

Homework Assignment No. 10 - Solutions

Problem 1 - (10 points)

Problem 8.13 of GHLM

Bias

$$I_{C1} + I_{C2} = \frac{5.3}{5} = 1.06 \text{ mA}$$

$$I_{C1} = \frac{V_{BE3}}{1.25} = \frac{0.7}{1.25} = 0.56 \text{ mA}$$

$$\therefore I_{C2} = 0.5 \text{ mA}$$

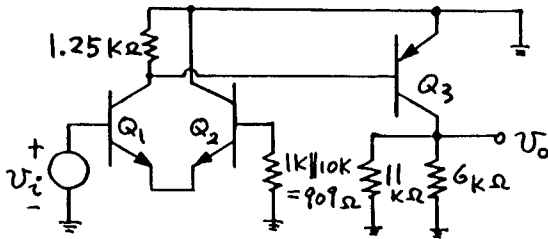
$$I_{C3} = \frac{6V}{6k\Omega} = 1 \text{ mA for } v_o|_{dc} = 0$$

Assume  $I_{C1} = I_{C2} = 0.53 \text{ mA}$

$$\text{Then } r_{\pi 1} = r_{\pi 2} = \frac{200 \times 26}{0.53} = 9.81 \text{ k}\Omega$$

$$r_{\pi 3} = 2.6 \text{ k}\Omega$$

Basic amplifier



$$\frac{v_o}{v_i} = \frac{g_{m1}}{1 + g_{m1} R_{E1}} R_1 g_{m3} R_2$$

$$R_{E1} = \frac{1}{g_{m2}} + \frac{909}{\beta_2} = \frac{26}{0.53} + \frac{909}{200} = 54 \Omega$$

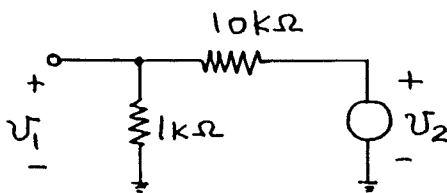
$$R_1 = 1.25 \text{ k}\Omega \parallel r_{\pi 3} = 844 \Omega$$

$$R_2 = 6 \text{ k}\Omega \parallel 11 \text{ k}\Omega = 3.88 \text{ k}\Omega$$

$$\therefore \frac{v_o}{v_i} = \frac{0.53}{26} \frac{1}{1 + \frac{0.53}{26} 54} 844 \frac{3880}{26}$$

$$\therefore a = 1222$$

$$f = h_{12} f = \frac{v_1}{v_2} = \frac{1}{11}$$



$$\therefore \text{loop gain} = \frac{1222}{11} = 111$$

$\therefore$  with feedback gain

$$\frac{v_o}{v_i} = \frac{1222}{1 + 111} = 10.9$$

For the basic amplifier

$$Y_{oa} = 11 \text{ k}\Omega \parallel 6 \text{ k}\Omega = 3.88 \text{ k}\Omega$$

$$Y_{ia} = r_{\pi 1} (1 + g_{m1} R_{E1})$$

$$= 9.81 (1 + \frac{0.53}{26} 54) = 20.6 \text{ k}\Omega$$

With feedback

$$R_o = \frac{3880}{112} = 34.6 \Omega$$

$$R_i = 20.6 \times 112 = 2.3 \text{ M}\Omega$$

FEEDBACK AMP

```
VCC 10 6V
VEE 20 -6V
RL 1 3 1.25K
Q1 3 5 4 NPN
Q2 1 6 4 NPN
REE 4 2 5K
Q3 7 3 1 PNP
RBIAS 7 2 6K
RF 7 6 10K
RE 6 0 1K
.MODEL NPN NPN BF=200 IS=1E-15
.MODEL PNP PNP BF=100 IS=1E-15
VI 5 0 SIN 0 0.25 10K 0 0
.TRAN 4US 200US
.PLOT TRAN V(7)
.FOUR 10K V(7)
.DC VI -1 1 0.05
.PLOT DC V(7)
.TF V(7) VI
.OPTIONS NOPAGE NOMOD
.WIDTH OUT=80
.OP
.END
```

