ENGR-2300 **Crib Sheet** **Quiz 1**

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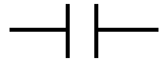
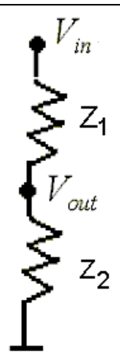
components	Resistors	Capacitors	Inductors
symbol	 **R**	 **C**	 **L**
general equation	$V_R = I_R R$	$I_C = C\frac{dV_C}{dt}$	$V_L = L\frac{dI_L}{dt}$
combining in series	$R_T = R_1 + R_2 + \ldots + R_n$	$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \cdots + \frac{1}{C_n}$	$L_T = L_1 + L_2 + \ldots + L_n$
combining in parallel	$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_n}$	$C_T = C_1 + C_2 + \ldots + C_n$	$\frac{1}{L_T} = \frac{1}{L_1} + \frac{1}{L_2} + \cdots + \frac{1}{L_n}$
impedance	$Z_R = R$	$Z_C = \frac{1}{j\omega C}$	$Z_L = j\omega L$
frequency→0	R	open circuit	short circuit
frequency→∞	R	short circuit	open circuit

Laws and Rules

Ohm's Law	$V = IR$ $\quad V_T = I_T R_T$	
Kirchoff's Voltage Law	Sum of voltages in a loop is zero.	
Kirchoff's Current Law	Sum of currents entering junction equals the sum of currents leaving junction.	
Reading Resistors	$XYZ = XY \times 10^Z$ ohms	black-brown-R-O-Y-G-B-V-grey-white 0 1 2 3 4 5 6 7 8 9
Reading Capacitors	$XYZ = XY \times 10^Z$ picofarads $= XY \times 10^{(Z-6)}$ microfarads	
Logarithmic Scales	log(f)=[decade].[percent across]	$f = 10^{\text{[decade].[percent across]}}$
suffixes	K (10^3) Meg(10^6) G(10^9) T(10^{12})	m(10^{-3}) μ(10^{-6}) n(10^{-9}) p(10^{-12})
Euler's Identity $e^{j\theta} = \cos\theta + j\sin\theta$	parallel combination shortcut $R_{12} = \frac{R_1 R_2}{R_1 + R_2}$	Power Equation $P = VI = I^2 R$

Voltage Dividers



$$V_{out} = \left(\frac{Z_2}{Z_1 + Z_2}\right)V_{in}$$

$$V_1 = \left(\frac{Z_1}{Z_1 + Z_2}\right)V_{in}$$

$$V_2 = \left(\frac{Z_2}{Z_1 + Z_2}\right)V_{in}$$

Sine Waves

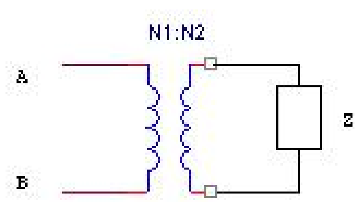
$$v(t) = A\sin(\omega t + \phi) + V_{DC}$$

$$\omega = 2\pi f \qquad f = \frac{1}{T}$$

$$\phi = -\omega t_0 = -2\pi\frac{t_0}{T}$$

$$V_{p-p} = 2A \qquad V_{rms} = \frac{A}{\sqrt{2}}$$

Transformers



ideal equations

$$a = \frac{N_2}{N_1} = \frac{V_2}{V_1} = \frac{I_1}{I_2} = \sqrt{\frac{L_2}{L_1}}$$

input impedance

$$Z_{in} = Z_{AB} = \frac{Z}{a^2}$$

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Calculating Inductance		Calculating Resistance
Long Coil	Ring shaped Coil	
$L = \frac{\mu N^2 \pi r_c^2}{d}$	$L = \mu N^2 r_c \left[\ln(\frac{8r_c}{r_w}) - 2 \right]$	$R = \frac{l}{\sigma A}$

Complex Polar Coordinates

Complex numbers: $z = x + jy = re^{j\theta}$ **(** $j = \sqrt{-1}$**,** 1/j = -j)

