_o / i_o$ (after removing R_L and replacing all sources with their internal resistance)
  - Voltage Gain $A_v=v_o / v_i = A_{vo} R_L / (R_L + R_o) \neq A_{vo}$
  - Current Gain $A_i=i_o / i_i=(v_o / R_L)/(v_i / R_i)=A_v R_i / R_L$
  - Power Gain $G=P_o / P_i=v_o i_o / v_i i_i=A_v A_i =(A_v)^2 R_i / R_L$

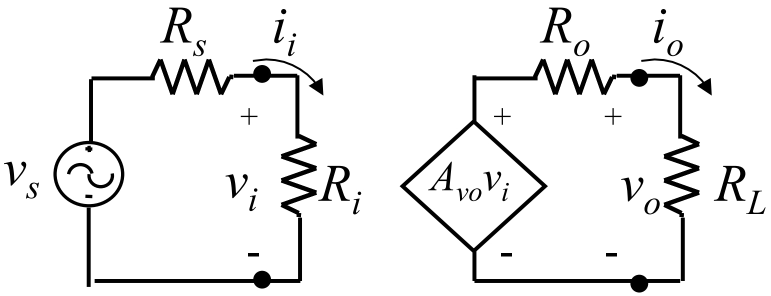


Voltage-Amplifier Model

- System Parameters:
  - Voltage Gain $A_{vs}=v_o / v_s = A_{vo} R_L / (R_L + R_o)*R_i/(R_i+R_s)$

    $\neq A_{vo} \neq Av$
  - Power Gain $G_s=P_o / P_s=v_o i_o / v_s i_s=A_{vs}A_i$

    $=(A_v)^2 R_i / R_L * R_i/(R_i+R_s)$



Voltage-Amplifier Model

Example:

v_s=10 mv, R_s=2MΩ, R_L=10Ω

A_{vo}=100, R_i=2MΩ, R_o=5Ω

$$v_i = v_s \frac{R_i}{R_i + R_s} = 10m \frac{2M}{2M + 2M} = 5mV$$

$$A_{vo} v_i = 100 \times 5m = .5V$$

$$v_o = A_{vo} v_i \frac{R_L}{R_L + R_o} = .5 \times \frac{10}{10+5} = 0.33V$$

$$A_v = \frac{v_o}{v_i} = \frac{0.33}{5m} = 66.7; A_{vs} = \frac{v_o}{v_s} = \frac{0.33}{10m} = 33.3$$

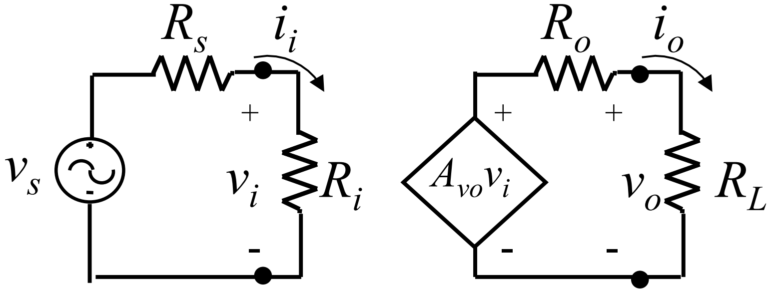
$$A_i = \frac{i_o}{i_i} = \frac{v_o/R_L}{v_i/R_i} = A_v \frac{R_i}{R_L} = 66.7 \times \frac{2M}{10} = 1.33 \times 10^7$$

$$G = 1.33 \times 10^7 \times 66.7 = 8.9 \times 10^8 ; G_s = 1.33 \times 10^7 \times 33.3 = 4.4 \times 10^8$$

