A. Stolp
3/25/03

Stuff

Micron Scholarship deadline extended to M, 3/31.
$3000 (Two years tuition)
I have some applications, you will also need a resume.

HW #17, due: W, 3/26 Hw 17 handout
answer 1e: 27.3Ω

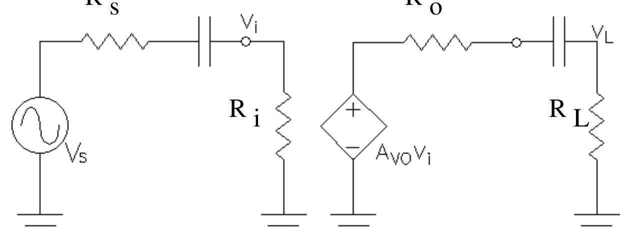
HW #18, due: F, 3/28 Hw 18 handout

HW #19, due: W, 4/2 Hw 19 handout

Spice #S2, due: F, 4/4 2 handouts

Effects of the load (R_L)

I've already been using the load in some calculations, in particular, the AC (signal) collector resistance: $r_c = R_C || R_L || r_o$
The gain, it turns out, is actually dependent on this r_c instead of R_C.
Another way to look at the gain:



No-load Voltage gain: $A_{vo} = \frac{R_o}{r_e + R_e}$

$$\frac{v_o}{v_b} = A_{vo}\cdot\frac{R_L}{R_o + R_L} = \frac{R_o}{r_e + R_e}\cdot\frac{R_L}{R_o + R_L} = \frac{r_c}{r_e + R_e}$$

Note: $v_o = v_c = v_L$

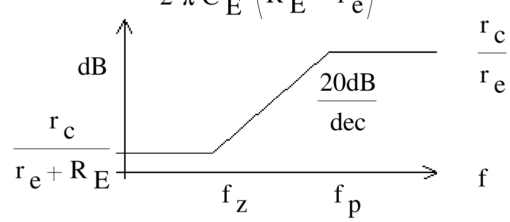
Common emitter (CE) with bypass capacitor (C_E) , continued

C_E causes another low corner frequency: "gain" = $\frac{r_c}{r_e + \frac{1}{\frac{1}{R_E} + j\cdot\omega\cdot C_E}}\cdot\left[\frac{\frac{1}{R_E} + j\cdot\omega\cdot C_E}{\frac{1}{R_E} + j\cdot\omega\cdot C_E}\right] = \frac{r_c\cdot\left(\frac{1}{R_E} + j\cdot\omega\cdot C_E\right)}{\frac{r_e}{R_E} + j\cdot\omega\cdot C_E\cdot r_e + 1}$

This results in a pole and a zero $f_z = \frac{1}{2\cdot\pi\cdot C_E\cdot R_E}$

pole: $\omega_p\cdot C_E\cdot r_e = \frac{r_e}{R_E} + 1$ $\qquad \omega_p = \left(\frac{r_e}{C_E\cdot r_e\cdot R_E} + \frac{1}{C_E\cdot r_e}\right)$ $\qquad f_p = \frac{1}{2\cdot\pi\cdot C_E}\cdot\left(\frac{1}{R_E} + \frac{1}{r_e}\right)$

$$f_{CL3} = \frac{1}{2\cdot\pi\cdot C_E}\cdot\left(\frac{1}{r_e} + \frac{1}{R_E}\right)$$



Because r_e is so small, this will usually dominate, even when C_E is big.

Partial bypass (C_E & R_e) p. 285

Bypass capacitor greatly increases gain, but also increases distortion, lowers input resistance, and can badly affect the low corner frequency (make it higher). The partial bypass is a compromise between this and the simple CE amp. Trade some of the gain of the fully bypassed CE amplifier for improvements in all the other parameters.
The relationships shown below work for the particular circuit shown. You MUST know why they work so that you can figure out relations like these for different configurations. (Exam 3 hint, hint)

Input impedance: $R_i = R_{B1} || R_{B2} || \beta\cdot(r_e + R_e)$

Output impedance: $R_o = R_C || r_o$

AC collector resistance: $r_c = R_C || R_L || r_o$
(signal)

