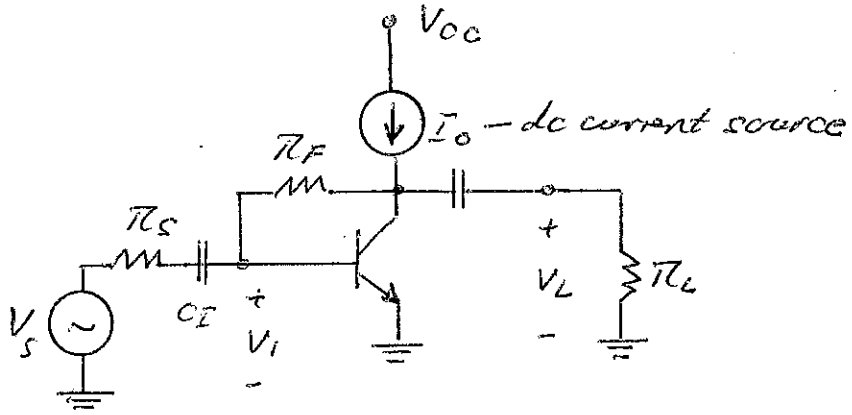
CE Amplifier with active Load

Basic Configuration



Transistor

$\beta = 150$

$V_A = 75\,V$

$nV_T = 30\,mV$

$V_{BEQ} \cong 0.7\,V$

Find: • Q-point (I_{CQ} and V_{CEQ})

• AC voltage gain $A_V = \frac{V_L}{V_I}$

$R_S = 50\,\Omega$

$R_F = 560\,k\Omega$

$R_L = 100\,k\Omega$

$I_o = 1\,mA$

Step 1: Q-point Analysis

KCL: $I_o = I_{CQ} + I_{BQ} = I_{CQ}\left(1 + \frac{1}{\beta}\right)$

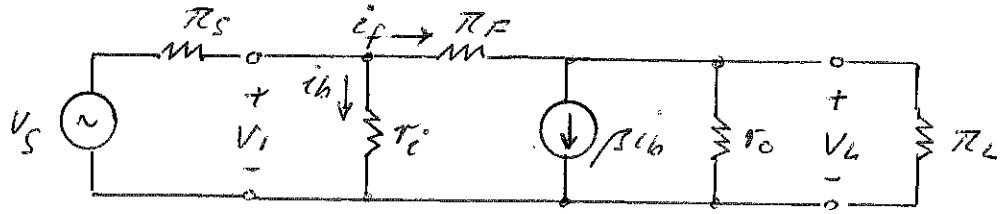
$$\| I_{CQ} \cong I_o\left(1 - \frac{1}{\beta}\right) \cong 1.0\,mA \|$$

KVL: $V_{CEQ} = V_{BEQ} + I_{BQ} R_F$

$$\| V_{CEQ} = V_{BEQ} + I_{CQ} \frac{R_F}{\beta} \cong 4.4\,V \|$$

Step 2: AC Analysis (caps acted as shorts)

Small signal eq. Circuit



Equations

(1) $V_1 = i_b r_i$

(2) $V_L = -\beta i_b \tilde{R}_L + i_f \tilde{R}_L$

(3) $i_f = (V_1 - V_L) \frac{1}{R_F}$

$r_i = \frac{\beta}{g_m} \cong 4.5 k\Omega$

$\tilde{R}_L = r_o \| R_L = 42.9 k\Omega$

(3) → (2) (1) ↗

$$V_L = -\beta i_b \tilde{R}_L + (i_b r_i - V_L) \frac{\tilde{R}_L}{R_F}$$

or

$$V_L = \left(-\beta i_b + i_b \frac{r_i}{R_F}\right) \frac{\tilde{R}_L R_F}{(\tilde{R}_L + R_F)}$$