Polar to Cartesian transform: $x = r\cos\theta$, $y = r\sin\theta$

Cartesian to Polar transform: $r = \sqrt{x^2 + y^2}$ $\theta = \tan^{-1}\left(\frac{y}{x}\right)$

$$\vec{V} = \frac{x_1 + jy_1}{x_2 + jy_2} \quad |\vec{V}| = \frac{\sqrt{x_1^{\;2} + y_1^{\;2}}}{\sqrt{x_2^{\;2} + y_2^{\;2}}} \quad \angle\vec{V} = \tan^{-1}\left(\frac{y_1}{x_1}\right) - \tan^{-1}\left(\frac{y_2}{x_2}\right)$$

$$\vec{V} = Ae^{j(\omega t + \phi)} = A\cos(\omega t + \phi) + jA\sin(\omega t + \phi)$$

phases	
A	0
-A	π or -π
jA	$\pi/2$
-jA	$-\pi/2$
$\tan^{-1}(1)$	$\pi/4$ or $-3\pi/4$
$\tan^{-1}(-1)$	$-\pi/4$ or $3\pi/4$
x+jy	$\tan^{-1}(y/x)$

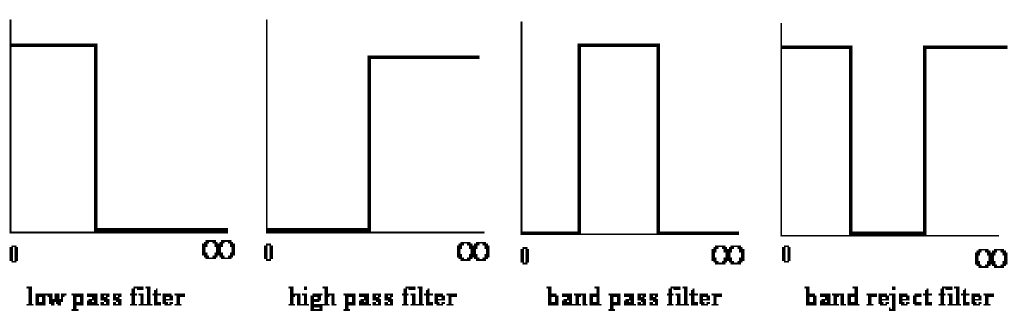
where A is a constant

Transfer Functions

$\vec{V} = \vec{I}\,Z$	$H(j\omega) = \frac{\vec{V}_{out}}{\vec{V}_{in}}$	$H(j\omega) = \frac{Z_2}{Z_1 + Z_2}$ *series circuit only*
Combining Impedances	$Z_{eq} = Z_1 + Z_2 + \ldots + Z_N$ *series*	$\frac{1}{Z_{eq}} = \frac{1}{Z_1} + \frac{1}{Z_2} + \ldots + \frac{1}{Z_N}$ *parallel*
Low Frequency Approximation	$\frac{A_n\omega^n + A_{n-1}\omega^{n-1} + \ldots + A_k\omega^k}{A_m\omega^m + A_{m-1}\omega^{m-1} + \ldots + A_r\omega^r} \approx \frac{A_k\omega^k}{A_r\omega^r} = \frac{A_k}{A_r}\omega^{k-r}$	
High Frequency Approximation	$\frac{A_n\omega^n + A_{n-1}\omega^{n-1} + \ldots + A_k\omega^k}{A_m\omega^m + A_{m-1}\omega^{m-1} + \ldots + A_r\omega^r} \approx \frac{A_n\omega^n}{A_m\omega^m} = \frac{A_n}{A_m}\omega^{n-m}$	
Using Transfer Functions	$A_{out} = \lvert H \rvert \cdot A_{in}$	$\phi_{out} = \angle H + \phi_{in}$

Filters

RC Circuit (corner)	RL Circuit (corner)	RLC Circuit (resonant)
$\omega_C = \frac{1}{RC}$ $f_C = \frac{1}{2\pi RC}$	$\omega_C = \frac{R}{L}$ $f_C = \frac{R}{2\pi L}$	$\omega_0 = \frac{1}{\sqrt{LC}}$ $f_C = \frac{1}{2\pi\sqrt{LC}}$



ENGR-2300 **Crib Sheet** **Quiz 2**

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Thevenin Voltage Sources		
Find Vth	Set load between A and B to open and find $V_A - V_B$	$V_L = \frac{R_L}{R_{th} + R_L} V_{th}$
Find Rth	Set voltage sources to shorts and find combined resistance between A and B.	