Note that A_v = 66.7 and A_{vo} = 100

This difference is due to R_L and R_o; that is the effects of the Load

Also A_{vs}=33 which is due to R_o and R_i



Power Supplies and Efficiency

- In addition to the DC power, there is power from the source which is delivered to the input of the amplifier, P_i. (note this not the total power provided by this source)
- Therefore, the total input power is $P_{DC} + P_i$
- A portion of this power is used to provide the gain and is delivered the output load, P_L
- The remainder of this power is dissipated by the components of the amplifier, P_d

$$P_{DC} + P_i = P_d + P_L$$

- The amount of from the DC source delivered to the load is called the power efficiency, η

$$\eta = P_L \, / \, P_{DC}$$

Power Supply Efficiency

$$P_i = \frac{v_i^{\,2}}{R_i}$$

$$v_i = v_s \frac{R_i}{R_i + R_s} = 2m\frac{100k}{200k} = 1mv$$

$$P_i = \frac{v_i^{\,2}}{R_i} = \frac{1\times10^{-6}}{10^5} = 10^{-11} = 10\,pW$$

$$P_o = \frac{v_o^{\,2}}{R_L}$$

$$v_o = A_{vo} v_i \frac{R_L}{R_L + R_o} = 10^4 \times 1m \times \frac{8}{8+2} = 8V$$

$$P_o = \frac{v_o^{\,2}}{R_L} = \frac{64}{8} = 8W$$

$$P_{DC} = V_{AA} I_{AA} + V_{BB} I_{BB} = 15\times1 + 15\times0.5 = 22.5W$$

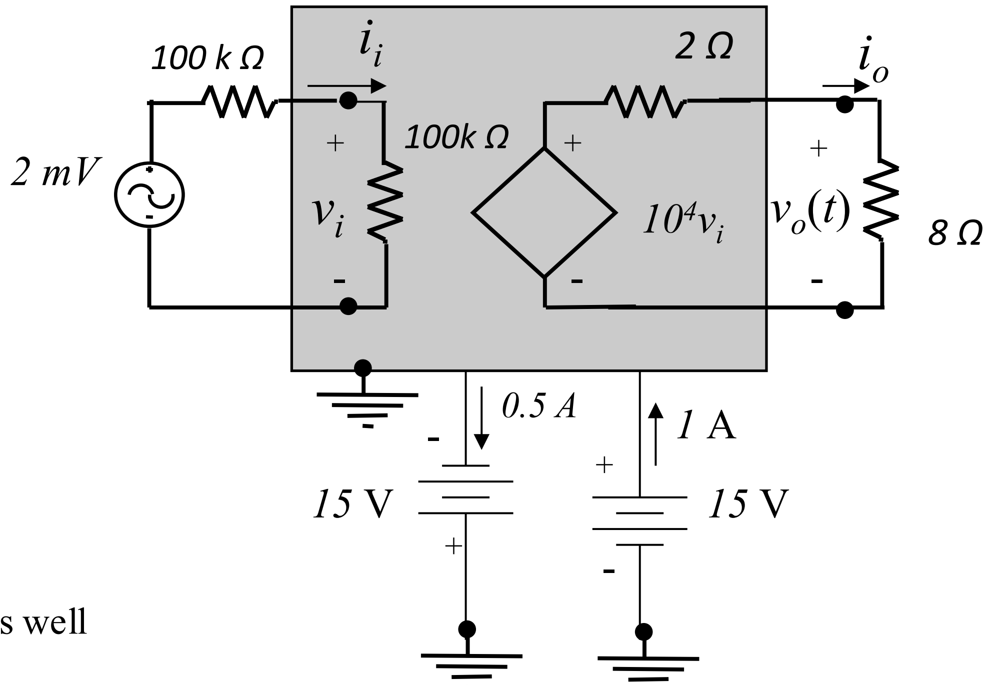
$$\eta = \frac{P_o}{P_{DC}} = \frac{8}{22.5} = 35.6\%$$

$$P_d = P_{DC} + P_i - P_o = 22.5 + 10p - 8 \approx 14.5W$$

Also the source resistor dissipates some power as well

$$i_i = \frac{v_i}{R_i} = \frac{1m}{100k} = 10^{-8}; i_i^{\,2} R_s = 10^{-16} 100k = 10^{-11} = 10\,pW$$

(But we should have known this already!!!! How?)

