## Metric Prefixes

| | | | |
|---|---|---|---|
| peta | P | $10^{15}$ | 1 000 000 000 000 000 |
| tera | T | $10^{12}$ | 1 000 000 000 000 |
| giga | G | $10^{9}$ | 1 000 000 000 |
| mega | M | $10^{6}$ | 1 000 000 |
| kilo | k | $10^{3}$ | 1 000 |
| hecto | h | $10^{2}$ | 100 |
| deca | da | $10^{1}$ | 10 |
| one | | $10^{0}$ | 1 |
| deci | d | $10^{-1}$ | 0.1 |
| centi | c | $10^{-2}$ | 0.01 |
| milli | m | $10^{-3}$ | 0.001 |
| micro | $\mu$ | $10^{-6}$ | 0.000 001 |
| nano | n | $10^{-9}$ | 0.000 000 001 |
| pico | p | $10^{-12}$ | 0.000 000 000 001 |
| femto | f | $10^{-15}$ | 0.000 000 000 000 001 |

## Ohm's Law $V = IR, \quad I = \frac{V}{R}, \quad R = \frac{V}{I}$

## Complex Numbers

- $z = x + iy = re^{i\theta} = r[\cos(\theta) + i\sin(\theta)]$
- $[r(\cos(\theta) + i\sin(\theta))]^n = r^n[\cos(n\theta) + i\sin(n\theta)]$
- $z^n = (re^{i\theta}) = r^n e^{in\theta}$
- $\frac{1}{i} = -i$
- $\sqrt[n]{z} = \sqrt[n]{r}e^{\frac{\theta}{n} + \frac{2k\pi}{n}}$ for $n \in N^*$ (ints $\geq 0$)
- $e^{j\theta} = \cos(\theta) + j\sin(\theta)$
- $e^{-j\theta} = \cos(\theta) - j\sin(\theta)$
- $\cos(\theta) = \frac{1}{2}(e^{j\theta} + e^{-j\theta})$
- $\sin(\theta) = \frac{1}{2j}(e^{j\theta} - e^{-j\theta})$
- normalized: $sinc(t) = \frac{\sin(\pi t)}{\pi t}$
- $|\frac{a}{b}| = \frac{|a|}{|b|}$
- $\angle\frac{a}{b} = \angle a - \angle b$

## Trig

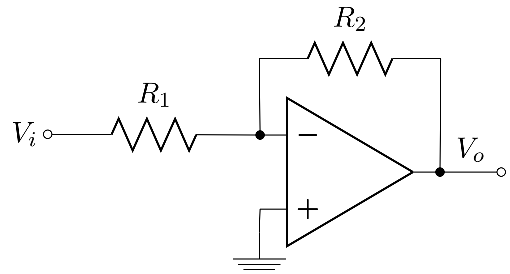
- $\cos^2(a) + \sin^2(a) = 1$
- $\cos(2a) = \cos^2(a) - \sin^2(a) = 2\cos^2(a) - 1 = 1 - 2\sin^2(a)$
- $\sin(2a) = 2\sin(a)\cos(a)$
- $\cos^2(a) = \frac{1}{2}(1 + \cos(2a))$
- $\sin^2(a) = \frac{1}{2}(1 - \cos(2a))$

## Bode Plots

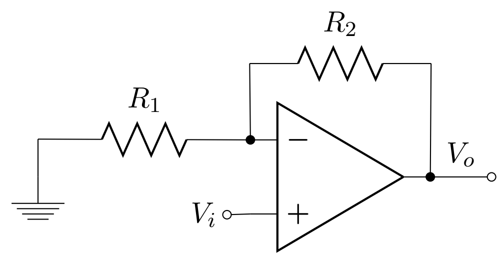
- magnitude is plotted in $dB$: $|T(j\omega)|_{dB} = 20\log_{10}|T(j\omega)|$
- starts on y-axis at DC offset with slope 0
- just add together the bode plots of each individual pole, zero, and the DC offset
- poles always slope down, zeros slope up (applies for both magnitude and phase)
- $dec$=decade, e.g. from $10^0$ to $10^1$
- magnitude:
  - ∗ Pole/Zero at origin: constant slope $\pm 20db/dec$ for all $\omega$; $0dB$ at $\omega = 10^0 = 1$
  - ∗ Pole/Zero at $\omega_0$: 0 for $\omega < \omega_0$ slope $\pm 20\frac{db}{dec}$ after
  - ∗ Constant $C$: constant line at $20\log_{10}(|C|)$
- phase:
  - ∗ Pole at origin: constant $-\frac{\pi}{2}$ or $-90°$
  - ∗ Zero at origin: constant $+\frac{\pi}{2}$ or $+90°$
  - ∗ Pole/Zero at $\omega_0$: 0 for $\omega < \frac{\omega_0}{10}$ slope linearly ($\pm 45°/dec$) until $10\omega_0$ 0 slope for $\omega > 10\omega_0$
  - ∗ Constant $C$: no effect (0 for all $\omega$)
- Prof wants us to actually show the -3dB drop curve, not just a straight intersection