0\*\*\*\* DC TRANSFER CURVES

VI V(7)  
-5.0D+00 0.0D+00 5.0D+00 1.0D+01 1.5D+01

|            |            |
|------------|------------|
| -6.000D-01 | -3.884D+00 |
| -5.500D-01 | -3.884D+00 |
| -5.000D-01 | -3.884D+00 |
| -4.500D-01 | -3.884D+00 |
| -4.000D-01 | -3.884D+00 |
| -3.500D-01 | -3.818D+00 |
| -3.000D-01 | -3.318D+00 |
| -2.500D-01 | -2.779D+00 |
| -2.000D-01 | -2.234D+00 |
| -1.500D-01 | -1.686D+00 |
| -1.000D-01 | -1.137D+00 |
| -5.000D-02 | -5.862D-01 |
| -4.441D-16 | -3.500D-02 |
| 5.000D-02  | 5.167D-01  |
| 1.000D-01  | 1.069D+00  |
| 1.500D-01  | 1.621D+00  |
| 2.000D-01  | 2.173D+00  |
| 2.500D-01  | 2.726D+00  |
| 3.000D-01  | 3.279D+00  |
| 3.500D-01  | 3.831D+00  |
| 4.000D-01  | 4.384D+00  |
| 4.500D-01  | 4.937D+00  |
| 5.000D-01  | 5.490D+00  |
| 5.500D-01  | 5.918D+00  |
| 6.000D-01  | 5.947D+00  |
| 6.500D-01  | 5.950D+00  |
| 7.000D-01  | 5.951D+00  |
| 7.500D-01  | 5.952D+00  |

8.13-Cont'd

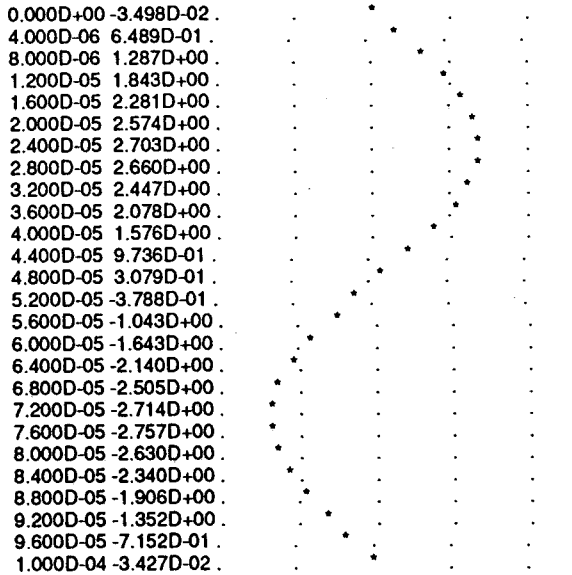
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0**** SMALL SIGNAL BIAS SOLUTION
NODE VOLTAGE
( 1) 6.0000 ( 2) -6.0000 ( 3) 5.2856 ( 4) -0.7006
( 5) -0.0000 ( 6) -0.0053 ( 7) -0.0350

0**** SMALL-SIGNAL CHARACTERISTICS
0 V(7)/VI = 1.103D+01
0 INPUT RESISTANCE AT VI = 2.280D+06
0 OUTPUT RESISTANCE AT V(7) = 3.505D+01

0**** BIPOLAR JUNCTION TRANSISTORS
0 Q1 Q2 Q3
OMODEL NPN NPN PNP
IB 2.91E-06 2.37E-06 -9.91E-06
IC 5.82E-04 4.74E-04 -9.91E-04
VBE 0.701 0.695 -0.714
VBC -5.286 -6.005 5.321
VCE 5.986 6.701 -6.035
BETADC 200.0 200.0 100.0

