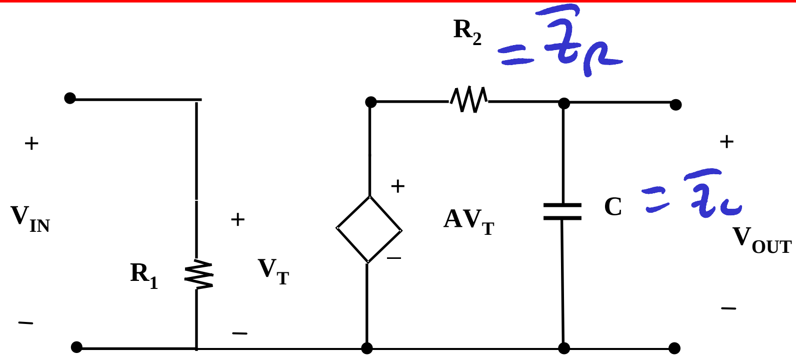
EE100Su08 Lecture #14 (July 28th 2008)

- Outline
  - MultiSim licenses: trying to get new licenses
  - HW #2: regrade deadline: Monday, 07/28, 5:00 pm PST.
  - Midterm #1 regrades: DONE!
  - QUESTIONS?
  - Bode plots
  - Diodes: Introduction
- Reading
  - Appendix E* (skip second-order resonance bode plots), Chapter 1 from your reader (skip second-order resonance bode plots)
  - Chapter 2 from your reader (Diode Circuits)

Example Circuit



$$\overline{V_{out}} = \frac{\overline{Z_c}}{\overline{Z_R} + \overline{Z_c}} \cdot A\overline{V_T}$$

$$TransferFunction = \frac{\mathbf{V}_{OUT}}{\mathbf{V}_{IN}}$$

$$\frac{\mathbf{V}_{OUT}}{\mathbf{V}_{IN}} = \frac{AZ_c}{Z_R + Z_c}$$

A = 100

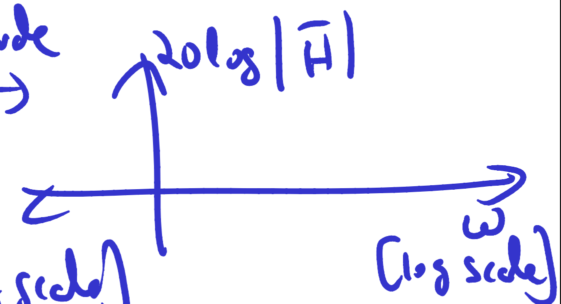
R_1 = 100,000 Ohms

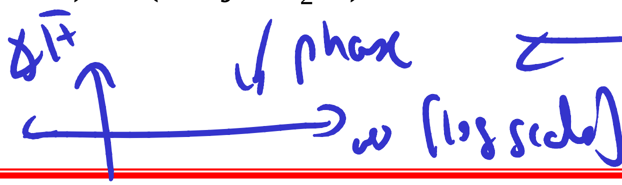
R_2 = 1000 Ohms

C = 10 uF

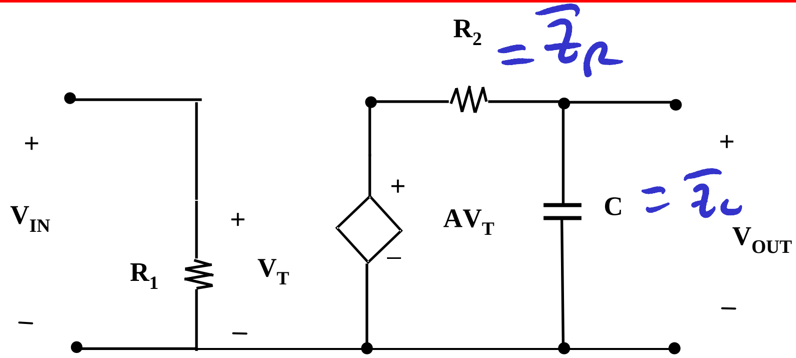
$$\overline{H} = \frac{\mathbf{V}_{OUT}}{\mathbf{V}_{IN}} = \frac{A(1/\,jwC)}{(R_2 + 1/\,j\omega C)} = \frac{A}{(1 + j\omega R_2 C)}$$

magnitude →





Example Circuit



$$\bar{V}_{out} = \frac{\bar{Z}_C}{\bar{Z}_R + \bar{Z}_C} \cdot A\bar{V}_T$$

$$\bar{H} = \frac{A}{(1 + j\omega R_2 C)}$$

$$20 \log |\bar{H}| = 20 \log \frac{|A|}{|1 + j\omega R_2 C|} = 20 \log \left(\frac{A}{\sqrt{1 + (\omega R_2 C)^2}} \right)$$

$$20 \log |\bar{H}| = 20 \log A - 20 \log \sqrt{1 + (\omega R_2 C)^2}$$

sketch individually & subtract!

ω (log-scale)

A = 100

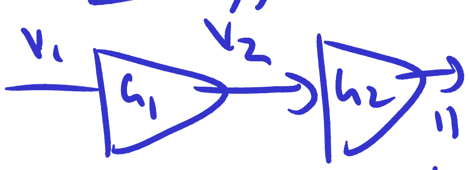
R_1 = 100,000 Ohms

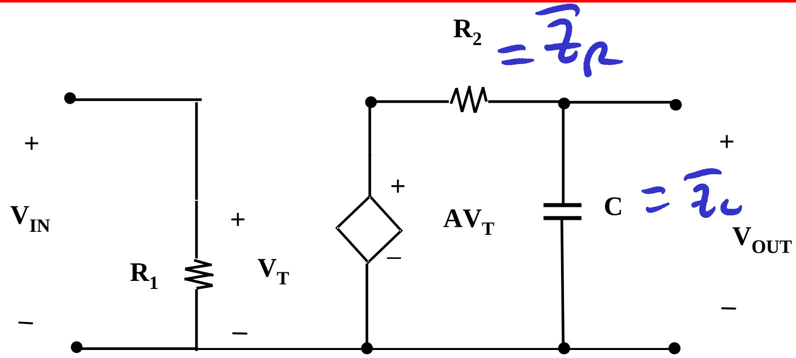
R_2 = 1000 Ohms

C = 10 uF

Example Circuit

Note: $G_1 V_1$ // V_2





$R_2 = Z_R$

$C = Z_C$

$$V_{OUT} = \frac{Z_C}{Z_R + Z_C} \cdot AV_T$$

$$H = \frac{A}{(1 + j\omega R_2 C)}$$

$V_3 = G_2 V_2 = G_2 G_1 V_1 \Rightarrow \boxed{\frac{V_3}{V_1} = G_2 G_1}$

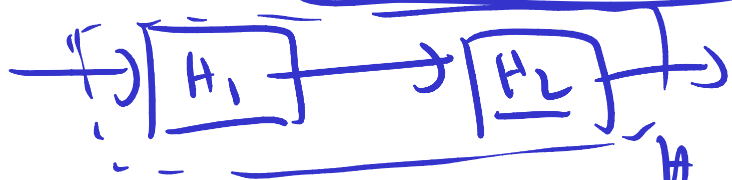
A = 100

R_1 = 100,000 Ohms

R_2 = 1000 Ohms

C = 10 uF

Transfer fns:



$H = H_1 H_2 \Rightarrow 20\log_{10}|H|$

$= 20\log_{10}|H_1 H_2| = 20\log_{10}|H_1| + 20\log_{10}|H_2|$

A Note on the form of transfer fcns.

(1) Only responsible for: $\bar{H} = \frac{A}{(1+j\omega\alpha_1)} \cdot \frac{1}{(1+j\omega\alpha_2)} \cdots \frac{1}{(1+j\omega\alpha_n)}$

(2) Not responsible for second-order transfer fcns:

$$\bar{H} = \frac{A}{(\omega^2 + \alpha\omega + \beta)}$$

Roots are complex conjugate.