Same as before, but may use some r_o correction

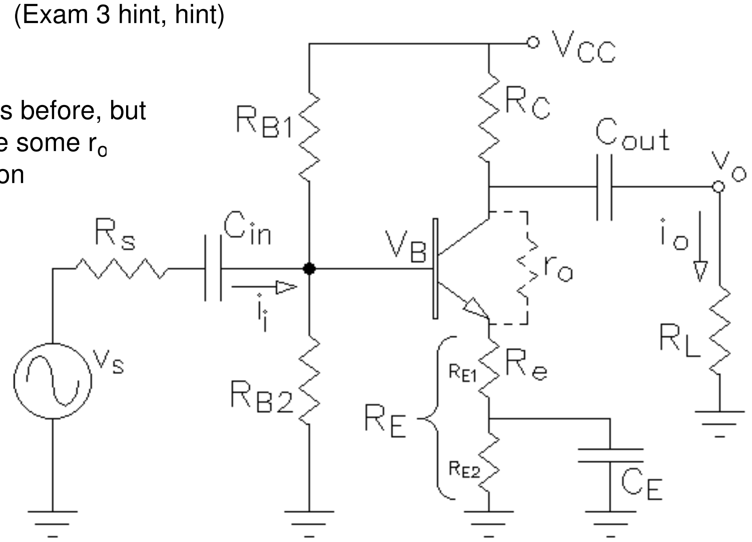
Voltage gain: $A_v = \frac{v_o}{v_b} = \frac{r_c}{r_e + R_e}$

Current gain: $A_i = A_v\cdot\frac{R_i}{R_L}$

The additional low corner frequency:

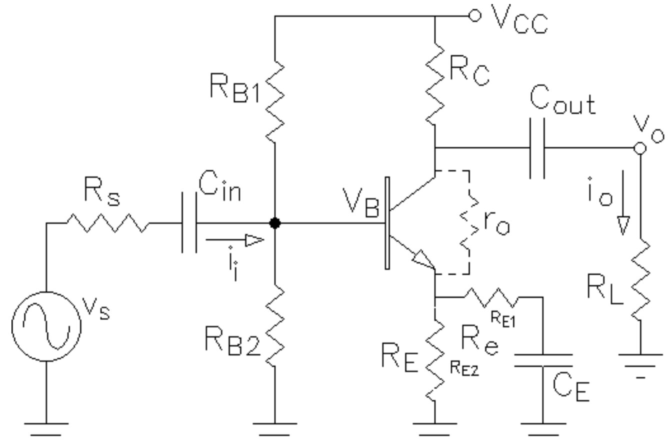
$$f_{CL3} = \frac{1}{2\cdot\pi\cdot C_E}\cdot\left(\frac{1}{r_e + R_e} + \frac{1}{R_{E2}}\right)$$

From same type of analysis as above



$R_e = R_{E1}$

Another type of partial bypass (C_E & R_e) p. 285



AC (signal) emitter resistance: $R_e = R_{E1} \| R_{E2}$

Same relations as before

The additional low corner frequency:

$$\text{"gain"} = \frac{r_c}{r_e + \dfrac{1}{\dfrac{1}{R_{E2}} + \dfrac{1}{R_{E1} + \dfrac{1}{j\cdot\omega\cdot C_E}}}} \cdot \left[\frac{\dfrac{1}{R_{E2}} + \dfrac{1}{R_{E1} + \dfrac{1}{j\cdot\omega\cdot C_E}}}{\dfrac{1}{R_{E2}} + \dfrac{1}{R_{E1} + \dfrac{1}{j\cdot\omega\cdot C_E}}} \right]$$

$$= \frac{r_c \cdot \left[\dfrac{1}{R_{E2}} + \dfrac{1}{R_{E1} + \dfrac{1}{j\cdot\omega\cdot C_E}} \right]}{\dfrac{r_e}{R_{E2}} + \dfrac{r_e}{R_{E1} + \dfrac{1}{j\cdot\omega\cdot C_E}} + 1} \cdot \left[\frac{R_{E1} + \dfrac{1}{j\cdot\omega\cdot C_E}}{R_{E1} + \dfrac{1}{j\cdot\omega\cdot C_E}} \right] = \frac{r_c \cdot \left[\dfrac{1}{R_{E2}} \cdot \left(R_{E1} + \dfrac{1}{j\cdot\omega\cdot C_E} \right) + 1 \right]}{\left[\dfrac{r_e}{R_{E2}} \cdot \left(R_{E1} + \dfrac{1}{j\cdot\omega\cdot C_E} \right) + r_e \right] + \left(R_{E1} + \dfrac{1}{j\cdot\omega\cdot C_E} \right)}$$

