(8.1)

8.1 $\measuredangle T = -[\tan^{-1}(f/10^5) + \tan^{-1}(f/2\times10^6)]$;

$$|T| = 10^3/\sqrt{[1+(f/10^5)^2]\times[1+(f/2\times10^6)^2]}.$$

Trial-and-error: $f_x = 14.07$ MHz; $\measuredangle T(jf_x) = 171.5°$; $\phi_m = 8.5°$; $\cos\phi_m = \sqrt{4\zeta^2+1} - 2\zeta^2 \Rightarrow \zeta = 0.0743$; $Q = 1/2\zeta = 6.74$; $GP = 16.58$ dB; $OS = 79\%$; $A = 1/(1+1/T) = 1/[1+10^{-3}\times(1+jf/f_1)(1+jf/f_2) = 10^3/[1+10^3+jf/(\frac{1}{f_1}+\frac{1}{f_2}) - \frac{f^2}{f_1 f_2}]$

$$A \cong \frac{10^3}{10^3+1}\,\frac{1}{1-f^2/(1001 f_1 f_2)+jf(1/f_1+1/f_2)/1001}$$

$$= 0.999\,\frac{1}{1-\left(\frac{f}{14.15\times10^6}\right)^2+\frac{jf}{14.15\times10^6}/6.74}.$$

8.2 $T = T_0/[1+jf/f_1]^3$, $T_0 = a_0\beta$. Imposing $180° = 3\tan^{-1}(f_{-180°}/f_1)$ gives $f_{-180°} = 1.732 f_1$.

$$T(jf_{-180°}) = \frac{-T_0}{(1+1.732^2)^{3/2}} = \frac{-T_0}{8}.$$

8.3 (a) $\measuredangle T = -\tan^{-1}\left(\frac{f}{10^5}\right) - \tan^{-1}\left(\frac{f}{10^6}\right) - \tan^{-1}\left(\frac{f}{2\times10^6}\right)$

$$|T| = \frac{10^2}{\sqrt{[1+(f/10^5)^2][1+(f/10^6)^2]\left[1+\left(\frac{f}{2\times10^6}\right)^2\right]}}.$$

By trial and error it is found that $|T|=1$ for $f = f_x = 2.42$ MHz, and that $\measuredangle T(jf_x) =$

(8.2)

$-205.6°$, so that $\phi_m = -25.6°$, an unstable system.

(b) By trial and error it is found that $\measuredangle T = -135°$ for $f = f_{-135°} = 685$ kHz, and that $|T(jf_{-135°})| = T_0/8.87$. Imposing $|T(jf_{-135°}) = 1$ yields $T_{0(new)} = 8.87$.

(c) $\measuredangle T = -\tan^{-1}\left(\frac{f}{f_1}\right) - \tan^{-1}\left(\frac{f}{10^6}\right) - \tan^{-1}\left(\frac{f}{2\times 10^6}\right)$

$$|T| = \frac{10^2}{\sqrt{[1+(f/f_1)^2][1+(f/10^6)^2][1+(\frac{f}{2\times 10^6})^2]}}.$$

Using Bode-plot reasoning, we find, as initial guess, $f_1 = f_2/T_0 = 10^6/10^2 = 10$ kHz. For this value of f_1, it is found that $f_x = 750$ kHz and $\phi_m = 33.3°$, which is a bit too low. Retry with a lower value of f_1. Eventually it is found that $f_1 = 6.8$ kHz yields $f_x = 570$ kHz and $\phi_m = 45°$.

(d) $f_{-120°} = 508$ kHz ; $T_0 = 6.0$.

$f_1 = 4.0$ kHz, $f_x = 369°$, $\measuredangle T = -120°$.

$\boxed{8.4}$ (a) $\phi_m \geq 45°$ for $f \leq 1.33$ kHz and $f \geq 7.65$ kHz. Since $|a(j\,1.33\text{ kHz})| \cong 456$ V/V and $|a(j\,7.65\text{ kHz})| \cong 21.3$ V/V, the permis-

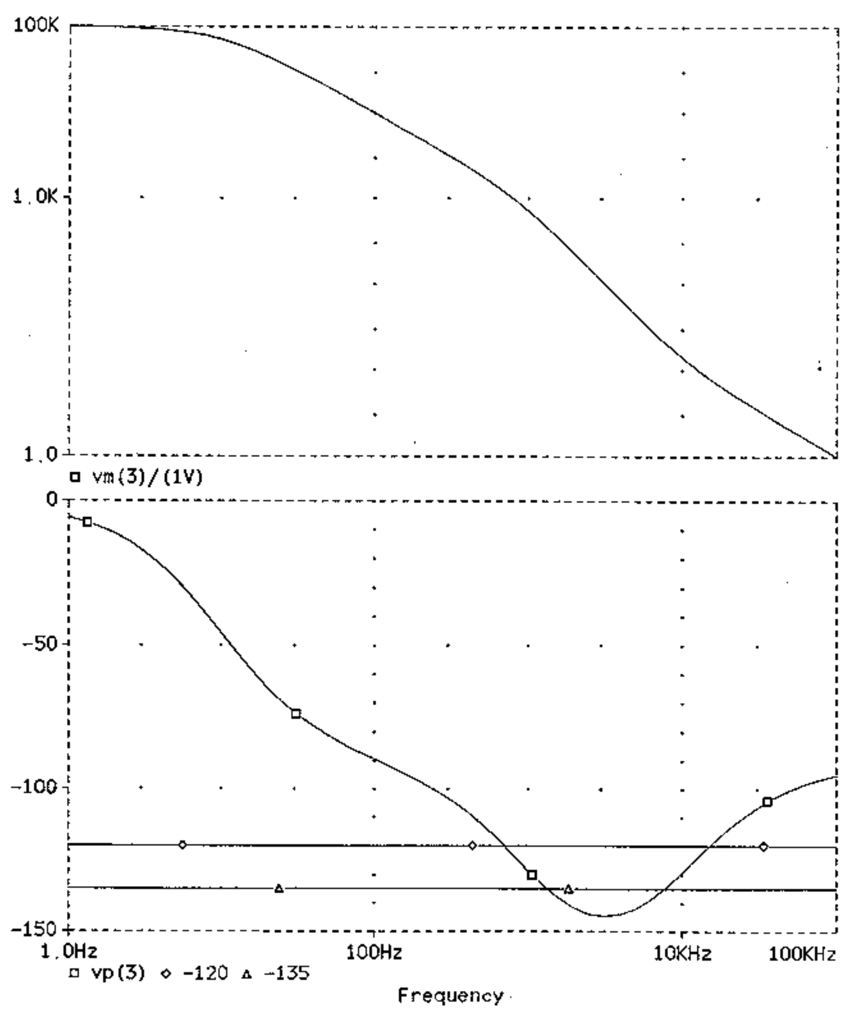
(8.3)

sible ranges for β are $\beta \leq 1/456$ V/V and $\beta \geq 1/21.3$ V/V.

(b) $f \leq 694$ Hz and $f \geq 14.9$ kHz;
$\beta \lessapprox 1/1187$ V/V and $\beta \geq 1/8.06$ V/V.

(c) $f = 3.16$ kHz, $\phi_{m(min)} \cong 35°$.

```
Problem 8.4
Vi 1 0 ac 1
R1 1 0 1
eHn 2 0 Laplace {V(1,0)}={1.0E5*(1+s/62830)}
R2 2 0 1
eHd 3 0 Laplace {V(2,0)}={1/((1+s/62.83)*(1+s/6283))}
R3 3 0 1
.ac dec 10 1 100k
.probe
.end
```



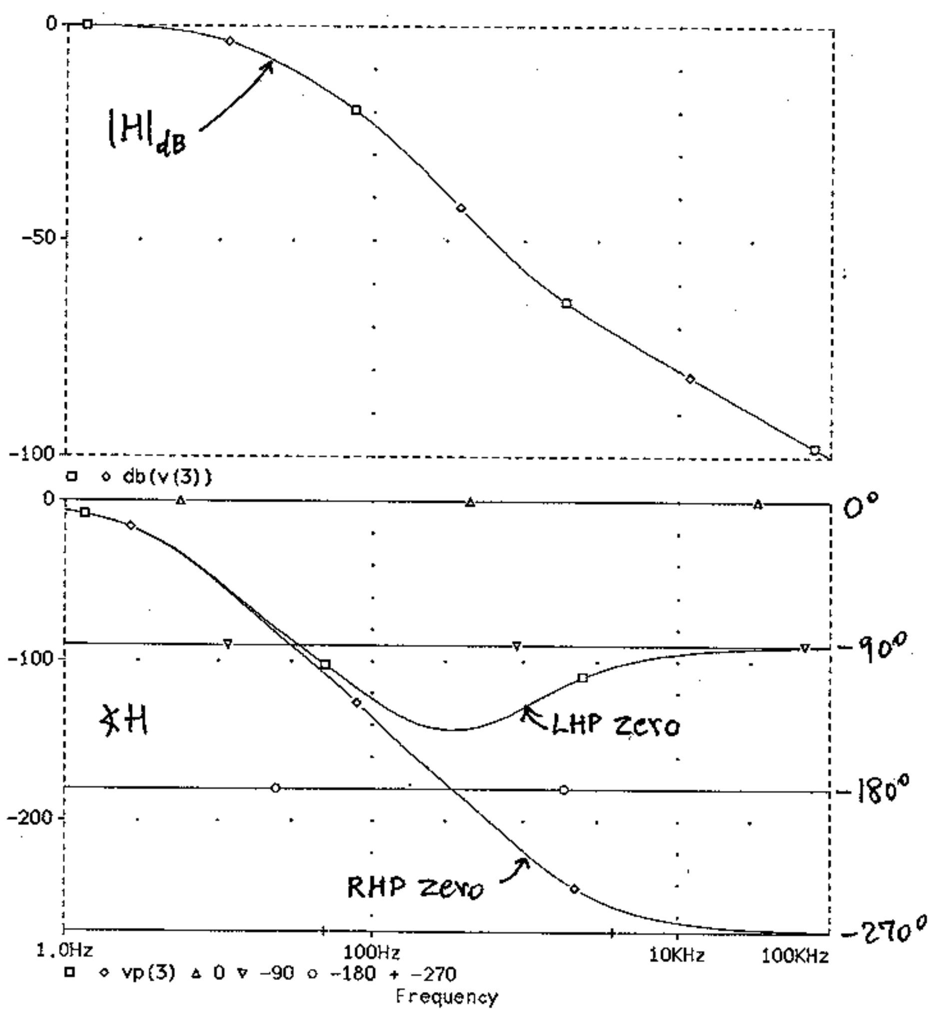
8.4

$\boxed{8.5}$ System 1: Error Function $= 1/(1+1/T) =$
$1/[1+1/(-10)] = 1.111\angle 0°$. System 2: Error

8.5

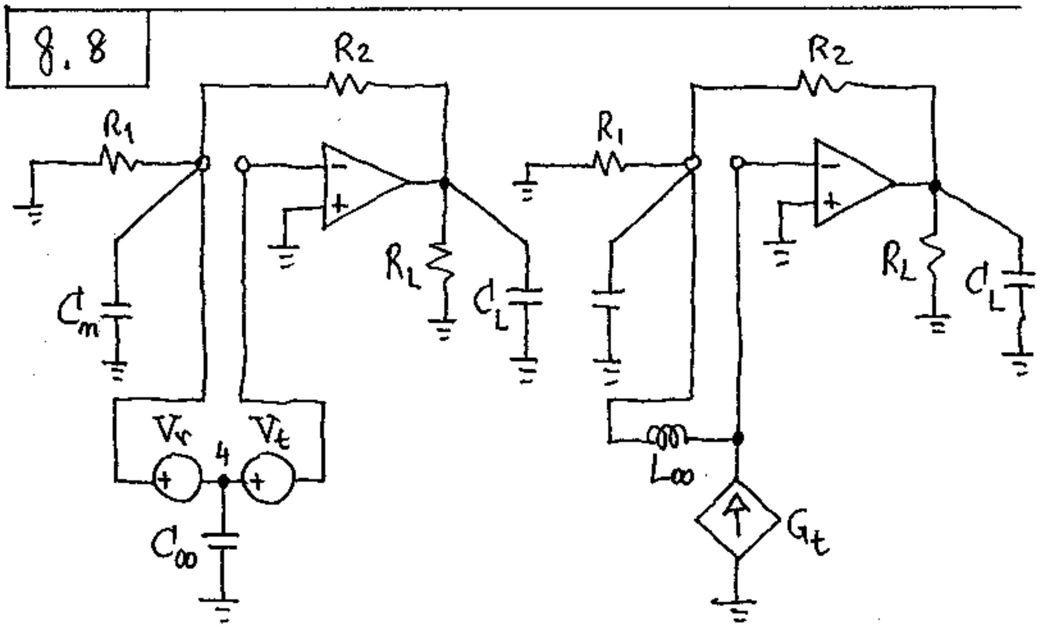
exhibits an overall phase shift of 270°, the same as a three-pole function.

```
Problem 8.7
*LHP zero
Vi 1 0 ac 1V
Ri 1 0 1
e1 2 0 Laplace {V(1,0)}={1+s/6283}
R1 2 0 1
e2 3 0 Laplace {V(2,0)}={1/((1+s/62.83)*(1+s/628.3))}
R2 3 0 1
.ac dec 10 1 100k
.probe
.end
Problem 8.7
*RHP zero
Vi 1 0 ac 1V
Ri 1 0 1
e1 2 0 Laplace {V(1,0)}={1-s/6283}
R1 2 0 1
e2 3 0 Laplace {V(2,0)}={1/((1+s/62.83)*(1+s/628.3))}
R2 3 0 1
.ac dec 10 1 100k
.probe
.end
```