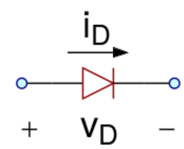
## Op Amp Equations

- general form: $T(s) = \frac{K_0}{1+\frac{s}{\omega_0}}$
  - ∗ $T(0) = K_0$: DC offset. For these simple ones, it's equal to ideal response
  - ∗ $\omega_0 = \frac{\omega_t}{1+R_2/R_1}$
- inverting op amp:
  - ∗ ideal: $T(s) = \frac{V_o}{V_i} = -\frac{R_2}{R_1}$
  - ∗ non-ideal: $T(s) = \frac{V_o}{V_i} = \frac{-R_2/R_1}{1+\frac{1+R_2/R_1}{A(s)}} = \frac{-R_2/R_1}{1+\frac{s}{\left(\frac{\omega_t}{1+R_2/R_1}\right)}} = \frac{-R_2/R_1}{1+\frac{s}{\omega_0}}$




- non-inverting op-amp:
  - ∗ ideal: $T(s) = \frac{V_o}{V_i} = 1 + \frac{R_2}{R_1}$
  - ∗ non-ideal: $T(s) = \frac{V_o}{V_i} = \frac{1+R_2/R_1}{1+\frac{1+R_2/R_1}{A(s)}} = \frac{1+R_2/R_1}{1+\frac{s}{\left(\frac{\omega_t}{1+R_2/R_1}\right)}} = \frac{1+R_2/R_1}{1+\frac{s}{\omega_0}}$




## Diodes

- ideal:
  - ∗ $I_D(V_D < 0) = 0$
  - ∗ $I_D(V_D \geq 0) = \infty$
- constant drop model: (just the ideal model shifted right by 0.7V)
  - ∗ $I_D(V_D < 0.7) = 0$
  - ∗ $I_D(V_D \geq 0.7) = \infty$
- exponential model: $I_D = I_S(e^{\frac{V_D}{nV_T}} - 1)$
  - ∗ $I_S = 10^{-12}$A (saturation current)
  - ∗ $V_T = 25$mV
- small signal resistance: $R_d = \frac{nV_T}{I_D}$
  - ∗ $I_D$: average (DC) current through diode (due to forward bias)
- bridge rectifier shape: square/diamond with all the diodes point toward the + end of the output (away from ground) current goes → from cathode (-) to anode (+)

## Design an (unregulated) AC adapter

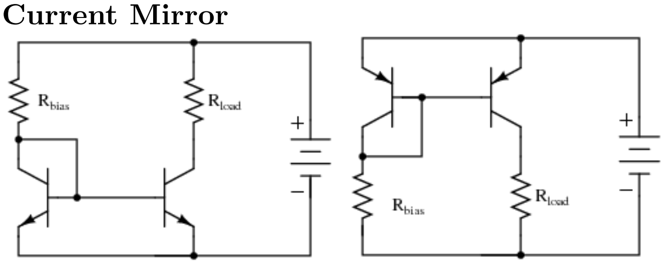
- $V_S$: AC voltage input
  - ∗ standard AC voltage is $110\sqrt{2}V \approx 155.563V$
- $V_{S2}$: output of transformer (still AC)
- $V_p$: peak DC output

- $V_r$: peak-to-peak ripple voltage (maximum variation)
  - $*$often given as a small percentage of $V_p$
- $V_p = V_{S2}-$ (diode voltage)
  - $*$diode voltage = 0.7V for single wave rectifier or center-tapped transformer
  - $*$diode voltage = 1.4V for full-wave rectifier
  - $*$(corresponds to how many diodes you need)
- turns ratio $= n = \frac{V_S}{V_{S2}}$
  - $*$if the transformer is center-tapped, each sub-coil only gets half of $V_{S2}$; so use $n = \frac{1}{2}\frac{V_S}{V_{S2}}$
- apparent load resistance: $R_L = \frac{V_o}{I_L}$
- ripple voltage: $V_r = V_p \frac{T}{R_L C}$
  - $*T$: period of ripple (half of frequency of AC input)
    - $\cdot T = \frac{1}{f}$
  - $*f$: actual ripple frequency (double for full-wave rectifier)
  - $*C$: filter cap size
- Peak Inverse Voltage: minimum reverse bias breakdown voltage of the diodes
  - $*$center-tapped transformer, two diodes: $PIV = 2V_{S2} - 0.7$
  - $*$bridge rectifier topology (two-terminal transformer): $PIV = V_{S2} - 0.7V$
- avg diode current: $I_{Davg} = I_L\left(1 + \pi\sqrt{\frac{2}{V_r}}\right)$
- max diode current: $I_{Dmax} = I_L\left(1 + 2\pi\sqrt{\frac{2}{V_r}}\right)$
  - $*$only difference is $\pi \rightarrow 2\pi$