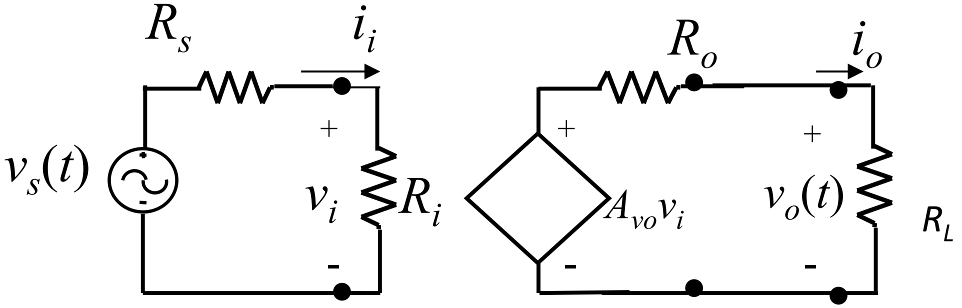


Decibel Notation

- A logarithmic scale is sometimes easier to use:
  - $G_{dB} = 10 \log G$
  - And if $G=G_1G_2$; then $G_{dB}=G_{1\ dB}+G_{2\ dB}$
- And to convert voltage and current to dBs.
  - $A_{v\ dB}= 20 \log |A_v|$
  - $A_{i\ dB}= 20 \log |A_i|$

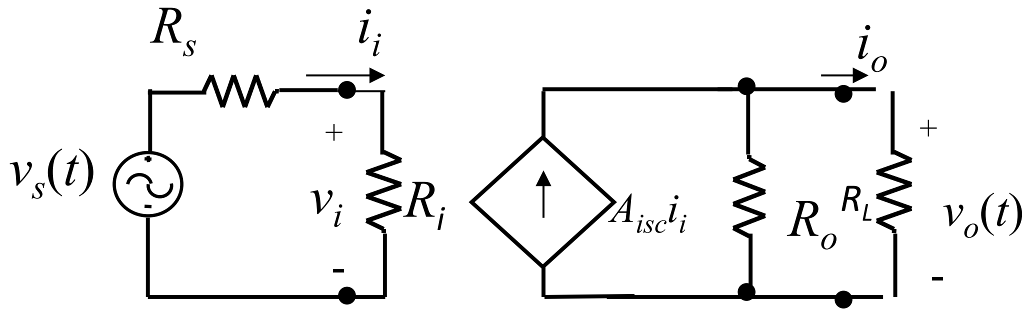
Other Amplifier Models

- Voltage-Amplifier
  - Open-circuit Voltage Gain $v_o = A_{vo} v_i$



Other Amplifier Models

- Current-Amplifier
  - Short Circuit Current Gain $i_o = A_{isc} i_i$



  - This is just the Norton Equivalent of the Voltage-Amplifier since

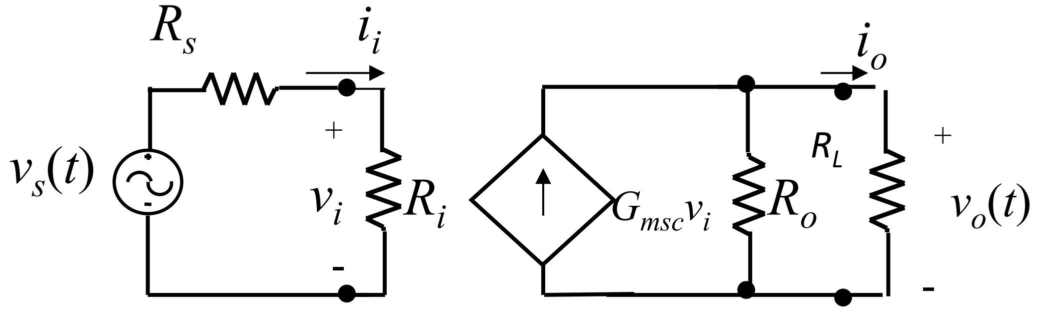
$$V_{oc} = i_o R_o = A_{isc} i_i R_o = A_{vo} v_i = A_{vo} i_i R_i$$