Bode Plot: Label as dB

$$\frac{\mathbf{V}_{OUT}}{\mathbf{V}_{IN}} = \frac{A}{(1 + j\omega R_2 C)}$$

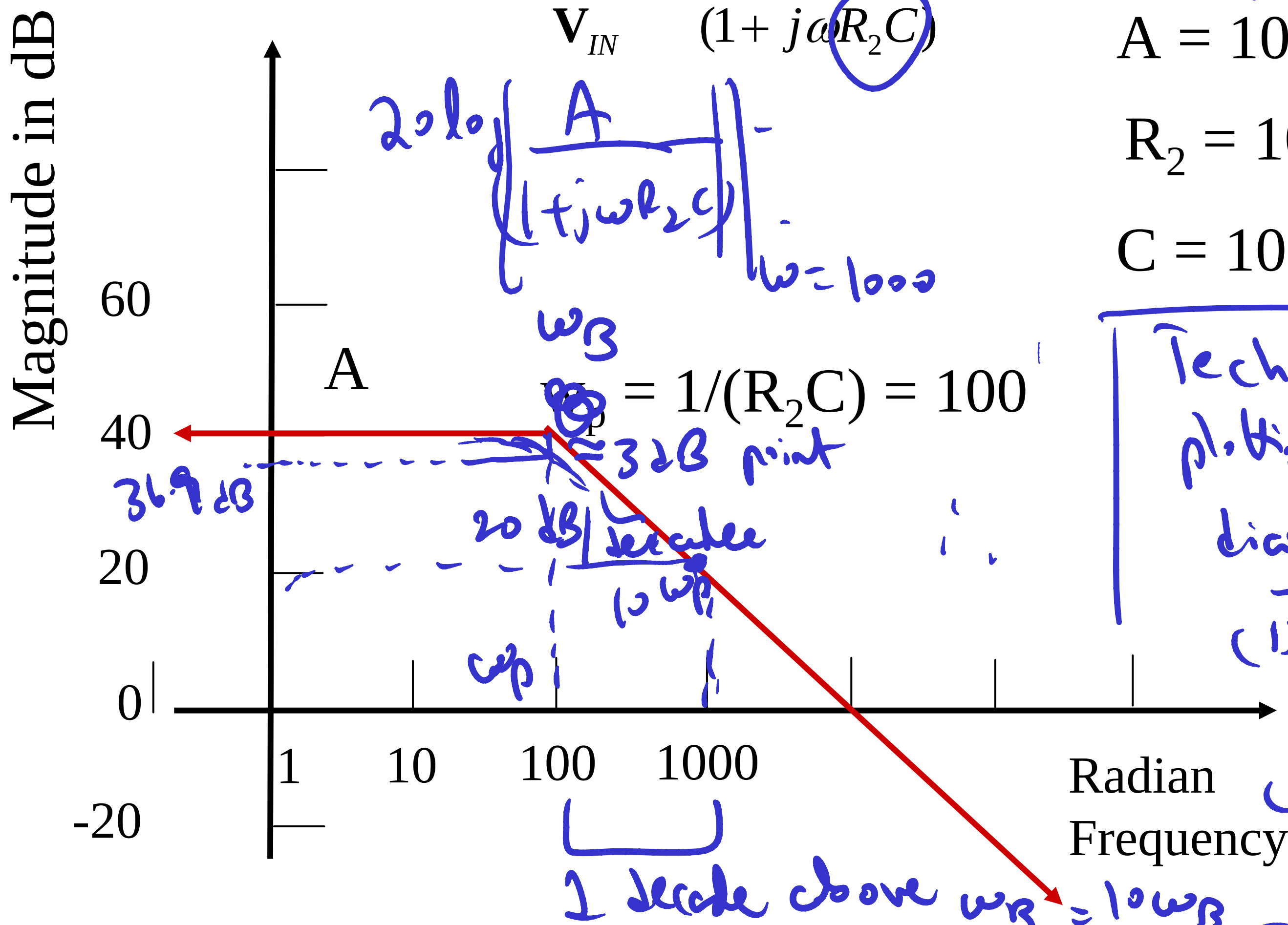
$\omega_B = \frac{1}{R_2 C}$

A = 100

R_2 = 1000 Ohms

C = 10 uF

$20 \log \left| \frac{A}{(1 + j\omega R_2 C)} \right|_{\omega = 1000}$



Techniques for plotting Bode diagrams:

(1) Find $\omega = \omega_B$ (Break freqs)

(2) Compute $\bar{H}(0.1\omega_B)$, $\bar{H}(\omega_B)$, $\bar{H}(10\omega_B)$

Note: Magnitude in dB = 20 $\log_{10}(V_{OUT}/V_{IN})$

For the given t.f

Consider: $\bar{H} = \dfrac{A}{1+j\omega R_2 C} = \dfrac{100}{(1+j\omega 100)}$

(1) $\bar{H}(0.1\omega_B) = \bar{H}\left(0.1\dfrac{1}{100}\right) = \dfrac{100}{\left(1+j\frac{0.1}{100}\cdot 100\right)} = \dfrac{100}{1+j0.1}$

[Recall: $\tau = R_2 C$, "$\omega \triangleq \dfrac{1}{\tau}$"]

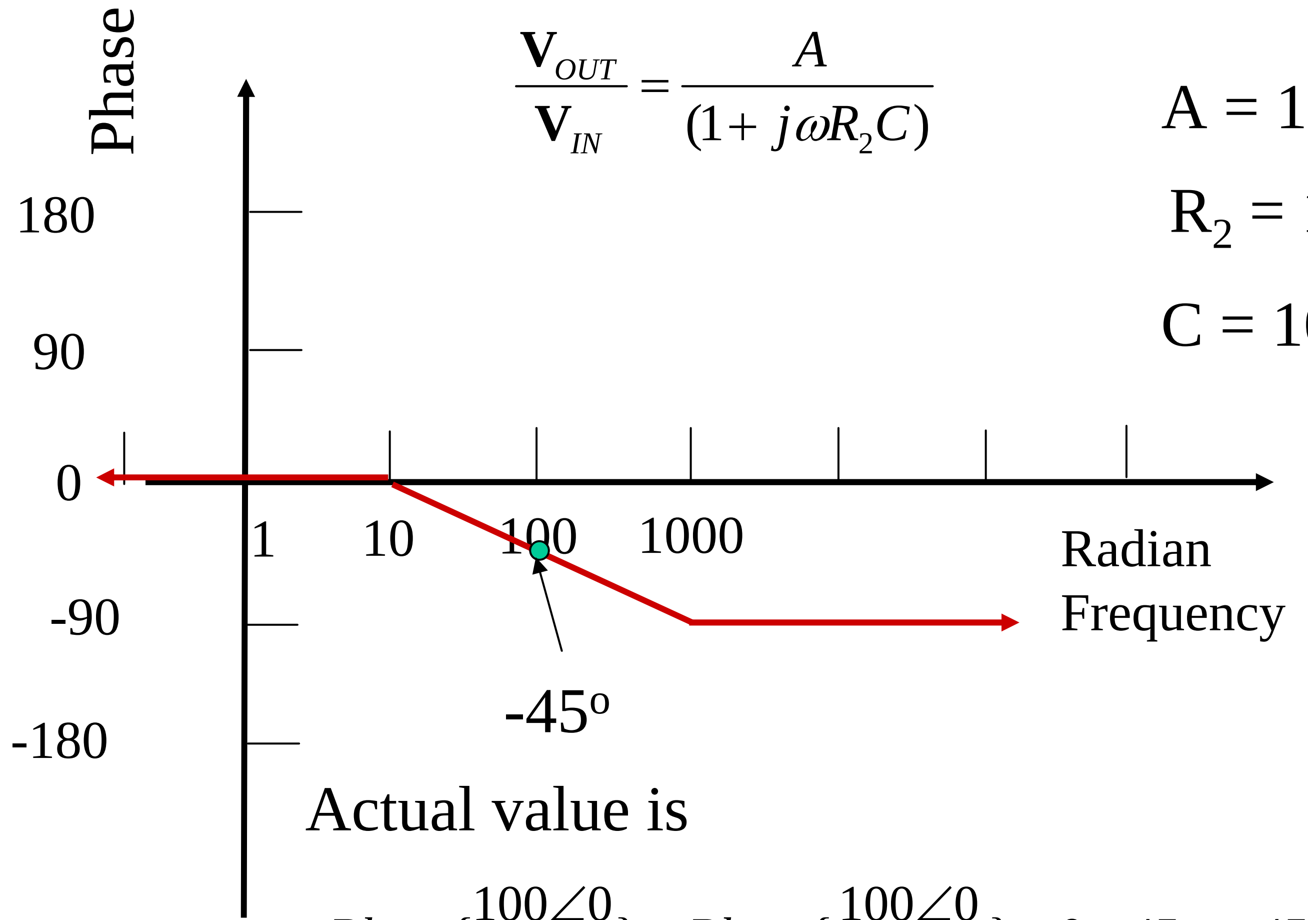
≈ 100

$\therefore 20\log|\bar{H}(0.1\omega_B)| = 20\underbrace{\log_{10} 100}_{=2}$

$= 20 \cdot 2 = 40\,dB$

$\measuredangle \bar{H}(0.1\omega_B) = \measuredangle 100 = 0^\circ$

Example: Phase plot



$$\frac{\mathbf{V}_{OUT}}{\mathbf{V}_{IN}} = \frac{A}{(1 + j\omega R_2 C)}$$

A = 100

R_2 = 1000 Ohms

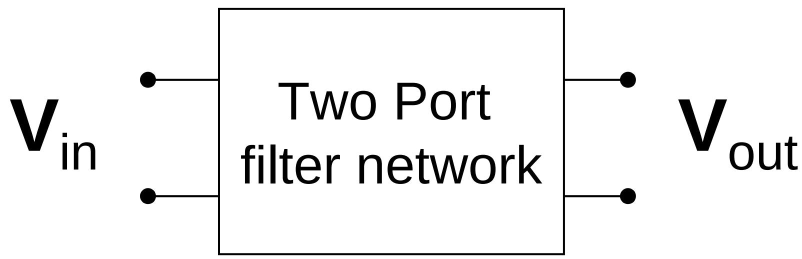
C = 10 uF

Actual value is

$$Phase\{\frac{100\angle 0}{|1+j|}\} = Phase\{\frac{100\angle 0}{\sqrt{2}\angle 45}\} = 0 - 45 = -45$$