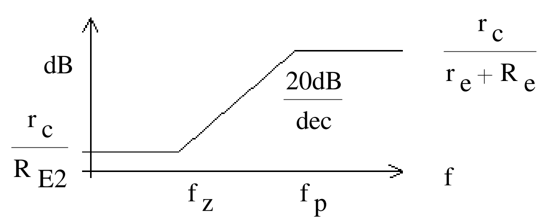
$$= \frac{r_c \cdot \left[\dfrac{1}{R_{E2}} \cdot \left(R_{E1} + \dfrac{1}{j\cdot\omega\cdot C_E} \right) + 1 \right]}{\left[\dfrac{r_e}{R_{E2}} \cdot \left(R_{E1} + \dfrac{1}{j\cdot\omega\cdot C_E} \right) + r_e \right] + \left(R_{E1} + \dfrac{1}{j\cdot\omega\cdot C_E} \right)} = \frac{r_c \cdot \left(\dfrac{R_{E1}}{R_{E2}} + \dfrac{1}{j\cdot\omega\cdot C_E \cdot R_{E2}} + 1 \right)}{\dfrac{r_e \cdot R_{E1}}{R_{E2}} + \dfrac{r_e}{j\cdot\omega\cdot C_E \cdot R_{E2}} + r_e + R_{E1} + \dfrac{1}{j\cdot\omega\cdot C_E}}$$

zero: $$\frac{1}{\omega_z \cdot C_E \cdot R_{E2}} = \frac{R_{E1}}{R_{E2}} + 1 \qquad \omega_z = \left[\frac{1}{C_E \cdot R_{E2} \cdot \left(\dfrac{R_{E1}}{R_{E2}} + 1 \right)} \right] = \left[\frac{1}{C_E \cdot \left(R_{E1} + R_{E2} \right)} \right]$$

pole: $$\frac{1}{\omega_p \cdot C_E} \cdot \left(\frac{r_e}{R_{E2}} + 1 \right) = \frac{r_e \cdot R_{E1}}{R_{E2}} + r_e + R_{E1} = R_{E1} \cdot \left(\frac{r_e}{R_{E2}} + 1 \right) + r_e \qquad \omega_p = \frac{1}{C_E} \cdot \left[\frac{\dfrac{r_e}{R_{E2}} + 1}{R_{E1} \cdot \left(\dfrac{r_e}{R_{E2}} + 1 \right) + r_e} \right]$$

$$\omega_p = \frac{1}{C_E} \cdot \left[\frac{1}{R_{E1} + \dfrac{r_e}{\dfrac{r_e}{R_{E2}} + 1}} \right] = \frac{1}{C_E} \cdot \left[\frac{1}{R_{E1} + \dfrac{r_e}{\dfrac{r_e}{R_{E2}} + \dfrac{r_e}{r_e}}} \right] = \frac{1}{C_E} \cdot \left[\frac{1}{R_{E1} + \dfrac{1}{\dfrac{1}{R_{E2}} + \dfrac{1}{r_e}}} \right]$$

$$f_{CL3} = \frac{1}{2\cdot\pi\cdot C_E} \cdot \left[\frac{1}{R_{E1} + \dfrac{1}{\dfrac{1}{R_{E2}} + \dfrac{1}{r_e}}} \right]$$



Clipping with no load (R_L)

No bypass or partial bypass

The + swing limit of the output voltage: $V_{CC} - V_C = 4 \cdot V$ = L+

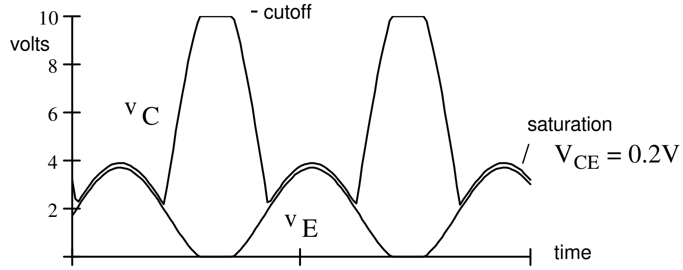
The - swing limit: $\left(V_C - V_E - 0.2 \cdot V\right) \cdot \frac{A_v}{A_v + 1}$ = L-