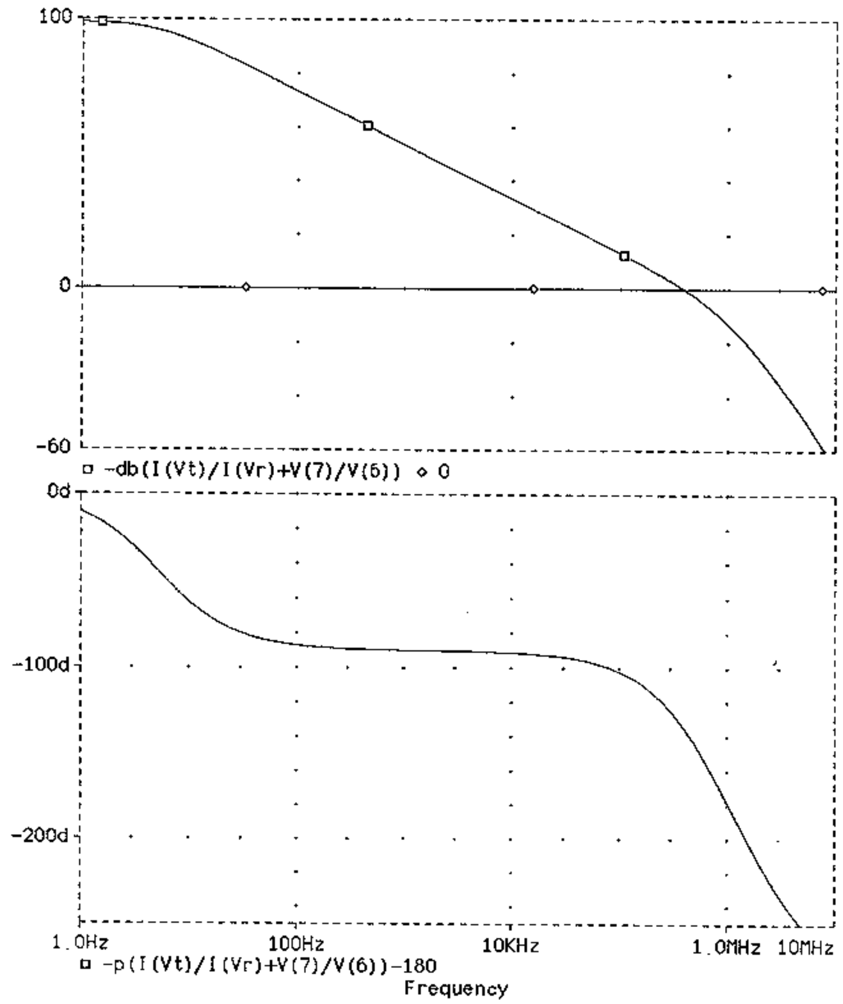
8.6

8.8

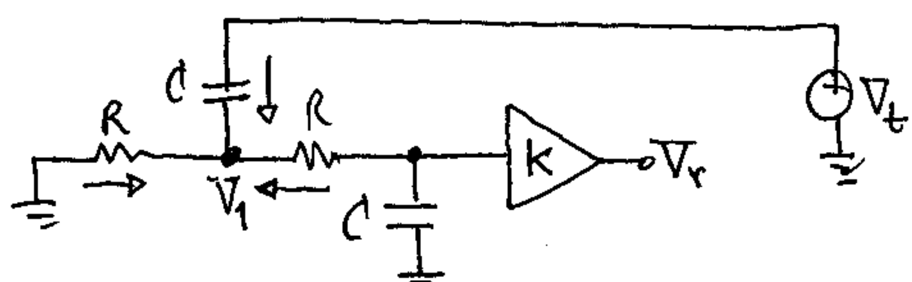



```
Problem 8.8
.lib eval.lib
VCC 10 0 dc 15V
VEE 11 0 dc -15V
*Circuit to find Tsc:
R1sc 0 2 100k
R2sc 2 1 100k
Cnsc 2 0 5pF
RLsc 1 0 2k
CLsc 1 0 100pF
XOAsc 0 3 10 11 1 ua741
Vr 2 4 dc 0V
Vt 4 3 ac 1V
C00 4 0 0.1kF
*Circuit to find Toc:
R1oc 0 6 100k
R2oc 6 5 100k
Cnoc 6 0 5pF
RLoc 5 0 2k
CLoc 5 0 100pF
XOAoc 0 7 10 11 5 ua741
L00 6 7 1MegH
Gt 0 7 4 3 1u
.ac dec 10 1 10MegHz
.probe ;Tsc = I(Vr)/I(Vt), Toc = V(6)/V(7)
.end
```

8.7



8.9 Suppress the input, break the loop at the op amp's output, and inject a test signal V_t:



The return signal is $V_r = K\frac{1}{1+sRC}V_1$. KCL:

$$\frac{0-V_1}{R} + (V_t - V_1)sC + \frac{V_r/K - V_1}{R} = 0$$

(8.8)

Eliminating V_1 we get

$$T = -\frac{V_r}{V_t} = \frac{-KsRC}{1+(sRC)^2+3sRC}$$

Letting $s \to j2\pi f$, $RC \to 1/(2\pi 10^3)$, $K \to 2.8$,

$$T = \frac{-2.8\,jf/10^3}{1-(f/10^3)^2+3jf/10^3}$$

We observe that $|T|$ is maximized for $f = 10^3$ Hz, where we have $T(j10^3) = -2.8/3$, or $T = \frac{2.8}{3}\angle{-180°}$. The circuit has therefore a gain margin of $20\log(3/2.8) = 0.6$ dB.

$\boxed{8.10}$ (a) For $f \gg 10$ Hz we can approximate $T = a\beta = a \cong \frac{10^6}{jf(1+jf/10^6)}$. By trial-and-error as in Example 8.1 we find that $|T| = 1$ for $f = f_x = 786$ MHz, where $\measuredangle T = -128.2°$. Thus, $\phi_m = 51.8°$.

(b) We now have $T \cong \frac{10^6}{}$; Since

$jf(1+jf/f_2)$

$f_2 > 10^6$ Hz. Try $f_2 =$

840 kHz and $\phi_m =$

. We thus need to try

$60° > 51.8°$, we must have

1.3 MHz. This gives $f_x =$

57.1°, which is too small

8.9

a higher value for f_2. After a few more attempts we find that for $\phi_m = 60°$ we need $f_2 = 1.5$ MHz. Moreover, $f_x = 866$ kHz.

(c) Since $45° < 51.8°$, we need $f_2 < 1$ MHz. By a similar trial-and-error technique we find $f_2 = 1/\sqrt{2}$ MHz and $f_x = f_2 = 707$ kHz.

$\boxed{8.11}$ $T = a\beta = \dfrac{10^5 \beta_0}{(1+jf/10)(1+jf/10^5)^2}$.

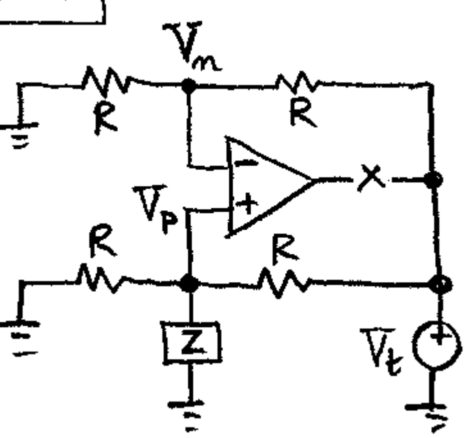
(a)

$\measuredangle T = -[\tan^{-1}(f/10) + 2\tan^{-1}(f/10^5)]$; $\measuredangle T = -180°$ for $f = f_{-180°} = 100$ kHz, where $|T| = 5\beta_0$. The onset of oscillation occurs for $\beta_0 = 1/5 = 0.2$ V/V.

(b) $f_{-135°} = 41.4$ kHz, $|T(j\,41.4 \text{ kHz})| = 20.6\beta_0$, $\beta_0 = 1/20.6$ V/V.

(c) $f_{-120°} = 26.8$ kHz, $\beta = 1/34.8$ V/V.

$\boxed{8.12}$

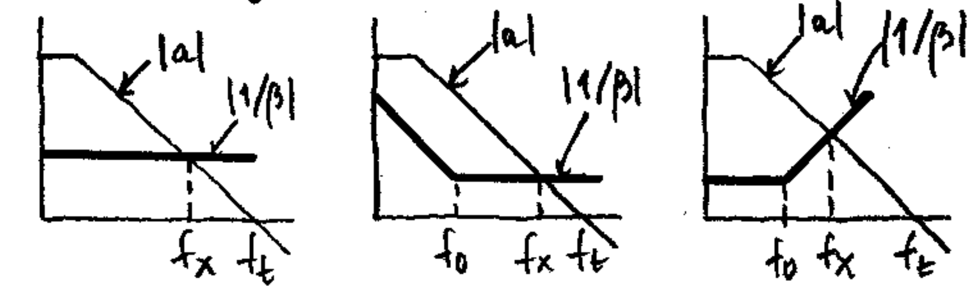


$$\beta = (V_n - V_p)/V_t$$
$$= \frac{1}{2} - \frac{Z \| R}{Z \| R + R}$$
$$= \frac{1}{2}\,\frac{1}{1+2Z/R};$$
$$\frac{1}{\beta} = 2(1 + 2Z/R).$$

$Z = R_L \Rightarrow 1/\beta > 2$, $1/\beta$ frequency-independent $\Rightarrow$ stable circuit with $f_x < f_t/2$.

$Z = C_L \Rightarrow 1/\beta = 2(1 + 2/sRC) = 2[1 + 1/(jf/f_0)]$, (8.10) $f_0 = 1/\pi RC$. $1/\beta_\infty \to 2$ V/V $\Rightarrow$ stable circuit with $f_x = f_t/2$.

$Z = L_L \Rightarrow 1/\beta = 2(1 + 2sL/R) = 2(1 + jf/f_0)$, $f_0 = R/4\pi L$. Since $1/\beta$ has a zero frequency at f_0, the $|1/\beta|$ curve bends upward and invites instability.



$Z = R_L$ $\quad$ $Z = C_L$ $\quad$ $Z = L_L$

Compensate by placing a resitance R_s in series with L_L so that at high frequencies the $|1/\beta|$ curve flattens out to $|1/\beta_\infty| = 2 \times (1 + 2R_s/R)$.

$\boxed{8.13}$ With R_s in place we have

$$\frac{1}{\beta} = 1 + \frac{R}{R_s + 1/sC} = \frac{1 + jf/f_z}{1 + jf/f_p}, \quad f_z = \frac{1}{2\pi(R + R_s)C}, \quad f_p =$$

$1/2\pi R_s C$. Since we expect $R_s \ll R$, it follows that $f_z \cong f_0 = 100$ Hz, so we can write

$$T = a\beta \cong \frac{10^6}{jf}\,\frac{1 + jf/f_p}{1 + jf/100}.$$

Since $60° > 45°$, we expect $f_p < 10$ kHz. Start out with the estimate $f_p = 8$ kHz, and then use the trial-and-error technique to find f_x and ϕ_m. This

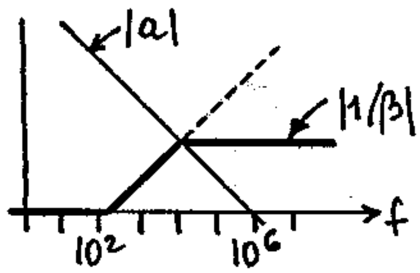
(8.11)

gives $f_x = 14.3$ kHz and $\phi_m \cong 61°$, which is close enough without warranting further trials. So, $R_5 = 1/(2\pi \times 8\times10^3 \times 10\times10^{-9}) \cong 2.0$ kΩ. The Xfer function is $H = H_{ideal}/(1+1/T) = \left(j\frac{f}{f_0}\right)/(1+1/T)$,

$$\frac{1}{1+1/T} \cong \frac{1}{1+\frac{jf(1+jf/100)}{10^6(1+jf/8{,}000)}} \cong \frac{1+jf/8{,}000}{1-\left(\frac{f}{10^4}\right)^2+\left(j\frac{f}{10^4}\right)/0.8}.$$

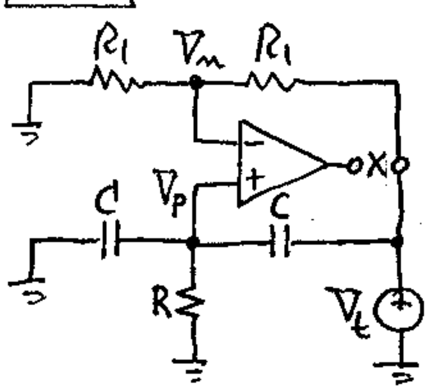
$\therefore Q \cong 0.8$

$\boxed{8.14}$ $f_0 = 1/(2\pi \times 78.7\times10^3 \times 10^{-8}) \cong 200$ Hz.



Eq. (8.14b): $f_x = (200\times10^6)^{1/2} = 14.1$ kHz. For $\phi_m = 45°$ impose $1/(2\pi RC_f) = f_x$. This yields $C_f = 143$ pF (use 150 pF).