Transfer Function

- Transfer function is a function of frequency
  - Complex quantity
  - Both magnitude and phase are function of frequency



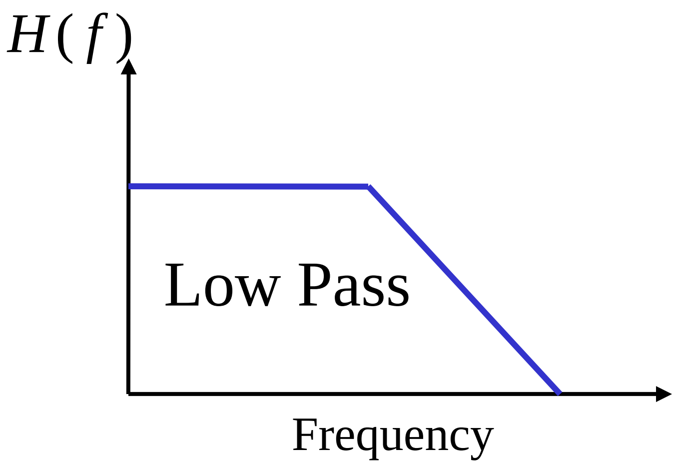
$$\mathbf{H}(f) = \frac{\mathbf{V_{out}}}{\mathbf{V_{in}}} = \frac{V_{out}}{V_{in}} \angle\left(\theta_{out} - \theta_{in}\right)$$

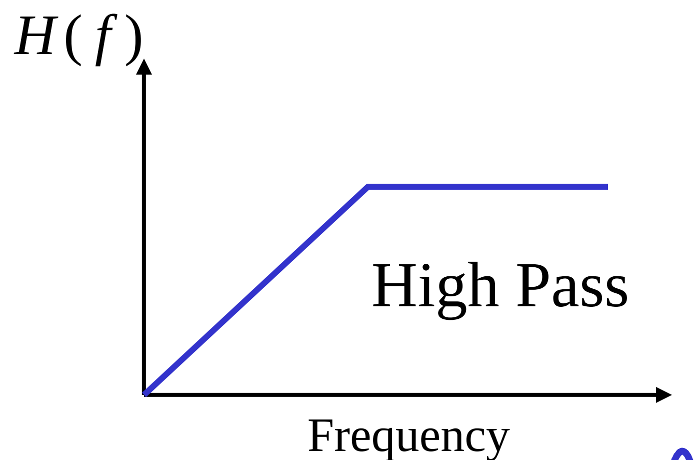
$$\mathbf{H(f)} = H(f)\angle\theta$$

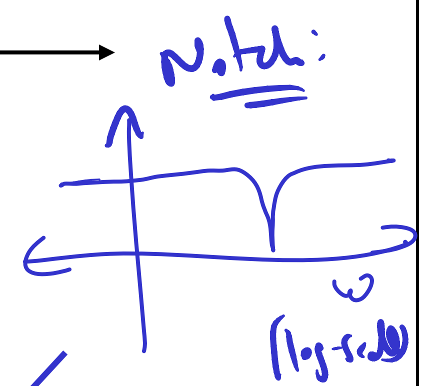
Filters

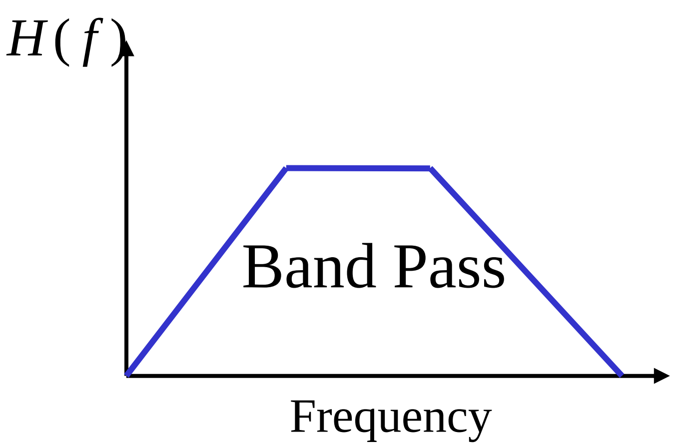
- Circuit designed to retain a certain frequency range and discard others
  - *Low-pass*: pass low frequencies and reject high frequencies
  - *High-pass*: pass high frequencies and reject low frequencies
  - *Band-pass*: pass some particular range of frequencies, reject other frequencies outside that band
  - *Notch*: reject a range of frequencies and pass all other frequencies

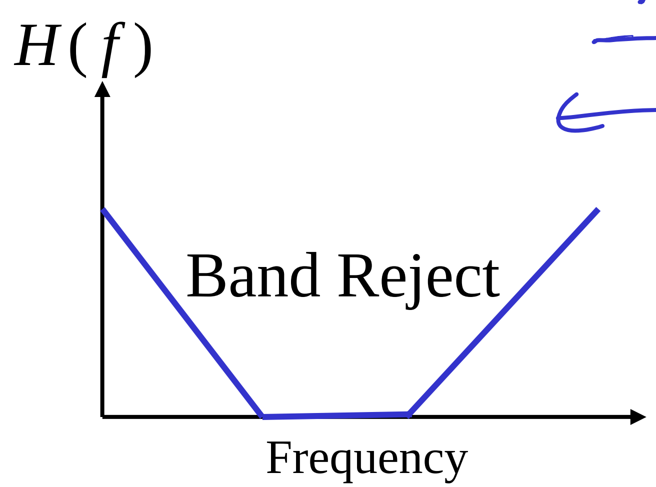
Common Filter Transfer Function vs. Freq (Magnitude Plots shown)











First-Order Lowpass Filter

$$\mathbf{H(f)} = \frac{\mathbf{V_C}}{\mathbf{V}} = \frac{1/(j\omega C)}{1/(j\omega C)+R} = \frac{1}{1+j\omega RC} = \frac{1}{\sqrt{1+(\omega RC)^2}}\angle -\tan^{-1}(\omega RC)$$

$\gg 1$

RC = 100

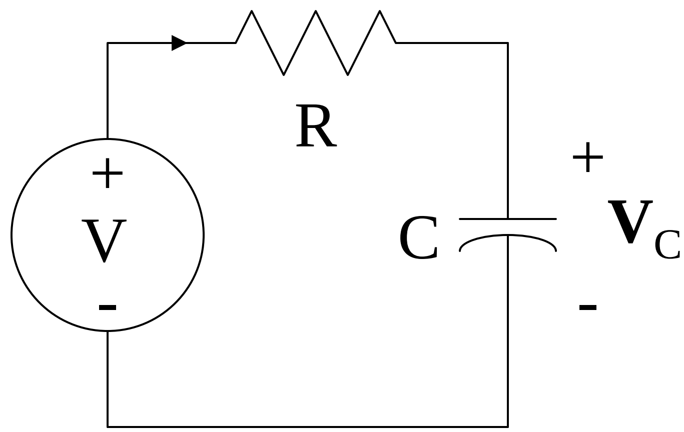
$$Let\ \omega_B = \frac{1}{RC} \quad and \quad f_B = \frac{1}{2\pi RC}$$

$$\mathbf{H(f)} = H(f)\angle\theta$$

$$H(f) = \frac{1}{\sqrt{1+\left(\frac{f}{f_B}\right)^2}}\ , \theta = -\tan^{-1}\left(\frac{f}{f_B}\right)$$

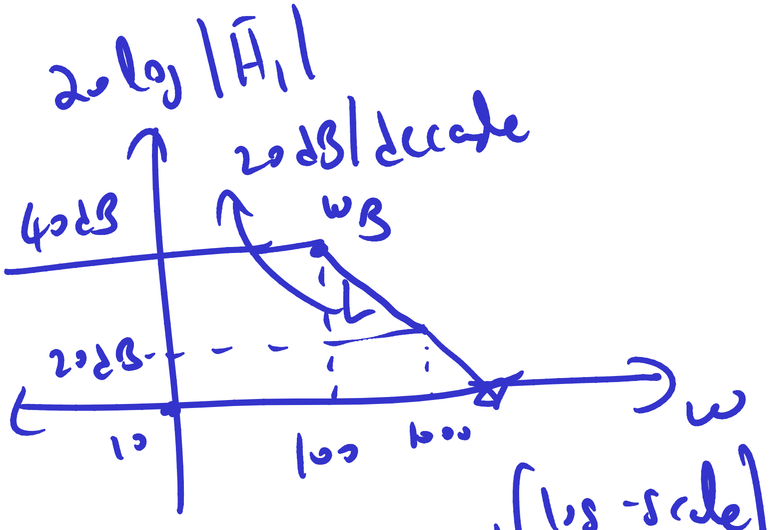
$$H(f_B) = \frac{1}{\sqrt{2}} = 2^{-1/2}$$

$$20\log_{10}\frac{H(f_B)}{H(0)} = 20(-\frac{1}{2})\log_{10} 2 = -3\ \ dB$$



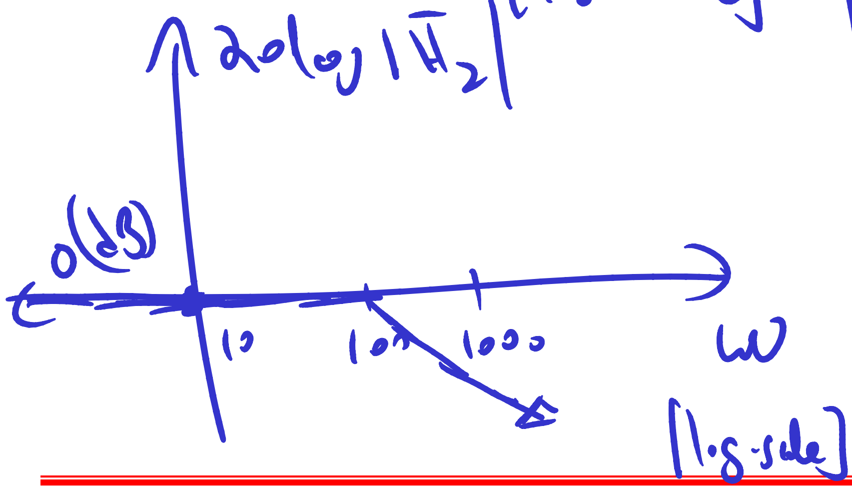
Question: What is the difference between the

