Review - Analog

Ch. 1

1. Resistive Circuits

a) Kirchoff's Laws: i) Loop Thrm: $\sum_i V_i = 0$

(ii) Branch Thrm: $I_{into} = I_{out}$
junction

b) Ohm's Law : $V = IR$

c) R_{out}, Z_{out}, R_{in}, Z_{in}

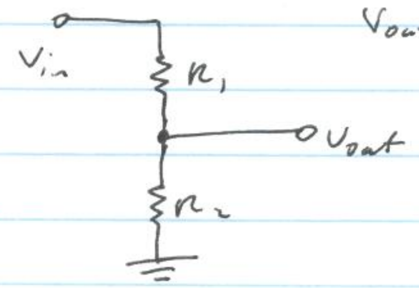
d) Thevenin model: To find V_{Th}, R_{Th}

i) $V_{Th} = V(\text{open circuit}) = V_{oc}$

ii) $R_{Th} = \dfrac{V(\text{open circuit})}{I(\text{short circuit})} = \dfrac{V_{oc}}{I_{sc}}$

(short circuit: put wire across output)

e) Voltage Dividers



$V_{out} = V_{in} \dfrac{R_2}{R_1 + R_2}$

f) Power : $P = IV$

g) Problem w/ Source Loadings - need $R_L >> R_s$ to prevent loadings.

RC Circuits

$Q = CV \quad V = IZ$

$Z_c = \frac{1}{j\omega C}$

a) General

i) time domain vs. frequency domain

ii) step response vs. sine response

iii) I leads V by 90°   ELI the ICEman.

b) Important RC Circuits

i) integrator (low-pass) $V_{out} = \frac{1}{RC}\int V_{in}(t)\,dt$

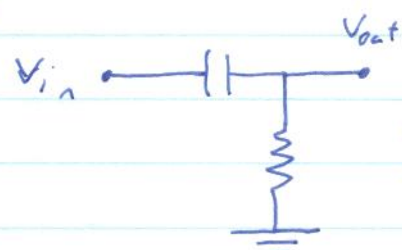
differentiator (high-pass) $V_{out} = RC\frac{dV_{in}}{dt}$

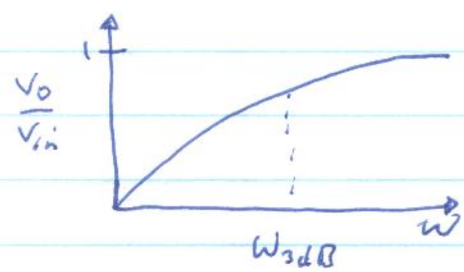
ii) filters

1. f_{3dB} (ω_{3dB})   dB: $10\log\frac{P_2}{P_1}$, $20\log\frac{V_2}{V_1}$

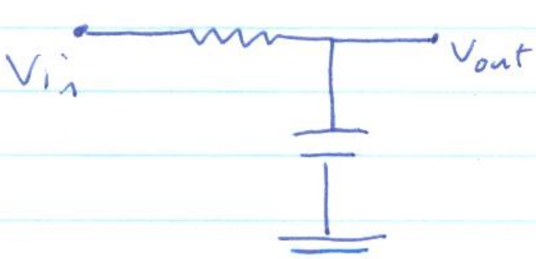
2. phase-shift $3dB \Rightarrow V_{out} = \frac{V_{in}}{\sqrt{2}}$

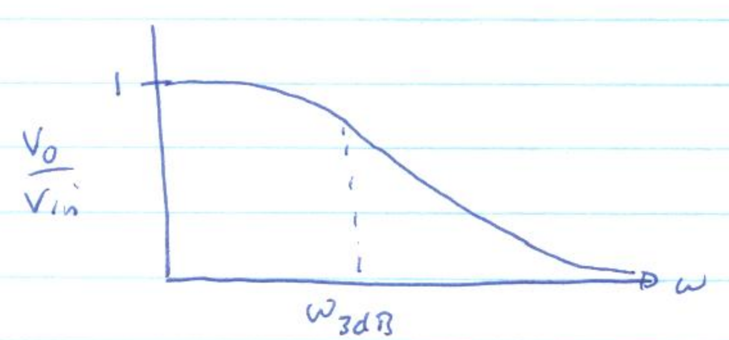
1) High-pass filter:





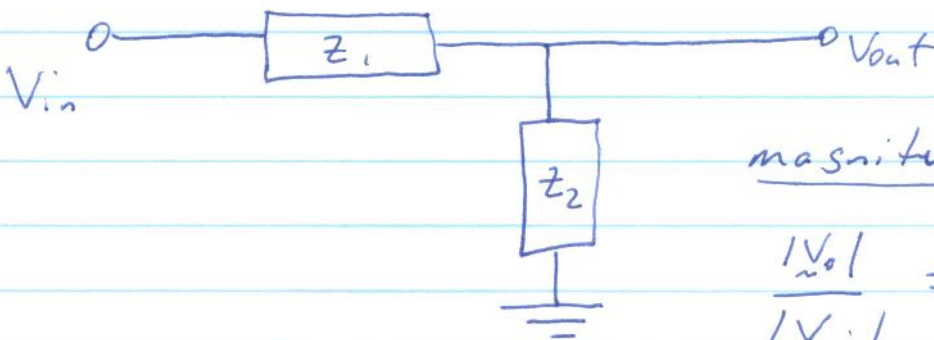
2) Low-pass filter:





2. phase-shift – need complex analysis
– ac circuits

Generalized Voltage Divider



magnitudes:

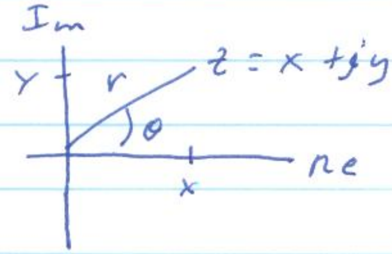
$$\frac{|\tilde{V}_o|}{|\tilde{V}_{in}|} = \frac{|\tilde{Z}_2|}{|\tilde{Z}_1 + \tilde{Z}_2|}.$$

Magnitude + Phase

$$\tilde{V}_{in} = V_{in} e^{j\omega t} \qquad \tilde{V}_{in} = \tilde{I}\,\tilde{Z}_{TOT} \Rightarrow I = \frac{\tilde{V}_{in}}{\tilde{Z}_{TOT}}$$

$$\tilde{V}_{out} = \tilde{I}\,\tilde{Z}_2 = \frac{V_{in} e^{j\omega t}}{|\tilde{Z}_{TOT}|^2}\,\tilde{Z}^*_{TOT}\,\tilde{Z}_2.$$

Complex Numbers:

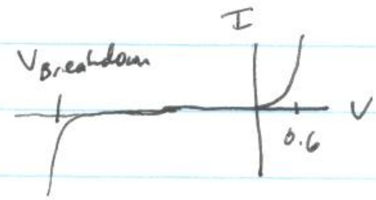


$$r = \sqrt{x^2 + y^2} \qquad \tan\theta = \frac{Y}{X} \qquad z = x + jy = re^{j\theta}.$$

$$e^{j\theta} = \cos\theta + j\sin\theta$$

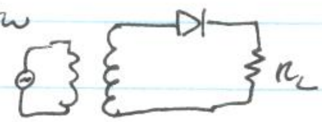
Transformer: $\frac{V_p}{N_p} = \frac{V_s}{N_s}$.

3. Diode Circuits

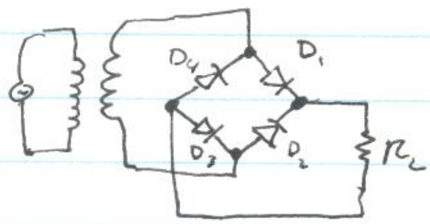


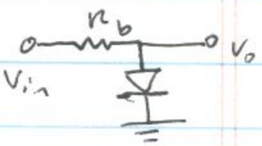
a) Rectifiers

Hw

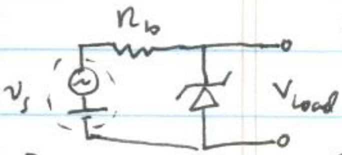


Fw Bridge





b) Clamp



Dc w/ ripple

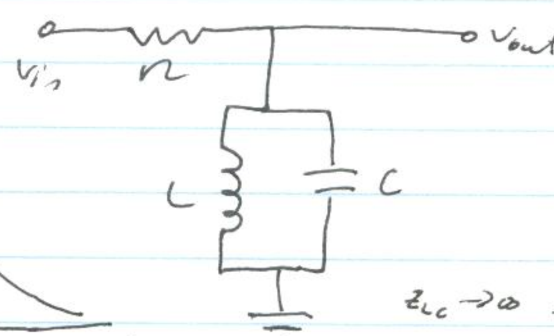
c) zener voltage reference

d) power-supply – ripple – add low pass filter

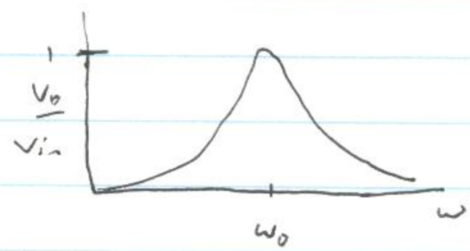
choose C ∴ $R_L C \gg \frac{1}{F}$.