0**** TRANSIENT ANALYSIS
TIME V(7)
-4.0D+00 -2.0D+00 0.0D+00 2.0D+00 4.0D+00
    
```



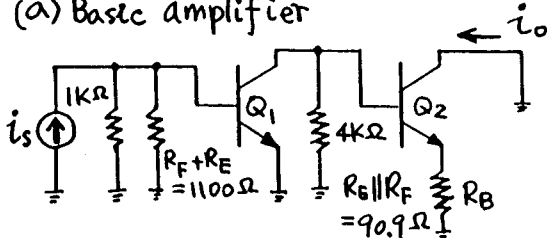
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0**** FOURIER ANALYSIS
FOURIER COMPONENTS OF TRANSIENT RESPONSE V(7)
ODC COMPONENT = -3.085D-02
HARMONIC FREQUENCY FOURIER NORMALIZED PHASE NORM
NO (HZ) COMPONENT COMPONENT (DEG) PHASE (DEG)
1 1.000D+04 2.739D+00 1.000000 -0.004 0.000
2 2.000D+04 4.456D-03 0.001627 -103.114 -103.110
3 3.000D+04 1.392D-03 0.000508 4.977 4.981

TOTAL HARMONIC DISTORTION = 0.170784 PERCENT
    
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8.17

(a) Basic amplifier



Basic amplifier gain

$$\frac{i_o}{i_s} = -(1k \parallel 1.1k \parallel r_{\pi 1}) g_{m1} R_1 \frac{g_{m2}}{1 + g_{m2} R_B}$$

$$R_1 = 4k \parallel r_{\pi 2} (1 + g_{m2} R_B) \parallel r_{o1} = 4k \parallel 5.2 \left(1 + \frac{90.9}{26}\right) k \parallel 100k = 3.30 k\Omega$$

$$\therefore \frac{i_o}{i_s} = -476 \times \frac{3300}{26} \times \frac{1}{26} \times \frac{1}{4.5}$$

$$\therefore a = -516$$

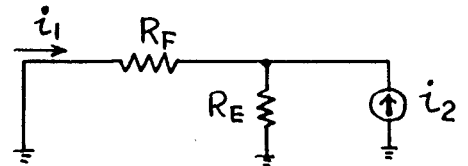
$$r_{ia} = 1k \parallel 1.1k \parallel r_{\pi 1} = 476 \Omega$$

$$r_{oa} = r_{o2} \left(1 + g_{m2} R_B \frac{r_{\pi 2}}{r_{\pi 2} + R_{S2}}\right)$$

$$R_{S2} = r_{o1} \parallel 4k = 3.85 k\Omega$$

$$\therefore r_{oa} = 100 \left(1 + \frac{90.9}{26} \frac{5.2}{5.2 + 3.85}\right) k = 300 k\Omega$$

Feedback network



$$f = g_{12} f = \frac{i_1}{i_2} = -\frac{R_E}{R_E + R_F} = -\frac{100}{1100} = -\frac{1}{11}$$

$$\therefore \text{loop gain} = \frac{516}{11} = 46.9 = af$$

$\therefore$  with feedback applied

$$\text{overall gain} = \frac{i_o}{i_i} = \frac{a}{1 + af} = \frac{-516}{47.9} = -10.8$$

Input resistance

$$R_i = \frac{r_{ia}}{1 + T} = \frac{476}{47.9} = 9.94 \Omega$$

Output resistance

$$R_o = r_{oa} (1 + T) = 300 \times 47.9 = 14.4 M\Omega$$

(b)  $f$  is unchanged

$a$  increases by about 10%

$\therefore$  change in overall gain is

$$\approx \frac{10}{47.9} = 0.2 \%$$

$R_i$  changes by -10% because

$$R_i = \frac{r_{ia}}{1 + af}$$

8.20

(a) Assume high  $\beta$

$$I_{Q8} = \frac{12 - 0.6}{11.4} = 1 \text{ mA}$$

$$\therefore I_{Q7} \approx \frac{1400}{300} \times 1 = 4.7 \text{ mA}$$

$$\therefore I_{Q1} = I_{Q2} = \frac{1}{2} \times 4.7 = 2.3 \text{ mA}$$

$$I_{Q9} = 4.7 \text{ mA}$$

$$\therefore I_{Q3} = I_{Q4} = 2.3 \text{ mA}$$

$$I_{Q10} = I_{Q11} = \frac{1400}{400} \times 1 = 3.5 \text{ mA}$$

$$V_{c3} = V_{c4} = 6 - 1.1 \times 2.3 = 3.5 \text{ V}$$

$$\therefore \text{DC output voltage} = 3.5 - 0.6 = 2.9 \text{ V}$$

Sum currents at collector of  $Q_1$

$$I_{Q1} = \frac{6 - V_{c1}}{2.4} + \frac{2.9 - V_{c1}}{7}$$

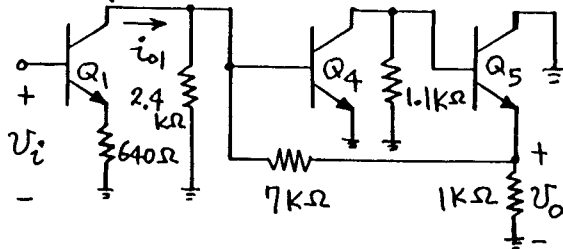
$$\therefore 2.3 = 2.5 - 0.42 V_{c1} + 0.41 - 0.14 V_{c1}$$

$$\therefore V_{c1} = 1 \text{ V}$$

$$\therefore \text{Current in } 7 \text{ k}\Omega \text{ resistor} = \frac{2.9 - 1}{7} = 0.27 \text{ mA}$$

$$\therefore I_{Q5} = I_{Q6} = I_{Q10} + 0.27 = 3.8 \text{ mA}$$

(b) Half - circuit