Bode plots: $\bar{H}_1 = \frac{100}{1+j\omega R_2C}$, $\bar{H}_2 = \frac{1}{1+j\omega R_2C}$



$R_2C = \frac{1}{100} = 0.01$

$$\left[\omega_B = \frac{1}{R_2C} = \frac{1}{0.01} = 100\right]$$



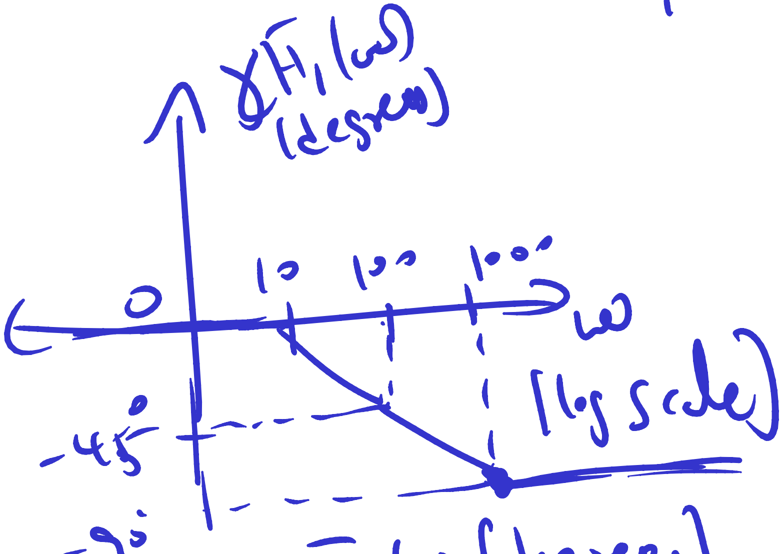
$$\bar{H}_2(0.1\omega_B) = \frac{1}{1+j\frac{0.1}{\cancel{R_2C}}\cdot \cancel{R_2C}}$$

$$= \frac{1}{1+j0.1} \approx 1$$

$\therefore 20\log|\bar{H}_2(0.1\omega_B)| = 0$

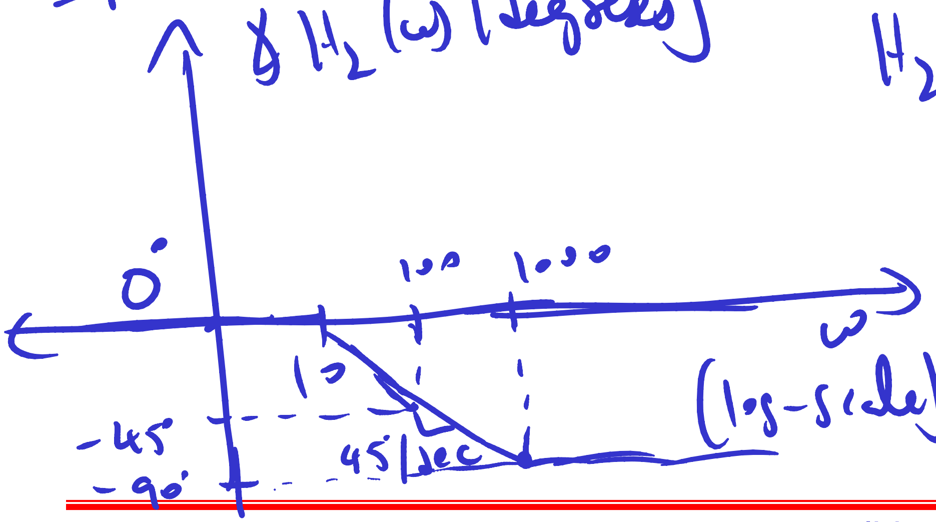
Question: What is the difference between the

Bode plots: $\bar{H}_1 = \frac{100}{1+j\omega R_2 C}$, $\bar{H}_2 = \frac{1}{1+j\omega R_2 C}$



$$R_2 C = \frac{1}{100} = 0.01$$

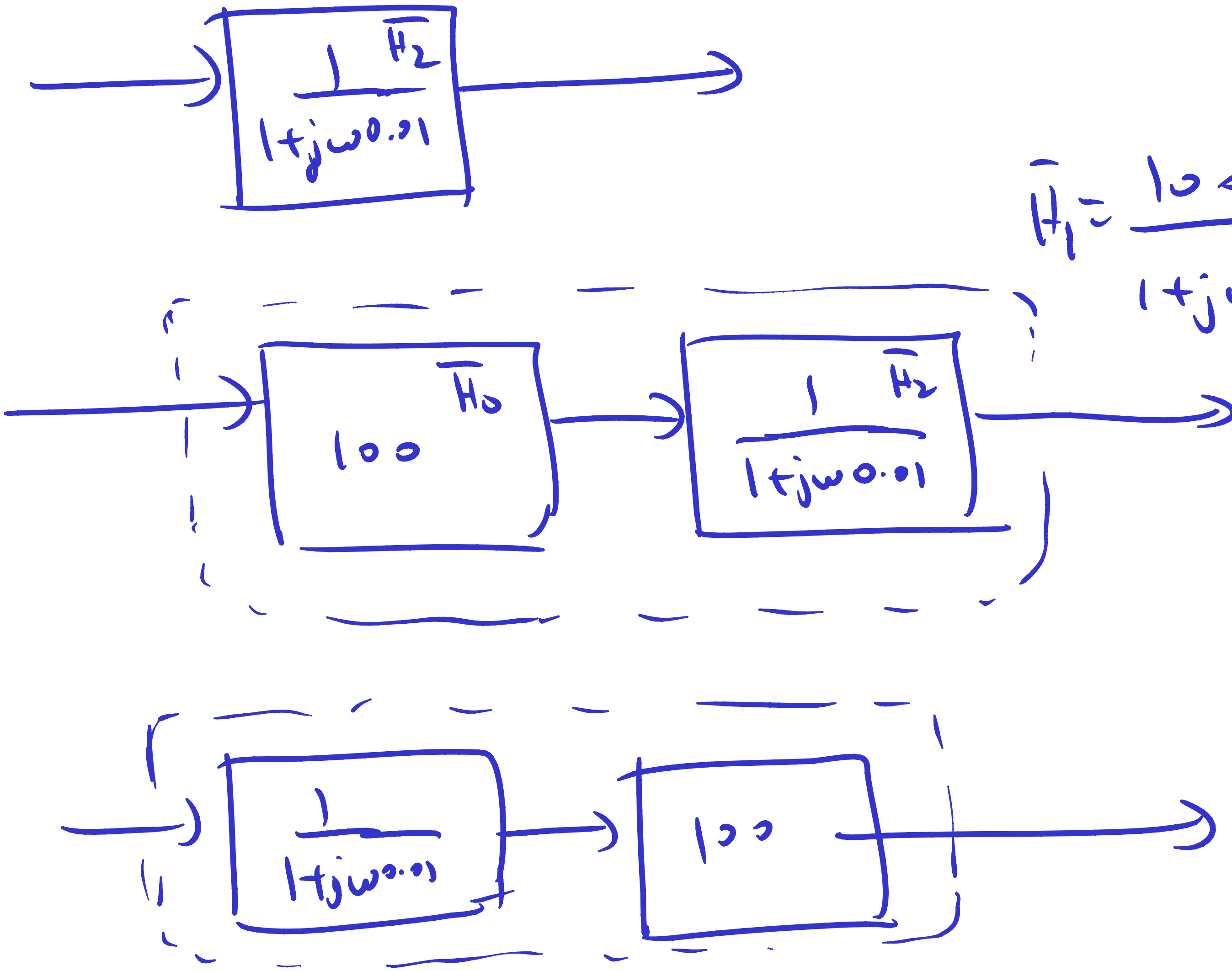
$$\left[\omega_B = \frac{1}{R_2 C} = \frac{1}{0.01} = 100\right]$$



$$\bar{H}_2(0.1\omega_B) = \frac{1}{1+j\frac{0.1}{\cancel{R_2C}}\cdot R_2C} \approx 1 \Rightarrow \measuredangle = 0°$$

$$\bar{H}_2(\omega_B) = \frac{1}{1+j\frac{1}{R_2C}\cdot R_2C} = \frac{1}{1+j} \Rightarrow \measuredangle \approx -45°$$