$\boxed{8.15}$

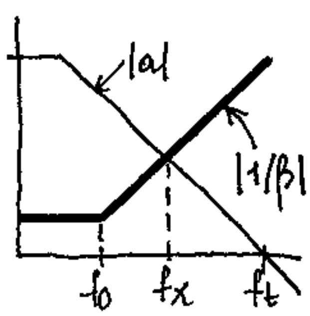


$$\beta = \frac{V_n - V_p}{V_t} = \frac{1}{2} - \frac{R \| 1/sC}{R\|1/sC + 1/sC}.$$

Expanding gives

$$\frac{1}{\beta} = 2\left(1 + j\frac{f}{f_0}\right),$$

$$f_0 = \frac{1}{4\pi RC} \cong 100 \text{ Hz}.$$



Using ROC considerations, we see that the circuit is on the verge of oscillation.

(8.12)

To stabilize the circuit we need to flatten out the $|1/\beta|$ curve above f_x. This can be achieved by connecting a suitable capacitance C_f between the

8.17 $T = a\beta = \frac{\beta_0 f_t}{jf}\frac{1+jf/f_p}{1+jf/f_z}$; $\frac{1}{f_p} = 2\pi R_2 C_f =$

$60\pi 10^3 C_f$; $\frac{1}{f_z} = 2\pi(R_1 \| R_2)(C_m + C_f) = 30\pi 10^3 (C_m + C_f) =$

$\frac{1}{663\times10^3} + \frac{1}{2f_p}$. Substituting actual values;

$T = \frac{10^7}{jf}\frac{1+jf/f_p}{1+jf(1/663\times10^3 + 1/2f_p)}$. Our goal is to find

f_p such that $\measuredangle T(jf_x) = -120°$. Starting out with the initial estimate $f_p = \sqrt{663\times10^3 \times 10\times10^6}$, and then using trial-and-error, we find $f_p = 2.56$ MHz. This gives $f_z = 587$ kHz, $f_x = 2.96$ MHz, and $C_f = 2.07$ pF.

With $\phi_m = 60°$, we have $GP \cong 0.3$ dB and $OS \cong 9\%$. Moreover, $A = (-R_2/R_1)H_{LP}$, where H_{LP} is the second-order low-pass response with (See Problem 8.16) $f_0 = (587\times10^3 \times 10^7)^{1/2} = 2.42$ MHz, and $Q = [10^7/(587\times10^3)]^{1/2}/[1+10^7/(2.56\times10^6)] = 0.841$.

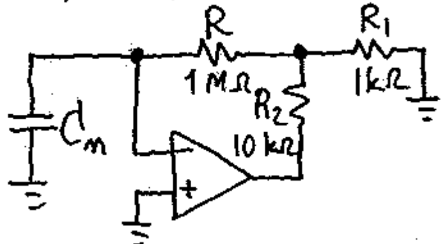
8.18 (a) For $\phi_m = 45°$ impose $f_z = f_x = \beta_0 f_t = 10$ MHz, or $1/[2\pi(R_1\|R_2)\times16\times10^{-12}] = 10^7 \Rightarrow R_1\|R_2 = 994\ \Omega$ $\Rightarrow R_1 = R_2 = 2.00$ kΩ.

(b) $T = a\beta = (\beta_0 f_t/jf)/(1+jf/f_z) = \frac{10^7}{jf(1+jf/f_z)}$.

Use trial-and-error to find f_z such that $\measuredangle T = -120°$ at $f = f_x$. Start out with initial estimate $f_z = 12$ MHz. The result is $f_z = 15$ MHz, (8.14) $f_x = 8.63$ MHz, and $R_1 \| R_2 = 663\ \Omega \Rightarrow R_1 = R_2$ $1.30\ \mathrm{k}\Omega$.

(c) The advantage is the avoidance of using C_f; the disadvantage is the need for low resistance values, which may pose power dissipation problems in certain applications.

8.19 (a)



Since $R >> R_1 \| R_2$, we can write

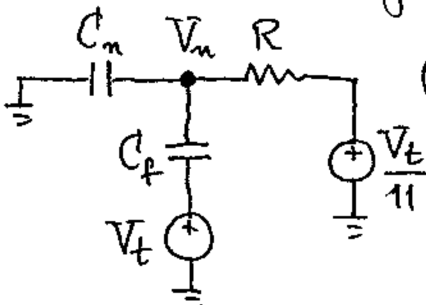
$$\beta \cong \frac{R_1}{R_1 + R_2}\frac{1}{1 + sRC_n}$$

$$= \frac{1/11}{1 + jf/(15.9\times 10^3)}$$

$$T = a\beta \cong \frac{4\times 10^6/11}{jf\,[1 + jf/(15.9\times 10^3)}.$$ Trial-and-error:

$f_x = 75$ kHz; $\phi_m \cong 12°$, not enough.

(b) Summing currents at node V_n gives



$$0 = \frac{0 - V_n}{1/sC_n} + \frac{V_t - V_n}{1/sC_f} + \frac{V_t/11 - V_n}{R}$$

Collecting and solving,

$$\beta = \frac{V_n}{V_t} = \frac{1}{11}\,\frac{1 + s11RC_f}{1 + sR(C_n + C_f)}.$$

To make β frequency independent impose $11C_f = C_n + C_f \Rightarrow C_f = C_n/10 = 1$ pF.

To find the bandwidth, find A_{ideal}.

Summing currents at the virtual-ground node,

$I_i + V_o/(1/sC_f) + (V_o/11)/R = 0 \Rightarrow A_{ideal} = V_o/I_i =$

8.15

$-11R/(1+jf/f_p)$, $f_p = 1/(2\pi 11 R C_f) = 14.5$ kHz. The actual gain, besides a pole at 14.5 kHz, has an additional one at $4\times10^6/11 \cong 364$ kHz.

8.20

$$T = a\beta \cong \frac{10^7}{jf(1+jf/f_p)}\frac{R_1}{R_1+R_2}, \quad f_p \cong \frac{1}{2\pi r_o C_L}.$$

For $\phi_m \cong 45°$, impose $f_p = \frac{R_1}{R_1+R_2}10^7$. We thus get

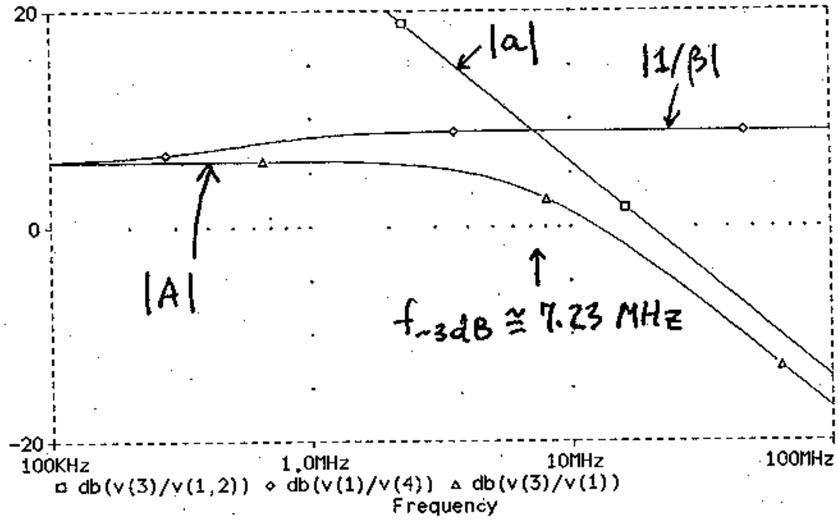
(a) $f_p = 5$ MHz, $C_L \le 318$ pF; (b) $f_p = 1$ MHz, $C_L \le$ 1.59 nF; (c) $C_L \le 159$ pF.

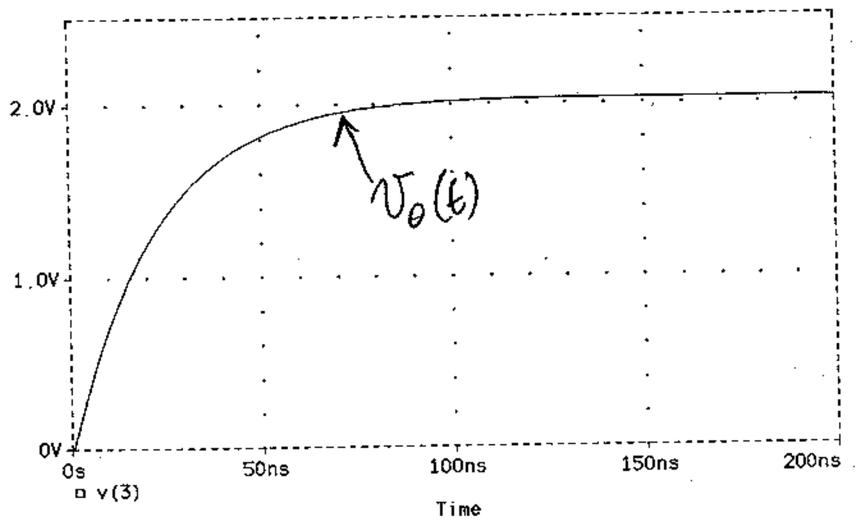
(d) $T = 10^7/[jf(1+jf/f_p)]$. Using trial and error, find f_p so that $\measuredangle T(jf_x) = -120°$, starting with $f_p = 10$ MHz as initial estimate. The result is $f_p = 15$ MHz. So, $C_L \le 106$ pF.

8.21

```
Problem 8.21(a)
Vi 1 0 ac 1V pulse (0 1V 0 1ns 1ns 1us 2us)
R1 0 2 30k
Cext 2 0 3pF
Cc/2 2 0 6pF
Cd 2 1 7pF
R2 2 3 30k
Cf 2 3 9pF
ea0 5 0 1 2 1Meg     ;dc gain
Req 5 6 1Meg         ;pole frequency at
Ceq 6 0 7.958nF      ;fb=20Hz
eout 3 0 6 0 1       ;output buffer
*feedback network:
R2f 1 4 30k
Cff 1 4 9pF
R1f 4 0 30k
Cnf 4 0 16pF
.ac dec 50 1k 100Meg
.probe
.tran 1ns 1us 0ns 1ns
*a=V(3)/V(1,2), A=V(3)/V(1), 1/beta=V(1)/V(4)
.end
```

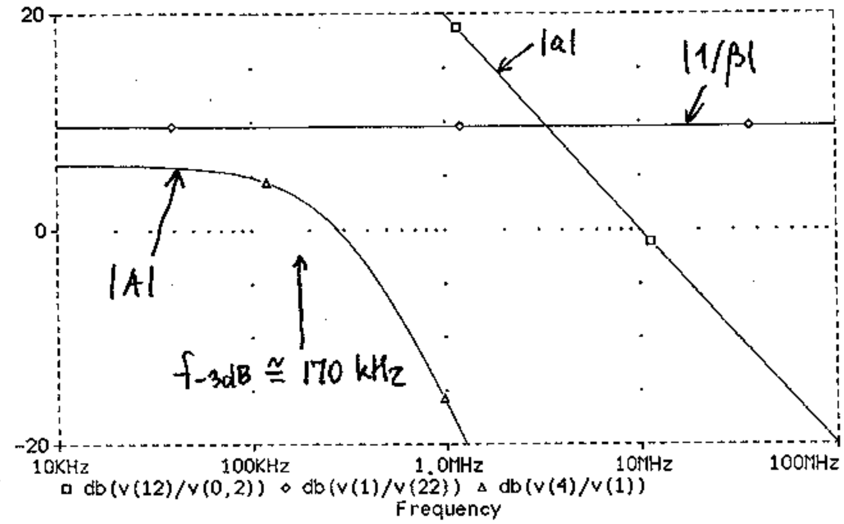
(8.16)

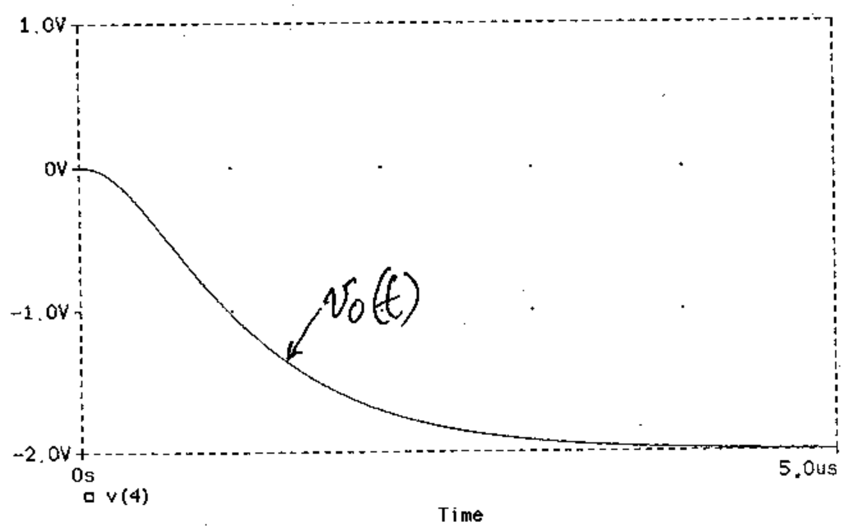




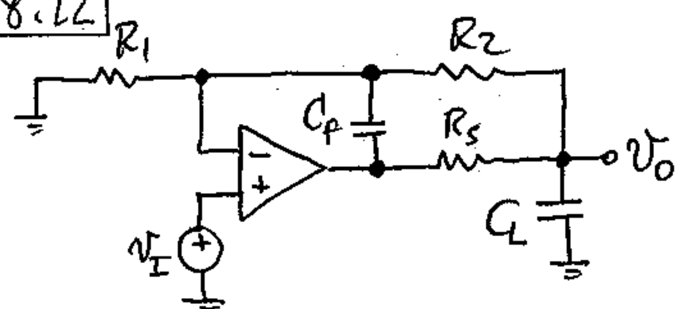

```
Problem 8.21 (b)
Vi 1 0 ac 1V pulse (0 1 0 10n 10n 5us 10us)
R1 1 2 10k
R2 2 4 20k
Cf 2 3 56.25pF
Rs 3 4 50
CL 4 0 5nD
*a0 1 Meg, fa = 10 Hz
ea0 10 0 0 2 1Meg
Req 10 11 1Meg
Ceq 11 0 15.92nF
ebuf 12 0 11 0 1
ro 12 3 100
*1/beta:
rof 1 33 100
Cff 33 22 56.25pF
Rsf 33 44 50
CLf 44 0 5nF
R2f 44 22 20k
R1f 22 0 10k
.ac dec 10 10k 1G
.tran 10ns 5us 0ns 10ns
.probe
.end
```