4. LC Circuits

LC resonant circuit

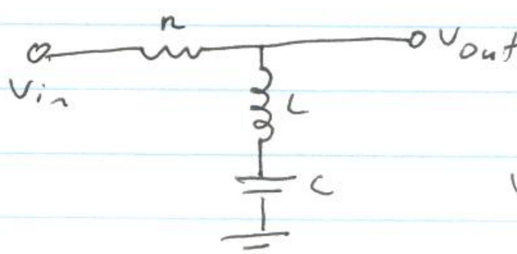


$\omega_0 = \frac{1}{\sqrt{LC}}$

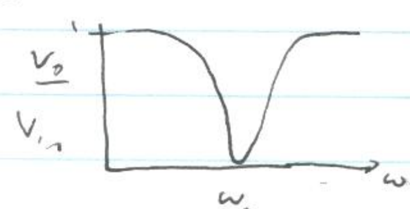


$Z_{LC} \to \infty \Rightarrow \omega \to \omega_0$.

Notch filter



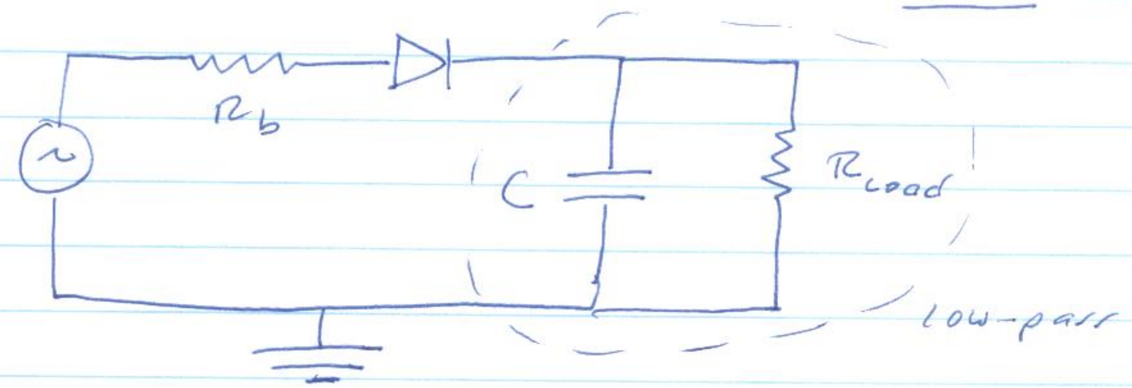
$\omega_0 = 1/\sqrt{LC}$



5. Bandpass Filter

– homework; chain HP + LP together w/ correct selection of ω_{3dB} for each to match bandpass range

Power Supply - Diode Rectifier + Low-Pass Filter



ripple - factor ≡ r

$$r = \frac{\Delta V}{V_{ac}} = \frac{1}{f R_{Load} C}$$

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

Essential Concept: Charged 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

npn

iii) I_C, I_B, V_{CE} have maxima

b) Two models

i) current amplifier $I_C = h_{FE} I_B = \beta I_B$

$\beta \sim 100$

ii) voltage amp (Ebers-Moll)