Harmonic Oscillation		
UnDamped	**Damped**	**Cantilever Beam**
$\frac{d^2V}{dt^2} + \omega_0^2 V = 0$ $v(t) = A\cos(\omega_0 t + \phi)$ $\omega_0 = \frac{1}{\sqrt{LC}}$	$\frac{d^2V}{dt^2} + 2\alpha\frac{dV}{dt} + \omega_0^2 V = 0$ $v(t) = Ae^{-\alpha t}\cos(\omega_0 t + \phi)$ $v_1 = v_0 e^{-\alpha(t_1 - t_0)}$ $\alpha = \frac{R}{2L}$	$\frac{Ewt^3}{4l^3} = (m + m_n)(2\pi f_n)^2$ $m = 0.23 m_{beam}$

Op-Amp Circuits

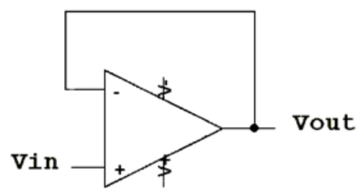
Op Amp Analysis Rules

1. $V_+ = V_-$
2. $I_+ = I_- = 0$

Op-Amp Analysis

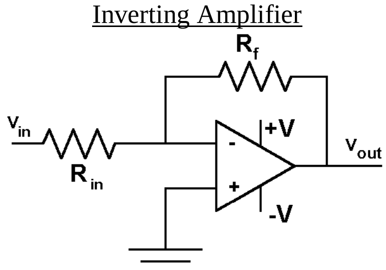
1. Remove Op-Amp
2. Draw a circuit at each input to the op-amp
3. Solve for Vout in terms of the input voltage(s).

Voltage Follower



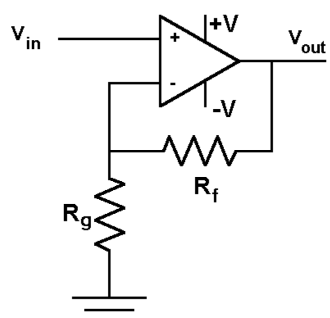
$$A_V = \frac{V_{out}}{V_{in}} = 1$$

Inverting Amplifier



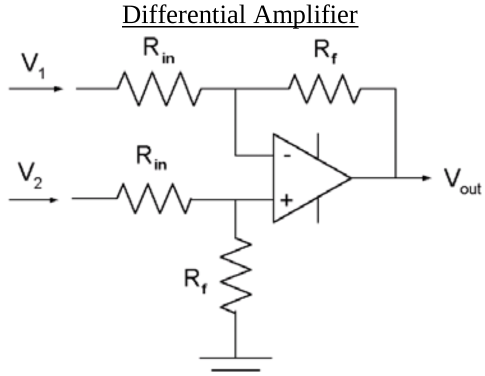
$$A_V = \frac{V_{out}}{V_{in}} = -\frac{R_f}{R_{in}}$$

Non-Inverting Amplifier



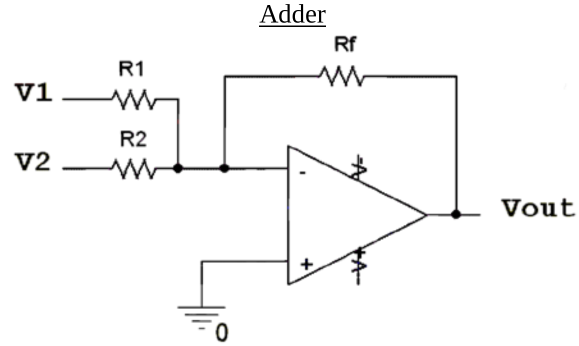
$$A_V = \frac{V_{out}}{V_{in}} = 1 + \frac{R_f}{R_g}$$