since $\frac{r_i}{R_F} \ll 1$

$$\boxed{V_L \cong -\beta i_b \tilde{R}_L \| R_F}$$

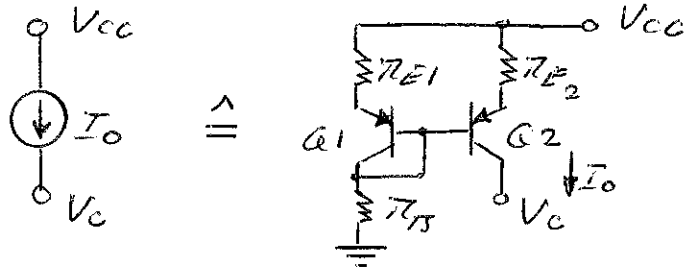
and

$$\boxed{A_V = \frac{V_L}{V_1} = -\frac{\beta}{r_i} \tilde{R}_L \| R_F = -g_m \tilde{R}_L \| R_F}$$

$\tilde{R}_L \| R_F \cong 39.8 k\Omega$

$\therefore \boxed{A_V \cong -1,327}$ very high gain!

Step 3: Replace ideal current source with current mirror



If Q_1 and Q_2 are reasonably well matched and $r_{E1} = r_{E2}$, then

$$\boxed{I_o \cong \frac{V_{cc} - V_{BEQ}}{r_{E1} + r_B}}$$

$V_{cc} = 10\,V$

$V_{BEQ} \cong 0.7\,V$

$r_{E1} = r_{E2} = 510\,\Omega$

$r_B \cong 9\,k\Omega$

$\therefore \quad I_o \cong 1\,mA$

Note: This current source implementation yields an equivalent source resistance of

$$\boxed{r_{out} = r_{o2} + \tilde{r}_E (1 + g_{m2} r_{o2})} \qquad \tilde{r}_E = r_{E2} \,\|\, r_{i2}$$