$$A_{isc} R_o = A_{vo} R_i$$

$$A_{isc} = A_{vo} R_i / R_o$$

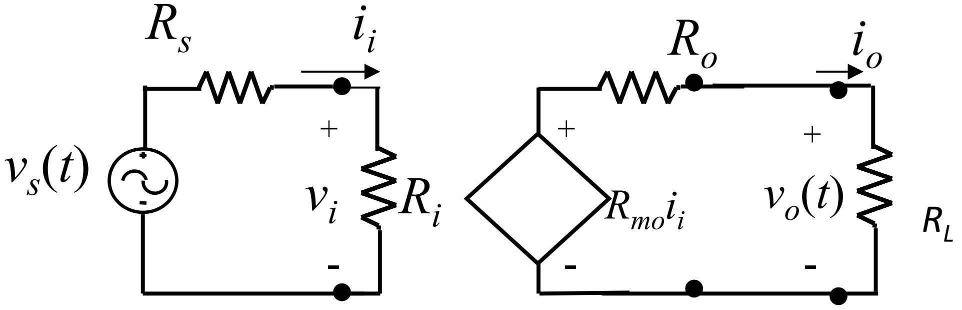
Other Amplifier Models

- Transconductance-Amplifier
  - Short Circuit Transconductance Gain $i_{osc} = G_{msc} v_i$



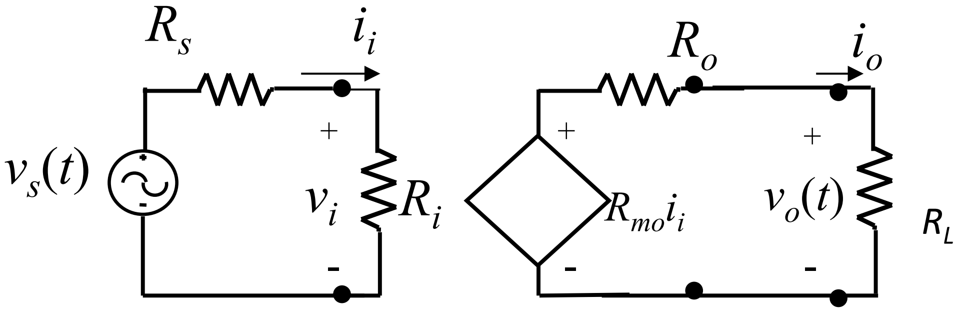
Other Amplifier Models

- Transresistance – Amplifier
  - OpenCircuit Transresistance Gain $v_{osc} = R_{moc}\, i_i$



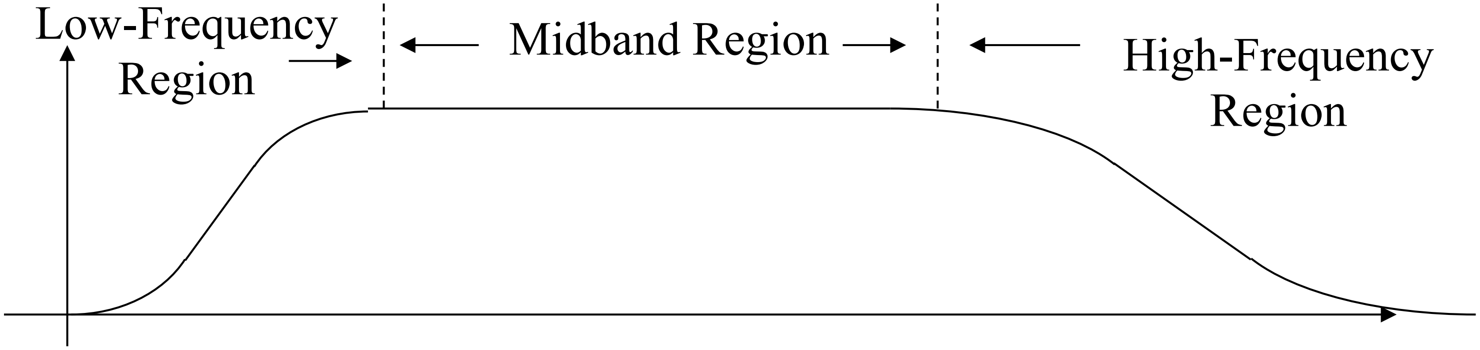
Other Amplifier Models

- Transresistance – Amplifier
  - OpenCircuit Transresistance Gain $v_{osc} = R_{moc}\, i_i$



