requirements dictate that M_2 and M_3 not enter the triode region so long as both carry current.

Suppose the gate voltages of M_2 and M_3 in Fig. 6.42 are held at the common-mode level of the differential LO waveforms, $V_{CM,LO}$ [Fig. 6.45(a)]. If M_1 is at the edge of saturation, then $V_N \geq V_{GS1} - V_{TH1}$:

$$V_{CM,LO} - V_{GS2,3} \geq V_{GS1} - V_{TH1}. \tag{6.61}$$

Now consider the time instant at which the gate voltages of M_2 and M_3 reach $V_{CM,LO} + V_0$ and $V_{CM,LO} - V_0$, respectively, where $V_0 = \sqrt{2}(V_{GS2,3} - V_{TH2})/2$, a value high enough to turn off M_3 [Fig. 6.45(b)]. For M_2 to remain in saturation up to this point, its drain voltage must not fall below $V_{CM,LO} + \sqrt{2}(V_{GS2,3} - V_{TH2})/2 - V_{TH2}$:

$$V_{X,min} = V_{CM,LO} + \frac{\sqrt{2}}{2}(V_{GS2,3} - V_{TH2}) - V_{TH2}, \tag{6.62}$$

which, from Eq. (6.61), reduces to

$$V_{X,min} = V_{GS1} - V_{TH1} + \left(1 + \frac{\sqrt{2}}{2}\right)(V_{GS2,3} - V_{TH2}). \tag{6.63}$$

Thus, $V_{X,min}$ must accommodate the overdrive of M_1 and about 1.7 times the "equilibrium" overdrive of each of the switching transistors. The maximum allowable dc voltage across each load resistor is equal to

$$V_{R,max} = V_{DD} - \left[V_{GS1} - V_{TH1} + \left(1 + \frac{\sqrt{2}}{2}\right)(V_{GS2,3} - V_{TH2})\right]. \tag{6.64}$$

Since each resistor carries half of I_{D1},

$$R_{D,max} = \frac{2V_{R,max}}{I_{D1}}. \tag{6.65}$$

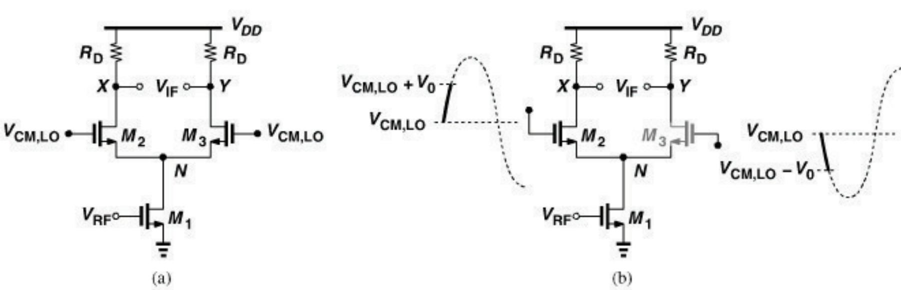

Figure 6.45 *(a) Active mixer with LO at CM level, (b) required swing to turn one device off.*

From (6.64) and (6.65), we obtain the maximum voltage conversion gain as

$$A_{V,max} = \frac{2}{\pi} g_{m1} R_{D,max} \tag{6.66}$$

$$= \frac{8}{\pi} \frac{V_{R,max}}{V_{GS1} - V_{TH1}}. \tag{6.67}$$

We therefore conclude that low supply voltages severely limit the gain of active mixers.

Example 6.12

A single-balanced active mixer requires an overdrive voltage of 300 mV for the input V/I converter transistor. If each switching transistor has an equilibrium overdrive of 150 mV and the peak LO swing is 300 mV, how much conversion gain can be obtained with a 1-V supply?

Solution:

From Eq. (6.64), $V_{R,max} = 444$ mV and hence

$$A_{V,max} = 3.77 \tag{6.68}$$

$$\approx 11.5\,\text{dB}. \tag{6.69}$$

Owing to the relatively low conversion gain, the noise contributed by the load resistors and following stages may become significant.

How much room for improvement do we have? Given by IP_3 requirements, the overdrive of the input transistor has little flexibility unless the gain of the preceding LNA can be reduced. This is possible if the mixer noise figure can also be lowered, which, as explained in Section 6.3.2, trades with the power dissipation and input capacitance of the mixer. The equilibrium overdrive of the switching transistors can be reduced by making the two transistors wider (while raising the capacitance seen at the LO port).

The conversion gain may also fall if the LO swing is lowered. As illustrated in Fig. 6.46, while M_2 and M_3 are near equilibrium, the RF current produced by M_1 is

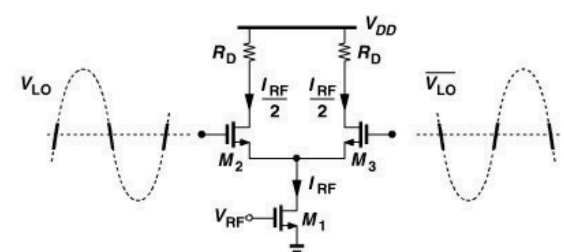

Figure 6.46 *RF current as a CM component near LO zero crossings.*