$I_{CQ2} = 1\,mA$

$V_{A2} = 40\,V$

$n V_T = 30\,mV$

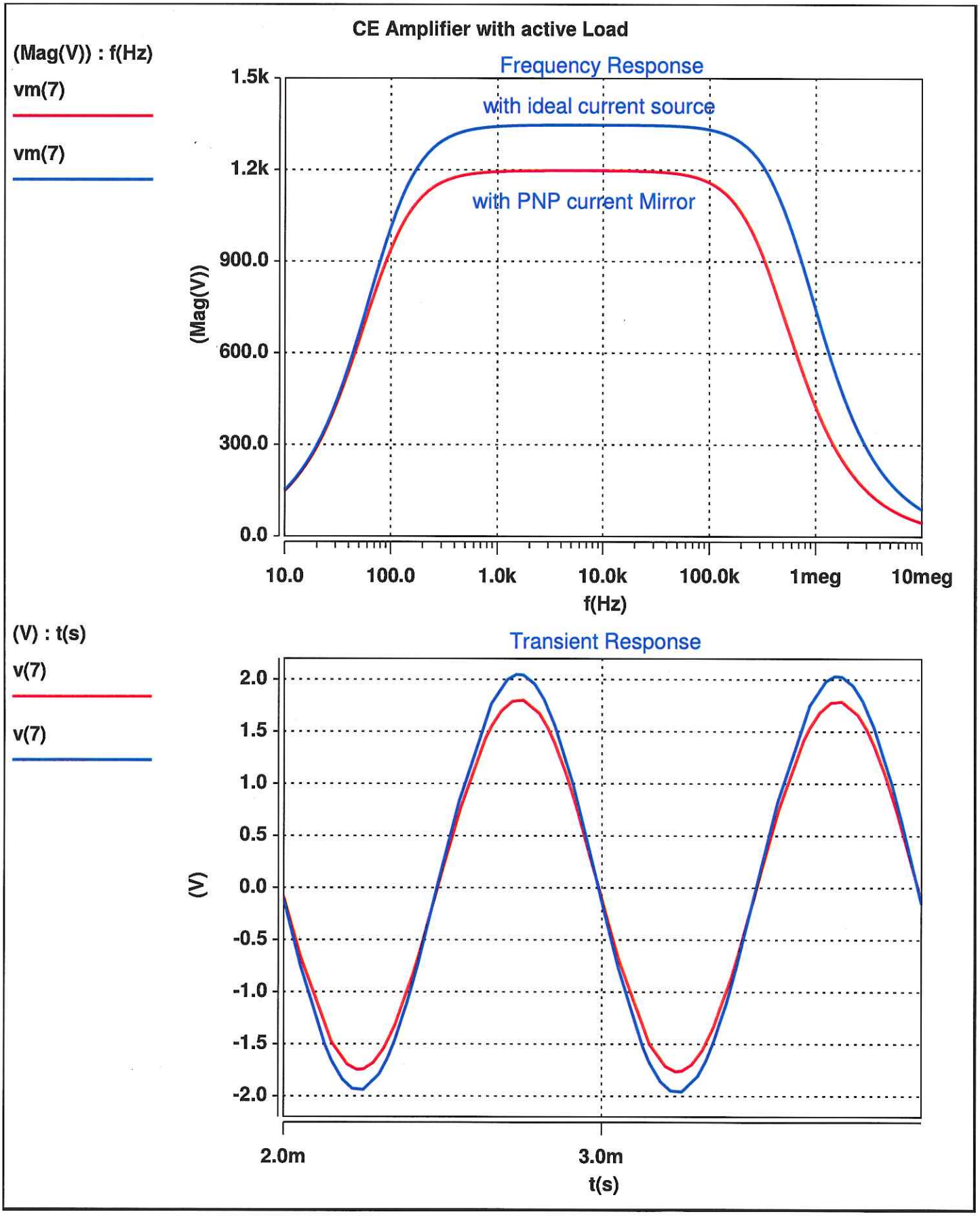
$\beta = 150$

$\therefore \boxed{r_{out} \cong 450\,k\Omega}$

$r_{o2} = \frac{V_{A2}}{I_{CQ2}}$

$g_{m2} = \frac{I_{CQ2}}{n V_T}$

```
CE Amplifier with active load

.model mod1 npn (bf=180 is=100f nf=1.2 va=80)
.model mod2 pnp (bf=180 is=100f nf=1.2 va=40)

.MODEL Q2N3904 NPN (Is=6.734f Xti=3 Eg=1.11 Vaf=74.03 Bf=416.4 Ne=1.259
+       Ise=6.734f Ikf=66.78m Xtb=1.5 Br=.7371 Nc=2 Isc=0 Ikr=0 Rc=1
+       Cjc=3.638p Mjc=.3085 Vjc=.75 Fc=.5 Cje=4.493p Mje=.2593 Vje=.75
+       Tr=239.5n Tf=301.2p Itf=.4 Vtf=4 Xtf=2 Rb=10)

.MODEL Q2N3906 PNP ((Is=1.41f Xti=3 Eg=1.11 Vaf=18.7 Bf=180.7 Ne=1.5 Ise=0
+       Ikf=80m Xtb=1.5 Br=4.977 Nc=2 Isc=0 Ikr=0 Rc=2.5 Cjc=9.728p
+       Mjc=.5776 Vjc=.75 Fc=.5 Cje=8.063p Mje=.3677 Vje=.75 Tr=33.42n
+       Tf=179.3p Itf=.4 Vtf=4 Xtf=6 Rb=10)

Vcc 1   0   dc 10

*Io   1   2   dc 1m
Rb   9   0   9k
Re1  1   8   330
Re2  1  10   330
q2   9   9   8 q2n3906
q3   2   9  10 q2n3906

Vs   5   0   dc 0 ac 1 sin(0,1.5m,1k)
rs   5   6   50
cs   6   3   4.7u
co   2   7   1u
r0   7   0   100k
rf   2   3   560k

q1 2 3 0 q2n3904

.opt probe post=1
.op
.ac dec 20 10 10meg
.tran 4u 4m 2m
.four 1k v(7)
.print tran v(2) v(3) v(7)
.print ac  vm(7) vp(7)
.end
```


CE Amplifier with active Load
(Mag(V)) : f(Hz)
vm(7)
vm(7)
Frequency Response
with ideal current source
with PNP current Mirror
1.5k
1.2k
900.0
600.0
300.0
0.0
(Mag(V))
10.0
100.0
1.0k
10.0k
100.0k
1meg
10meg
f(Hz)
(V) : t(s)
v(7)
v(7)
Transient Response
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
(V)
2.0m
3.0m
t(s)