Intuitively understand difference between Bode plot of $\bar{H}_1$ & $\bar{H}_2$



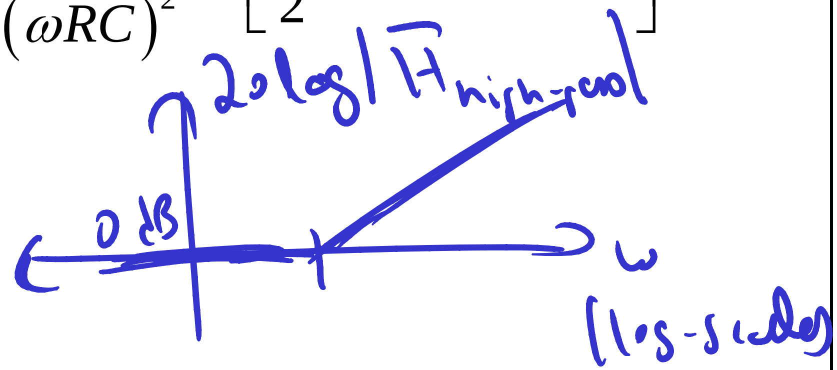
$$\bar{H}_1 = \frac{100}{1+j\omega 0.01} = \bar{H}_2 \bar{H}_0$$

$$= \left(\frac{1}{1+j\omega 0.01}\right) \cdot \bar{H}_0$$

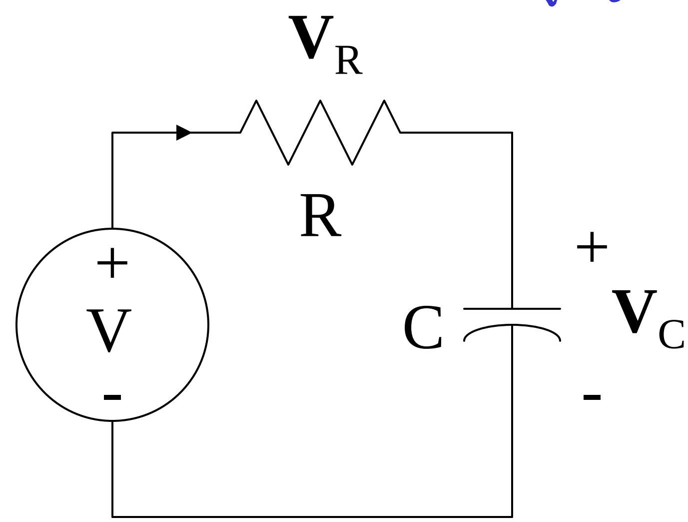
$$= \bar{H}_0 \bar{H}_2$$

First-Order Highpass Filter

$$\mathbf{H(f)} = \frac{\mathbf{V}_R}{\mathbf{V}} = \frac{R}{1/(j\omega C)+R} = \frac{j\omega RC}{1+j\omega RC} = \frac{(\omega RC)}{\sqrt{1+(\omega RC)^2}} \angle\left[\frac{\pi}{2} - \tan^{-1}(\omega RC)\right]$$



$$H(f) = \frac{\left(\frac{f}{f_B}\right)}{\sqrt{1+\left(\frac{f}{f_B}\right)^2}} \quad , \theta = \frac{\pi}{2} - \tan^{-1}\left(\frac{f}{f_B}\right)$$



$$H(f_B) = \frac{1}{\sqrt{2}} = 2^{-1/2}$$

$$20\log_{10}\frac{H(f_B)}{H(0)} = 20\left(-\frac{1}{2}\right)\log_{10} 2 = -3 \ dB$$

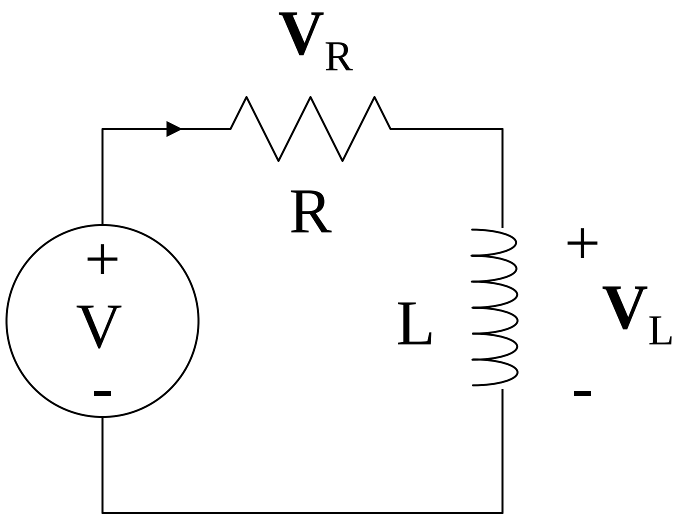
First-Order Lowpass Filter

$$\mathbf{H(f)} = \frac{\mathbf{V}_R}{\mathbf{V}} = \frac{1}{\frac{j\omega L}{R}+1} = \frac{1}{\sqrt{1+\left(\frac{\omega L}{R}\right)^2}}\angle -\tan^{-1}\left(\frac{\omega L}{R}\right)$$

$$Let\ \omega_B = \frac{R}{L} \quad and \quad f_B = \frac{R}{2\pi L}$$

$$\mathbf{H(f)} = H(f)\angle\theta$$

$$H(f) = \frac{1}{\sqrt{1+\left(\frac{f}{f_B}\right)^2}}\ ,\theta = -\tan^{-1}\left(\frac{f}{f_B}\right)$$



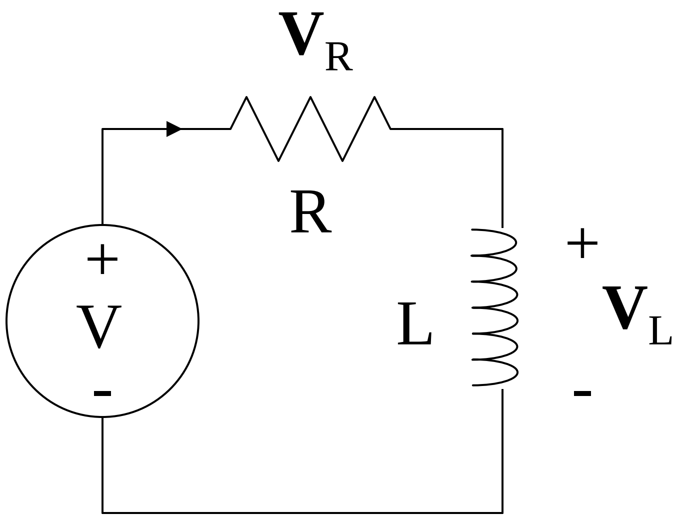
First-Order Highpass Filter

$$\mathbf{H(f)} = \frac{\mathbf{V}_L}{\mathbf{V}} = \frac{\frac{j\omega L}{R}}{\frac{j\omega L}{R}+1} = \frac{\frac{\omega L}{R}}{\sqrt{1+\left(\frac{\omega L}{R}\right)^2}} \angle\left[\frac{\pi}{2} - \tan^{-1}\left(\frac{\omega L}{R}\right)\right]$$

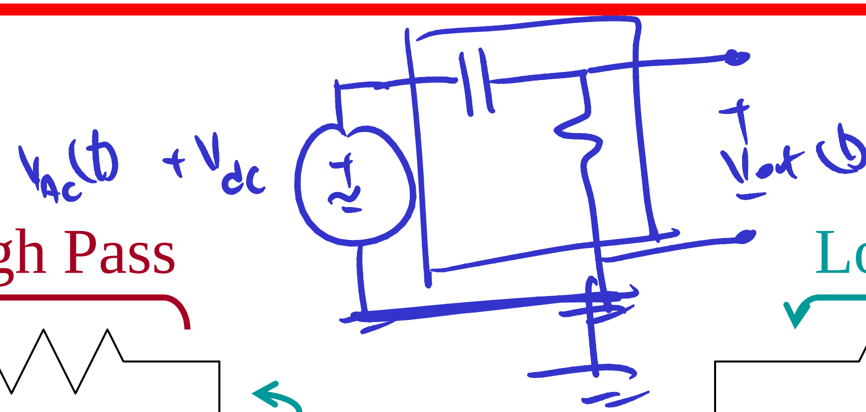
$$Let\ \omega_B = \frac{R}{L} \quad and \quad f_B = \frac{R}{2\pi L}$$

