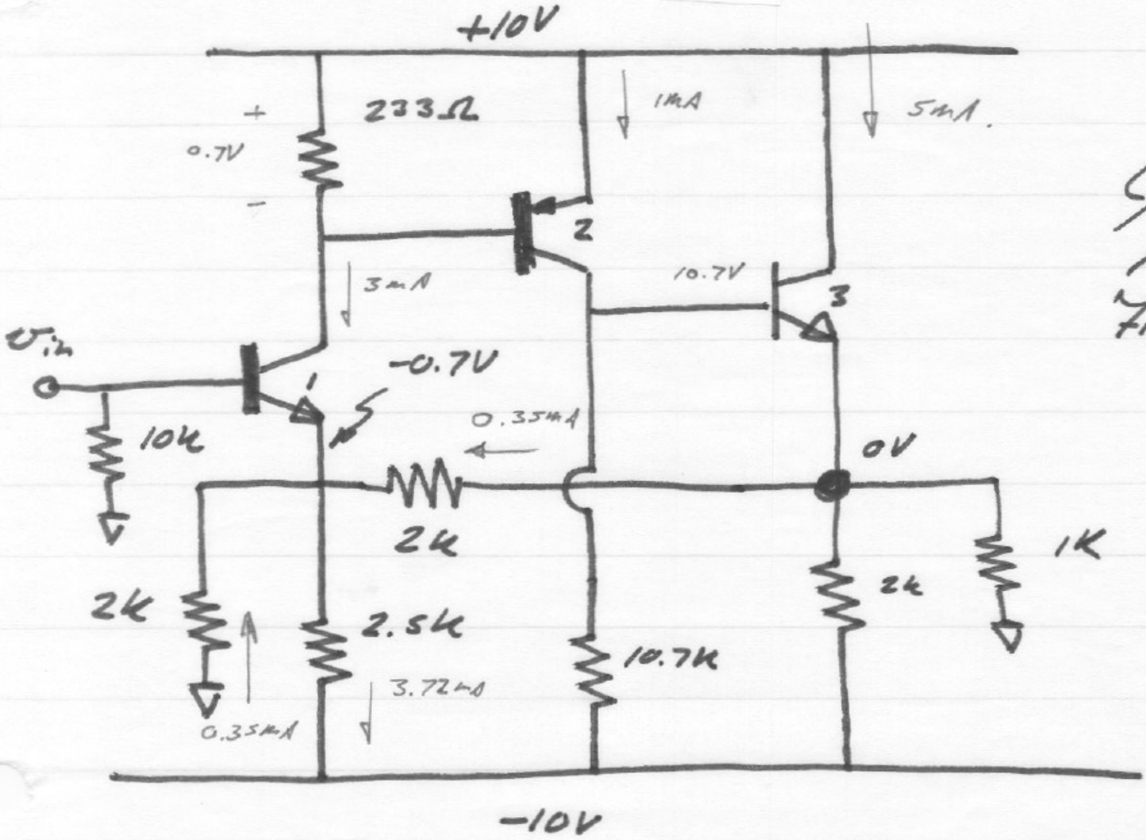
ECE137B Notes set 16 : Feedback example



$C_\mu = 2.5pF$

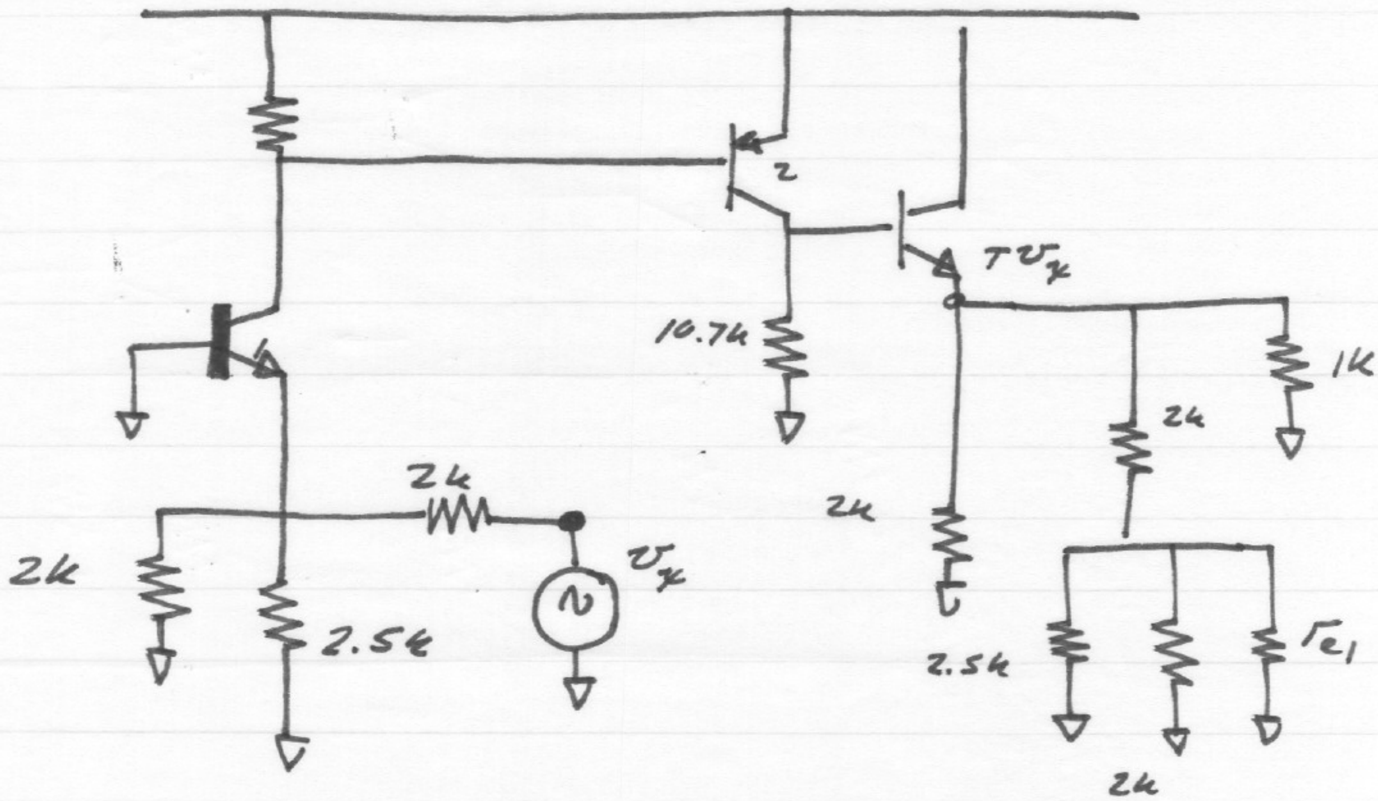
$\beta = 300$

$f_T = 500MHz$

First find $A_\infty = \left.\frac{v_o}{v_i}\right|_{A_d \to \infty}$

$$A_\infty = \frac{2k + 2k \| 2.5k}{2k \| 2.5k} = 2.8$$

Now find T:



Lets calculate T at mid-band:

$$\frac{v_{e1}}{v_x} = \frac{r_{e1} \,//\, 2k \,//\, 2.5k}{r_{e1} \,//\, 2k \,//\, 2.5k + 2k} = 0.0043$$

