ECEN325 Ref Sheet © Josh Wright April 19, 2017

**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** $V = IR, \quad I = \frac{V}{R}, \quad R = \frac{V}{I}$

**Battery Symbol**

The side with the longer line is the positive side

**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: $sinc(t) = \frac{\sin(\pi t)}{\pi t}$
- $|\frac{a}{b}| = \frac{|a|}{|b|}$ $\qquad \angle\frac{a}{b} = \angle a - \angle b$

**Trig**

$\cos(2a) = \cos^2(a) - \sin^2(a) = 2\cos^2(a) - 1 = 1 - 2\sin^2(a)$

$\cos^2(a) + \sin^2(a) = 1$ | $\sin(2a) = 2\sin(a)\cos(a)$

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

**Voltage Division between two non-zero points**

$V_{DD} \to R_1 \to V_1 \to R_2 \to V_{EE}$ (superposition)

$V_1 = V_{DD}\frac{R_2}{R_1+R_2} + V_{EE}\frac{R_1}{R_1+R_2}$

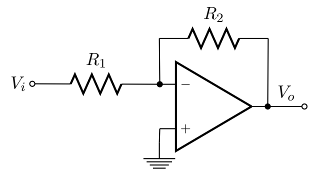
**Bode Plots**

- 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 $\pm 20 db/dec$ 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

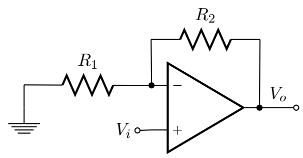
**Solving systems with Op Amps**

- only applies if the op-amp has feedback
- step 0: if the op amp is ideal, write out ideal properties:
  - $V_+ = V_-$
  - $I_- = 0, I_+ = 0$
  - $A \approx \infty$
- avoid doing KCL/KVL directly on the output node of the op amp
- ignore resistors from a point at $0V$ to ground

**Op Amp Equations**




Inverting Amplifier




Non-Inverting Amplifier

- ideal open-loop behavior: $(V_p - V_n) > 0 \to V_o = V_{DD}$
  $(V_p - V_n) < 0 \to V_o = -V_{DD}$
- 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:
    $T(s) = \frac{V_o}{V_i} = \frac{1+R_2/R_1}{1+\frac{1+R_2/R_1}{A(s)}} = \frac{1+R_2/R_1}{1+\frac{s}{\left(\frac{\omega_t}{1+R_2/R_1}\right)}} = \frac{1+R_2/R_1}{1+\frac{s}{\omega_0}}$

**MOS DC Biasing**

- this is all for NMOS. PMOS is backward
- $\beta = k_n'(\frac{W}{L})$
- cutoff: $V_{GS} < V_{th}$
  - $I_D = 0$
- triode (linear): $V_{DS} < V_{GS} - V_{th}$
  - $I_D = k_n'\frac{W}{L}\left((V_{GS} - V_{th})V_{DS} - \frac{V_{DS}^2}{2}\right)$
- active (saturation): $V_{DS} > V_{GS} - V_{th}$
  - $I_D = \frac{k_n'}{2}\frac{W}{L}(V_{GS} - V_{th})^2$
  - overdrive voltage $V_{ov} = V_{GS} - V_{th}$
- to show it's active: show that $V_{DS} > V_{ov}$ or $V_{DS} > V_{GS} - V_{th}$

**MOS Small Signal**

- $g_m = k_n'\frac{W}{L}(V_{GS} - V_t) = k_p'\frac{W}{L}(V_{SG} - V_t) = k_n'\frac{W}{L}(V_{ov})$
- CS: Common Source
  - $R_i = R_G = R_{G1}||R_{G2}$
  - $R_o = R_D$
  - $\frac{V_o}{V_g} = \frac{R_D||R_L}{\frac{1}{g_m} + R_S}$
- CD: Common Drain (buffer)
  - $R_i = R_G = R_{G1}||R_{G2}$
  - $R_o = \frac{1}{g_m}$
  - $\frac{V_o}{V_g} = \frac{R_L}{\frac{1}{g_m} + R_L}$
- CG: Common Gate
  - $R_i = \frac{1}{g_m}$

$* R_o = R_D$

$* \frac{V_o}{V_s} = \frac{R_D || R_L}{R_i}$