```

733 AMP
VCC 1 0 6V
VEE 2 0 -6V
RC1 1 5 2.4K
RC2 1 6 2.4K
Q1 5 3 7 NPN
Q2 6 4 8 NPN
RE1 7 16 640
RE2 8 16 640
Q3 9 6 15 NPN
Q4 10 5 15 NPN
RC3 1 9 1.1K
RC4 1 10 1.1K
Q5 1 10 11 NPN
Q6 1 9 12 NPN
RF1 11 5 7K
RF2 12 6 7K
RL 11 12 2K
Q7 16 17 18 NPN
Q8 17 17 19 NPN
Q9 15 17 20 NPN
Q10 11 17 13 NPN
Q11 12 17 14 NPN
RQ7 18 2 300
RQ8 19 2 1.4K
RQ9 20 2 300
RQ10 13 2 400
RQ11 14 2 400
RBIAS 1 17 10K
.MODEL NPN NPN BF=100 IS=1E-13
VI1 3 0 0V
VI2 4 0 0V
.TF V(11,12) VI1
.OPTIONS NOPAGE NOMOD
.WIDTH OUT=80
.OP
.END
    
```

0\*\*\*\* SMALL SIGNAL BIAS SOLUTION

| NODE VOLTAGE |         |      |         |
|--------------|---------|------|---------|
| ( 1)         | 6.0000  | ( 2) | -6.0000 |
| ( 3)         | -0.0000 | ( 4) | -0.0000 |
| ( 5)         | 1.7678  | ( 6) | 1.7678  |
| ( 7)         | -0.6128 | ( 8) | -0.6128 |
| ( 9)         | 3.8225  | (10) | 3.8225  |
| (11)         | 3.1973  | (12) | 3.1973  |
| (13)         | -4.8003 | (14) | -4.8003 |
| (15)         | 1.1550  | (16) | -1.8721 |
| (17)         | -4.1766 | (18) | -4.8076 |
| (19)         | -4.7686 | (20) | -4.8076 |

| 0**** BIPOLAR JUNCTION TRANSISTORS |          |          |          |          |          |          |          |
|------------------------------------|----------|----------|----------|----------|----------|----------|----------|
|                                    | Q1       | Q2       | Q3       | Q4       | Q5       | Q6       | Q7       |
| OMODEL                             | NPN      | NPN      | NPN      | NPN      | NPN      | NPN      | NPN      |
| IB                                 | 1.95E-05 | 1.95E-05 | 1.95E-05 | 1.95E-05 | 3.14E-05 | 3.14E-05 | 3.94E-05 |
| IC                                 | 1.95E-03 | 1.95E-03 | 1.95E-03 | 1.95E-03 | 3.14E-03 | 3.14E-03 | 3.94E-03 |
| VBE                                | 0.613    | 0.613    | 0.613    | 0.613    | 0.625    | 0.625    | 0.631    |
| VBC                                | -1.768   | -1.768   | -2.055   | -2.055   | -2.178   | -2.178   | -2.305   |
| VCE                                | 2.381    | 2.381    | 2.667    | 2.667    | 2.803    | 2.803    | 2.936    |
| BETADC                             | 100.00   | 100.00   | 100.00   | 100.00   | 100.00   | 100.00   | 100.00   |
| GM                                 | 7.53E-02 | 7.53E-02 | 7.53E-02 | 7.53E-02 | 1.22E-01 | 1.22E-01 | 1.52E-01 |
| RPI                                | 1.33E+03 | 1.33E+03 | 1.33E+03 | 1.33E+03 | 8.23E+02 | 8.23E+02 | 6.57E+02 |