Q3: $R_{Leq3} = 670\,\Omega$ $A_{v3} = 0.992$ $R_{i3} = 151\,k\Omega$

Q2: $R_{Leq2} = 10.0k\,\Omega$, $r_e = 26\,\Omega$, $A_v = 384$

Q1// $R_{Leq} = 223\,\Omega$, $r_e = 8.7\,\Omega$, $A_v = 25.7$

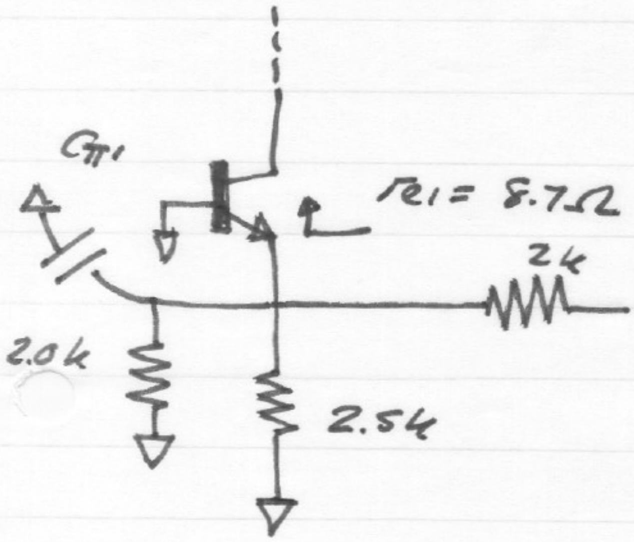
$$\boxed{T_o = 42}$$

$$A_{CL}(DC) = A_\infty \frac{T}{1+T} = 2.8 \cdot \frac{42}{43}$$

$$= 2.73$$

First lets rough-out the high-frequency response using the Node-by-Node Miller Approximations.

Pole @ emitter of Q1



$$C = C_{\pi 1} = \frac{1}{2\pi f_T r_{e1}} - C_{\mu 1} = 34pF$$

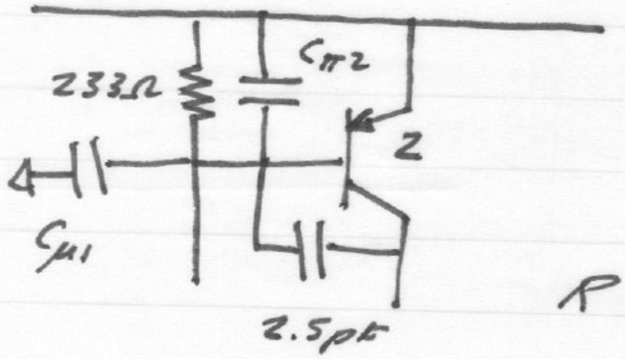
$$R = 8.7\Omega // 2k // 2k // 2.5k$$
$$\simeq 8.7\Omega$$

$$f_{pole} = 1/2\pi(34pF)(8.7\Omega)$$
$$= 535 MHz$$

which is somewhat larger than f_T.

$\Rightarrow$ Pole at or near f_T.

Pole at base of Q2 - Miller effect



$$A_{v2} = \frac{-10k\Omega}{26\Omega} = -385$$

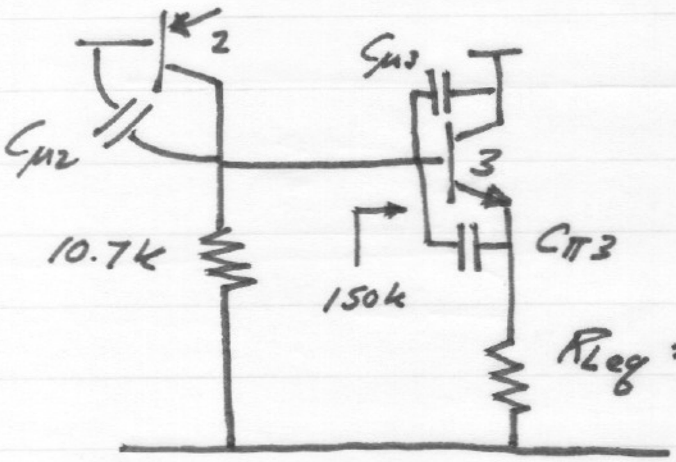
$$R = 233\Omega \,//\, R_{\pi 2} = 226\Omega$$

