6.1

Solution: For $V_{G1}= V_{G2}= 0$ V, $I_{D1}= I_{D2} = 0.4/2 = 0.2$ mA

To obtain

VD1 = VD2 = 0.1 V

V_{DD}-$ID_{1,2}$RD = 0.1

$0.9-0.2R_D = 0.1 \rightarrow R_D = 4$ KΩ

For Q1 and Q2: $I_{D1,2} = \frac{1}{2}\mu_a C_{ox}(\frac{W}{L})_{1,2}V_{OV}^2 \rightarrow 0.2 = \frac{1}{2} \times 0.4(\frac{W}{L})_{1,2} \times 0.15^2 \rightarrow \left(\frac{W}{L}\right)_{1,2} = 44.4$

For Q3:

$0.4 = \frac{1}{2} \times 0.4 \times (\frac{W}{L})_3 \times 0.15^2 \rightarrow (\frac{W}{L})_3 = 88.8$

Since Q3 and Q4 form a current mirror with $I_{D3}=4I_{D4}$:

$\left(\frac{W}{L}\right)_4 = \frac{1}{4}\left(\frac{W}{L}\right)_3 = 22.2$

$V_{GS4} = V_{GS3} = V_{tn} + V_{OV} = 0.4 + 0.15 = 0.55$ V

$R = \frac{0.9-(-0.9)-0.55}{0.1} = 12.5$kΩ.

The lower limit on V_{CM} is determined by the need to keep Q_3 operating in saturation. For his to happen, the minimum value of V_{DS3} is $V_{OV}= 0.15$ V. Thus

$V_{ICMmin} = -V_{SS} + V_{OV3} + V_{GS1,2} = -0.9 + 0.15 + 0.4 + 0.15 = -0.2$ v

The upper limit on V_{CM} is determined by the need to keep Q_1 and Q_2 in saturation, thus

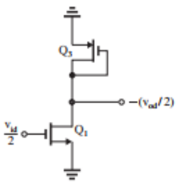
$V_{ICMmax} = V_t + V_{DD} - \frac{I}{2}R_D = V_{D1,2} + V_{tn} = 0.1 + 0.4 = 0.5$v

Thus,

$-0.2\text{v} \leq V_{ICM} \leq +0.5\ v$

6.2

Solution:



(a) The figure shows the differential half-circuit. Recalling that the incremental (small-signal) resistance of a diode-connected transistor is given by ($\frac{1}{g_m}||r_o$), the equivalent load resistance of Q_1 will be: $R_D = \frac{1}{g_{m3}}||r_{o3}$ and the differential gain of the amplifier will be $A_d = \frac{Vod}{Vid} = g_{m1}$ $[\frac{1}{gm3}||ro3||ro1]$

Since both sides of the amplifier are matched, this expression can be written in a more general way as

$Ad = g_{m1,2}[\frac{1}{gm3,4}||r_{o3,4}||r_{o1,2}]$

(b) Neglecting $r_{o1,2}$, $r_{o3,4}$ (much larger that 1/gm3,4),

$$Ad \cong \frac{g_{m1,2}}{g_{m3,4}} = \frac{\sqrt{2\mu_n C_{ox}(W/L)_{1,2}(I/2)}}{\sqrt{2\mu_p C_{ox}(W/L)_{3,4}(I/2)}} = \sqrt{\frac{\mu_n (W/L)_{1,2}}{\mu_p (W/L)_{3,4}}}$$

(c)

$\mu_n = 4\mu_p$ and all channel lengths are equal, $A_d = 2\sqrt{\frac{W_{1,2}}{W_{3,4}}}$; $A_d = 10 \rightarrow 10 = 2\sqrt{\frac{W_{1,2}}{W_{3,4}}} \rightarrow \frac{W_{1,2}}{W_{3,4}} = 25$

6.3

Solution:

The value of R is found as follows:

$$R = \frac{V_{G6} - V_{G7}}{I_{REF}} = \frac{0.8 - (-0.8)}{0.2} = 8\ k\Omega$$

Since $I = I_{REF}$, Q_3 and Q_6 are matched and are operating at $|V_{OV}| = 1.5 - 0.8 - 0.5 = 0.2\ V$

Thus,

$0.2 = \frac{1}{2} \times 0.1 \times (\frac{W}{L})_{6,3} \times 0.2^2 \rightarrow (\frac{W}{L})_3 = (\frac{W}{L})_6 = 100$

Each of Q_4 and Q_5 is conducting a ds current of (I/2) while Q_7 is conducting a dc current I_{REF} = I. Thus, Q_4 and Q_5 are matched and their W/L ratios are equal while Q_7 has twice the (W/L) ration of Q_4 and Q_5. Thus,

$\frac{I}{2} = \frac{1}{2}\mu_n C_{ox}(\frac{W}{L})_{4,5} V_{OV4,5}^2$; where: $V_{OV4,5} = -0.8 - (-1.5) - 0.5 = 0.2\ V$

Thus,

$0.1 = \frac{1}{2} \times 0.25 \times \left(\frac{W}{L}\right)_{4,5} \times 0.04 \rightarrow 0.1 = \frac{1}{2} \times 0.25 \times \left(\frac{W}{L}\right)_{4,5} \times 0.04 \rightarrow \left(\frac{W}{L}\right)_4 = \left(\frac{W}{L}\right)_5 = 20$

And $\left(\frac{W}{L}\right)_7 = 40$

$$r_{o4} = r_{o5} = \frac{|V_{AP}|}{\frac{I}{2}} = \frac{10}{0.1} = 100\ k\Omega$$

$$r_{o1} = r_{o2} = \frac{|V_{AP}|}{\frac{I}{2}} = \frac{10}{0.1} = 100\ k\Omega$$

$$A_d = g_{m1,2}(r_{o1,2}||r_{o4,5}) \rightarrow 50 = g_{m1,2}(100||100) \rightarrow g_{m1,2} = 1\ mA/V$$

But

$$g_{m1,2} = \frac{2(\frac{I}{2})}{|V_{OV1,2}|} \rightarrow 1 = \frac{0.2}{|V_{OV1,2}|} \rightarrow |V_{OV1,2}| = 0.2\ V$$

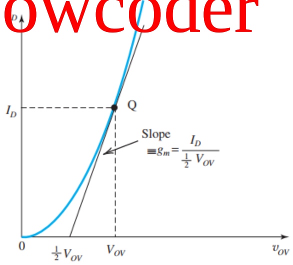


Figure 7.14 The slope of the tangent at the bias point Q intersects the v_{OV} axis at $\frac{1}{2}V_{OV}$. Thus, $g_m = I_D/(\frac{1}{2}V_{OV})$.

The $\frac{W}{L}$ ratio for Q_1 and Q_2 can now be determined from:

$0.1 = \frac{1}{2} \times 0.1 \times \left(\frac{W}{L}\right)_{1,2} \times 0.2^2 \rightarrow \left(\frac{W}{L}\right)_1 = \left(\frac{W}{L}\right)_2 = 50$

A summary of the results is provided in the table below:

Transistor	W/L	I_D(mA)	$\lvert V_{GS}\rvert$(V)
Q_1	50	0.1	0.7
Q_2	50	0.1	0.7
Q_3	100	0.2	0.7
Q_4	20	0.1	0.7
Q_5	20	0.1	0.7
Q_6	100	0.2	0.7
Q_7	40	0.2	0.7