8.17





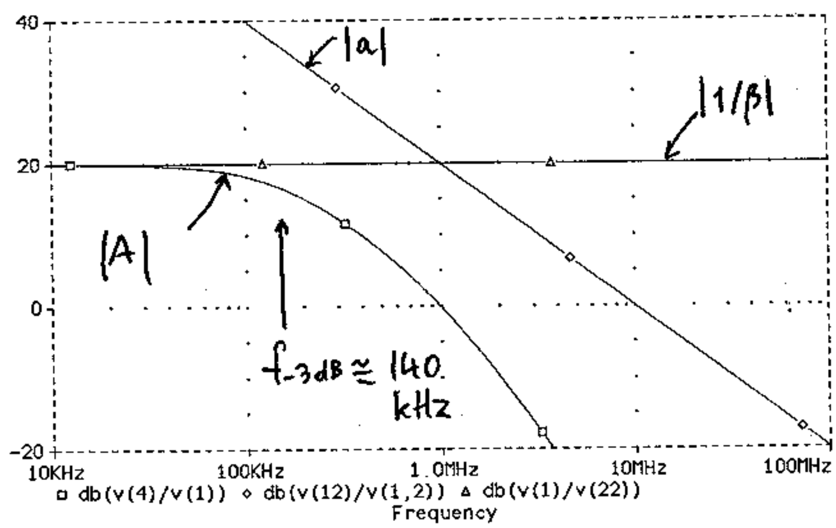
8.22

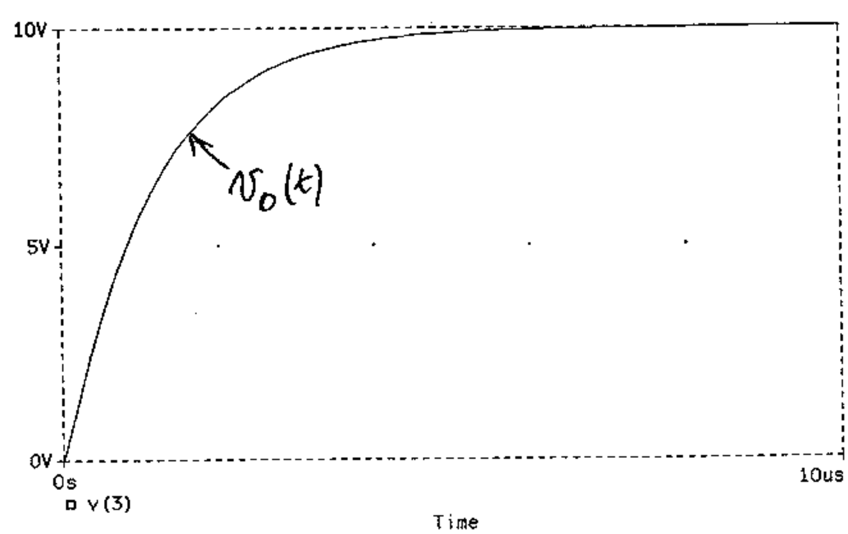


$R_1 = 20\,k\Omega$, $R_2 = 180\,k\Omega$, $C_f = 6.26\,\mu F$, $R_s = 11.11\,\Omega$.

8.18

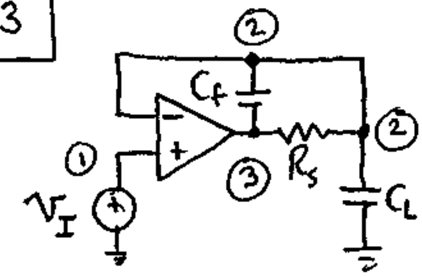
```
Problem 8.22
*a0 = 1Meg, fb = 10Hz
ea0 10 0 1 2 1Meg
Req 10 11 1Meg
Ceq 11 0 15.92nF
ebuf 12 0 11 0 1
ro 12 3 100
Vi 1 0 ac 1V pulse (0 1V 0 10ns 10ns 10us 20us)
RVi 1 0 1
R1 0 2 20k
R2 2 4 180k
Cf 2 3 6.86pF
Rs 3 4 11.11
CL 4 0 10nF
*1/beta:
rof 1 33 100
Cff 33 22 6.86pF
Rsf 33 44 11.11
CLf 44 0 10nF
R2f 44 22 180k
R1f 22 0 20k
.ac dec 10 10k 1G
.tran 0.1us 10us 0 0.1us
.probe
.end
```





8.19

8.23

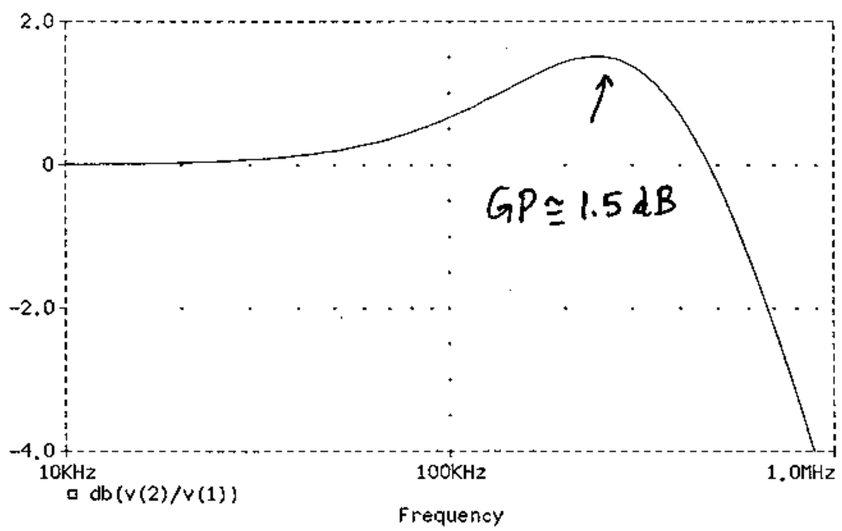


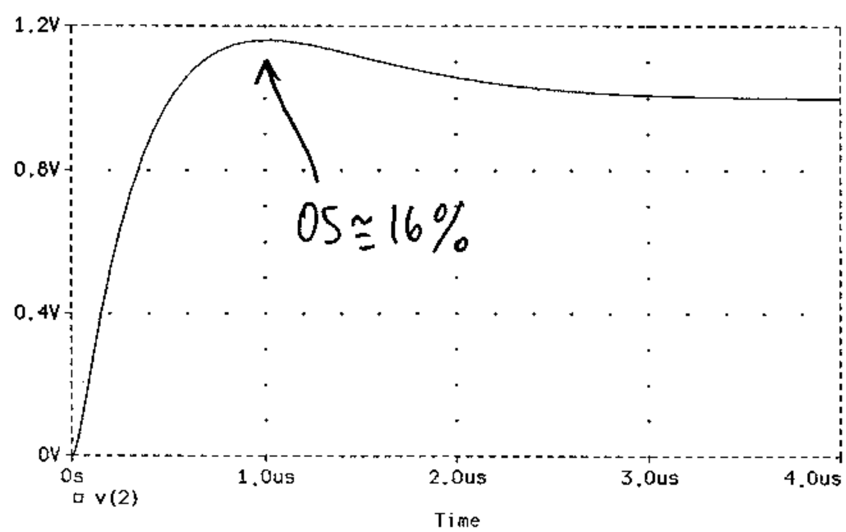
$R_s = 30 r_o = 3\,k\Omega$

$C_f = \left(\dfrac{5\times10^{-9}}{18\pi\times100\times10^{7}}\right)^{1/2}$

$\cong 300\,pF.$

```
Problem 8.23
ea0 10 0 1 2 1Meg
Req 10 11 1Meg
Ceq 11 0 15.92nF
ebuf 12 0 11 0 1
ro 12 3 100
Vi 1 0 ac 1V Pulse (0 1V 0 1ns 1ns 4us 8us)
RVi 1 0 1
Cf 2 3 300pF
Rs 2 3 3k
CL 2 0 5nF
.ac dec 50 10k 1Meg
.tran 25ns 4us 0ns 25ns
.probe
.end
```



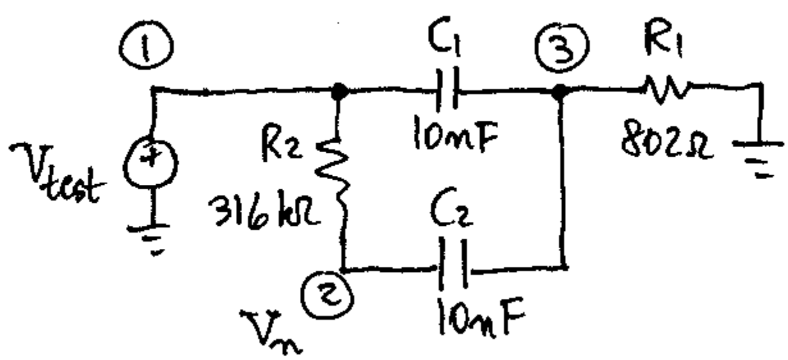


8.20

8.24 (a) $\beta_\infty = 1$ V/V because C_2 acts as a short in the limit $f \to \infty$. Consequently, $f_x = \beta_\infty f_t = f_t$, indicating that as long as the op amp is unity-gain stable, so is the wideband band-pass filter.

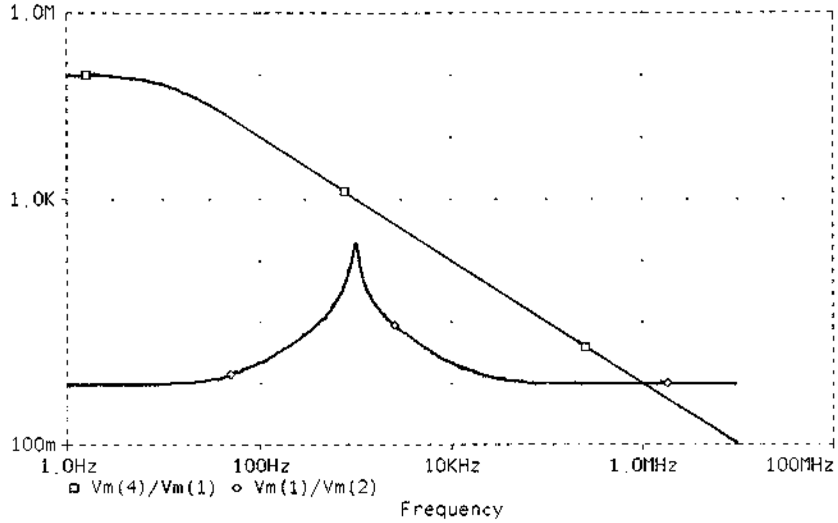
(b) At high frequencies the caps act as shorts, so $\beta_\infty = 1/(1+KR_4/R_4) = 1/(1+K)$, indicating a stable circuit with $f_x = f_t/(1+K)$.

8.25 (a) Suppress V_i, break the loop at the op amp's output, insert a test source V_{test}, and plot $1/\beta = V_{test}/V_n$.



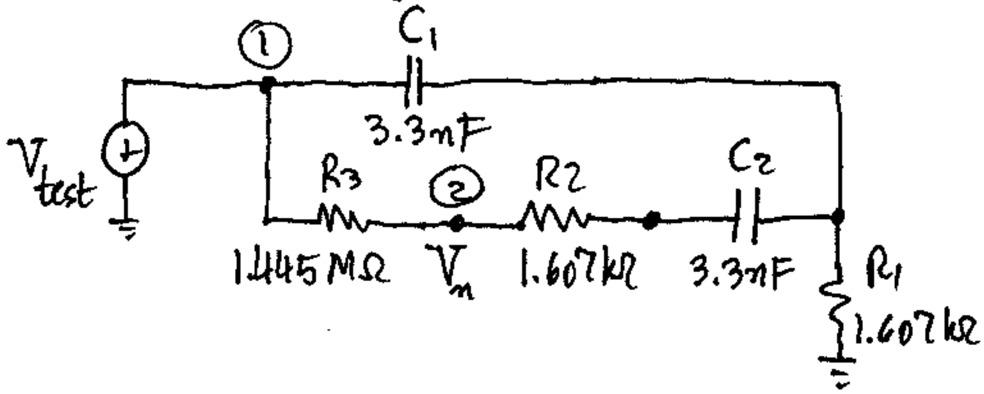

```
PROBLEM 8.25a
Vtest 1 0 AC 1
R1 0 3 802
C1 3 1 10n
C2 3 2 10n
R2 2 1 316k
EOA 4 0 Laplace {V(1,0)}={100k/(1+s/62.83)}
.ac dec 10 1 10Meg
.probe
.end
```

8.21



The above plot reveals a stable circuit with $f_x = f_t$ and $\phi_m = 90°$.