$$I_C \simeq I_S e^{V_{BE}/V_T}$$

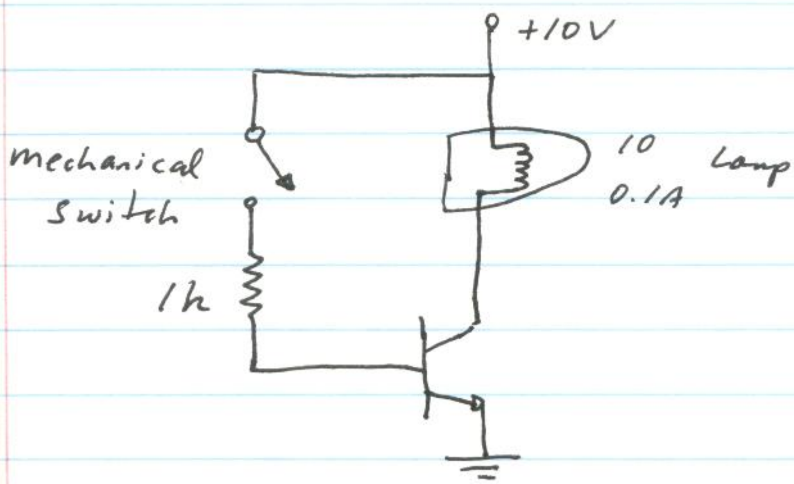
$V_T = 25.3 mV = \frac{kT}{e}$ (T_{room})

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 $10\, I_B$.

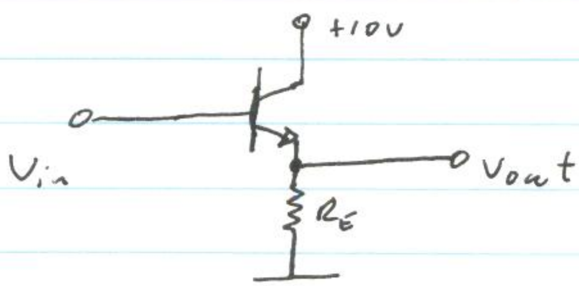


$V_B \simeq V_E + 0.6V$

b) Emitter Follower

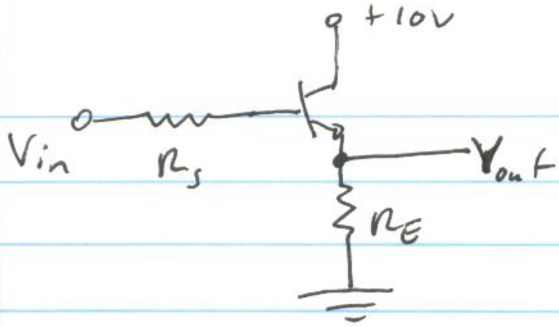
- impedance changing: here is one of the few cases where you need to use β in your calculation (but a worst-case β).

- a variation is the push pull which can swing both ways.



$$V_E \simeq V_B - 0.6V$$

$r_{in} \simeq h_{FE} R_E$ (looking into base)



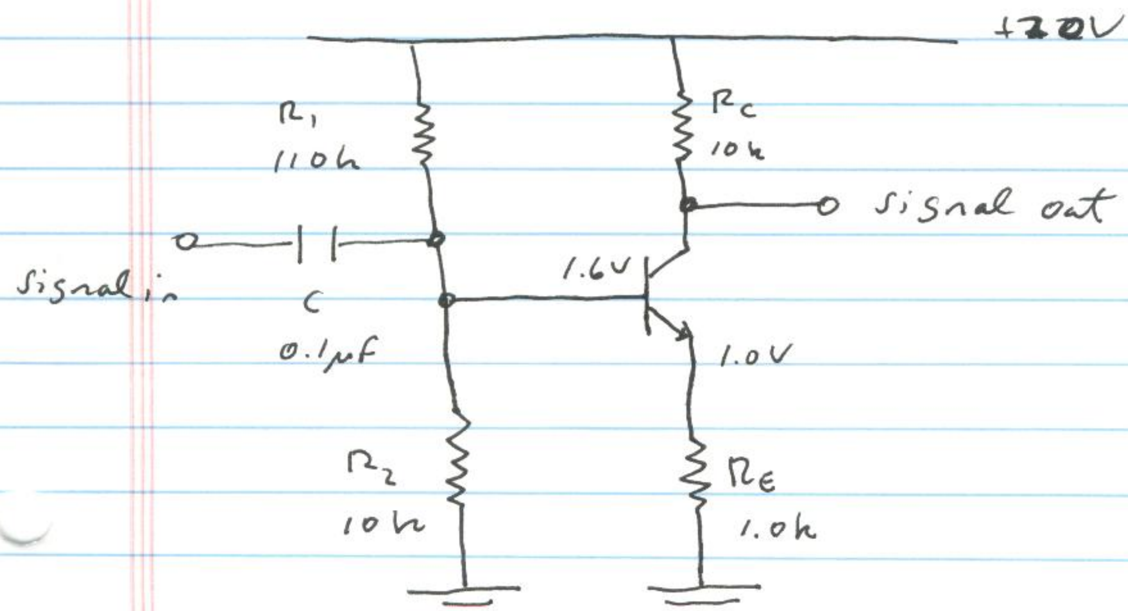
$$R_{out} = \frac{R_S}{h_{FE}+1}$$

looking into emitter
(we ignore R_E in parallel w/ R_{out})

