ELG4135: DGD on Op Amp Circuit

Q1 (10.22): Fourth Edition

Consider the 741 input stage as modeled in Fig. 10.6, with two additional *npn* diode-connected transistors, Q_{1a} and Q_{2a}, connected between the present *npn* and *pnp* devices, one per side. Convince yourself that the additional devices will each be biased at the same current as Q_1 to Q_4—that is, 9.5 µA. What does R_{id} become? What does G_{m1} become? What is the value of R_{o4} now? What is the output resistance of the first stage, R_{o1}? What is the new open-circuit voltage gain, $G_{m1} R_{o1}$? Compare these values to the original ones.

Solution:

Series connection of devices assures the same bias currents

$$R_{id} = (\beta + 1)(6r_e)$$

$$r_e = \frac{V_T}{9.5\mu A} = 2.63K\Omega$$

$$R_{id} = 3.17M\Omega$$

$$i_e = \frac{v_{id}}{6r_e}; i_o = 2i_e$$

$$\Rightarrow G_{m1} = \frac{i_o}{v_{id}} = \frac{2}{6r_e} = \frac{1}{3r_e} = 127\mu A/V$$

$$R_{o4} = r_o(1 + g_m(R_E \| r_x))$$

$$g_m \cong 1/r_e$$

$$R_E = 2r_e = 5.26K\Omega$$

$$r_x = (\beta_P + 1)r_e = 134K\Omega$$

Thus $R_{o4} = 15.4M\Omega$

$R_{o6} = 18.2M\Omega$ (from text)

$$R_{o1} = R_{o4} \| R_{o6} = 8.34M\Omega$$

$$G_{M1}R_{o1} = 127 \times 8.34 = 1059V/V$$

See gain decreases due to negative feedback.

Q2 (D10.23)

What relatively simple change can be made to the mirror load of stage 1 to increase its output resistance, say by a factor of two?

Solution:

$R_o = r_{o6}(1 + g_{m6}(R_2 \| r_{x6}))$

-need to double the second factor

Since $r_{x6} >> R_2$

$R_{o6} \cong r_{o6}(1 + g_{m6} R_2)$

Thus $1 + g_{m6} R_2' = 2(1 + g_{m6} R_2)$

$g_{m6} = \dfrac{1}{2.63K\Omega}, R_2 = 1K$

$\Rightarrow R_2' = 4.63K\Omega$

Q3 (10.26)

Through a processing imperfection, the β of Q_4 in Fig. 10.1 is reduced to 25, while the β of Q_3 remains at its regular value of 50. Find the input offset voltage that this mismatch introduces. (*Hint*: Follow the general procedure outlined in Example 10.1.)

Solution:

Current in the collector of φ_3 remains unchanged at 9.5μA

Thus $I_{E3} = I_{E4} = \dfrac{51}{50} 9.5\mu A = 9.69\mu A$

$I_{C4} = \dfrac{25}{26} I_{E4} = 9.317\mu A$

$\Rightarrow \Delta I = 9.5 - 9.317 = 0.183\mu A$

$V_{os} = \dfrac{\Delta I}{G_{m1}} = 2r_e \Delta I = 2(2.63K\Omega)(0.183\mu A) = 0.96mV$

Q4 (10.31)

Consider a variation on the design of the 741 second stage in which $R_8 = 50\ \Omega$. What R_{i2} and G_{m2} correspond?

Solution:

$$R_{i2} = (\beta + 1)\left[r_{e16} + R_{i17} \| R_9\right]$$
$$r_{e16} = 1.54K\Omega$$
$$r_{e17} = 45.5\Omega$$
$$R_{i17} = 201(45.5 + 50) = 19.2K\Omega$$
$$\Rightarrow R_{i2} = 201(1.54 + 19.2 \| 50)K\Omega = 3.1M\Omega$$
$$v_{b17} = \frac{R_{i17} \| R_9}{r_{e16} + R_{i17} \| R_9} v_{i2} = 0.9v_{i2}$$
$$i_{C17} = \frac{\alpha}{r_{e17} + R_8} 0.9v_{i2}$$
$$\Rightarrow G_{m2} = \frac{\alpha(0.9)}{45.5 + 50} = 9.38mA/V$$

Q5 (10.32)

In the analysis of the 741 second stage, note that R_{o2} is affected most strongly by the low value of R_{o13B}. Consider the effect of placing appropriate resistors in the emitters of Q_{12}, Q_{13A}, and Q_{13B} on this value. What resistor in the emitter of Q_{13B} would be required to make R_{o13B} equal to R_{o17} and thus R_{o2} half as great? What resistors in each of the other emitters would be required?

Solution:

$$R_{O17} = 787K\Omega$$
$$i_{C13B} = 550\mu A$$
$$g_{m13B} = 22mA/V; r_{x13B} = (\beta + 1)/g_m = 2.32K\Omega$$
$$r_o = \frac{50}{550\mu A} = 90.9K\Omega$$
$$R_{o13B} = r_o(1 + g_m(R_E \| r_x)) = 90.9\left[1 + 22(R_E \| 2.32)\right] = 787$$
$$\Rightarrow R_E \| 2.32) = 0.348$$

and $\frac{1}{R_E} = 2.44$ or $R_E = 0.410K\Omega = 410\Omega$

Current $\frac{R_{E12}}{R_E} = \frac{550\mu A}{730\mu A} \Rightarrow R_{E12} = 309\Omega$

$$\frac{R_{E13A}}{R_E} = \frac{550}{180} \Rightarrow R_{E13A} = 1.25K\Omega$$