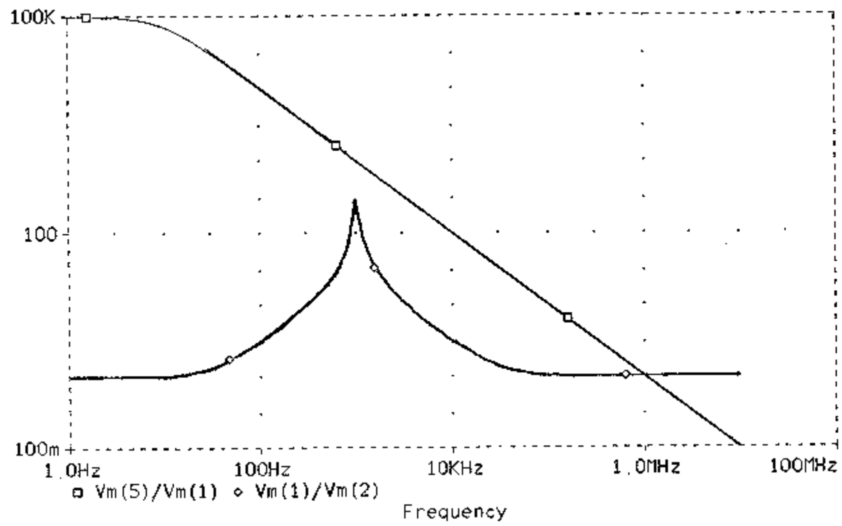
(b) Proceeding as in (a), we have:




```
PROBLEM 8.25b
Vtest 1 0 AC 1
R1 4 0 1.6k
R2 2 3 1.6k
R3 1 2 1.445Meg
C1 1 4 3.3n
C2 3 4 3.3n
EOA 5 0 Laplace {V(1,0)}={100k/(1+s/62.83)}
.ac dec 10 1 10Meg
.probe
.end
```

The result is again a stable circuit with $f_x = f_t$ and $\phi_m = 90°$.

(8.22)



8.26 $a_{old} = \dfrac{3600}{(1+jf/10^6)(1+jf/4\times10^6)(1+jf/40\times10^6)}$

$a_{new} = \dfrac{1}{1+jf/f_d} a_{old}$; $T = \beta a_{new} = \dfrac{1}{10} a_{new}$;

for $f >> f_d$, $\measuredangle a_{new} \cong \measuredangle a_{old} + 90^\circ$.

(a) For $\phi_m = 60$, find the frequency f_{-30° at which $\measuredangle a = -30^\circ$. Using trial and error (PSpice plots also help), we find $f_{-30^\circ} = 430$ kHz, where $|\beta a_{old}| = 329$. So, $f_d = 430\times10^3/329 \cong 1.31$ kHz.

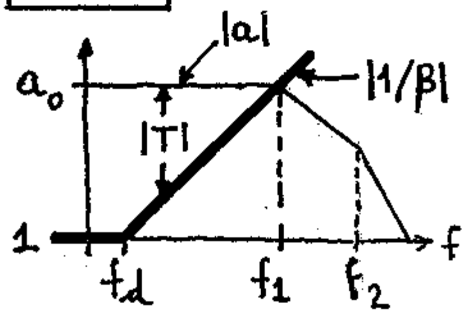
(b) The frequency at which $\measuredangle a_{old} = -90^\circ$ is $f_{-90^\circ} = 1.87$ MHz, where $|\beta a_{old}| = 154$. For GM = 12 dB, we want $|T(jf_{-90^\circ})| = 10^{-12/20} = \frac{1}{4}$, indicating that $f_d = 1.87\times10^6/(154\times4) = 3.04$ kHz.

(c) With a second-order approximation, Eq. (8.4) indicates that for GP = 2 dB we need $Q = 1.13$, or $\phi_m \cong 47^\circ$, by Eq. (8.6). So, use $f_d \cong 650\times10^3/298 = 2.2$ kHz.

8.23

(d) $OS = 5\% \Rightarrow \zeta = 0.69 \Rightarrow \phi_m = 64.6° \Rightarrow$
$f_d = 360 \times 10^3 / 337 = 1.07\ \mathrm{k\Omega}$.

8.27



(a) Introduce a pole at $f = f_d$. Thus, $a_0 f_d = 1 f_1 \Rightarrow f_d = 10^6/10^3 = 1\ \mathrm{KHz} = 1/(2\pi RC)$. Let $C = 1\ \mathrm{nF}$. Then, $R = 158\ \mathrm{k\Omega}$.

(b) $SSBW \cong f_1 = 1\ \mathrm{MHz}$.

8.28

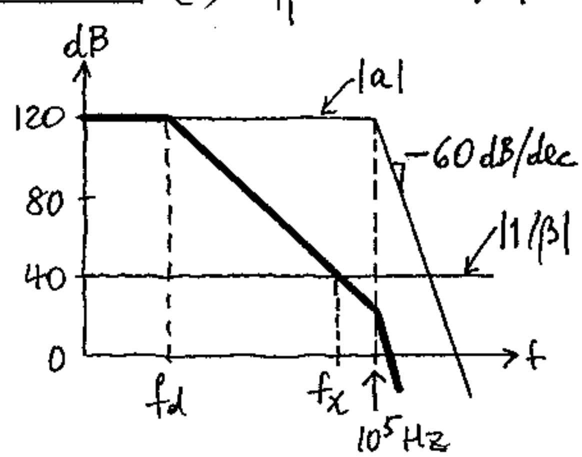
$$a = \frac{10^4}{(1+jf/10^3)(1+jf/f_2)}\ \mathrm{V/V}.$$

$$A_0 = 60\ \mathrm{dB} = 1000\ \mathrm{V/V} \Rightarrow 10^3 = \frac{10^4}{1+10^4\beta} \Rightarrow \beta = 9 \times 10^{-4}$$

V/V. $T = 9/[(1+jf/10^3)(1+jf/f_2)]$. $Q = 1/\sqrt{2} \Rightarrow \phi_m = 65.5°$. Use trial and error to find f_2 such that $\angle T(jf_x) = -114.5°$. Trial and error: $f_2 = 12\ \mathrm{kHz}$, $f_x = 7.55\ \mathrm{kHz}$.

8.29

(a) $1/\beta = 1 + R_2/R_1 = 101 \cong 40\ \mathrm{dB}$. The ROC between the $|a|$ and $|1/\beta|$ curves is $-60\ \mathrm{dB/dec} \Rightarrow \phi_m \cong -90°$. $\Rightarrow$ unstable.



8.24

(b) Since f_d contributes -90° at $f = f_x$, if we want $\phi_m = 45$, the phase contribution of a at f_x must be -45°. Since a has three identical poles, the contribution of each pole at f_x must be $-45^\circ/3 = -15^\circ$. Imposing $-15^\circ = \tan^{-1} f_x/10^5$ gives $f_x = 26.8$ kHz. Finally, $f_d = f_x/(\beta a_0)$ $= 26.8 \times 10^3/(10^6/101) = 2.7$ Hz. Use $C = 0.1\,\mu F$, $R =$ 620 kΩ.

8.30

$$g_1 V_d + \frac{V_1}{R_1} + sC_1 V_1 + sC_c(V_1 - V_2) = 0$$

$$g_2 V_1 + \frac{V_2}{R_2} + sC_2 V_2 + sC_c(V_2 - V_1) = 0$$

Eliminating V_1 and collecting,

$$\frac{V_2}{V_d} = g_1 g_2 R_1 R_2 \frac{1 - sC_c/g_2}{1 + As + Bs^2}, \text{ where}$$

$$A = R_1 R_2 g_2 C_c + R_1(C_1 + C_c) + R_2(C_2 + C_c)$$

$$B = R_1 R_2 (C_1 C_2 + C_1 C_c + C_2 C_c).$$

Writing

$$1 + As + Bs^2 = \left(1 + \frac{s}{\omega_a}\right)\left(1 + \frac{s}{\omega_b}\right) \cong 1 + \frac{s}{\omega_a} + \frac{s^2}{\omega_a \omega_b}$$

allows us to derive $\omega_1 = 1/A$ and $\omega_2 = 1/B\omega_1$, or

$$\omega_1 = \frac{1}{R_2(C_2 + C_c) + R_1(C_1 + C_c) + g_2 R_1 R_2 C_c} \cong \frac{1}{R_1 g_2 R_2 C_c}$$

$$\omega_2 \cong \frac{g_2 C_c}{C_1 C_2 + (C_1 + C_2) C_c}$$

Where we have exploited the fact that the

8.25

Miller effect renders the last denominator term of ω_a much bigger than the others. Letting $\omega_z = g_2/C_c$ we thus have

$$\frac{V_2}{V_d} = g_1 R_1 g_2 R_2 \frac{1 - s/\omega_z}{(1+s/\omega_1)(1+s/\omega_2)}.$$

8.31

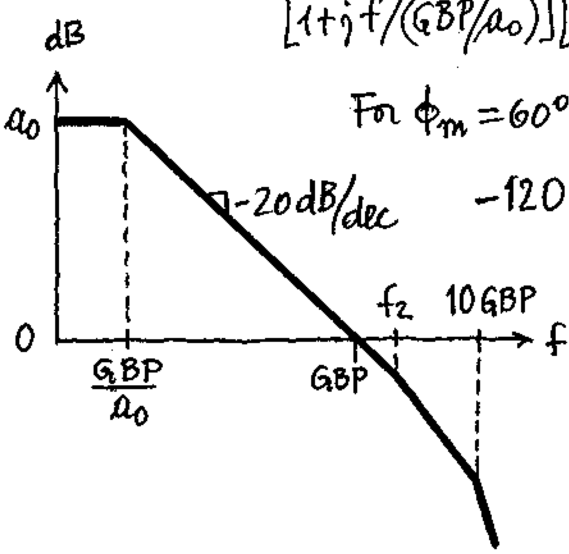
$$T = 10^5 \frac{1 - jf/50\times10^6}{(1+jf/100)(1+jf/10^7)(1+jf/77\times10^6)}$$

Using trial and error, we find $f_x = 7.9$ MHz and $\measuredangle T(jf_x) = -\tan^{-1}(7.9/50) - [\tan^{-1}(7.9\times10^6/100) + \tan^{-1}(7.9/10) + \tan^{-1}(7.9/77)] = -9° - 90° - 38.3° - 5.9° = -143.1° \Rightarrow \phi_m = 36.9°$.

8.32

In both cases assume the follower configuration, since it is the hardest to compensate.

(a) $$T = \frac{a_0}{[1+jf/(GBP/a_0)][1+jf/f_2][1+jf/(10GBP)]}$$



For $\phi_m = 60°$ we need $\measuredangle T(jGBP) = -120°$, or $-[\tan^{-1} a_0 + \tan^{-1}(GBP/f_2) + \tan^{-1}(0.1)] = -120°$, or $f_2 = \frac{GBP}{\tan 24.29°} = 2.2 \times GBP$.

8.26

(b) $T = \dfrac{a_0[1-jf/(10\,GBP)]}{[1+jf/(GBP/a_0)]\times[1+jf/f_2]}$

For $\phi_m = 45°$ impose $\measuredangle T(jGBP) = -135°$, or $-[\tan^{-1} 0.1 - \tan^{-1} a_0 - \tan^{-1}(GBP/f_2)] = -135° \Rightarrow f_2 = 1.2\,GBP$.