| RO                                 | 9.46E+11 | 9.46E+11 | 9.54E+11 | 9.54E+11 | 9.56E+11 | 9.56E+11 | 9.58E+11 |

|        | Q8       | Q9       | Q10      | Q11      |
|--------|----------|----------|----------|----------|
| OMODEL | NPN      | NPN      | NPN      | NPN      |
| IB     | 8.71E-06 | 3.94E-05 | 2.97E-05 | 2.97E-05 |
| IC     | 8.71E-04 | 3.94E-03 | 2.97E-03 | 2.97E-03 |
| VBE    | 0.592    | 0.631    | 0.624    | 0.624    |
| VBC    | 0.000    | -5.332   | -7.374   | -7.374   |
| VCE    | 0.592    | 5.963    | 7.998    | 7.998    |
| BETADC | 100.000  | 100.000  | 100.000  | 100.000  |
| GM     | 3.37E-02 | 1.52E-01 | 1.15E-01 | 1.15E-01 |
| RPI    | 2.97E+03 | 6.57E+02 | 8.71E+02 | 8.71E+02 |
| RO     | 2.05E+11 | 9.82E+11 | 9.87E+11 | 9.87E+11 |

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HAND ANALYSIS STARTS WITH BIAS STRING: Q8 AND RESISTORS OF 10K AND 1.4K AND FINDS IC8=1MA. BUT IT FAILS TO ACCOUNT FOR BASE CURRENTS OF Q7, Q9, Q10, Q11.

USING SPICE, WE SEE THAT THIS 1MA IS DIVIDED AMONG THESE TRANSISTORS: 1MA=IC8+IB7+IB9+IB10+IB11

SO THE SPICE DC BIAS CURRENTS OF TRANSISTORS ARE DIFFERENT FROM THE VALUES OBTAINED BY HAND.

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***** SMALL-SIGNAL CHARACTERISTICS
V(11,12)/VI1 = 9.531D+00
INPUT RESISTANCE AT VI1 = 1.319D+05
OUTPUT RESISTANCE AT V(11,12) = 3.793D+00
    
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$$R_i = r_{\pi 1} + (1 + \beta) R_{E1} = \frac{100 \times 26}{2.3} + 101 \times 640 = 66 \text{ k}\Omega$$

— for the half circuit

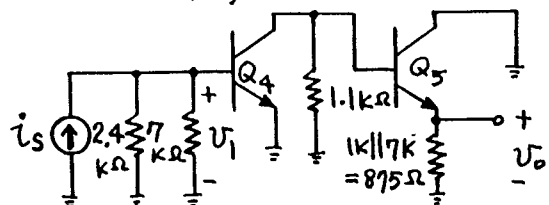
$$\therefore R_i = 132 \text{ k}\Omega \text{ — for the complete circuit}$$

For the first stage

$$\frac{i_{o1}}{v_i} = - \frac{1}{640} \frac{1}{1 + \frac{1}{600} \left( \frac{26}{2.3} + 100 \right)} = -1.52 \text{ mA/V}$$

Consider the shunt-shunt feedback stage.

Basic amplifier is



8.20-Cont'd

$$V_i = i_s(2.4k \parallel 7k \parallel r_{\pi 4})$$

$$= i_s \times 0.69k$$

$$R_{i5} = r_{\pi 5} + (1+\beta) \times 875$$

$$= 684 + 88.4k = 89k \Omega$$

$$\therefore \frac{v_o}{i_s} = -0.69k \times g_{m4} [1.1k \parallel 89k]$$

$$= -0.69k \times \frac{2.3}{26} \times 1087$$

$$\therefore a = -66.3 k\Omega$$

$$f = -\frac{1}{7k}$$

\(\therefore\) For the output stage with feedback applied

$$\frac{v_o}{i_{o1}} = \frac{a}{1+af} = \frac{-281k}{1+9.47} = -6.33 k\Omega$$

\(\therefore\) for the overall circuit

$$\frac{v_o}{v_i} = 1.52 \times 10^{-3} \times 6.33 \times 10^3 = 9.6$$