Differential Amplifier



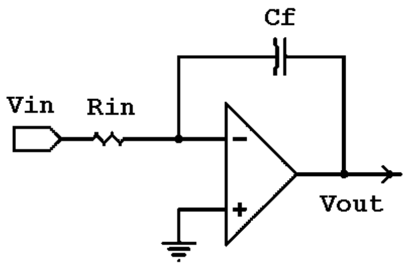
$$V_{out} = \frac{R_f}{R_{in}}(V_2 - V_1)$$

Adder



$$V_{out} = -\frac{R_f}{R_1}V_1 - \frac{R_f}{R_2}V_2$$

Ideal Active Integrator

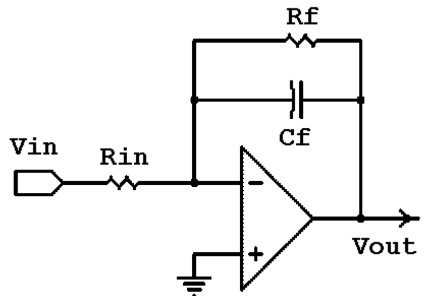


$$H(j\omega) = \frac{V_{out}}{V_{in}} = -\frac{1}{j\omega R_{in} C_f}$$

$$v_{out}(t) = -\frac{1}{R_{in} C_f} \int v_{in}(t) dt$$

$$\int \sin(\omega t) dt = \frac{-1}{\omega} \cos(\omega t) + K$$

Miller Integrator

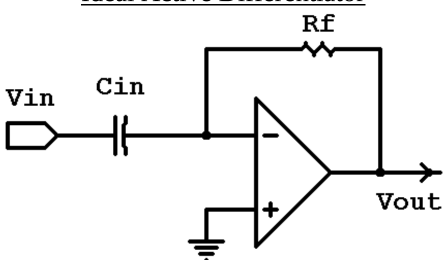


$$H(j\omega) = \frac{V_{out}}{V_{in}} = -\frac{R_f}{R_{in}(1 + j\omega R_f C_f)}$$

$$\omega >> \frac{1}{R_f C_f} \Rightarrow H(j\omega) \approx -\frac{1}{j\omega R_{in} C_f}$$

$$\omega >> \frac{1}{R_f C_f} \Rightarrow v_{out}(t) \approx -\frac{1}{R_{in} C_f} \int v_{in}(t) dt$$

Ideal Active Differentiator

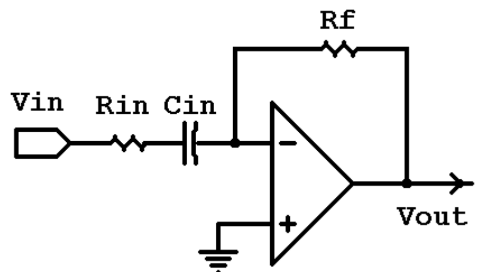


$$H(j\omega) = \frac{V_{out}}{V_{in}} = -j\omega R_f C_{in}$$

$$v_{out}(t) = -R_f C_{in} \frac{dv_{in}(t)}{dt}$$

$$\frac{d \sin(\omega t)}{dt} = \omega \cos(\omega t)$$

Practical Active Differentiator

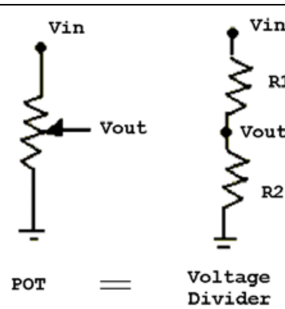


$$H(j\omega) = \frac{V_{out}}{V_{in}} = -\frac{j\omega R_f C_{in}}{1 + j\omega R_{in} C_{in}}$$

$$\omega << \frac{1}{R_{in} C_{in}} \Rightarrow H(j\omega) \approx -j\omega R_f C_{in}$$