$$C = 386(2.5pF) + 2.5pF + 9.7pF$$
$$= 977\ pF$$

$$f_{pole} = 1/2\pi(226\Omega)(977pF)$$

$$= 720\ kHz$$

Pole at Collector of Q2 - Miller



$C_{\pi 3} = 59pF$

$C_{\mu 3} = 2.5pF$

$A_{v3} = 0.992$

$R_{node} = 10.7k \,//\, 150k = 10\,k\Omega$

$C_{node} = 2.5pF + (1-0.992)\,59pF + 2.5\,pF$

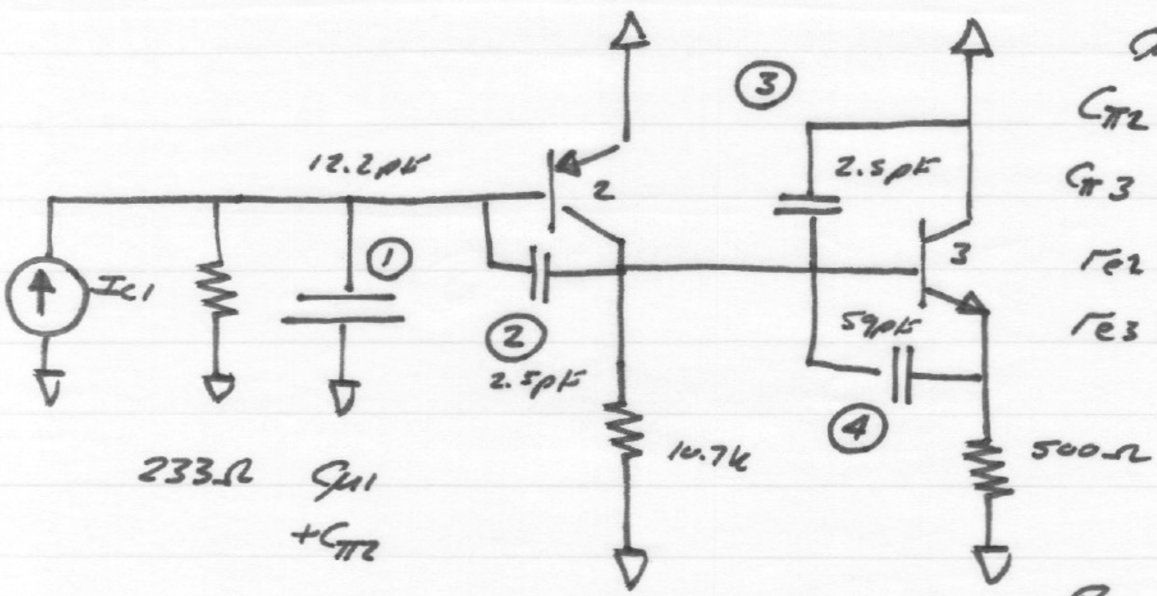
$= 5.47pF$

$f_{pole} = 1/2\pi(10k\Omega)(5.5pF) = 2.9MHz$

Danger - this has neglected pole-splitting.

We really must use a more accurate method.

Lets do it all instead by M.O.T.C. :



$\beta = 300$

$C_\mu = 2.5pF$

$C_{\pi 2} = 9.7pF$

$C_{\pi 3} = 59pF$

$r_{e2} = 26\Omega$

$r_{e3} = 5.2\Omega$.

$R_{\pi 4} = 1.56k\Omega$.

... and there is a pole @ the emitter of Q_1 @ $f = 500MHz$.