Loop gain of output stage

$$T = af = 9.47$$

Output impedance of half circuit

$$= 875 \parallel \left[ \frac{1}{g_{m5}} + \frac{1100}{\beta} \right]$$

$$= 875 \parallel [7 + 11] = 18 \Omega$$

\(\therefore\) For the complete circuit

$V_{oA} = 36 \Omega$ , and with feedback applied,  $R_o = \frac{36}{1+T} = 3.6 \Omega$

8.23

$$\frac{V_{DD} - V_{GS2}}{10k} = I_{D2} = \frac{30\mu}{2} 20(V_{GS2} - 0.8)^2$$

$$5 - a = 3(a - 0.8)^2$$

$$= 3a^2 - 4.8a + 1.92$$

$$0 = 3a^2 - 3.8a - 3.08$$

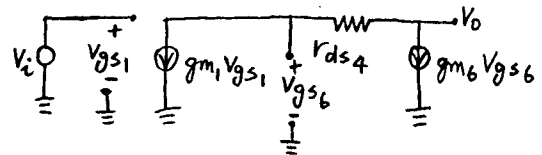
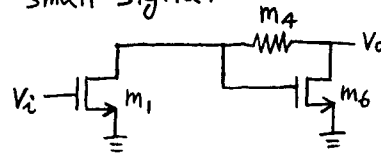
$$a = \frac{+3.8 \pm \sqrt{3.8^2 - 4(3)(-3.08)}}{6}$$

$$V_{GS2} = 1.83V$$

$$I_{D2} = \frac{30\mu}{2} 20(1.83 - 0.8)^2$$

$$= 317 \mu A = I_{D1} = I_{D5} = I_{D6}$$

small signal



$$V_o = V_{gs6} - g_{m6} V_{gs6} r_{ds4}$$

$$g_{m1} = g_{m6}$$

$$-g_{m1} V_{gs1} = g_{m6} V_{gs6}$$

$$-V_{gs1} = V_{gs6} = -V_i$$

$$V_o = -V_i + g_{m6} V_i r_{ds4}$$

$$\frac{V_o}{V_i} = -1 + g_{m6} r_{ds4}$$

$$g_{m6} = \sqrt{2(317\mu)(60\mu)(20)}$$

$$= 872 \mu A/V$$

$$g_{ds4} = \mu_n C_{ox} \frac{W}{L} (V_{GS4} - V_{t4})$$

$$= 150 \mu (V_c - 1.53 - 1.14)$$

$$= 150 \mu (V_c - 2.67)$$

$$V_{t4} = V_{t0} + \gamma (\sqrt{V_{SB4} + 2\phi_f} - \sqrt{2\phi_f})$$

$$= 0.8 + 0.5 (\sqrt{1.53 + 0.6} - \sqrt{0.6})$$

$$= 1.14V$$

$$V_{SB4} = V_{GS6} = V_{t6} + \sqrt{\frac{2I_{D6}}{\mu C_{ox} \frac{W}{L}_6}}$$

$$= 0.8 + \sqrt{\frac{2(317\mu)}{60\mu(20)}}$$

$$= 1.53V$$

$$V_c = 3V$$

$$g_{ds4} = 150\mu(3 - 2.67)$$

$$= 49.5 \mu$$

$$r_{ds4} = 20.2 k$$

$$\frac{V_o}{V_i} = -1 + (872\mu)(20.2k) = 16.6$$

8.23-Cont'd

$$V_c = 4V$$

$$g_{ds4} = 150\mu(4 - 2.67) \\ = 200\mu$$

$$r_{ds4} = 5.01k$$

$$\frac{V_o}{V_i} = -1 + (872\mu)(5.01k) \\ = 3.37$$

$$R_o = \frac{1}{g_{m6}} = \frac{1}{872\mu} = 1.15k\Omega$$

8.24

$$I_{D1} = I_{D2} = \frac{1}{2} I_{D6} = 100\mu A = I_{D3}$$

$$I_{D8} = 200\mu A$$

$$a = \frac{1}{2} g_{m1} (2r_{o2} \parallel r_{o3}) \frac{g_{m8}(21k)}{1 + g_{m8}(21k)}$$

$$= \frac{1}{2} (693\mu)(222k)(0.954)$$

$$= 73.4$$

$$g_{m1} = \sqrt{2(100\mu)(60\mu)40} \\ = 693\mu A/V$$

$$r_{o2} = r_{o3} = \frac{1}{\lambda I_D} = \frac{1}{0.03(100\mu)} \\ = 333k$$

$$g_{m8} = \sqrt{2(200\mu)(60\mu)40} \\ = 980\mu A/V$$

$$f = \frac{1k}{1k + 20k} = \frac{1}{21}$$

$$T = af = 3.5$$

$$A = \frac{a}{1+T} = \frac{73.4}{4.5} = 16.3 = \frac{V_o}{V_i}$$

$$R_o = \frac{r_{out}}{1+T} = \frac{973}{4.5} \\ = 216\Omega$$

$$r_{out} = 21k \parallel \frac{1}{g_{m8}} \\ = 21k \parallel 1.02k \\ = 973\Omega$$

