Review - Analog

Ch. 1

1. Resistive Circuits

a) Kirchhoff's Laws: i) Loop Thrm: \( \sum V_i = 0 \)

   (ii) Branch Thrm: \( \sum I_{\text{in}} = I_{\text{out}} \)

b) Ohm's Law: \( V = I R \)

c) \( R_{out}, R_{out}, R_{in}, R_{in} \)

d) Thevenin model: To find \( V_{Tm}, R_{Tm} \)

   i) \( V_{Tm} = V \) (open circuit) = \( V_{oc} \)

   ii) \( R_{Tm} = \frac{V \text{ (open circuit)}}{I \text{ (short circuit)}} = \frac{V_{oc}}{I_{sc}} = \text{put wire across output} \)

\( V_{out} = V_{in} \frac{R_2}{R_1 + R_2} \)

f) Power: \( P = IV \)

g) Problem w/ Source Loading - need \( R_2 >> R_5 \) to prevent loading.
**RC Circuits**

\[ Q = CV \quad V = IZ \]

\[ 2c = \frac{1}{j\omega C} \]

a) General

   i) time domain vs. frequency domain
   
   ii) step response vs. sine response
   
   iii) I leads V by 90° ECI the ICEman.

b) Important RC Circuits

   i) integrator (low-pass)

   \[ v_{out} = \frac{1}{\omega C} \int v_{in}(t) dt \]

   differentiator (high-pass)

   \[ v_{out} = \frac{1}{C} \frac{dv_{in}}{dt} \]

ii) Filters

   1. \( f_{3dB} \) \((w_{3dB})\)

   \[ \text{dB: } 10 \log \frac{P_2}{P_1} \quad 20 \log \frac{V_2}{V_1} \]

   2. phase-shift

   \[ 3 \text{dB} \Rightarrow v_{out} = \frac{v_{in}}{\sqrt{2}} \]

1) High-pass Filter:

\[ \frac{v_{out}}{v_{in}} \]

2) Low-pass Filter:

\[ \frac{v_{out}}{v_{in}} \]
2. phase-shift - need complex analysis
- ac circuits

**Generalized Voltage Divider**

\[ V_{in} \]
\[ \frac{1}{\sqrt{Z_1}} = \frac{1}{\sqrt{Z_2}} \]
\[ \frac{|V_{in}|}{|V_{out}|} = \frac{1}{Z_1 + Z_2} \]

**Magnitude + Phase**

\[ V_{in} = V_{in} e^{j\omega t} \]
\[ V_{in} = I \frac{Z_{tot}}{} \Rightarrow I = \frac{V_{in}}{Z_{tot}} \]

\[ V_{out} = I \frac{Z_2}{Z_2} = V_{in} e^{j\omega t} \frac{Z_{tot}}{1} \frac{Z_2}{Z_2} \]

**Complex Numbers:**

\[ r = \sqrt{x^2 + y^2} \]
\[ \tan \theta = \frac{y}{x} \]
\[ z = x + jy = r e^{j\theta} \]
\[ e^{j\theta} = \cos \theta + j \sin \theta \]
Transformer: \( \frac{V_p}{N_p} = \frac{V_s}{N_s} \)

3. Diode Circuit

a) Rectifiers

b) Clamp

c) Zener voltage reference

d) Power-supply - ripple - add low pass filter

Choose \( C \) such that \( RC \gg \frac{1}{F} \)

4. LC Circuits

LC resonant circuit

\[ w_0 = \frac{1}{\sqrt{LC}} \]

\[ f_0 = \frac{1}{2\pi \sqrt{LC}} \]

5. Bandpass Filter - Homework; chain HP + LP

Together w/ correct selection of \( w_0 \) for each to match bandpass range
Power Supply - Diode Rectifier + Low-Pass Filter

\[ V = \frac{\Delta V}{V_{ac}} = \frac{1}{R C R_{load}} \]

So pick capacitor large enough to give desired ripple factor for a given load (at frequency).