$\boxed{8.33}$ $V_1 = -g_1 V_d Z$, where Z is such that

$$\frac{1}{Z} = \frac{1}{R_1} + sC_1 + \frac{1}{R_c + 1/sC_c} = \frac{1+s[R_1(C_1+C_c)+R_cC_c]+s^2R_1C_1R_cC_c}{R_1(1+sR_cC_c)}$$

$$\frac{V_1}{V_d} = -g_1R_1\frac{1+sR_cC_c}{1+s[R_1(C_1+C_c)+R_cC_c]+s^2R_1C_1R_cC_c}.$$ Rewriting

$$\frac{V_1}{V_d} = -g_1R_1\frac{1+s/\omega_z}{(1+s/\omega_a)(1+s/\omega_b)} \cong \frac{1+s/\omega_z}{1+s/\omega_a+s^2/\omega_a\omega_b}$$ gives

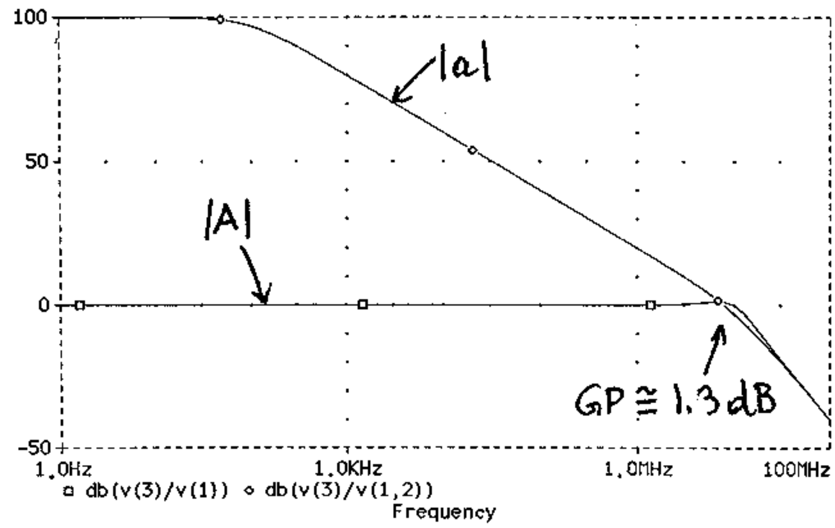
$\omega_z = 1/R_cC_c$, $\omega_a = 1/[R_1(C_1+C_c)+R_cC_c] \cong 1/R_1C_c$,

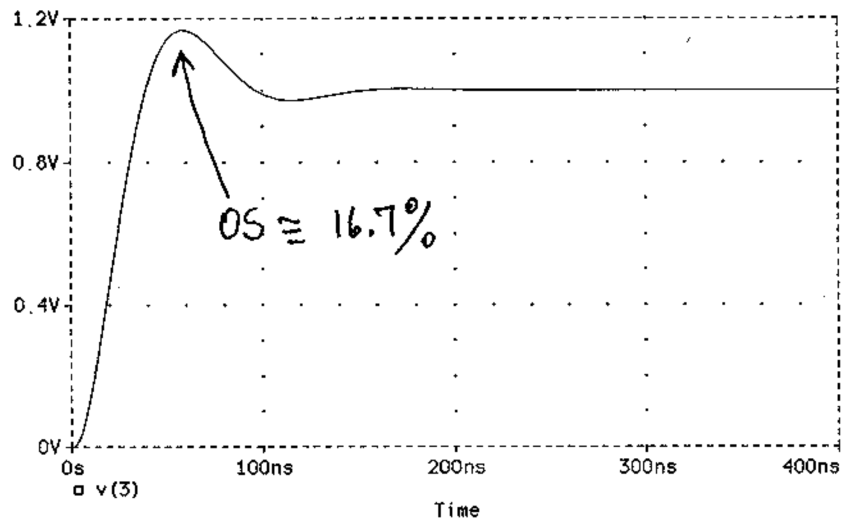
$\omega_b = [R_1(C_1+C_c)+R_cC_c]/R_1C_1R_cC_c \cong 1/R_cC_1$.

$\boxed{8.34}$

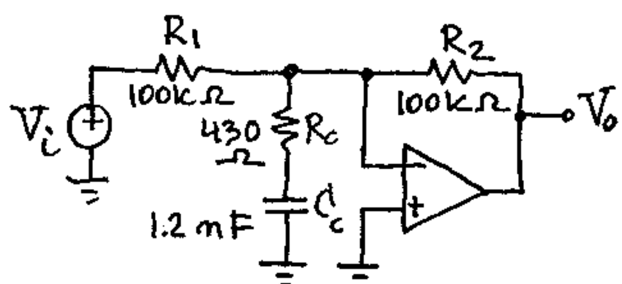
```
Problem 8.34
rd 1 2 1Meg
g1 4 0 1 2 2m
R1 4 0 100k
C1 4 0 15.92pF
*Pole-zero comp:
Cc 4 44 15.9nF
Rc 44 0 10
g2 5 0 4 0 10m
R2 5 0 50k
C2 5 0 3.183pF
e3 6 0 5 0 1
R3 6 7 10k
C3 7 0 1.592pF
e0 8 0 7 0 1
ro 8 3 100
vi 1 0 ac 1 pulse (0 1V 0 1ns 1ns 0.4us 0.8us)
Rf 2 3 1k
.ac dec 10 1 100Meg
.tran 2ns 0.4us 0 2ns
.probe
.end
```

8.27





8.35



$$R_c = \frac{100\ \text{k}\Omega}{234.5 - (1 + 100/100)} \cong 430\ \Omega$$

$$C_c = \frac{5}{\pi \times 430 \times 3 \times 10^6} \cong 1.2\ \text{nF}.$$

8.28

To find $A(jf)$, refer to Fig. 8.25(b) and note that for $f < f_2/10$, $|T|$ is fairly large, indicating that $A(jf) \cong A_{ideal} = -1\ V/V$ there. For $f > f_2/10$ we can write $1/\beta \cong |a(jf_2)|$ and $a \cong a_0/[(jf/f_1)(1+jf/f_2)(1+jf/f_3)]$, so

$$\frac{1}{T} = \frac{1}{a\beta} \cong \frac{|a(jf_2)|}{a_0}(jf/f_1)(1+jf/f_2)(1+jf/f_3).$$

But, $|a(jf_2)| \times f_2 = a_0 f_1$, so $A = -1/(1+1/T)$, or

$$A(jf) = \frac{-1}{1+(jf/f_2)(1+jf/f_2)(1+jf/f_3)}$$

$$= \frac{-1}{1+jf/f_2-(f/f_2)^2+(jf/f_3)[jf/f_2-(f/f_2)^2]}$$

In the neighbourhood of f_2 ($f_2 \ll f_3$) we can approximate

$$A(jf) \cong \frac{-1}{1+jf/f_2-(f/f_2)^2} = -H_{LP},\ f_0 = f_2,\ Q = 1$$

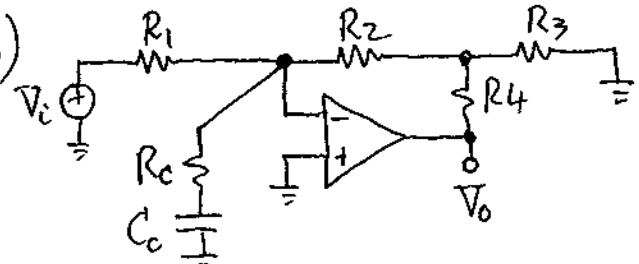
8.36

(a) $$\beta = \frac{R_1}{R_1+R_2} \times \frac{(R_1+R_2)\|R_3}{R_4+(R_1+R_2)\|R_3} = \frac{1}{23}\ V/V.$$

$$T = \frac{10^5/23}{(1+jf/10^4)(1+jf/2\times10^5)(1+jf/2\times10^6)}$$

Trial and error: $f_x = 2.36$ MHz, $\phi_m = -44.6°$.

(b)

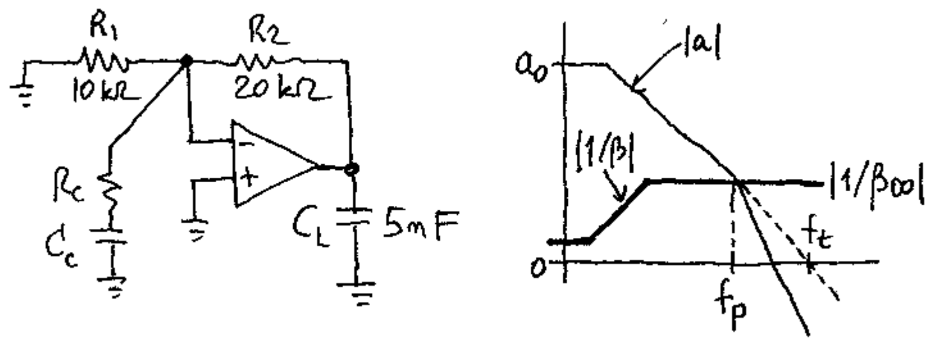


8.29

At high frequencies, where C_c acts as a short, we have $1/\beta_\infty = (1+R_2/R_p)\times[1+R_4/(R_p+R_2)\|R_3] = (1+R_2/R_p)\times[1+R_4/(R_p+R_2)+R_4/R_3]$, where $R_p = R_1\|R_c$. Imposing $1/\beta_\infty = |a(jf_2)|$, or $(1+100/R_p)\times[1+10+100/(R_p+100)] = 3514$ gives $R_p = 342.7\ \Omega$. Then, $1/R_c = 1/R_p - 1/R_1 = 344\ \Omega$, $C_c = 5/\pi f_2 R_c = 23.1$ nF.

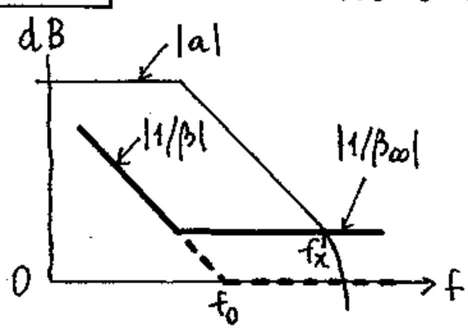
(c) $f_{-3dB} \cong f_2 = 200$ kHz.

8.37



$f_p = \frac{1}{2\pi r_o C_L} = 318$ kHz. Near f_p, $a \cong 10^7/[jf(1+jf/318\text{ kHz})]$. So $|a(jf_p)| = 22.2$ V/V. Find R_c such that $1+R_2/(R_1\|R_c) = |a(jf_p)|$, or $1+R_2/R_1+R_2/R_c = 22.2 \Rightarrow R_c = 1.04$ kΩ. Then, $C_c = 5/(\pi f_p R_c) = 4.8$ nF.

8.38



With $C_c = 0$ the $|1/\beta|$ curve (broken) would intercept the $|a|$ curve in the region of excessive phase shift: $(1/\beta_\infty) = 0$ dB. With C_c in place, $1/\beta_\infty = 1 + C_c/C$; imposing $1/\beta_\infty = 5$ V/V gives $C_c = 4C = 160$ pF. To find f_x, impose

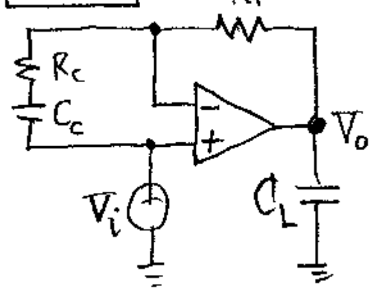
8.30

$|80\times10^6/jf_x| = 5$ V/V $\Rightarrow f_x = 16$ MHz.

(b) $f_0 = 1/2\pi RC = 1.59$ MHz;

$H(jf) \cong -\frac{1}{jf/1.59\,\text{MHz}} \times \frac{1}{1+jf/16\,\text{MHz})}$. Useful range is $f < 16$ MHz.

$\boxed{8.39}$



$f_p = 1/2\pi r_o C_L = 1.06$ MHz

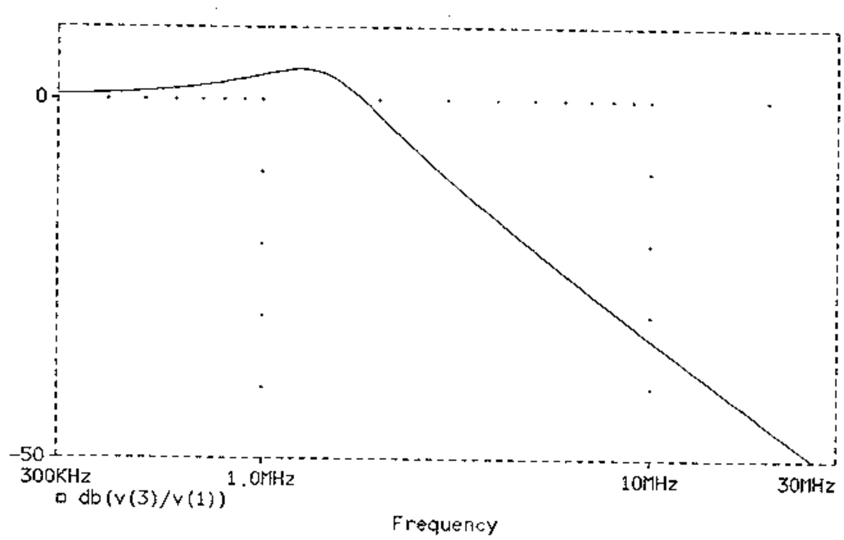
$a_{new} \cong \frac{6\times10^6}{jf} \times \frac{1}{1+jf/1.06\times10^6}$

$|a_{new}(jf_p)| = 4$ V/V $\Rightarrow$

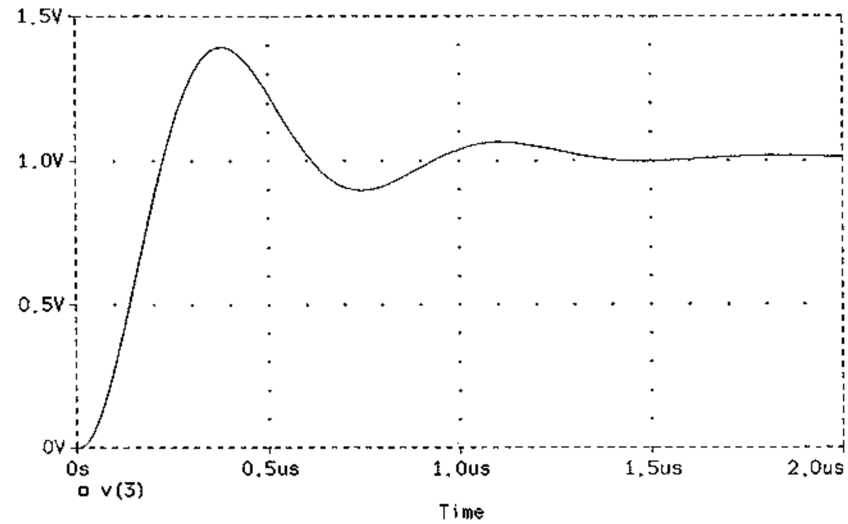
$1 + R_f/R_c = 4 \Rightarrow R_f = 3R_c$.