$= \left(V_{CE} - 0.2 \cdot V\right) \cdot \frac{A_v}{A_v + 1} = 3.363 \cdot V$

Better limit $= \left(V_{CE} - 0.5 \cdot V\right) \cdot \frac{A_v}{A_v + 1} = 3.153 \cdot V$

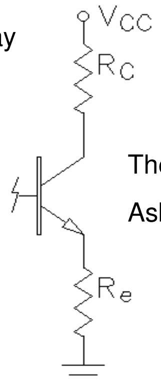
because sometimes the effects of saturation can already be seen at $V_{CE} = 0.5V$.

Clipping Cutoff clipping: $i_E = 0$



Δ analysis

Another way to find this



The voltage across the transistor changes from V_{CE} to 0.2V, total change = $\left(V_{CE} - 0.2 \cdot V\right)$

Ask yourself, "How much of this change appears across R_C and how much appears across R_E?"

You can find this using the voltage divider: $\Delta v_{RC} = \left(V_{CE} - 0.2 \cdot V\right) \cdot \frac{R_C}{R_C + R_E}$ = L-

That's also how much change you'll see at the output, so it's the - swing limit

This method is actually better if A_v was calculated using r_e, r_e doesn't really make sense when the transistor is saturated. This method eliminates the r_e problem

Again, it's better to limit the output to: L- = $\left(V_{CE} - 0.5 \cdot V\right) \cdot \frac{R_C}{R_C + R_E}$

Partial bypass: L- = $\left(V_{CE} - 0.5 \cdot V\right) \cdot \frac{R_C}{R_C + R_e}$

USE THESE RELATIONS to find V_{oppmax}

Full bypass

V_E is now held quite constant by C_E, so clipping isn't so strange looking as it was for the simple CE amp.

The picture at right shows what the clipping would be <u>without</u> a load ($R_L = \infty$).

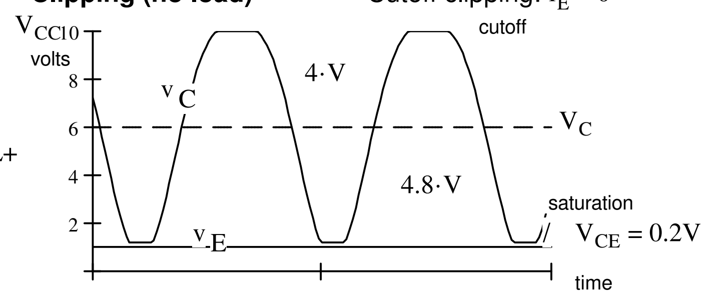
The + swing limit of the output voltage: $V_{CC} - V_C = 4 \cdot V$ = L+
$= I_C R_C$

The - swing limit: $\left(V_C - V_E - 0.2 \cdot V\right) = 4.8 \cdot V$= L-

$V_{CE} - 0.5 \cdot V = 4.5 \cdot V$

is a better limit because sometimes the effects of saturation can already be seen at $V_{CE} = 0.5V$.

Clipping (no load) Cutoff clipping: $i_E = 0$



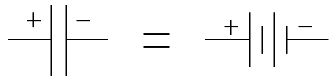
The maximum peak-to-peak output is twice the smallest of the two limits. $V_{oppmax} = 2L+ = 2 \cdot 4 \cdot V = 8 \cdot V_{pp}$

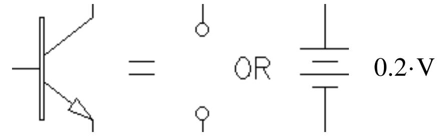
Clipping with a load (R_L)

Clipping is the result of too large an input signal which forces the transistor out of the active region into either the **saturation** or **cutoff** region. For an npn CE amplifier, cutoff will limit the + swing of the output (L+) and saturation will limit the - swing (L-). Clipping can be characterized by these limits or by the maximum peak-to-peak output (V_{oppmax}), which is twice the smaller of these two. V_{oppmax} is often the most important of the three numbers.