**Transistors**

- $V_T = 25\text{mV}$ at room temperature (according to textbook and prof),
  $V_T = 26\text{mV}$ at room temperature (according to lab)
- $\beta$: a physical constant of the transistor. Usually about 100 or 200
- $I_B + I_C = I_E$, $I_C = \beta I_B$, $I_E = (1+\beta)I_B$
- $\alpha = \frac{\beta}{1+\beta}$, $I_C = \alpha I_E$
- $I_C = I_S(e^{\frac{V_{BE}}{nV_T}})$,
- AC (assumes correct DC bias): $g_m = \frac{1}{r_e} = \frac{I_C}{V_T}$

**Current Mirror**

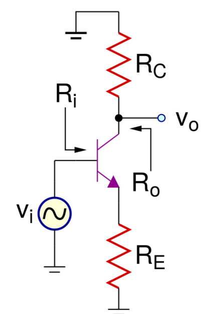



(a) current sinking (b) current-sourcing

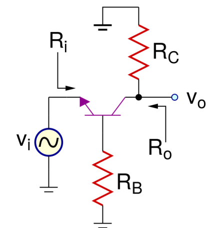
- Q1 has the base shorted to collector, Q2 does not
- $R_{bias} = R_{ref}$: the current that is mirrored
- $I_{ref} = (V_{CC} - 0.7)/R_{ref}$
- $R_{load}$ has the same current through it as $R_{ref}$ does
  - $*$that is, $I_{ref} = I_{load}$
- you can chain together multiple transistors (Q3,Q4...) all off of the same Q1 and they will all get the same current
  - $*$In this case, each Q2,Q3... output is considered separate from each other in both DC and AC analysis
- only applies when transistors are matched! (we assume they are)

**Transistor circuits by inspection**

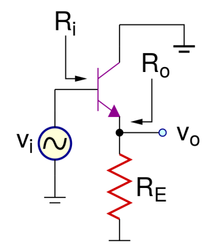
- this all assumes that the transistor is properly DC biased
- three types of amplifier circuits: common emitter, common base, common collector
  - $*$CE, CB, CC
  - $*$the "common" pin is the one that is neither AC input nor output
- intrinsic gain: gain directly from the input pin of the transistor to the output, ignoring any source resistance or such things whatever
  - $*$when you chain multiple amplifiers together, this is the one you use
- when you're driving a finite-impedance load (a load other than open circuit), you have to consider $R_o$ as $R_o||R_L$
  - $*$this will change the gain, which is why it's often helpful to put a CC buffer at the end of an amplifier
- $R_i$: input impedance: impedance as seen from the input
  - $*$includes the transistor, does not include $R_s$
- $g_m = \frac{I_C}{V_T}$
  $r_\pi = \frac{beta}{g_m}$
  $r_e = \frac{V_T}{I_E} = \frac{\alpha}{g_m} \approx \frac{1}{g_m}$
  $r_o = \frac{V_A}{I_C} \approx \infty$




Common Emitter (CE)




Common Base (CB)




Common Collector (CC)

- CE: Common Emitter
  - $*$input: base; output: collector
  - $*$intrinsic gain: $\frac{V_o}{V_b} = -\alpha\frac{R_C}{r_e + R_E} \approx -\frac{R_C}{r_e + R_E}$
  - $*R_i = (\beta + 1)(r_e + R_E)$
  - $*R_o = R_C$
  - $*$if you have a $R_L$ then you have to put that in parallel with $R_C$ when calculating $\frac{V_o}{V_b}$
- CB: Common Base
  - $*\frac{V_o}{V_b} = \alpha\frac{R_C}{R_i} \approx \frac{R_C}{R_i}$
  - $*R_i = r_e + \frac{R_B}{\beta+1}$
  - $*R_o = R_C$
- CC: Common Collector
  - $*$gain $\approx 1$ because it's a buffer
  - $*\frac{V_o}{V_b} = \frac{R_E}{r_e + R_E}$
  - $*R_i = (\beta + 1)(r_e + R_E)$
  - $*R_o = R_E||r_e = \frac{R_E * r_e}{R_E + r_e}$