$R_{11}^{o} C_1$:

$R_{11}^{o} = 233\Omega \,||\, R_{i2} = 226\Omega$

$R_{11}^{o} C_1 = 2.76\,ns$

$R_{22}^{o} C_2$

$R_{Log2} = 10k$

$R_{22}^{o} = 226\Omega\left(1 + \frac{10k}{25\Omega}\right) + 10k = 97.1\,k\Omega$

$R_{22}^{o} C_2 = 0.243\,\mu s$

$R_{33}^{o}\ C_3$: -

$R_{33}^{o} = 10k$

$R_{33}^{o} C_3 = 25\,ns$

$R_{44}^{o} C_4$:

$R_{44}^{o} = 1.56k\Omega \,||\, \{5.2\Omega \,||\, 500\Omega + 10k(1-0.992)\}$

$= 1.56k\Omega \,||\, \{5.14\Omega + 80\Omega\}$

$= 80.7\Omega$

$R_{44}^{o} C_4 = 4.76\,ns$

$A_1 = 2.76\,ns + 0.243\,\mu s + 25\,ns + 4.76\,ns$

$A_1 = 0.275\,\mu s$

$R_{11}^0 R_{22}^1 C_1 C_2$

$$R_{22}^1 = 10k\Omega$$
$$R_{11}^0 R_{22}^1 C_1 C_2 = 6.89(10^{-17})\ s^2$$

$R_{11}^0 R_{33}^1 C_1 C_3$

$$R_{33}^1 = R_{33}^0 = 10k$$
$$R_{11}^0 R_{33}^1 C_1 C_3 = 6.9(10^{-17})\ s^2$$

$R_{11}^0 R_{44}^1 C_1 C_4$

$$R_{44}^1 = R_{44}^0 = 80.7\Omega$$

$$R_{11}^0 R_{44}^1 C_1 C_4 = 1.31(10^{-17})\ s^2$$

$R_{22}^0 R_{33}^2 C_2 C_3$

$$R_{33}^2 = 233\Omega \,||\, 10.7k \,||\, R_{i3} \,||\, r_{e2} \cong r_{e2} = 26\Omega$$
$$R_{22}^0 R_{33}^2 C_2 C_3 = 1.58(10^{-17})\ sec^2$$

$\underline{R_{22}^{0} R_{44}^{2} C_2 C_4}$

$$R_{44}^{2} = 1.56k\Omega \,\|\, \{5.2\Omega \| 500\Omega + 2k\Omega(1-0.992)\}$$

$$= 1.56k \,\|\, (5.14\Omega + 0.21\Omega)$$

$$= 5.33\Omega$$

$$R_{22}^{0} R_{44}^{2} C_2 C_4 = 7.6(10^{-17})\ s^2$$

$\underline{R_{33}^{0} R_{44}^{3} C_3 C_4}$

$$R_{44}^{3} = 500\Omega \| r_{e3} = 5.1\Omega$$

$$R_{33}^{0} R_{44}^{3} C_3 C_4 = 0.76(10^{-17})\ \text{sec}^2.$$

$$a_2 = 2.5(10^{-16})\,\text{sec}^2 = [1.59(10^{-8})\,\text{sec}]^2 = (15.8\,\text{ns})^2$$

note terms C_1C_2, C_1C_3, C_2C_4 are the largest in a_2

$a_1 = 0.275\,\mu s$
$a_2 = (15.8\,ns)^2$

Try the separated-pole approximation:

$f_{p1} = 1/2\pi a_1 = 578\ kHz$
$f_{p2} = a_1/2\pi a_2 = 175\ MHz$

} clearly very separated, so approximation is ok

also at emitter of Q1: $f_{pole} = 500\ MHz$.

Compare answers:

Miller	MotC
500 MHz (Q1 E)	500 MHz (Q1 E)
720 kHz (Q2 B) ↔	578 kHz
2.9 MHz (Q2 C) ↔ !	175 MHz
zero @ 500 MHz from Q3	zero @ 500 MHz from Q3.