Frequency Response

- We look at the spectrum in terms of regions or bands:
  - Low, mid, and high frequency bands



Frequency Response

- We define parameters associated with the spectrum of the output of an amplifier
  - Half power frequencies or (3 dB points):
    - f_L low frequency 3db point
    - f_H High frequency 3db point
  - Bandwidth (the distance in frequency between 3 dB points

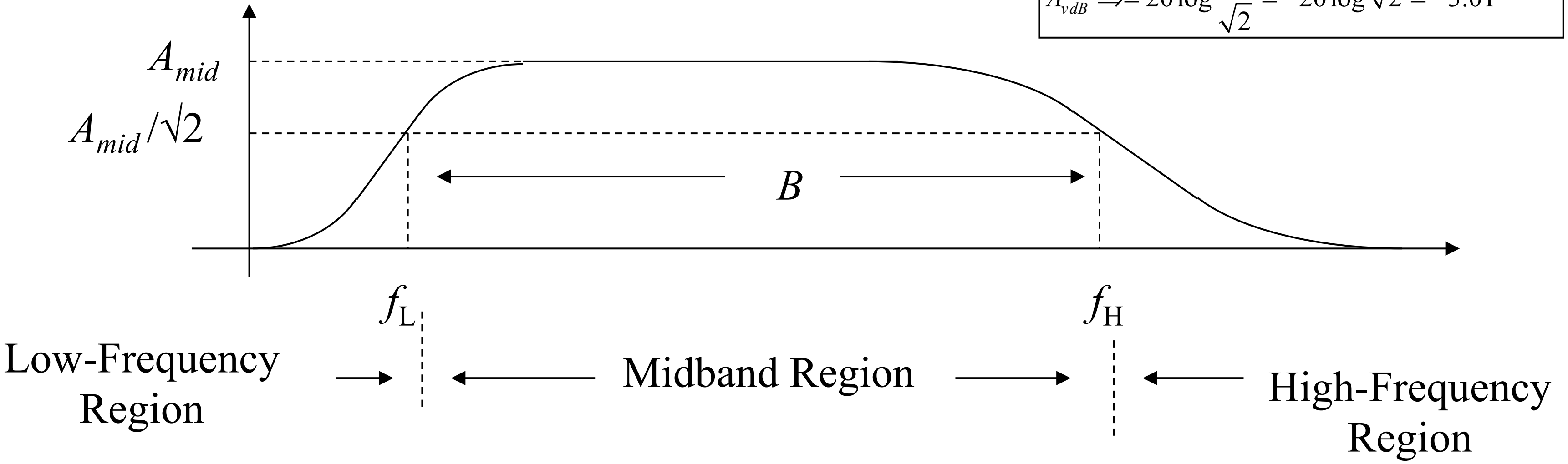
$$\text{Gain at max} = A_{mid}$$

$$\text{Power at max} = \frac{A_{mid}^2}{R_L}; \text{Half Power} = \frac{A_{mid}^2}{2R_L}$$

$$\frac{\text{Half Power}}{\text{Power at max}} = \frac{A_{mid}^2}{2R_L} \Big/ \frac{A_{mid}^2}{R_L} = \frac{1}{2}$$

