The publisher's errata for textbook pages 632 and 633 are themselves errata. The example as originally printed in the textbook is essentially correct. However, some of the example is awkwardly presented with various units omitted. The presentation below shows more of the algebra and shows the units more consistently.

Example 9.4b

More complete algebra and units more consistently represented.

In this example we consider the design of the current source that supplies the bias current of a MOS differential amplifier. Let it be required to achieve a CMRR of 100 dB and assume that the only source of mismatch between Q_1 and Q_2 is a 2% mismatch in their W/L ratios. Let $I = 200\ \mu\text{A}$ and assume that all transistors are to be operated at $V_{OV} = 0.2\text{ V}$. For the 0.18 µm CMOS fabrication process available, $V_A' = 5\ V/\mu\text{m}$. If a simple current source is utilized for I, what channel length is required? If a cascode current source is utilized, what channel length is needed for the two transistors in cascode?

Solution

A mismatch in W/L results in a g_m mismatch that can be found from the expression of g_m. The expression on the next line can be derived from Eq (7.41) on Page 388 and Eq (5.11) on Page 254.

$$g_m = \sqrt{2(\mu_n C_{ox})\left(\frac{W}{L}\right) I_D} \qquad 9.89b$$

Define $\left(\frac{W}{L}\right)_{max} = 1.02\left(\frac{W}{L}\right)$, a 2% increase. Similarly define $g_{m_{max}} = g_m + \Delta g_m$

$$g_{m_{max}} = \sqrt{2(\mu_n C_{ox})\left(\frac{W}{L}\right)_{max} I_D} = \sqrt{2(\mu_n C_{ox})(1.02)\left(\frac{W}{L}\right)_{max} I_D} = \sqrt{1.02}\,g_m = 1.01 g_m$$

It is thus shown that an error of 2% in W/L will result in an error in g_m of 1%. That is, the 2% mismatch in the W/L ratios of Q_1 and Q_2 will result in a 1% mismatch in their g_m values. The resulting CMRR can be found from Eq. (9.88), repeated here:

$$CMRR = (2 g_m R_{SS}) / \left(\frac{\Delta g_m}{g_m}\right) \qquad 9.90b$$

Now, a 100 dB CMRR corresponds to a ratio of 10^5; thus,

$$10^5 = (2 g_m R_{SS})/0.01$$

The value of g_m can be found from

$$g_m = \frac{2I_D}{V_{OV}} = \frac{2(I/2)}{V_{OV}} = \frac{2(200\ \mu\text{A})/2}{(0.2\text{ V})} = (1000\ \mu\text{A/V}) = 1\text{ mA/V}$$

Solving Eq. (9.90b) for R_{SS} gives

$$R_{SS} = CMRR\left(\frac{\Delta g_m}{g_m}\right)/(2 g_m) = [10^5(0.01)]/[2(1\text{ mA/V})] = 1000/(2\text{ mA/V}) = 500\text{ k}\Omega$$

Now if the current source is implemented with a single transistor, its r_o must be

$$r_o = R_{SS} = 500\text{ k}\Omega$$

Thus,

$$\frac{V_A}{I} = 500 \text{ k}\Omega$$

Substituting $I = 200\ \mu\text{A} = 0.2\ \text{mA}$, we find the required value of V_A as

$$V_A = Ir_o = (0.200\ \text{mA})(500\ \text{k}\Omega) = 100\ \text{V}$$

Since $V_A = V_A'L = (5\ \text{V}/\mu\text{m})L$, the required value of L will be

$$L = V_A/V_A' = (100\ \text{V})/(5\ \text{V}/\mu\text{m}) = 20\ \mu\text{m}$$

which is very large!

Using a cascode current source, we have

$$R_{SS} = (g_m r_o)r_o \quad \text{or, solving for } r_o, \quad r_o = \sqrt{R_{SS}/g_m}$$

where

$$g_m = \frac{2I}{V_{OV}} = \frac{2(200\ \mu\text{A})}{(0.2\ \text{V})} = 2\ \text{mA/V}$$

Thus,

$$r_o = \sqrt{\frac{500\ \text{k}\Omega}{2\ \text{mA/V}}} = \sqrt{250 \times 10^6\ \Omega^2} = 15.81\ \text{k}\Omega$$

and the required V_A now becomes

$$r_o = V_A/I \quad \text{or, solving for } V_A, \quad V_A = Ir_o$$

$$V_A = (0.200\ \text{mA})(15.81\ \text{k}\Omega) = 3.16\ \text{V}$$

which implies a channel length for each of the two transistors in the cascode of

$$L = \frac{V_A}{V_A'} = \frac{3.16\ \text{V}}{5\ \text{V}/\mu\text{m}} = 0.63\ \mu\text{m}$$

a considerable reduction from the case of a simple current source, and indeed a practical value.