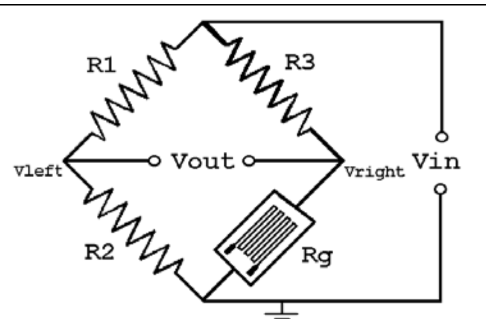
$$\omega << \frac{1}{R_{in} C_{in}} \Rightarrow v_{out}(t) = -R_f C_{in} \frac{dv_{in}(t)}{dt}$$

Potentiometers



$$RT = R1 + R2 \quad Vout = \frac{R2}{RT} Vin$$

Strain Gauge Bridge



$$Vout = dV = Vleft - Vright = Vin\left[\frac{R2}{R1 + R2} - \frac{Rg}{R3 + Rg}\right]$$

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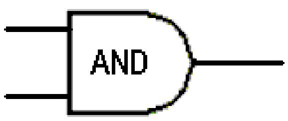
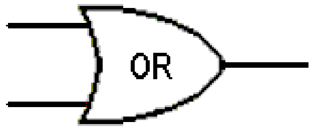
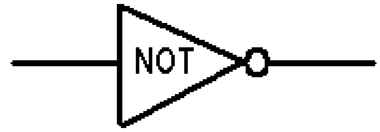
Logic Gates



A	B	$Y = A \bullet B$
0	0	0
0	1	0
1	0	0
1	1	1



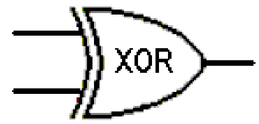
A	B	$Y = A + B$
0	0	0
0	1	1
1	0	1
1	1	1



A	$Y = \overline{A}$
0	1
1	0

A	B	$Y = \overline{A \bullet B}$
0	0	1
0	1	1
1	0	1
1	1	0

A	B	$Y = \overline{A + B}$
0	0	1
0	1	0
1	0	0
1	1	0



A	B	$Y = A \oplus B$
0	0	0
0	1	1
1	0	1
1	1	0

Boolean Algebra Properties

$A \bullet 0 = 0$

$A + 0 = A$

$A \bullet 1 = A$

$A + 1 = 1$

$A \bullet A = A$

$A + A = A$

$\overline{\overline{A}} = A$

$A \bullet \overline{A} = 0$

$A + \overline{A} = 1$

$A \oplus B = \overline{A} \bullet B + A \bullet \overline{B}$

$\overline{A \oplus B} = \overline{A} \bullet \overline{B} + A \bullet B$

$A \bullet B = B \bullet A$

$A + B = B + A$

$A + A \bullet B = A$

$A \bullet (A + B) = A$

$A \bullet (\overline{A} + B) = A \bullet B$

$A + \overline{A} \bullet B = A + B$

$\overline{A} + A \bullet B = \overline{A} + B$

$\overline{A} + A \bullet \overline{B} = \overline{A} + \overline{B}$

$A \bullet (B + C) = A \bullet B + A \bullet C$

$A + B \bullet C = (A + B) \bullet (A + C)$

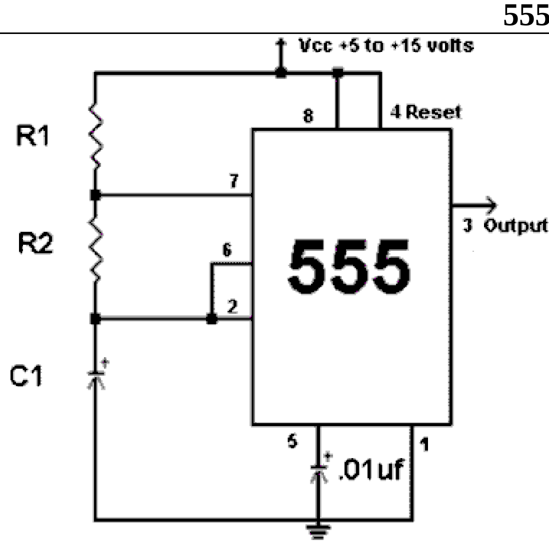
$A \bullet (B \bullet C) = (A \bullet B) \bullet C$