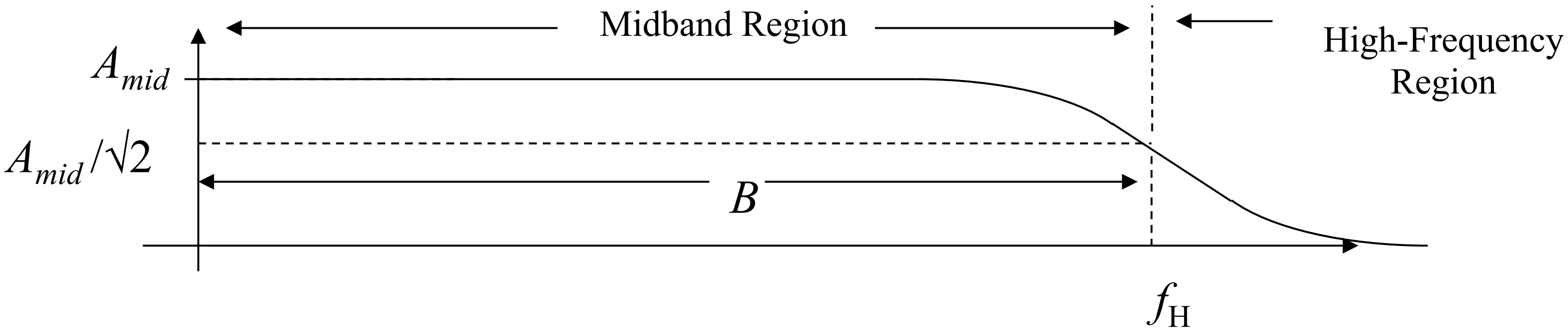
$$\text{Voltage reduction at Half Power} = \frac{1}{\sqrt{2}}$$