Instantaneous analysis

Clipping only happens at certain instances of the input AC signal and is a nonlinear effect. In fact it occurs when the transistor is forced out of it's "linear" region. That can make it difficult to analyze by normal means. Instead, we'll analyze the circuit at an instant in time. This helps because all the capacitors (whose voltages should change very little over the period of a waveform anyway) can be looked at as though they are constant DC voltages (like batteries). Then just assume the transistor is either in cutoff or saturation and see how big the output is.

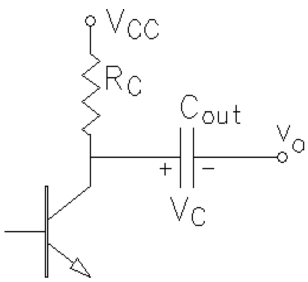


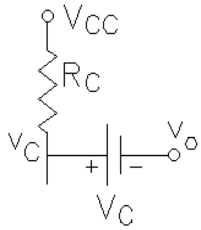


At an instant in time Cutoff Saturation

Full bypass

Let's see if we get the same results we got above:

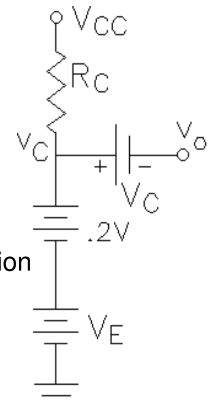




$v_o = V_{CC} - V_C = 4 \cdot V$

$= L+$

Cutoff



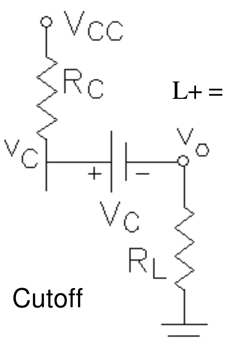
$v_o = V_E + 0.2 \cdot V - V_C = -4.8 \cdot V$

$= -L-$

Saturation

YES, good

Now add the load: say: $R_L := 600 \cdot \Omega$



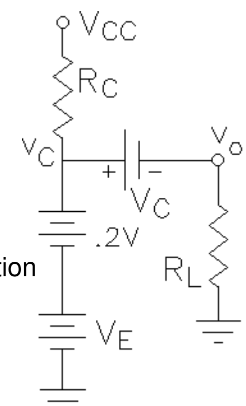
Cutoff

$L+ =$

$v_o = \left(V_{CC} - V_C\right) \cdot \frac{R_L}{R_C + R_L} = 2.4 \cdot V$

$= I_C \cdot R_C \cdot \frac{R_L}{R_C + R_L}$

$= I_C \cdot r_c$



Saturation

$v_o = V_E + 0.2 \cdot V - V_C = -4.8 \cdot V$

$= -L-$

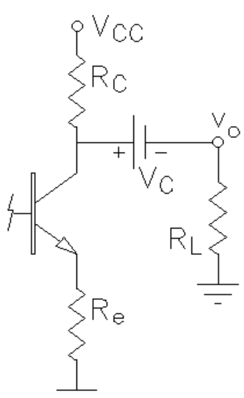
Same as before

No bypass or partial bypass

L+ is exactly the same as for the full bypass.

To find the L-, I want to use the same Δ analysis as before.

Δ analysis



The voltage across the transistor changes from V_{CE} to 0.2V, total change = $\left(V_{CE} - 0.2 \cdot V\right)$

How much of this change appears across R_C and how much appears across R_E?

You can find this using the voltage divider: $\Delta v_{RC} = \left(V_{CE} - 0.2 \cdot V\right) \cdot \frac{r_c}{r_c + R_e} = L-$

That's also how much change you'll see at the output, so it's the - swing limit

Again, it's better to limit the output to: $L- = \left(V_{CE} - 0.5 \cdot V\right) \cdot \frac{r_c}{r_c + R_e}$

The Upshot of all this junk: $L+ = I_C \cdot r_c$ $L- = \left(V_{CE} - 0.5 \cdot V\right) \cdot \frac{r_c}{r_c + R_e}$

V_{oppmax} = 2x the smallest of L+ or L-