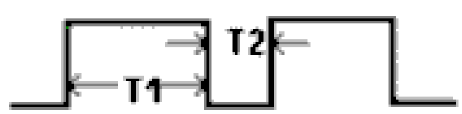
$A + (B + C) = (A + B) + C$

$\overline{A \bullet B} = \overline{A} + \overline{B}$

$\overline{A + B} = \overline{A} \bullet \overline{B}$

555-Timer





Charge Cycle: $T1 = 0.693(R1 + R2)C1$

$\tau 1 = (R1 + R2)C1$

Off Time: $T2 = 0.693(R2)C1$

$\tau 2 = (R2)C1$

Frequency: $f = \dfrac{1.44}{(R1 + 2R2)C1}$

Period: $T = T1 + T2$

Duty Cycle (percentage): $D = \dfrac{T1}{T} \times 100$

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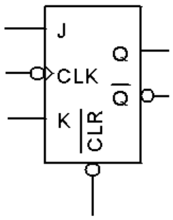
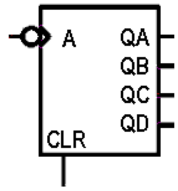
J-K flip-flop



J	K	C	Q	$\bar{Q}$
0	0	p	no change	
0	1	p	0	1
1	0	p	1	0
1	1	p	toggle	

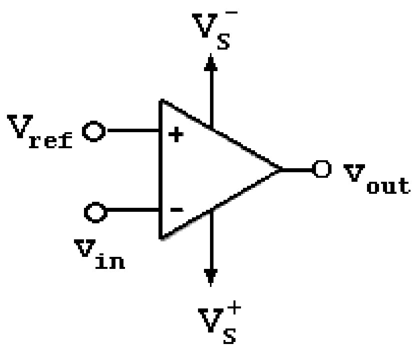
4-bit Counter



C	QD	QC	QB	QA
–	0	0	0	0
p	0	0	0	1
p	0	0	1	0
p	0	0	1	1
p	0	1	0	0
(etc.)				

$$Q_D \times 2^3 + Q_C \times 2^2 + Q_B \times 2^1 + Q_A \times 2^0$$

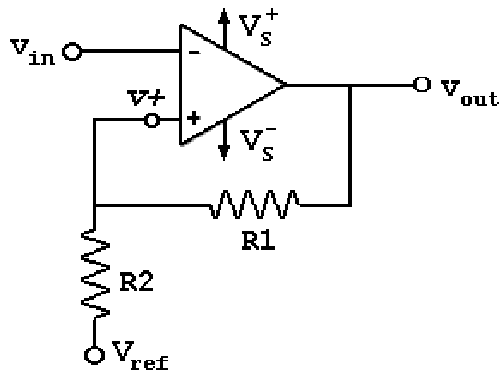
Inverting Comparator



$$if\ \ v_{in} > V_{ref}\ \ then\ v_{out} = V_S^-$$

$$if\ \ v_{in} < V_{ref}\ \ then\ v_{out} = V_S^+$$

Schmitt Trigger



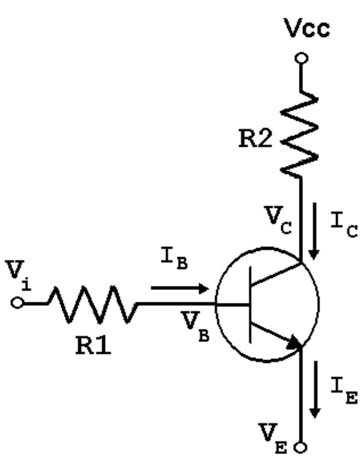
$$v+ = \left(\frac{R_2}{R_1 + R_2}\right)(v_{out} - V_{ref}) + V_{ref}$$

$$if\ \ v_{in} > v+\ \ then\ v_{out} = V_S^-$$

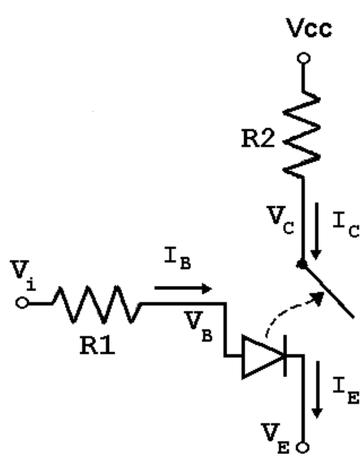
$$if\ \ v_{in} < v+\ \ then\ v_{out} = V_S^+$$