$$A_{vdB} \Rightarrow = 20\log\frac{1}{\sqrt{2}} = -20\log\sqrt{2} = -3.01$$

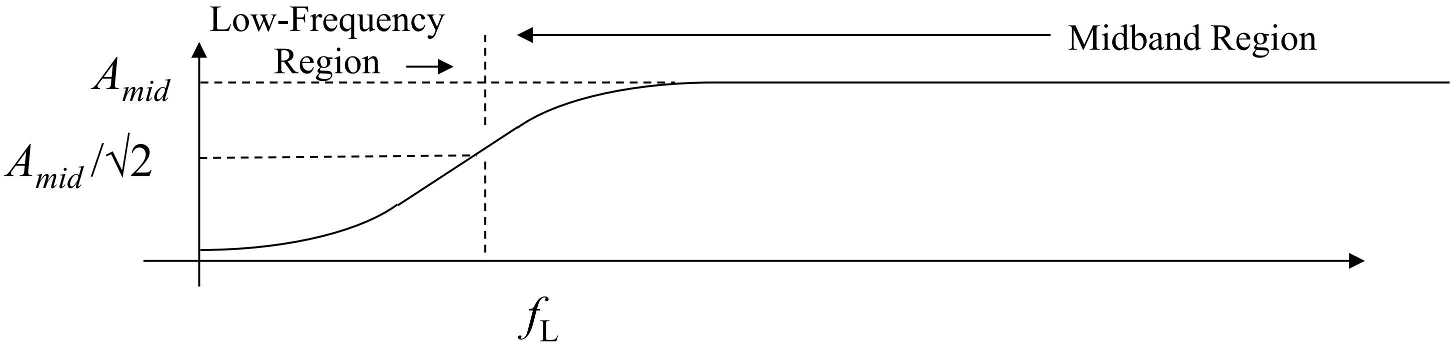


Different Types of Amplifiers

- Low pass amplifier – Let’s lower frequencies pass; rejects higher frequencies

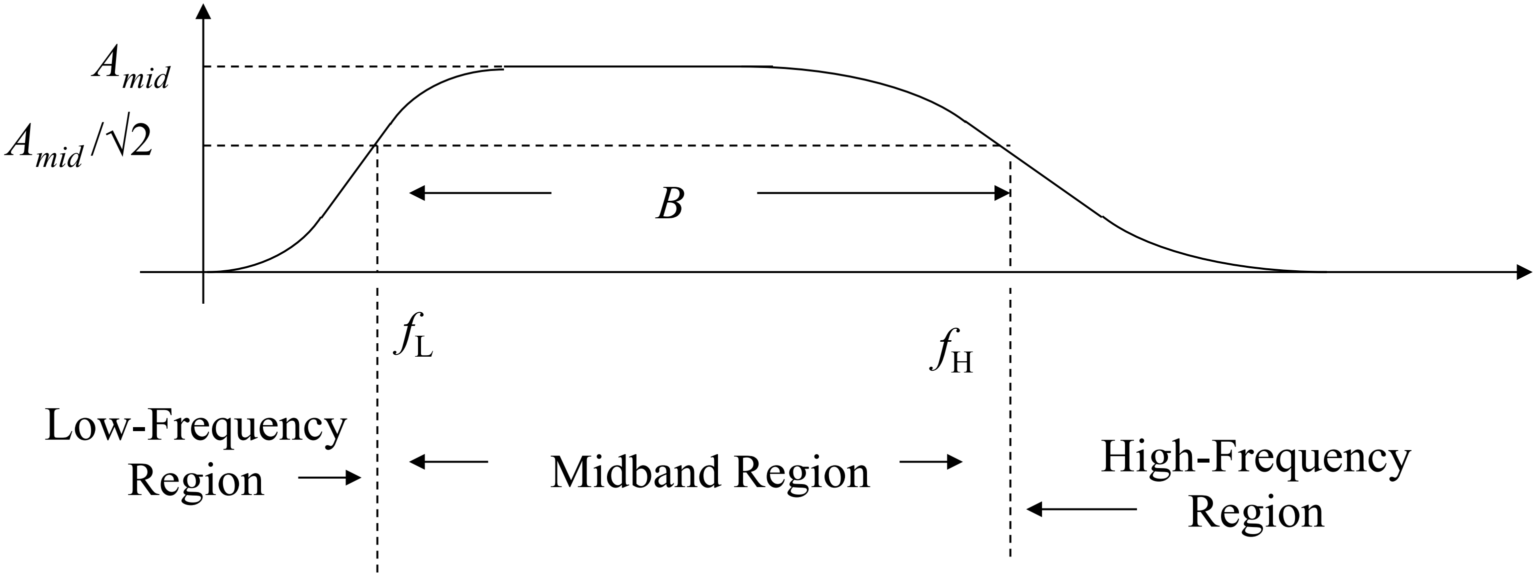


- High pass amplifier – Let’s higher frequencies pass; rejects lower frequencies



Frequency Response

- Band pass amplifier – Let's a narrow band frequencies pass; rejects higher frequencies



Differential Amplifiers

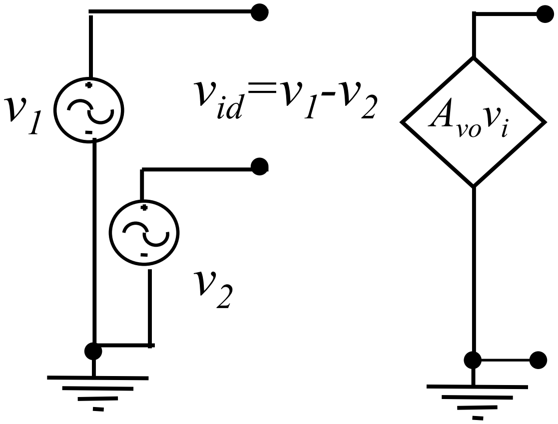
- Output of the amplifier is a function of the difference of the inputs:

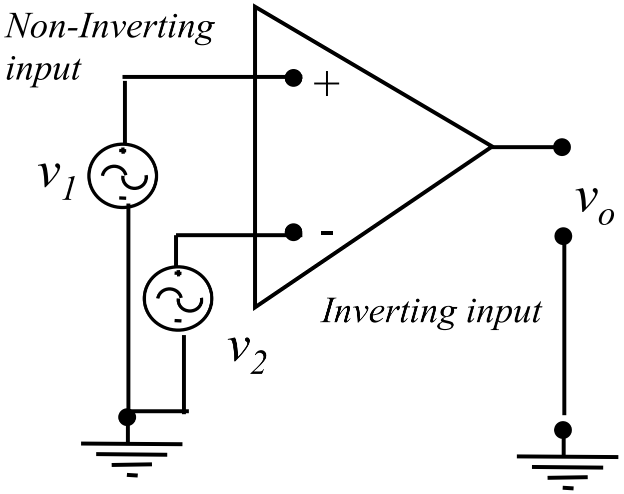
$$v_o=A_d(v_{i1} - v_{i2})$$

- However, most real Differential Amplifier are affected by the average of the input and we define the common mode input signal