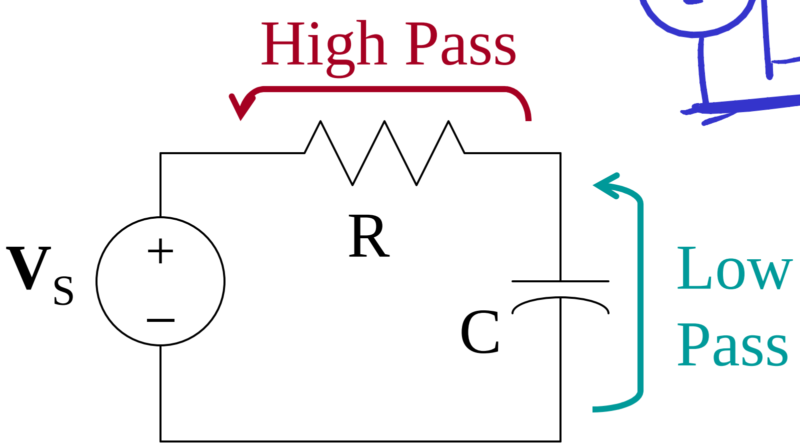
$$\mathbf{H(f)} = H(f)\angle\theta$$

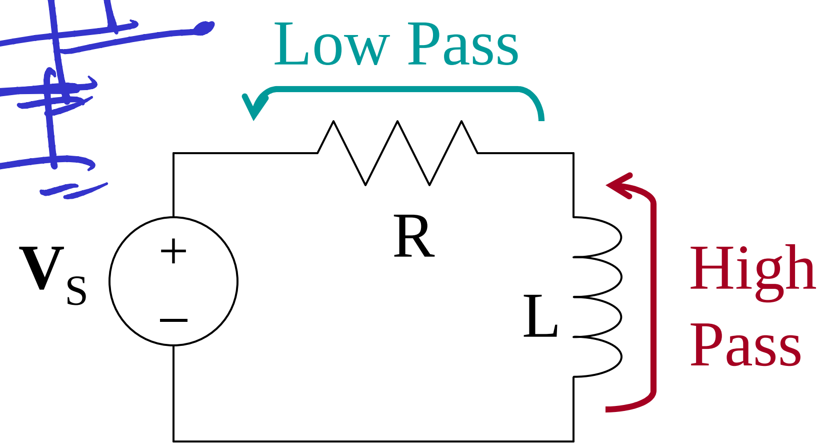
$$H(f) = \frac{\left(\frac{f}{f_B}\right)}{\sqrt{1+\left(\frac{f}{f_B}\right)^2}},\ \theta = \frac{\pi}{2} - \tan^{-1}\left(\frac{f}{f_B}\right)$$



First-Order Filter Circuits







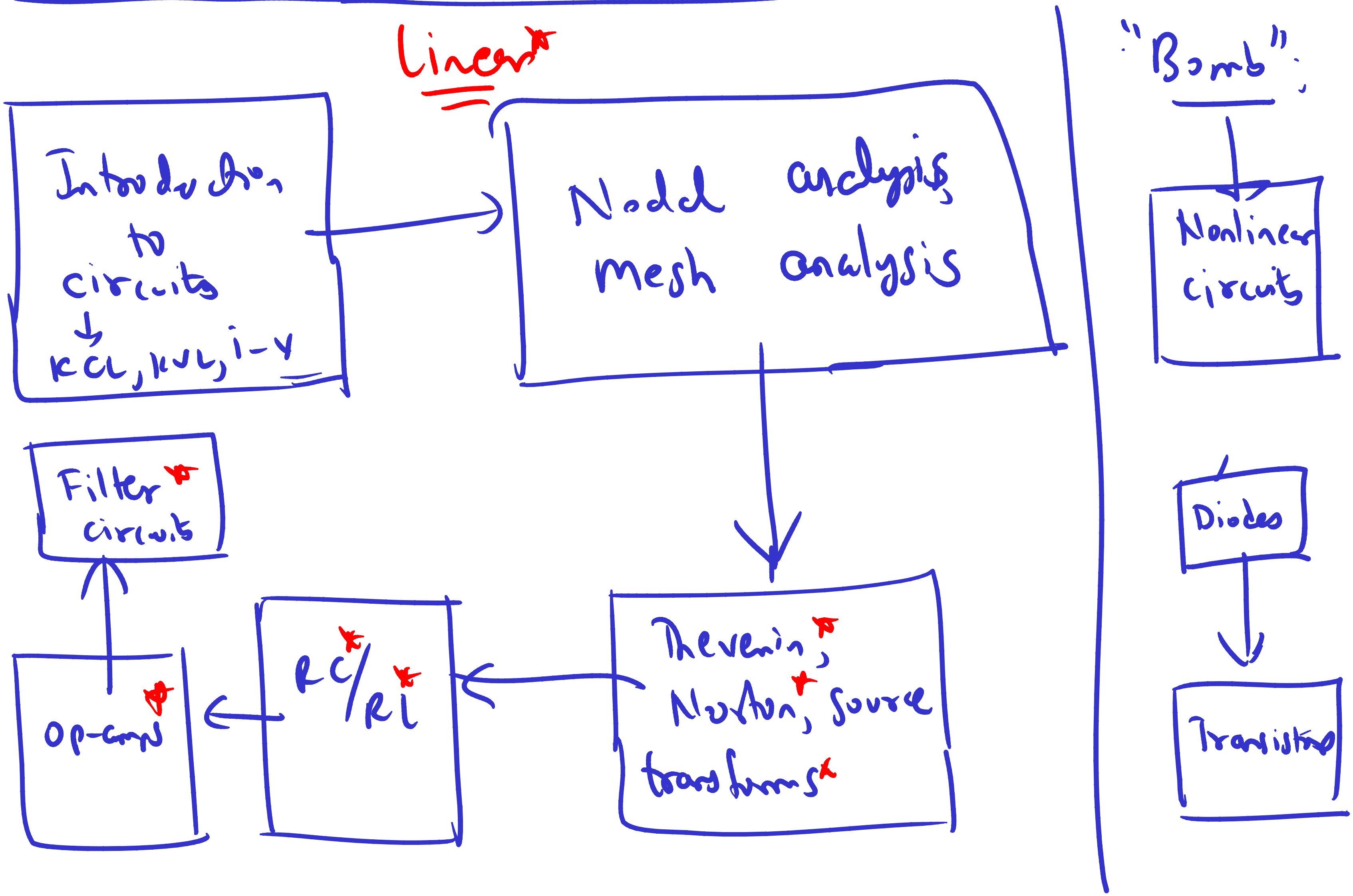
$\mathbf{H_R} = R\,/\,(R + 1/j\omega C)$

$\mathbf{H_C} = (1/j\omega C)\,/\,(R + 1/j\omega C)$

$\mathbf{H_R} = R\,/\,(R + j\omega L)$

$\mathbf{H_L} = j\omega L\,/\,(R + j\omega L)$

Recall / Summary of course material



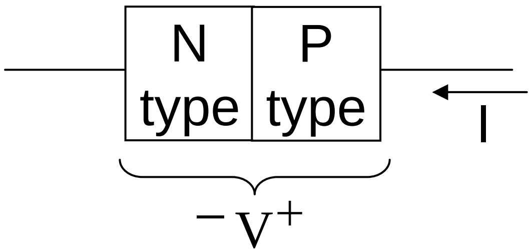
Diodes

- OUTLINE
  - Diode Model(s)
  - Circuit Analysis with Diodes
  - Diode Logic Gates
  - Load Line Analysis
  - Zener Diodes
  - Diode Peak Detector
- Reading
  - Reader: Chapter 2

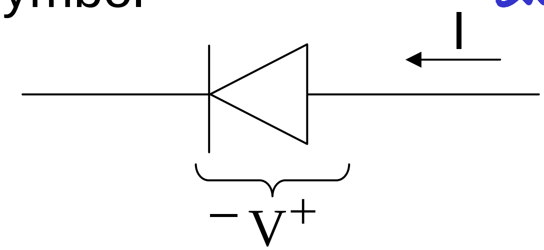
Diode Physical Behavior and Equation

Ref: Howe & Sodini, Microelectronics: An Integrated Approach.

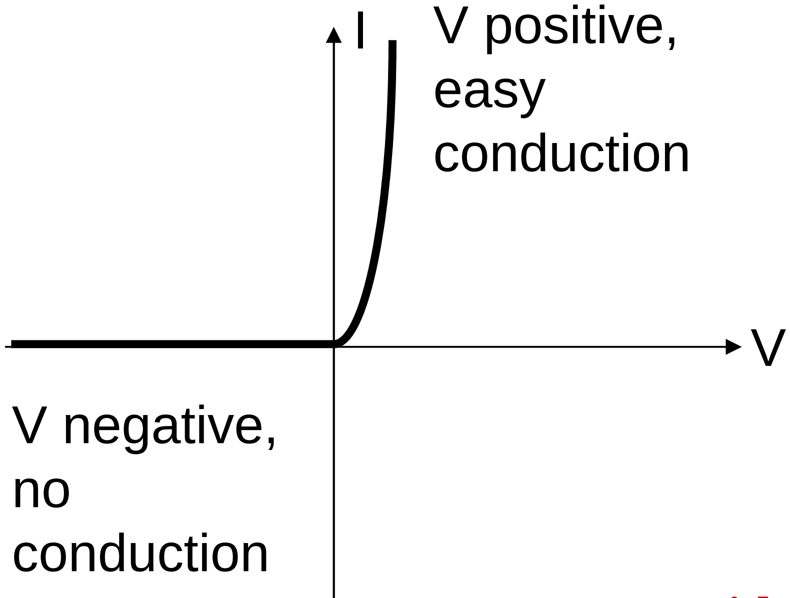
Schematic Device



Symbol



Qualitative I-V characteristics:



Quantitative I-V characteristics:

$$\boxed{I = I_0(e^{qV/kT} - 1)}$$

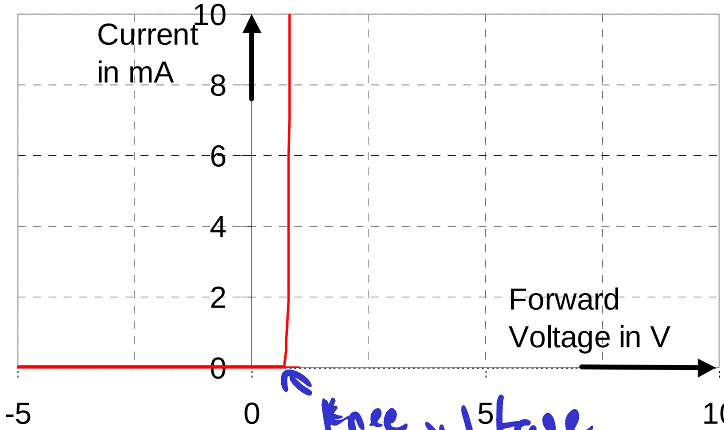
In which kT/q is 0.026V and I_O is a constant depending on diode area. Typical values: 10^{-12} to 10^{-16} A. Interestingly, the graph of this equation looks just like the figure to the left.

A non-ideality factor n times kT/q is often included.

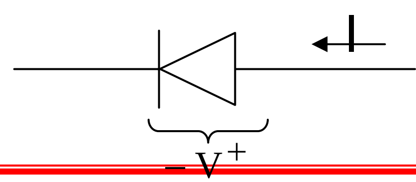
Diode Ideal (Perfect Rectifier) Model

The equation $I = I_0 \exp(qV/kT - 1)$

is graphed below for $I_0 = 10^{-15}$ A



The characteristic is described as a "rectifier" – that is, a device that permits current to pass in only one direction. (The hydraulic analog is a "check value".) Hence the symbol:



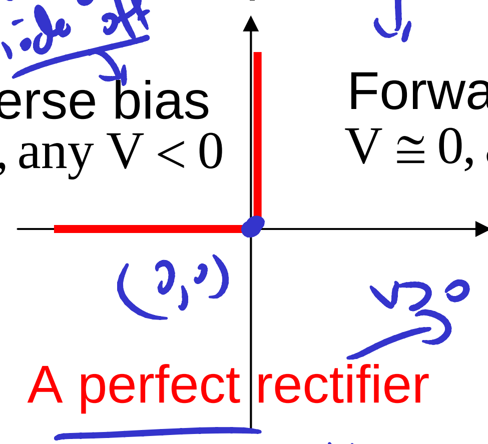
Simple "Perfect Rectifier" Model

If we can ignore the small forward-bias voltage drop of a diode, a simple effective model is the "perfect rectifier," whose I-V characteristic is given below:

Diode-on voltage ≈ 0.7 V

Diode off

Diode on



Anode

Cathode

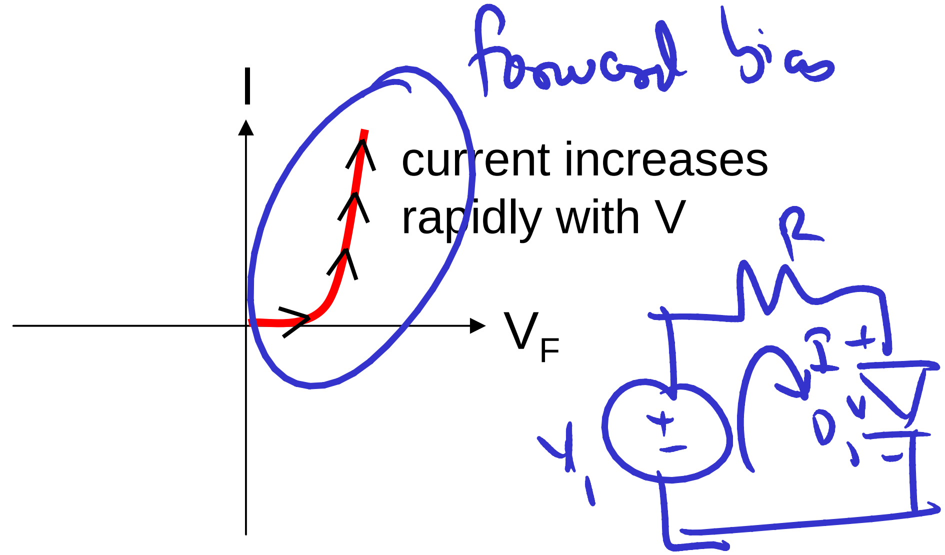
V≥0

V≤0

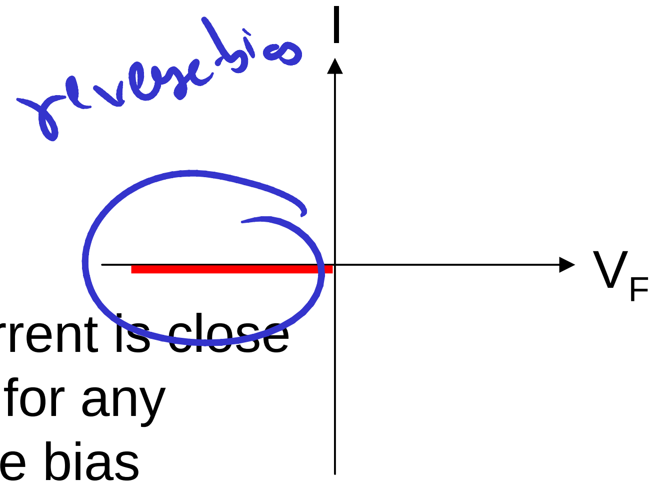
I=0

I-V Characteristics

In forward bias (+ on p-side) we have almost unlimited flow (very low resistance). Qualitatively, the I-V characteristics must look like:



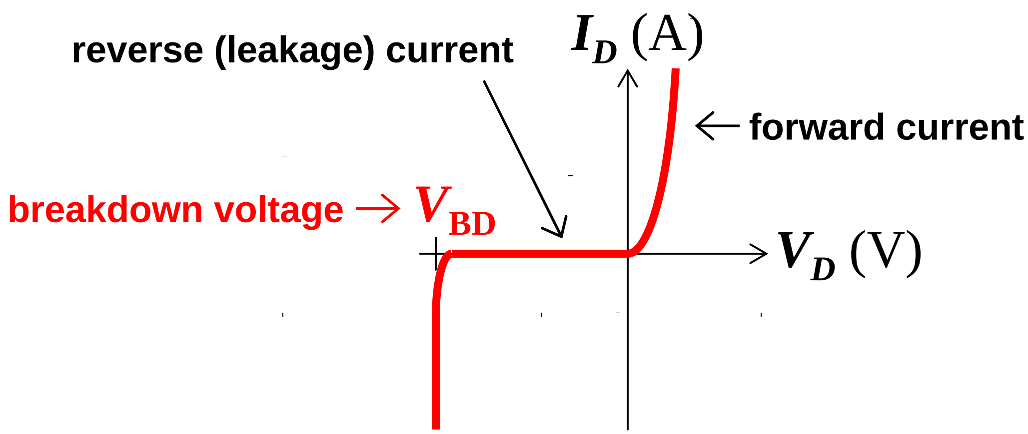
In reverse bias (+ on n-side) almost no current can flow. Qualitatively, the I-V characteristics must look like:



The current is close to zero for any negative bias

pn-Junction Reverse Breakdown

- As the reverse bias voltage increases, the peak electric field in the depletion region increases. When the electric field exceeds a critical value ($E_{crit} \cong 2x10^5$ V/cm), the reverse current shows a dramatic increase:



The pn Junction I vs. V Equation

I-V characteristic of PN junctions

In EECS 105, 130, and other courses you will learn why the I vs. V relationship for PN junctions is of the form

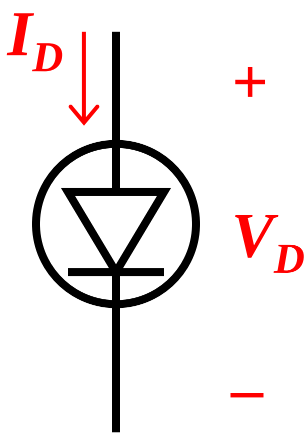
$$\boxed{I = I_0(e^{qV/kT} - 1)}$$

where I_0 is a constant proportional to junction area and depending on doping in P and N regions, $q = \text{electronic charge} = 1.6 \times 10^{-19}$, k is Boltzman constant, and T is absolute temperature.
$KT/q = 0.026\text{V at} 300°\text{K}$, a typical value for I_0 is $10^{-12} - 10^{-15}\text{A}$

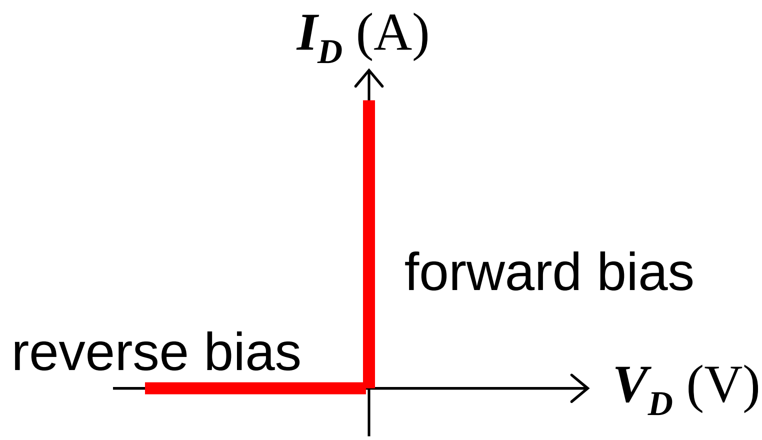
We note that in forward bias, I increases **exponentially** and is in the μA-mA range for voltages typically in the range of 0.6-0.8V. In reverse bias, the current is essentially zero.