Transistor as a switch

Transistor circuit



Transistor model



if $(V_i - V_E) < 0.7$
- * transistor is off
- * switch is open
- * $I_C = 0$ mA
- * $V_C = V_{CC}$

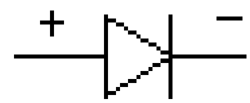
if $(V_i - V_E) > 0.7$
- * transistor is on
- * switch is closed
- * $I_C >> I_B$
- * $(V_B - V_E) = 0.7$
- * $V_{R1} = (V_i - (0.7 + V_E))$
- * $V_C = V_E$

Diodes

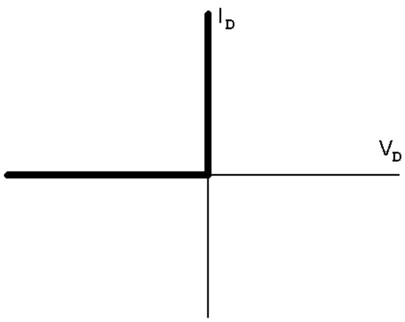
$$I_D = I_S\left(e^{\frac{V_D}{nV_T}} - 1\right)$$

I_S: Saturation current, $V_T = 25.9mV$, $n \approx 1-2$

4148 silicon diode: $V_{on} = 0.7$ Volts

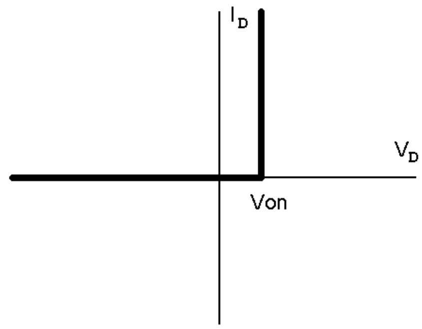


Ideal Diode



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

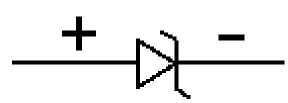
V_{on} Model



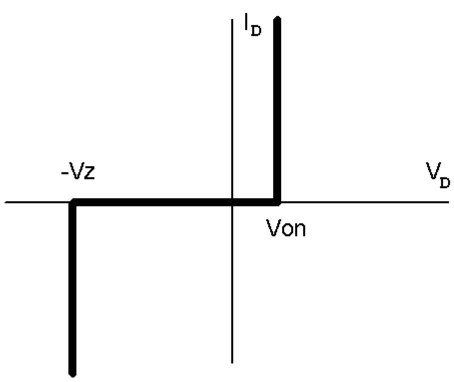
$$\begin{cases} On: & V_D = V_{on} \quad I_D > 0 \\ Off: & V_D < V_{on} \quad I_D = 0 \end{cases}$$

Zener Diodes

750 Zener diode: $V_{on} = 0.7V$ $V_z = 4.7V$
751 Zener diode: $V_{on} = 0.7V$ $V_z = 5.3V$

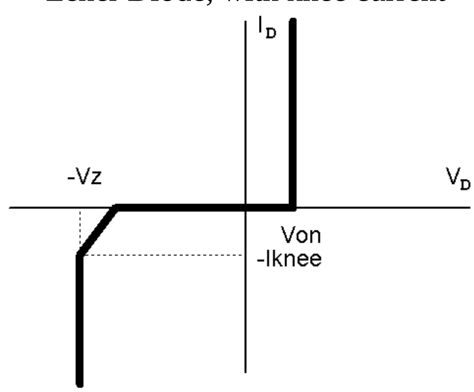


Zener Diode



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

Zener Diode, with knee current



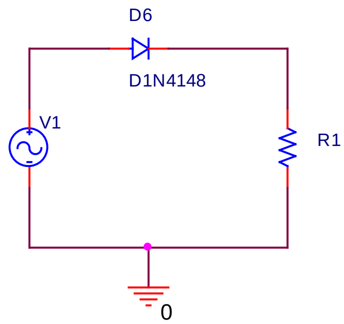
$$\begin{cases} On: & V_D = V_{on} & I_D > 0 \\ Off: & -V_z < V_D < V_{on} & I_D = 0 \\ Zener: & V_D = -V_z & I_D < -I_{knee} \end{cases}$$