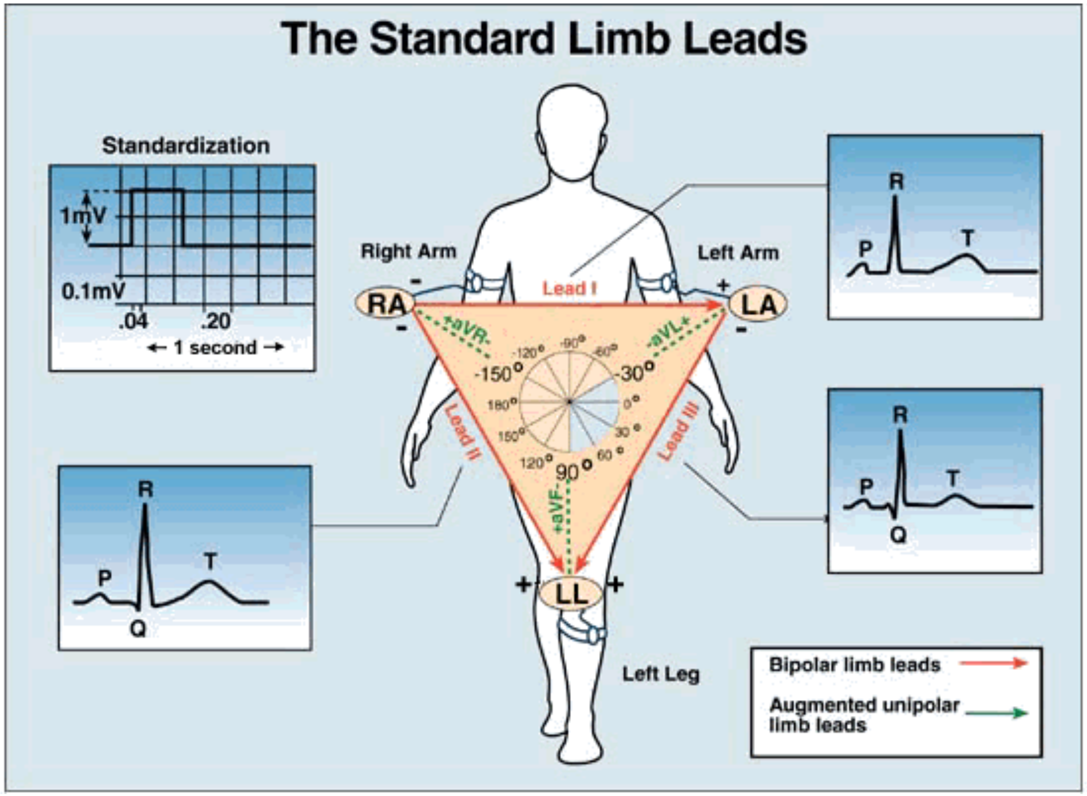
$$v_{\text{icm}} =1/2(v_{i1} + v_{i2})$$

- Therefore, $v_o=A_d(v_{i1}-v_{i2})+A_m\, v_{\text{icm}}$ and the ratio of A_d to A_m is called the common mode rejection ratio





Uses of the Differential Amplifier



Homework

- Probs
  - 1.15 repeat using a load resistance of 8 Ω and then a load resistance of 2 Ω*;* describe what happens and why – prove it for extra credit.
  - 1.17 Use input resistance = 100 Ω, input voltage 10*m* V rms and output voltage 10 V rms
  - 1.18,
  - 1.19 use load resistor of 100k Ω and source resistor of 500k Ω