Pick $C_c = 220$ pF. Then, $R_c = 5/\pi C_c f_p \cong 6.8$ k, $R_f \cong$ 20 kΩ.

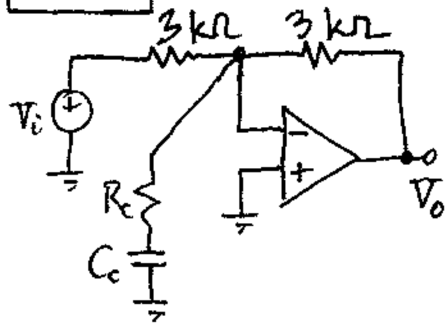
```
Problem 8.39
Vi 1 0 ac 1 pulse (0 1 0 10ns 10ns 2us 4us)
eOA 33 0 Laplace {V(1,2)}={8E6/(1+s/6.283)}
ro 33 3 30
Rf 3 2 20k
CL 3 0 5nF
Rc 2 21 6.8k
Cc 21 1 220pF
.tran 10ns 2u 0 20ns
.ac dec 50 300k 30Meg
.probe
.end
```



8.31



8.40

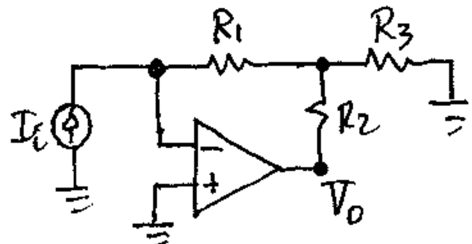


$R_c = 3\times10^3/[5-(1+1)]$
$= 1\ k\Omega$; $f_x = \beta_{max} \times f_t =$
$0.2\times 80 = 16$ MHz;
$C_c = 5/(\pi \times 1\times10^3 \times 16\times10^6)$
$= 100$ pF.

$$A(jf) \cong \frac{-1}{1+jf/16\times10^6}\ V/V.$$

8.41

$A = -R_1(1+R_2/R_3+R_2/R_1)$; $\beta_\infty = R_3/(R_2+R_3)$.

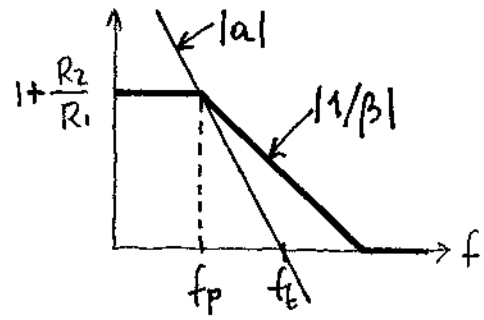


Imposing $\beta_\infty = \beta_{max} =$ 0.2 V/V gives $R_2 = 4R_3$. let $R_3 = 3k\Omega$, $R_2 = 12\ k\Omega$.

Imposing $A = -0.1 V/\mu A = -100\times10^3$ V/A yields $R_1 =$ 17.6 kΩ. We also have $f_x = 0.2\times 20 = 4$ MHz, so
$A(jf) \cong [-0.1\ V/\mu V]/(1+jf/4MHz)$.

(8.32)

8.42 (a) $|a(jf)| \cong (10^7/f)^2$; $1/\beta_0 = 21$ V/V;



$|a(jf_p)| = 1/\beta_0 \Rightarrow f_p =$ 2.18 MHz $\Rightarrow C_f = 3.6$ pF;

$$A(jf) = \frac{-20 \text{ V/V}}{1 + jf/(2.18 \text{ MHz})}.$$

(b) ϕ_m is maximized when $f_x = (2.18 \text{ MHz} \times 10 \text{ MHz})^{1/2} = 4.67$ MHz, or $f_p = f_x/\sqrt{21} = 1.02$ MHz; this requires $C_f = 7.8$ pF. $T = a\beta \cong$

$$-\left(\frac{10^7}{f}\right)^2 \frac{1}{21} \frac{1 + jf/(1.02 \text{ MHz})}{1 + jf/(21.4 \text{ MHz})}; \; \measuredangle T(jf_x) = -114.6^\circ$$

$\Rightarrow \phi_m = 65.4^\circ$. Moreover, $f_{-3dB} = 1.02$ MHz.

8.43 At high fequencies, where C_1 is virtually a short, $1/\beta \simeq 1 + Z_2/R_1$ where $Z_2 = R_2 // (1/j\omega C_2)$. Substituting and manipulating,

$$\frac{1}{\beta} \simeq \left(1 + \frac{R_2}{R_1}\right) \frac{1 + j(f/f_z)}{1 + j(f/f_p)}, \; f_z = \frac{1}{2\pi(R_1//R_2)C_2},$$

$$f_p = \frac{1}{2\pi R_2 C_2}.$$ Numerically,

$$\frac{1}{\beta} \simeq 11 \frac{1 + j(f/220 \text{ kHz})}{1 + j(f/20 \text{ kHz})} \text{ V/V}$$

Moreover, $a = \dfrac{a_0}{[1 + j(f/f_1)][1 + j(f/f_2)]}$. At

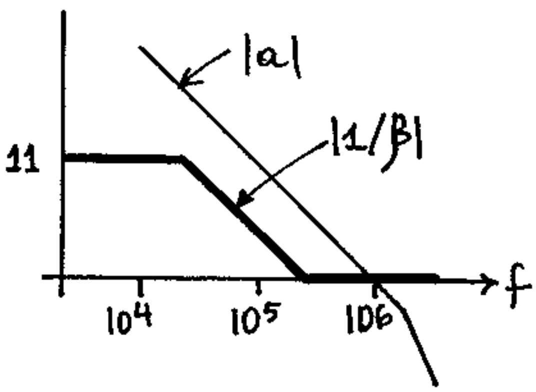
(8.33)

high frequencies, $a \cong \dfrac{1}{j[f/(a_0 f_1)][1+j(f/f_2)]}$.

Numerically,

$$a \cong \frac{1}{j(f/10^6)[1+j(f/2\,\text{MHz})]}.$$

$$T = a\beta \cong \frac{(1/11)[1+j(f/20\,\text{kHz})]}{j(f/10^6)[1+j(f/2\,\text{MHz})][1+j(f/220\,\text{kHz})]}$$



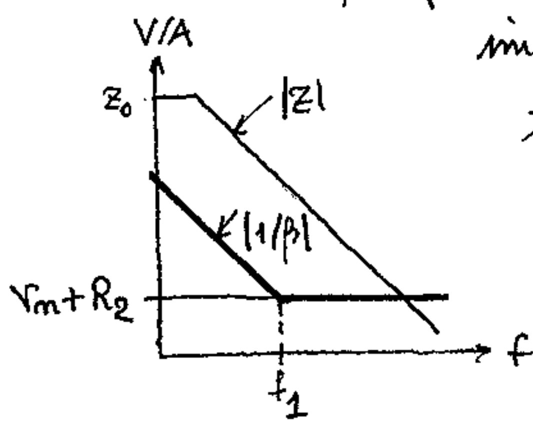
By trial and error we find $f_x = 890$ kHz, and $\phi_m = 78.6°$.

8.44 (a) Use Eq. (6.58), but with $R_1 \to R$, $R_2 \to 1/sC$, $r_m \to r_m + R_2$. The result is

$$\frac{1}{\beta} = \frac{1}{sC} + (r_m + R_2)\left(1 + \frac{1}{sRC}\right) = \frac{R + (r_m+R_2)(1+sRC)}{sRC}$$

$$\frac{1}{\beta} = (R + r_m + R_2)\frac{1+jf/f_1}{jf/f_0},\quad f_0 = \frac{1}{2\pi RC},\quad f_1 = [1 + R/(r_m+R_2)]f_0;\quad 1/\beta_\infty = r_m + R_2.$$

As long as we impose $r_m + R_2 \geq (1/\beta)_{min}$, the circuit will be stable.



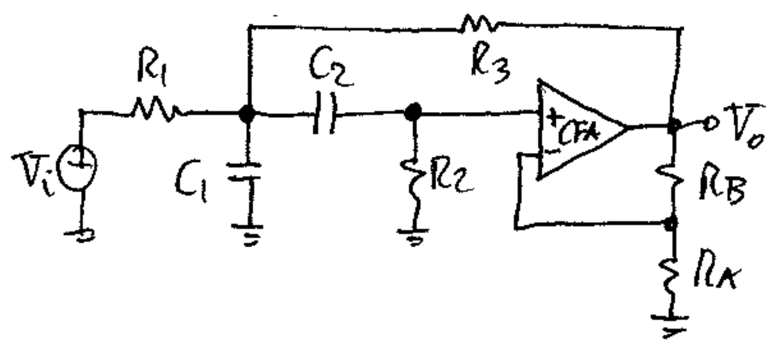
(b) $R_2 = 10^3 - 50 = 950\,\Omega$. To maximize the region of high $|T|$,

(8.34)

keep f_1 as low as possible, say, $R < 1\ k\Omega$.
Choose $C = 220\ pF$, $R = 723\ \Omega$.

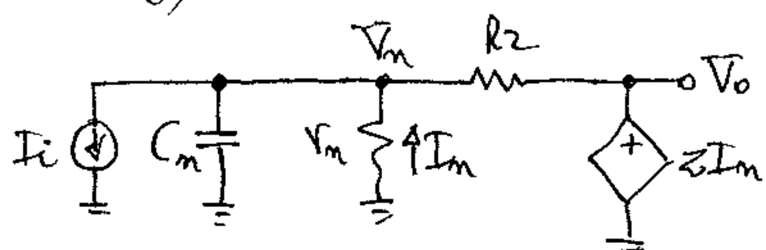
(c) Error due to I_N flowing through R_2.

$\boxed{8.45}$ You cannot use the MF configuration (Fig. 3.30) because the series C_1–C_2 provides a direct capacitive feedback path, jeopardizing stability. Use the KRC configuration since the CFA is configured as an ordinary amplifier.



By Eq. (3.67), $K=2$, $H_{0BP} = 1$ V/V; $R_A = R_B = 1\ k\Omega$, $C_1 = C_2 = 100\ nF$, $R_1 = R_2 = R_3 = 225\ \Omega$.

$\boxed{8.46}$ (a)



$V_n = -r_n I_n$; $V_o = zI_n \Rightarrow V_n = (-r_n/z)V_o$.

KCL: $(V_o - V_n)/R_2 = I_i + sC_n V_n + V_n/r_n$.

Eliminating V_n and collecting,

8.35

$$\frac{V_o}{I_i} = R_2 \frac{1}{1+\frac{r_n+R_2}{z}\left[1+s(r_n \| R_2)C_n\right]}$$

Letting $z \to z_0 f_a / jf$ and $s \to j2\pi f$, we get

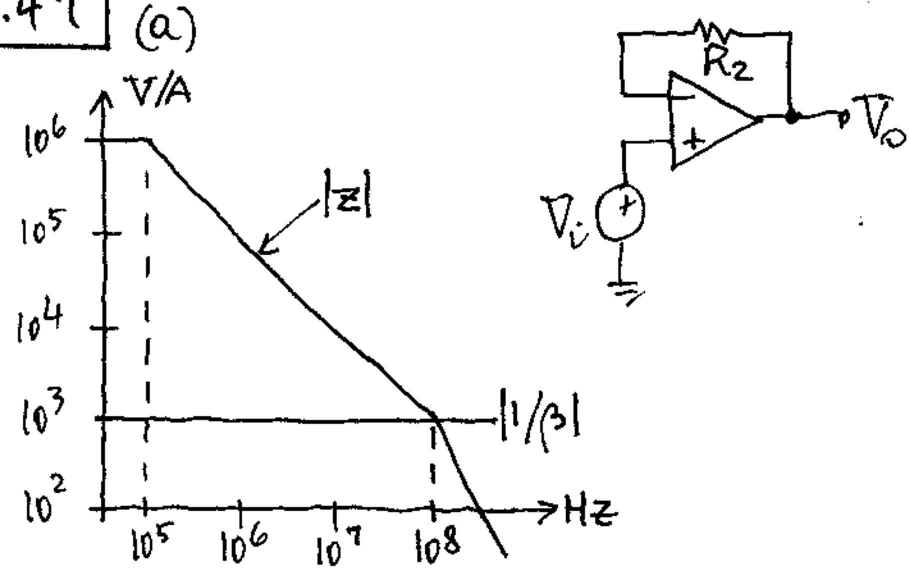
$$\frac{V_o}{I_i} = R_2 \frac{1}{1+jf\frac{r_n+R_2}{z_0 f_a} - f^2 2\pi \frac{r_n R_2}{z_0 f_a} C_n} = R_2 H_{LP},$$

$$f_0 = \sqrt{\frac{z_0 f_a}{2\pi r_n R_2 C_n}}, \quad \frac{r_n+R_2}{z_0 f_a} = \frac{1}{f_0 Q}, \text{ or } Q = \frac{z_0 f_a}{(r_n+R_2) f_0}.$$

(b) $f_0 = \left[\frac{750\times10^3 \times 200\times10^3}{2\pi 50\times1.5\times10^3 \times 100\times10^{-12}}\right]^{1/2} = 56.4 \text{ MHz}$

$Q = 1.72$. By Eq. (8.4), $GP = 0.127$. $\zeta = \frac{1}{2Q} = 0.291$.
Eq. (8.5): $OS = 38.4\%$.