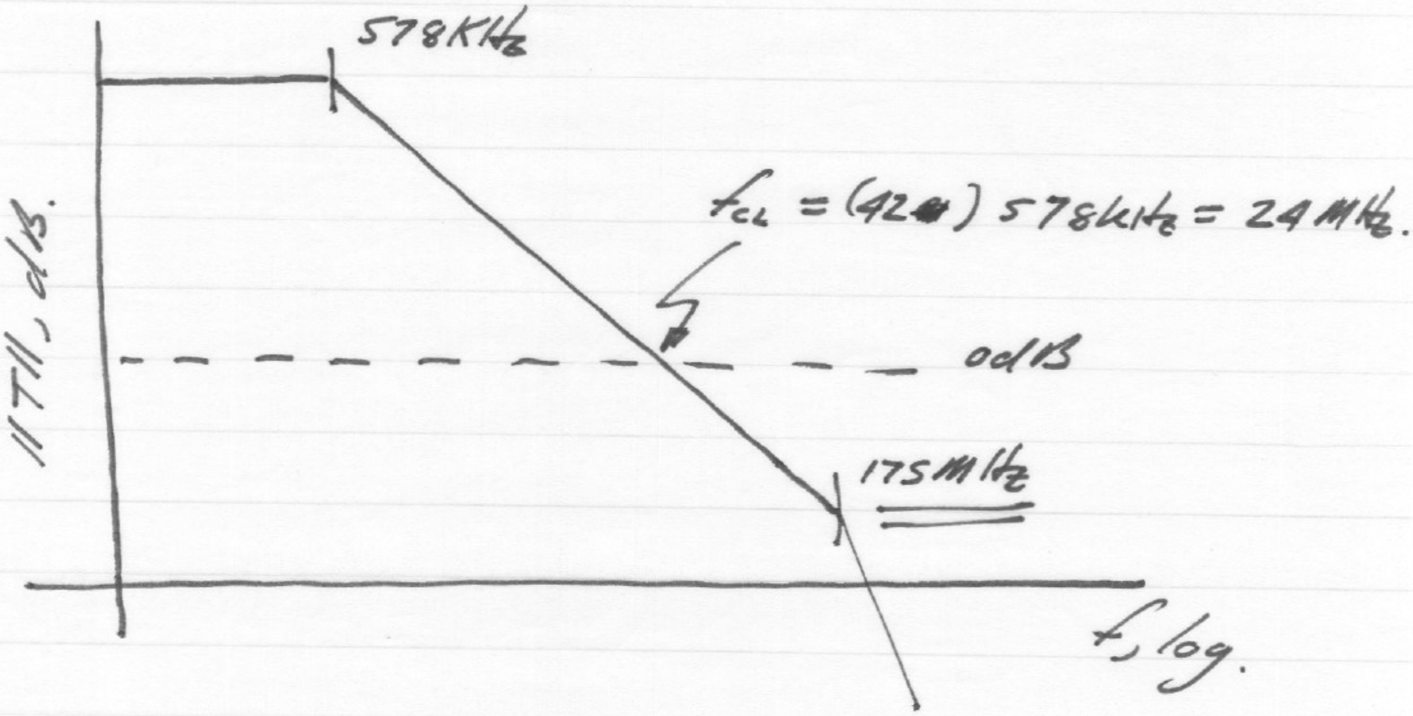
Again Note that the node-by-node Miller approximations got the first pole nearly right - but got the second pole amazingly wrong. This is because of pole interaction - pole splitting. We would have got wildly wrong conclusions regarding the loop phase margin if we had just used the Miller Methods.

Despite this, I still personally use the Miller Methods first, to get a quick mental picture so overall loop transfer function has:

$T_0 = 42$ dc loop transmission.

& poles at 578 kHz & 175 MHz.

Lets do a Bode Plot:



$$\text{Phase Margin} \cong 180° - \arctan\frac{24MHz}{175MHz} - \arctan\frac{24MHz}{578kHz}$$

$$= 180° - 7.8° - 88.6°$$

$$= 83.6° \leftarrow \text{very stable!}$$

Bode Stability analysis, example from last lecture