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 ← greed for gain



3. General Problems

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

— temperature effects

drift of I_c (& ∴ of V_{out}) with T since
$V_{BE} = -2.1\, mV/^{o}C$ (Ebers moll $I_c \simeq I_s e^{V_{BE}/V_T}$
strong dependence on T!!)

this will cause gain to significantly vary w/ signal & will distort the signal

i) Solution: use R_E as feedback — degenerated emitter common-emitter amplifier

This reduces voltage gain: $G = -\frac{R_c}{R_E}$

solution - bypass emitter (put C in parallel w/ R_E)
+ add small R in C leg

$r_e = \frac{25}{I_c(mA)}\ \Omega$ (intrinsic emitter resistance)

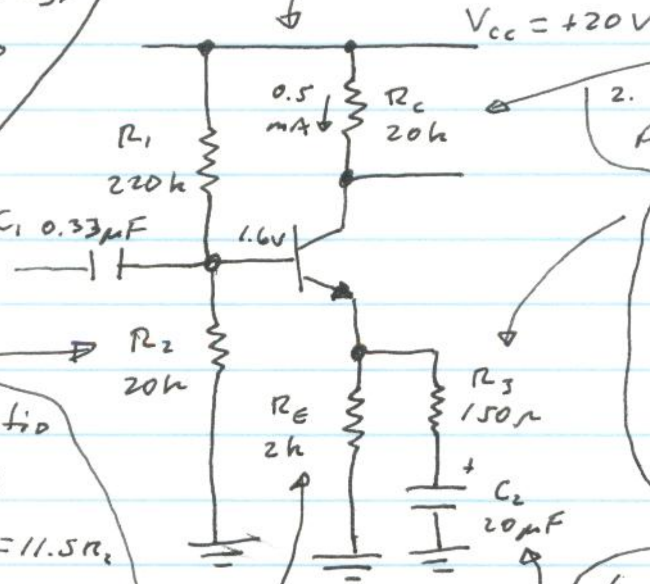
ii) Solution to temp problem - compensation - see differential amp.

— Miller effect - problem with capacitance

solution - differential amp.

Worked Example - Bypass Common-Emitter Amp

(High-Gain, Temp. Stable amplifier).



1. Choose I_Q

2. To center V_{out} for $I_Q = 0.5mA$, $R_C = 20k$

3. Put $V_E \simeq 1V$, for temp. stab. $\Rightarrow R_E = 2k$

4. Find $R_1 : R_2$ ratio to put $V_B \simeq 1.6V$:

$$\frac{1.6V}{18.4V} = \frac{R_2}{R_1} \Rightarrow R_1 = 11.5 R_2$$

— — — — then — — — —

Set $R_{Th}(bias) << R_{in}(base)$:

$R_{in}(base) \simeq h_{FE} R_E = 200k$

so $R_{Th}(bias) \lesssim 20k$.

Let $R_2 = 20k$, since $R_1 >> R_2 \Rightarrow R_{Th}(bias) \simeq R_2$

5. Choose R_3 for req'd gain.

$$G = \frac{R_C}{r_e + (R_E \| R_3)}, \text{ and}$$

$r_e = 50\Omega$ @ $I_C = 0.5mA$.

Thus $100 = \frac{20k}{50\Omega + R_3}$ and $R_3 = 150\Omega$

(note effect of R_E negligible)

6. Choose C_2.

Circuit $f_{3dB} = 100Hz \Rightarrow$ this "filter's" $f_{3dB} \simeq 50Hz$. Relevant "R" is $R_3 + r_e$

$$\Rightarrow C_2 = 1/2\pi f_{3dB}(R_3 + r_e) = 16\mu F$$

use 20µF (or 22µF)

7. Choose C_1. Note that at signal freq.

$$R_{in} \simeq R_{Th}(bias) \| h_{FE}(r_e + R_3)$$

$$\simeq 20k \| 100 \times 200$$

$$= 10k$$

$$\Rightarrow C_1 = \frac{1}{2\pi \cdot 50 \cdot 10k}$$

$$\simeq 0.33\mu F$$