8.47 (a)



From Eq. (8.34a), $1/\beta = R_2 + r_n(1+R_2/R_1) = R_2 + r_n$ for $R_1 = \infty$ (Voltage follower).

For $\phi_m = 45°$ impose $f_x = 10^8$ Hz, or $R_2 + r_n = 10^3\ \Omega$, or $R_2 = 10^3 - 50 = 950\ \Omega$; $f_{-3dB} = 10^8$ Hz.

(8.36)

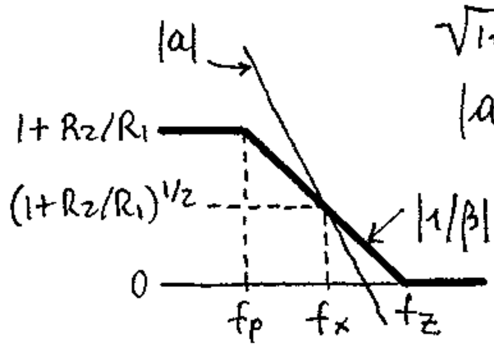
(b) Using the expressions

$$|z| = \frac{10^6}{\sqrt{[1+(f/10^5)^2]\times[1+(f/10^8)^2]}}$$

$$\measuredangle z = -\left[\tan^{-1}(f/10^5) + \tan^{-1}(f/10^8)\right]$$

we find $f_{-120^\circ} = 57.8$ MHz, where $|z(j57.8\text{ MHz})| = 1498\ \Omega$. We now use $R_2 = 1498 - 50 = 1.448$ kΩ, and we get $f_{-3dB} = 57.8$ MHz.

8.48 (a) ϕ_m is maximized for $f_x = \sqrt{f_p f_z} = \sqrt{1+R_2/R_1}\, f_p$. For $f = f_x$, $|a(jf_x)| = (1+R_2/R_1)^{1/2}$, or



$$\frac{f_{t1} f_{t2}}{f_x^2} = (1+R_2/R_1)^{1/2}$$

Eliminating f_x gives $f_p^2 = f_{t1} f_{t2}/(1+R_2/R_1)^{3/2}$; then, $C_f = 1/2\pi R_2 f_p = (1+R_2/R_1)^{3/4}/[2\pi R_2 \sqrt{f_{t1} f_{t2}}]$.

(b) Since $\measuredangle a(jf_x) \cong -180^\circ$, for $\phi_m \geq 45^\circ$ we need $\measuredangle[1/\beta(jf_x)] \geq 45^\circ$, or $\tan^{-1}(f_x/f_p) - \tan^{-1}(f_x/f_z) \geq 45^\circ$, or $\tan^{-1}(1+R_2/R_1)^{1/2} - [90^\circ - \tan^{-1}(1+R_2/R_1)^{1/2}] \geq 45^\circ$, or $2\tan^{-1}(1+R_2/R_1)^{1/2} \geq 135^\circ$, or $1+R_2/R_1 \geq \tan^2(135/2) = 5.83$.

8.37

(c) $R_1 = 10\ k\Omega$, $R_2 = 100\ k\Omega$, $C_f = 11^{3/4}/(2\times\pi\times 10^5 \times 10^6) = 9.6\ pF$; $\phi_m = \tan^{-1}(11)^{1/2} - \tan^{-1}(11)^{-1/2} = 56.4°$. $A(jf) = -10/(1+1/T)\ V/V$. To find T, note that $f_p = 10^6/11^{3/4} = 166\ kHz$, $f_z = 1.82\ MHz$, $a \cong -f_t^2/f^2$, so

$$A = \frac{-10\ V/V}{1+1/T} = \frac{-10\ V/V}{1 - \frac{f^2}{f_t^2}\frac{1}{\beta_0}\frac{1+jf/f_p}{1+jf/f_z}}$$

$$= \frac{-10\,(1+jf/1.82\times 10^6)}{1 + j\frac{f}{1.82\times 10^6} - \frac{f^2}{1.1\times 10^{13}} - \frac{jf^3}{1.8\times 10^{18}}}\ V/V.$$

8.49 (a) Composite: $A_0 = (100\ V/V)/(1+2.5\times 10^{-9})$; $f_B = 100\ kHz$. Cascade: $A_{01} = A_{02} = (10\ V/V)/(1+5\times 10^{-5}) \Rightarrow A_0 \cong (100\ V/V)/(1+10^{-4})$; $f_A = (\sqrt{2}-1)^{1/2}\times 10^6/10 = 64\ kHz$.

(b) Composite: $A_0 = (-100\ V/V)/(1+5\times 10^{-5})$, $f_B = 100\ kHz$. Cascade: Let $A_{01} = (+10\ V/V)/(1+5\times 10^{-5})$, $A_{02} = (-10\ V/V)/(1+5.5\times 10^{-5})$; then $A_0 = (-100\ V/V)/(1+10^{-4})$. Moreover, $f_{B1} = 100\ kHz$, $f_{B2} = 90.9\ kHz$, $f_B = 61\ kHz$.

8.50 (a) Let $\beta = 1/(1+R_2/R_1)$. Then,

$$T = a\beta = a_1 A_2 \beta \cong \frac{f_t}{jf}\,\frac{1+R_4/R_3}{1+jf/[f_t/(1+R_4/R_3)]}\,\frac{1}{1+R_2/R_1}$$

8.38

$$T = \frac{f_t}{jf}\frac{\sqrt{(1+R_2/R_1)/2}}{1+R_2/R_1} \times \frac{1}{1+jf/[f_t/\sqrt{(1+R_2/R_1)/2}}$$

$$= \frac{f_2}{2jf}\frac{1}{1+jf/f_2}, \quad f_2 = f_t/\sqrt{(1+R_2/R_1)/2}$$

$$\frac{1}{1+1/T} = \frac{1}{1+\frac{2jf}{f_2}(1+jf/f_2)} = \frac{1}{1+2j\frac{f}{f_2}-2\left(\frac{f}{f_2}\right)^2}$$

$$= H_{LP}, \; f_0 = f_2/\sqrt{2}, \; Q = 1/\sqrt{2} \Rightarrow \phi_m \simeq 65^\circ.$$

(b) $R_1 = 2.00$ kΩ, $R_2 = 100$ kΩ, $R_4/R_3 = \sqrt{51/2} - 1 = 4.05$; Use $R_3 = 2.00$ kΩ, $R_4 = 8.06$ kΩ.
$f_0 = (4.5\times10^6/\sqrt{51/2})/\sqrt{2} = 630$ kHz;

$$A = \frac{-50 \text{ V/V}}{1+(jf/630\text{ kHz})/(1/\sqrt{2})-(f/630\text{ kHz})^2}.$$

8.51 $R_1 = 10$ kΩ, $R_2 = 100$ kΩ. $f_{b2} = f_{t2}/a_{20} = 500\times10^6/(25\times10^3) = 20$ kHz.
Imposing $f_1 = f_{b2}$ gives $R_3C_1 = 1/(2\pi\times20\times10^3)$. Use $C_1 = 1$ nF, $R_3 = 7.96$ kΩ. For $f_2 = f_1/10$ use $R_4 = 7.96$ kΩ, $C_2 = 10$ nF.

The total error at OA_2's input can be as large as $5\text{ mV} + 7.96\times10^3 \times 20\times10^{-6} = 159$ mV; reflected to OA_1's input, it yields an error $E_I = 159\text{ mV}/(100\text{ V/mV}) = 1.59\ \mu\text{V}$; then, $E_o = 11\times E_I = 17.5\ \mu\text{V}$. $f_B = f_{t2}/11 = 45.5$ MHz.

8.52 Above $f_1 = 20\text{kHz}$, C_1 acts as a short and OA_1 thus contributes $e_{n01} = 2\,nV/\sqrt{Hz}$, so things go as if the voltage noise at the input of OA_2 was $e_{n2} = \sqrt{2^2+5^2} \cong 5.4\ nV/\sqrt{Hz}$. Most of the noise will come from the frequency spectrum near $f_B = 45.5\ MHz$, where $C_2 \simeq$ short.

$$E_{no} = 11\Big\{(5.4\times10^{-9})^2 + [(7.96 + 10\|20)\times10^3]^2 \times (5\times10^{-12})^2 + 1.65\times10^{-20}(7.96+10\|20)\times10^3\Big\}^{1/2} \times (1.57\times 45.5\times10^6)^{1/2} = 93\times10^3\left[(5.4\times10^{-9})^2 + (73\times10^{-9})^2 + (15.5\times10^{-9})^2\right]^{1/2} \cong 7\ mV.$$

The main culprit is current noise, which can be reduced by scaling all resistances. The minimum output noise would be $93\times10^3 \times 5.4\times10^{-9} = 502\ \mu V$. To reduce noise further, filtering must be used, with a reduction in signal bandwidth.

8.53 (a) By Eq. (8.39), $Q = 1$; by Eq. (8.6), $\phi_m \simeq 52°$. Using PSpice, $GP \cong 3.3$ dB, $OS = 34.4\%$.

(b) $-\tan^{-1}(f/10^5)^3 = -1° \Rightarrow f_{-1°} \cong 26\ kHz$. Single op amp: $\measuredangle A = -\tan^{-1}(f/10^5) = -1° \Rightarrow f_{-1°} = 1.7\ kHz$. Cascade: $f_{B1} = f_{B2} = 10^6/\sqrt{10}$

(8.40)

$= 316$ kHz. Imposing $-\tan^{-1}(f/316\text{ kHz}) = -0.5°$ gives $f_{-1°} = 2.76$ kHz.

$\boxed{8.54}$ The output of OA_2 is $V_3 = \dfrac{1}{1+jf/\beta_2 f_{t2}} V_0$ where $\beta_2 = R_3/(R_3+R_4)$. By the superposition principle, $V_0 = a_1\left[V_2 - \left(\dfrac{R_2}{R_1+R_2}V_1 + \dfrac{R_1}{R_1+R_2}V_3\right)\right]$. Substituting V_3,

$$V_0 \cong \frac{f_{t1}}{jf}\left[V_2 - (1-\beta)V_1\right] - \frac{\beta f_{t1}/jf}{1+jf/\beta_2 f_{t2}} V_0,$$

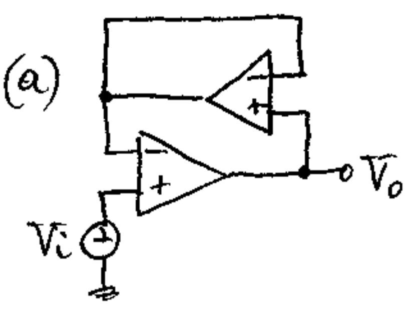
$\beta = R_1/(R_1+R_2)$. Collecting,

$$V_0 = \left[\frac{1}{\beta}V_2 + \left(1-\frac{1}{\beta}\right)V_1\right] \frac{1+jf/\beta_2 f_{t2}}{1+jf/\beta f_{t1} - f^2/\beta f_{t1}\beta_2 f_{t2}}$$

$\boxed{8.55}$ Using matched op amp with $\beta_2 = \beta$, the error function becomes

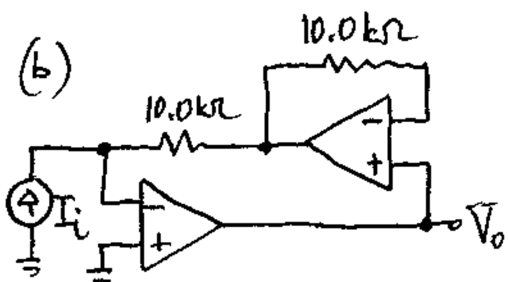
$$\frac{1}{1+1/T} = \frac{1+jf/\beta f_t}{1-(f/\beta f_t)^2 + jf/\beta f_t} = \frac{1-j(f/\beta f_t)^3}{1-\left(\frac{f}{\beta f_t}\right)^2 - (f/\beta f_t)^4}.$$

(a)



$$A = \frac{1-j(f/10^7)^3}{1-(f/10^7)^2-(f/10^7)^4}$$

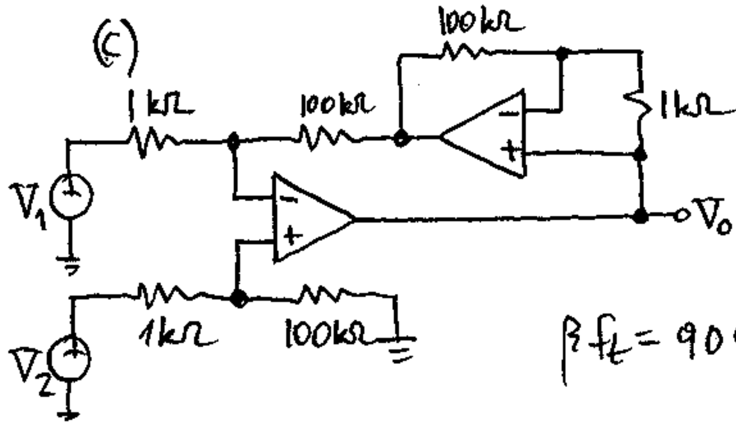
(b)



$$A = -10^4 \frac{1-j(f/10^7)^3}{1-(f/10^7)^2-(f/10^7)^4} \frac{\text{V}}{\text{mA}}$$

(8.41)

(c)



$\beta f_t = 909$ kHz

$$V_o = 100\,(V_2 - V_1) \times \frac{1 - j\,(f/909\,\text{kHz})^3}{1 - (f/909\,\text{kHz})^2 - (f/909\,\text{kHz})^4}.$$