Essential Concept: Chosen capacitor is discharging between cycles through \( R_{load} \).
Chapter 2

Transistors

1. General

   a) Ground Rules
      i) $V_{ce} > 0$
      ii) BE + BC act like diodes
      iii) $I_c, I_d, V_{ce}$ have maxima

   b) Two models

      i) Current amplifier
         \[ I_c = h_{FE} I_B = \beta I_0 \]
         \[ \beta \approx 100 \]

      ii) Voltage amp (Ebers-Moll)
         \[ I_c = I_s e^{V_{be}/N_t} \]
         \[ V_t = 25.3 mV = h_T \frac{V}{e} \]
         (Typhon)

   c) Biasing - design rule - set voltage at base,
      not current.
2. Important Circuits

a) Switch

Here, with transistor saturated, usual β rule does not apply: $I_c = $ typically about 10 $I_b$.

\[ V_b \approx V_c + 0.6V \]

b)Emitter Follower

- Impedance changing: here is one of the few cases where you need to use β in your calculation (but a worst-case β).

- A variation is the push pull which can swing both way

\[ V_{se} = V_b - 0.6V \]

\[ V_{in} = h_{fe} R_E \text{ (looking into base)} \]
c. Common-emitter amplifier

- degenerated emitter resistor (placing of resistor b/w emitter and ground (or other negative supply) in common emitter amp. Source of term: gain is reduced or "degenerated" (performance is much improved however!)

- distortion vs. speed for gain

\[
R_{out} = \frac{R_2}{b_{re} + 1}
\]

(we ignore \( R_5 \) in parallel w/ \( R_{out} \))
3. General Problems

- swing on ac input in both directions on output
  solution: bias the base - use a voltage divider

- temperature effects

\[ \text{drift of } I_C \text{ (i.e.: of } V_{out} \text{) with } T \text{ since} \]
\[ V_{BE} = -2.1 \text{mV} / I_C \]
(Edward Miller) \[ I_C = I_T e^{V_{BE}/V_T} \]
this will cause gain to significantly
very small signal will distort the signal

i) Solution: use \( R_C \) as feedback - degenerated
emitter common-emitter amplifier

This reduces voltage gain: \( G = -\frac{R_C}{R_E} \)

Solution - bypass emitter (put \( C \) in parallel to \( R_E \))
+ add small \( R \) in \( C \) (es)

\[ R_E = \frac{25}{I_C (\text{mA})} \]

ii) Solution to temp problem - compensation - see differential amp.

- Miller effect - problem with capacitance

solution - differential amp.
Worked Example - Bypass Common-Emitter Amp

1. Choose $I_C$. Note that at signal freq., $R_{in} \approx R_m(bias) \approx \frac{1}{\beta} \frac{1}{h_{fe}(r_e + r_f)}$.
   $\approx 20 \Omega \approx 100 \times 200$
   $= 10 \Omega$
   $\Rightarrow C_1 = \frac{1}{2\pi f_c 10 \Omega}$
   $= 0.33 \mu F$

2. To center $V_{out}$ for $I_C = 0.5 \text{mA}$, $R_e = 20 \Omega$

3. Put $V_e = 1\text{V}$, for temp. stab.
   $\Rightarrow R_e = 2 \Omega$

4. Find $R_1$, $R_2$ ratio.
   Input $V_b \approx 1.6V$:
   $1.6V = \frac{R_2}{R_1}$
   $\Rightarrow R_2 = 11.5R_1$
   
   Set $R_{m(bias)} < C R_{m(base)}$:
   $R_{m(base)} = h_{fe} R_e = 200\Omega$
   $\Rightarrow R_{m(bias)} \leq 20\Omega$
   Let $R_1 = 20\Omega$, since
   $R_2 >> R_1 \Rightarrow R_{m(bias)} \approx R_2$

5. Choose $R_3$ for req'd gain.
   $G = \frac{R_e}{R_e + (R_3 + r_f)}$
   $re = 50\Omega$ & $I_C = 0.5 \text{mA}$.
   $\Rightarrow R_3 = \frac{20\Omega}{\frac{50\Omega}{r_f} + R_3}$
   (note effect of $R_e$ negligible)

6. Choose $C_e$.
   Circuit $f_{3dB} = 100kHz$ $\Rightarrow R_{c(e)}$
   $f_{3dB} = 50kHz$. Relevant "$r"; R_3 + r_e$
   $\Rightarrow C_e = \frac{1}{2\pi f_{3dB}} (R_3 + r_e) = 16\mu F$
   Use $20\mu F$ (or $22\mu F$)