Ideal Diode Model of PN Diode

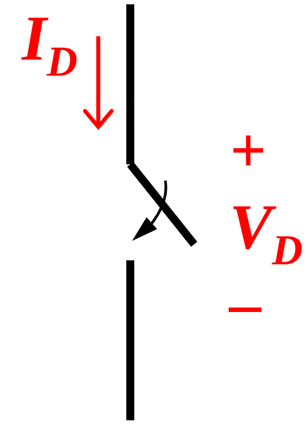
Circuit symbol



***I-V* characteristic**



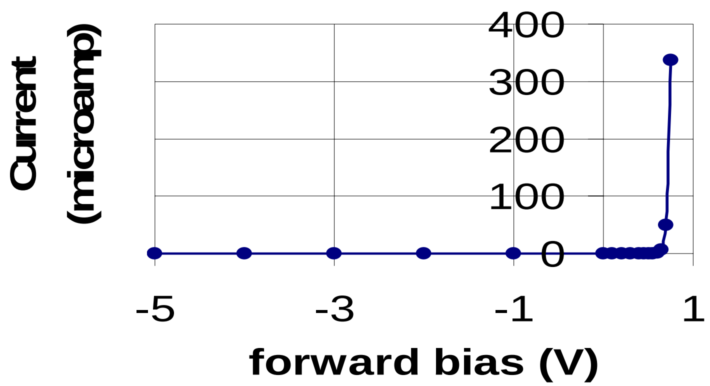
Switch model

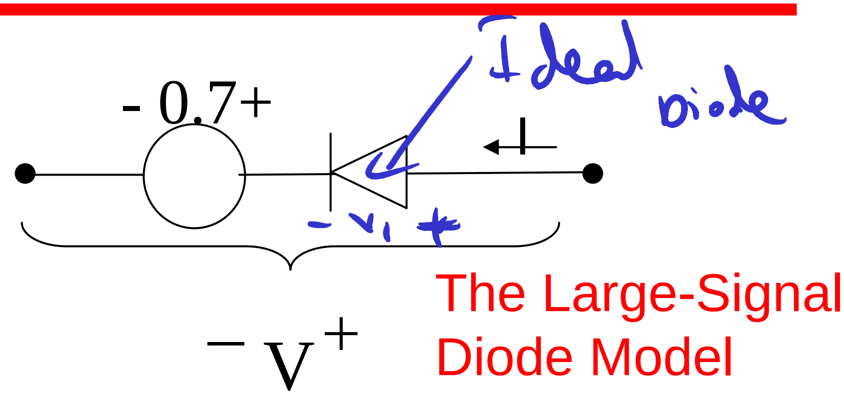


- An ideal diode passes current only in one direction.
- An ***ideal diode*** has the following properties:
  - when $I_D > 0$, $V_D = 0$
  - when $V_D < 0$, $I_D = 0$

Diode behaves like a switch:
- closed in forward bias mode
- open in reverse bias mode

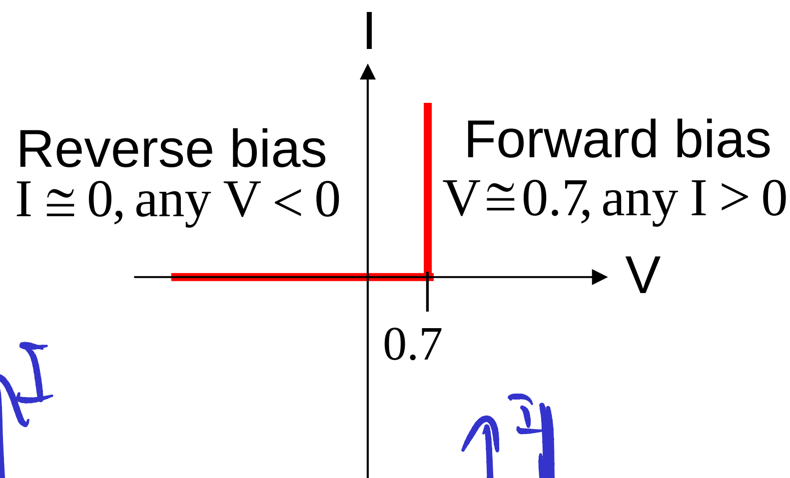
Diode Large-Signal Model (0.7 V Drop)

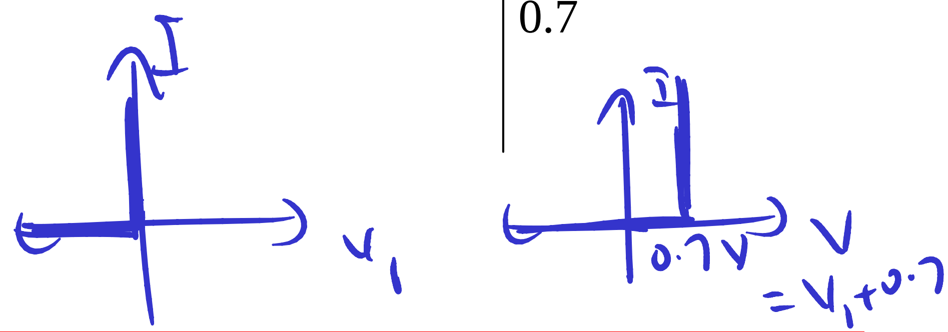




Improved "Large-Signal Diode" Model:

If we choose not to ignore the small forward-bias voltage drop of a diode, it is a very good approximation to regard the voltage drop in forward bias as a constant, about 0.7V. the "Large signal model" results.

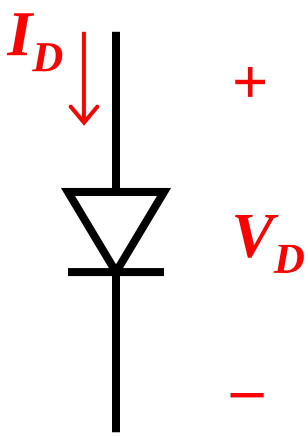




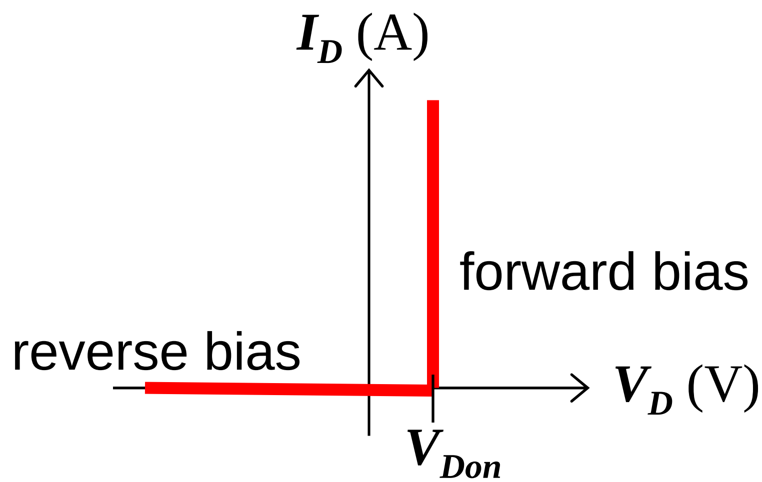
Large-Signal Diode Model

Circuit symbol	***I-V* characteristic**	**Switch model**

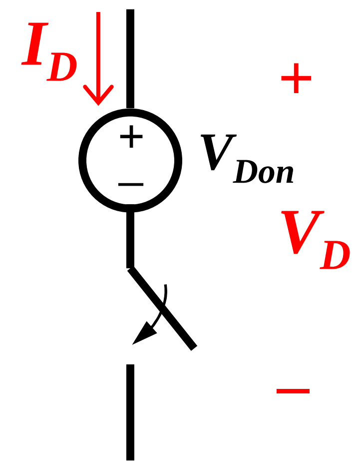
Circuit symbol



***I-V* characteristic**



Switch model



For a Si pn diode, $V_{Don} \cong 0.7$ V

RULE 1: When $I_D > 0$, $V_D = V_{Don}$

RULE 2: When $V_D < V_{Don}$, $I_D = 0$

Diode behaves like a voltage source in series with a switch:
- closed in forward bias mode
- open in reverse bias mode