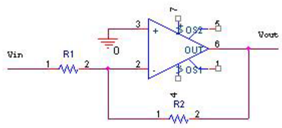
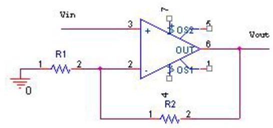
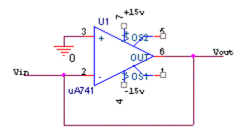
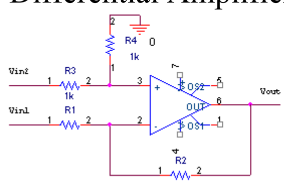
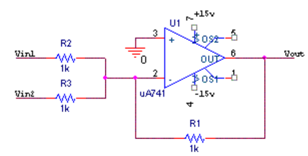
Op-Amps:

- Op-Amp Rules(when negative feedback exists): 1. $V_+ = V_-$ 2. $I_+ = I_- = 0$
- Op-Amp Circuits:

<table>
<tr>
<td>Inverting Amplifier

$A_V = \frac{V_{out}}{V_{in}} = -\frac{R_2}{R_1}$</td>
<td>Non-Inverting Amp.

$A_V = \frac{V_{out}}{V_{in}} = 1 + \frac{R_2}{R_1}$</td>
<td>Buffer

$A_V = \frac{V_{out}}{V_{in}} = 1$</td>
</tr>
<tr>
<td colspan="2">Differential Amplifier

If $R_1 = R_3$ and $R_2 = R_4 \Rightarrow V_{out} = \frac{R_2}{R_1}(V_{in2} - V_{in1})$</td>
<td>Adder

$V_{out} = -\frac{R_1}{R_2}V_{in1} - \frac{R_1}{R_3}V_{in2}$</td>
</tr>
</table>

Some useful identities on complex numbers:

- Complex number representations: $z = x + jy = re^{j\theta}$, $j = \sqrt{-1}$
- Euler's identity: $e^{j\theta} = \cos\theta + j\sin\theta$
- Polar to Cartesian transform: $x = r\cos\theta$, $y = r\sin\theta$
- Cartesian to Polar transform: $r = \sqrt{x^2 + y^2}$, $\theta = \tan^{-1}\frac{y}{x}$
- $z_3 = z_2 z_1 \Rightarrow |z_3| = r_3 = r_2 r_1, \angle z_3 = \theta_3 = \theta_2 + \theta_1$
- $z_3 = z_2 / z_1 \Rightarrow |z_3| = r_3 = r_2 / r_1, \angle z_3 = \theta_3 = \theta_2 - \theta_1$

Table of $\tan^{-1}$

A	$\tan^{-1} A$
0	$0, \pi$
∞	$\pi/2$
$-\infty$	$-\pi/2$
1	$\pi/4, 3\pi/4$
-1	$-\pi/4, -3\pi/4$

Phasors:

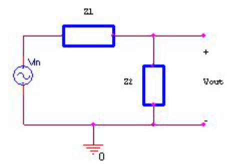
- Definition of phasor: $v(t) = A\cos(\omega t + \phi) \Rightarrow \vec{V} = Ae^{j\phi}$
- Time signal given phasor $v(t) = \mathrm{Re}\{\vec{V}e^{j\omega t}\} = \mathrm{Re}\{Ae^{j(\omega t + \phi)}\} = A\cos(\omega t + \phi)$

Impedances:

Resistor	Capacitor	Inductor
$\vec{V}_R = Z_R \vec{I}_R$	$\vec{V}_C = Z_C \vec{I}_C$	$\vec{V}_L = Z_L \vec{I}_L$
$Z_R = R$	$Z_C = \frac{1}{j\omega C}$	$Z_L = j\omega L$

- Impedances in series: $Z_{eq} = Z_1 + Z_2 + ... + Z_N$
- Impedances in parallel: $\frac{1}{Z_{eq}} = \frac{1}{Z_1} + \frac{1}{Z_2} + ... + \frac{1}{Z_N}$

Transfer Functions



- Definition: $H(j\omega) = \dfrac{\vec{V}_{out}}{\vec{V}_{in}}$
- For a voltage divider (see figure): $H(j\omega) = \dfrac{Z_2}{Z_1 + Z_2}$
- Corner Frequencies RC circuit: $\omega_c = 1/RC$ RL circuit: $\omega_c = R/L$
- Resonance Frequency RLC circuit: $\omega_0 = 1/\sqrt{LC}$

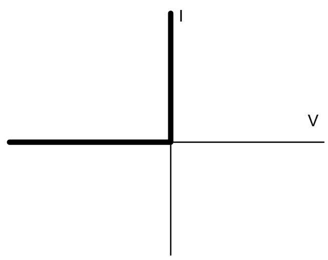
Approximations of transfer functions:

- Low Frequencies: $\dfrac{A_n\omega^n + A_{n-1}\omega^{n-1} + \ldots + A_k\omega^k}{A_m\omega^m + A_{m-1}\omega^{m-1} + \ldots + A_r\omega^r} \approx \dfrac{A_k\omega^k}{A_r\omega^r} = \dfrac{A_k}{A_r}\omega^{k-r}$
- High Frequencies: $\dfrac{A_n\omega^n + A_{n-1}\omega^{n-1} + \ldots + A_k\omega^k}{A_m\omega^m + A_{m-1}\omega^{m-1} + \ldots + A_r\omega^r} \approx \dfrac{A_n\omega^n}{A_m\omega^m} = \dfrac{A_n}{A_m}\omega^{n-m}$

Diodes models:

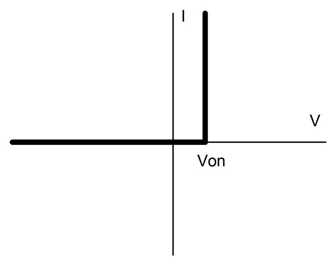
- Exact formula: $I_D = I_S(e^{\frac{V_D}{nV_T}} - 1)$, I_S: Saturation current, V_T=25.9mV, $n \approx 1-2$

Ideal Diode



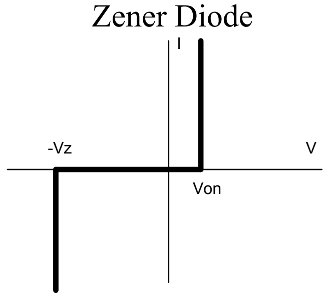
$$\begin{cases} On: & V_D = 0 \quad I_D > 0 \\ Off: & I_D = 0 \quad V_D < 0 \end{cases}$$

Von Model



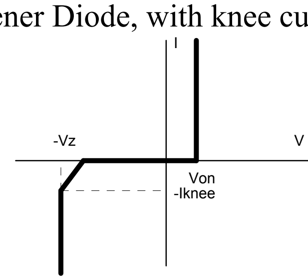
$$\begin{cases} On: & V_D = V_{on} \quad I_D > 0 \\ Off: & I_D = 0 \quad V_D < V_{on} \end{cases}$$

Zener Diode



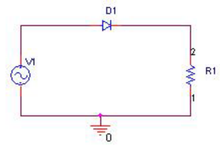
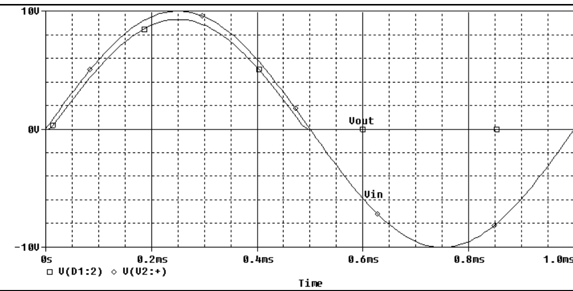
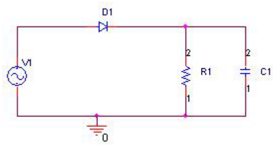
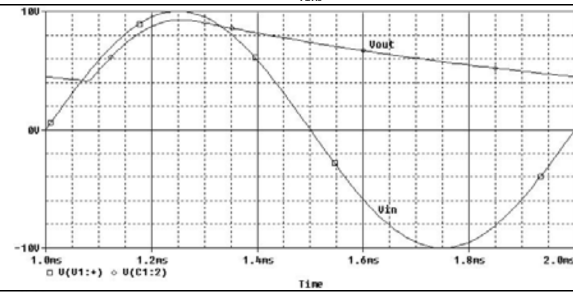
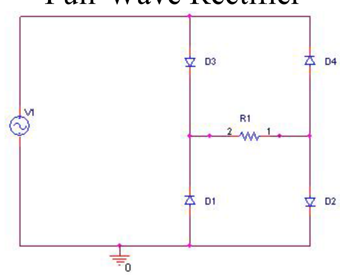
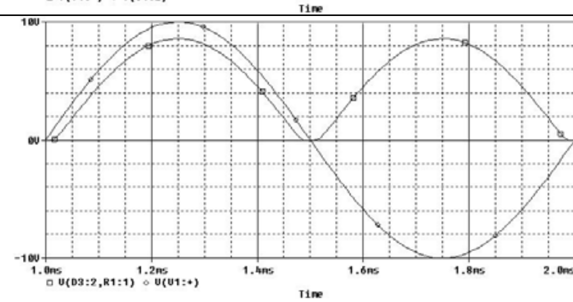
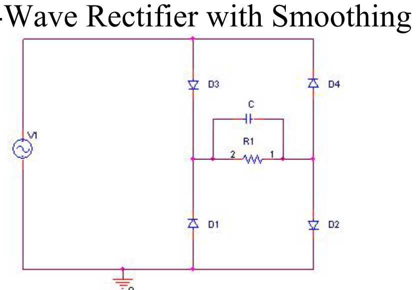
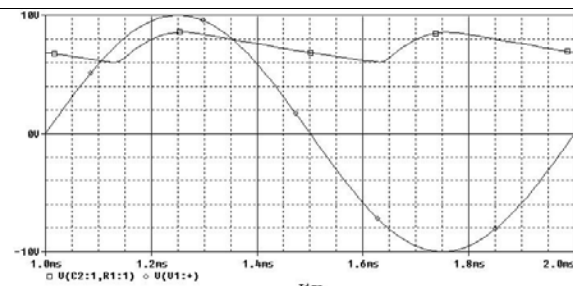
$$\begin{cases} On: & V_D = V_{on} \quad I_D > 0 \\ Off: & I_D = 0 \quad V_z < V_D < V_{on} \\ Zener: & V_D = -V_z \quad I_D < 0 \end{cases}$$

Zener Diode, with knee current



$$\begin{cases} On: & V_D = V_{on} \quad I_D > 0 \\ Off: & I_D = 0 \quad V_z < V_D < V_{on} \\ Zener: & V_D = -V_z \quad I_D < -I_{knee} \end{cases}$$

Diode Circuits:

Half-Wave Rectifier 	
Half-Wave Rectifier with Smoothing 	
Full-Wave Rectifier 	
Full-Wave Rectifier with Smoothing 	
Limiter