```
VARIABLE GAIN CMOS AMP
VDD 1 0 5V
M1 3 4 0 0 NMOS W=20U L=1U
M2 2 2 1 1 PMOS W=20U L=1U
R1 2 0 10K
M3 3 2 1 1 PMOS W=20U L=1U
M5 5 2 1 1 PMOS W=20U L=1U
M6 5 3 0 0 NMOS W=20U L=1U
M4 5 6 3 0 NMOS W=5U L=2U
VC 6 0 3V
VI 4 0 1.527V
.DC VI 1.47 1.6 0.005
.PLOT DC V(5)
.TF V(5) VI
.NODESET V(2)=3.17V V(3)=1.53V V(5)=1.53V
.MODEL NMOS NMOS KP=60U VTO=0.8 GAMMA=0.5
.MODEL PMOS PMOS KP=30U VTO=0.8 GAMMA=0.5
.OPTIONS NOPAGE NOMOD
.WIDTH OUT=80
.OP
.END
0**** DC TRANSFER CURVES
VI          V(5)
1.0D+00    2.0D+00    3.0D+00    4.0D+00    5.0D+00
```

```
1.470D+00  1.065D+00  *
1.475D+00  1.092D+00  *
1.480D+00  1.119D+00  *
1.485D+00  1.149D+00  *
1.490D+00  1.180D+00  *
1.495D+00  1.213D+00  *
1.500D+00  1.248D+00  *
1.505D+00  1.287D+00  *
1.510D+00  1.329D+00  *
1.515D+00  1.376D+00  *
1.520D+00  1.430D+00  *
1.525D+00  1.495D+00  *
1.530D+00  1.580D+00  *
1.535D+00  1.707D+00  *
1.540D+00  4.292D+00  *
1.545D+00  4.463D+00  *
1.550D+00  4.563D+00  *
1.555D+00  4.632D+00  *
1.560D+00  4.683D+00  *
1.565D+00  4.722D+00  *
1.570D+00  4.753D+00  *
1.575D+00  4.777D+00  *
1.580D+00  4.796D+00  *
1.585D+00  4.811D+00  *
1.590D+00  4.822D+00  *
1.595D+00  4.830D+00  *
1.600D+00  4.836D+00  *
```

```
0**** SMALL SIGNAL BIAS SOLUTION
NODE VOLTAGE
( 1) 5.0000 ( 2) 3.1718 ( 3) 1.5271 ( 4) 1.5270
( 5) 1.5259 ( 6) 3.0000
```

```
0**** MOSFETS
0 M1 M2 M3 M5 M6 M4
OMODEL NMOS PMOS PMOS PMOS NMOS NMOS
ID 3.17E-04 -3.17E-04 -3.17E-04 -3.17E-04 3.17E-04 -5.96E-08
VGS 1.527 -1.828 -1.828 -1.828 1.527 1.473
VDS 1.527 -1.828 -3.473 -3.474 1.526 -0.001
VBS 0.000 0.000 0.000 0.000 0.000 -1.527
VTH 0.800 -0.800 -0.800 -0.800 0.800 1.142
VDSAT 0.727 -1.028 -1.028 -1.028 0.727 0.332
GM 8.72E-04 6.17E-04 6.17E-04 6.17E-04 8.73E-04 1.80E-07
GDS 0.00E+0 0.00E+0 0.00E+0 0.00E+0 0.00E+0 4.97E-05
GMB 2.82E-04 1.99E-04 1.99E-04 1.99E-04 2.82E-04 3.08E-08
```

```
0**** SMALL-SIGNAL CHARACTERISTICS
0 V(5)/VI = 1.649D+01
0 INPUT RESISTANCE AT VI = 1.000D+03
0 OUTPUT RESISTANCE AT V(5) = 1.141D+03
```

8.24-Cont'd

VARIABLE GAIN CMOS AMP

```
VDD 1 0 5V
M1 3 4 0 0 NMOS W=20U L=1U
M2 2 2 1 1 PMOS W=20U L=1U
R1 2 0 10K
M3 3 2 1 1 PMOS W=20U L=1U
M5 5 2 1 1 PMOS W=20U L=1U
M6 5 3 0 0 NMOS W=20U L=1U
M4 5 6 3 0 NMOS W=5U L=2U
VC 6 0 4V
VI 4 0 1.527V
.DC VI 1.0 1.8 0.05
.PLOT DC V(5)
.TF V(5) VI
.NODESET V(2)=3.17V V(3)=1.53V V(5)=1.53V
.MODEL NMOS NMOS KP=60U VTO=-0.8 GAMMA=0.5
.MODEL PMOS PMOS KP=30U VTO=-0.8 GAMMA=0.5
.OPTIONS NOPAGE NOMOD
.WIDTH OUT=80
.OP
.END
0**** DC TRANSFER CURVES
VI V(5)
0.0D+00 2.0D+00 4.0D+00 6.0D+00 8.0D+00
-----
1.000D+00 7.255D-01 . * . . . .
1.050D+00 7.496D-01 . * . . . .
1.100D+00 7.806D-01 . * . . . .
1.150D+00 8.197D-01 . * . . . .
1.200D+00 8.687D-01 . * . . . .
1.250D+00 9.299D-01 . * . . . .
1.300D+00 1.003D+00 . * . . . .
1.350D+00 1.089D+00 . * . . . .
1.400D+00 1.188D+00 . * . . . .
1.450D+00 1.303D+00 . * . . . .
1.500D+00 1.441D+00 . * . . . .
1.550D+00 1.607D+00 . * . . . .
1.600D+00 1.803D+00 . * . . . .
1.650D+00 2.038D+00 . * . . . .
1.700D+00 2.339D+00 . * . . . .
1.750D+00 4.054D+00 . * . . . .
1.800D+00 4.132D+00 . * . . . .
-----
```