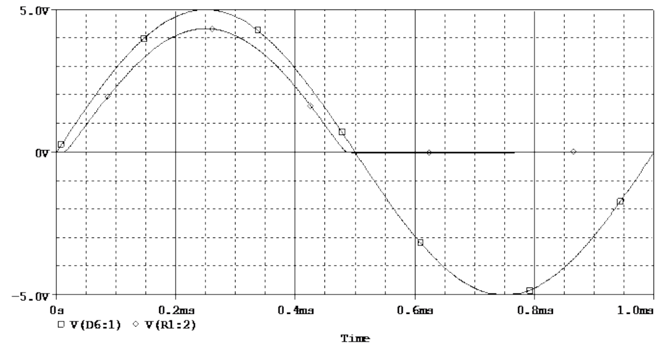
ENGR-2300 **Crib Sheet** **Quiz 4**

DO NOT WRITE ON THIS SHEET **RETURN SHEET AFTER QUIZ**

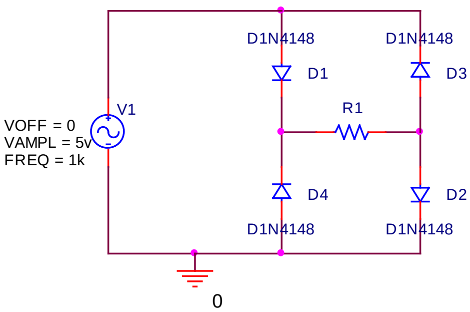
Diode Circuits

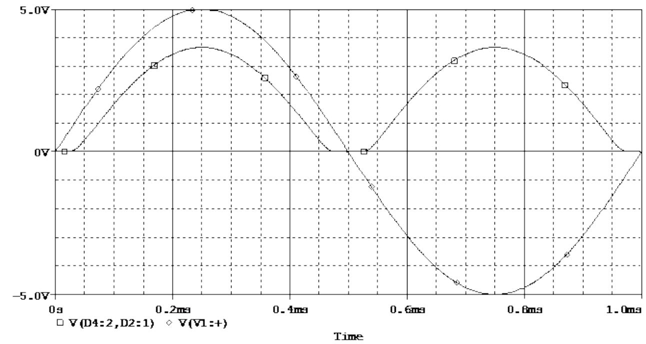
Half-Wave Rectifier



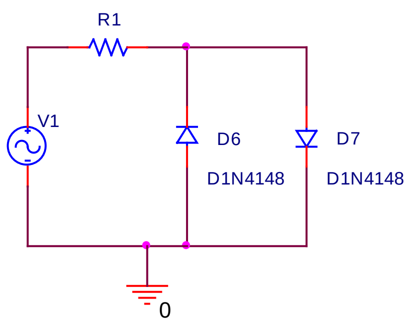


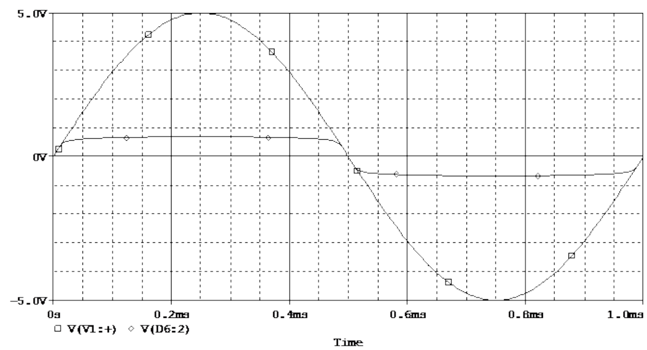
Full-Wave Rectifier





Limiter





Zener Limiter