```
0**** SMALL SIGNAL BIAS SOLUTION
NODE VOLTAGE
( 1) 5.0000 ( 2) 3.1718 ( 3) 1.5271 ( 4) 1.5270
( 5) 1.5268 ( 6) 4.0000
```

```
0**** MOSFETS
0 M1 M2 M3 M5 M6 M4
OMODEL NMOS PMOS PMOS PMOS NMOS NMOS NMOS
ID 3.17E-04 -3.17E-04 -3.17E-04 -3.17E-04 3.17E-04 -5.96E-08
VGS 1.527 -1.828 -1.828 -1.828 1.527 2.473
VDS 1.527 -1.828 -3.473 -3.473 1.527 0.000
VBS 0.000 0.000 0.000 0.000 0.000 -1.527
VTH 0.800 -0.800 -0.800 -0.800 0.800 1.142
VDSAT 0.727 -1.028 -1.028 -1.028 0.727 1.331
GM 8.72E-04 6.17E-04 6.17E-04 6.17E-04 8.73E-04 4.48E-08
GDS 0.00E+0 0.00E+0 0.00E+0 0.00E+0 0.00E+0 2.00E-04
GMB 2.82E-04 1.99E-04 1.99E-04 1.99E-04 2.82E-04 7.68E-09
```

```
0**** SMALL-SIGNAL CHARACTERISTICS
0 V(5)/VI = 3.369D+00
0 INPUT RESISTANCE AT VI = 1.000D+20
0 OUTPUT RESISTANCE AT V(5) = 1.146D+03
```

CMOS FEEDBACK AMP

```
VDD 1 0 5V
VSS 9 0 -5V
M4 2 2 1 1 PMOS W=20U L=1U
I1 2 3 100UA
M5 3 3 9 9 NMOS W=20U L=1U
M6 6 3 9 9 NMOS W=40U L=1U
M1 1 4 6 9 NMOS W=40U L=1U
M2 5 7 6 9 NMOS W=40U L=1U
M3 5 2 1 1 PMOS W=20U L=1U
M8 1 5 8 9 NMOS W=40U L=1U
M7 8 3 9 9 NMOS W=40U L=1U
RF 8 7 20K
RE 7 0 1K
VI 4 0 0V
.TF V(8) VI
.MODEL NMOS NMOS KP=60U VTO=-0.8 LAMBDA=0.03
.MODEL PMOS PMOS KP=30U VTO=-0.8 LAMBDA=0.03
.OPTIONS NOPAGE NOMOD
.WIDTH OUT=80
.OP
.END
0**** SMALL SIGNAL BIAS SOLUTION
NODE VOLTAGE
( 1) 5.0000 ( 2) 3.6341 ( 3) -3.7989 ( 4) -0.0000
( 5) 1.4134 ( 6) -1.0776 ( 7) 0.0096 ( 8) 0.2016
( 9) -5.0000

0**** MOSFETS
0 M4 M5 M6 M1 M2 M3 M8
OMODEL PMOS NMOS NMOS NMOS NMOS PMOS NMOS
ID -1.00E-04 1.00E-04 2.16E-04 1.09E-04 1.06E-04 -1.06E-04 2.33E-04
VGS -1.366 1.201 1.201 1.078 1.087 -1.366 1.212
VDS -1.366 1.201 3.922 6.078 2.491 -3.587 4.798
VBS 0.000 0.000 0.000 -3.922 -3.922 0.000 5.202
VTH -0.800 0.800 0.800 0.800 0.800 -0.800 0.800
VDSAT -0.566 0.401 0.401 0.278 0.287 -0.566 0.412
GM 3.54E-04 4.99E-04 1.08E-03 7.88E-04 7.41E-04 3.76E-04 1.13E-03
GDS 2.88E-06 2.90E-06 5.79E-06 2.77E-06 2.97E-06 2.88E-06 6.10E-06
```

```
0 M7
OMODEL NMOS
ID 2.23E-04
VGS 1.201
VDS 5.202
VBS 0.000
VTH 0.800
VDSAT 0.401
GM 1.11E-03
GDS 5.79E-06
```

```
0**** SMALL-SIGNAL CHARACTERISTICS
0 V(8)/VI = 1.662D+01
0 INPUT RESISTANCE AT VI = 1.000D+20
0 OUTPUT RESISTANCE AT V(8) = 1.707D+02
```