Chapter 7

Single-Stage Operational Amplifiers

In this chapter, we will complete the design of three single-stage opamps which have rail-to-rail input common mode range but without the rail-to-rail output range. Simulation results of the opamps are provided and their performances are discussed.

7.1 Opamp 1: A Simple Folded-Cascode Opamp

Opamp 1 is the simplest opamp designed here, and its performance will be compared with the performance of other opamps. The circuit is shown in Figure 7.1. The opamp output node is the output of the cascode stage and thus the swing in each direction is limited as can be seen in the simulation result shown in Figure 7.2(a). Opamp 1 was connected in a unity gain buffer configuration and the input voltage, $V_{in}$ connected to $V_{in1}$, was swept from 0 to 3V for $V_{DD} = 3V$ and $V_{SS} = 0V$. The linear output range is from 0.5V to 2.3V. Figure 7.2(b) shows the input stage transconductance of the opamp 1. There are two observations to be made from this plot; first, for input voltages which result in nonlinear transfer characteristics, the virtual short between $V_{in1}$ (positive input) and $V_{in2}$ (negative input) no longer exists and hence the common mode current in $M_1$ and $M_{1a}$, or in $M_2$ and $M_{2a}$, are not the same anymore. In the plot, $g_{mT+}$ and $g_{mT-}$ are the input stage transconductance of the $V_{in1}$ side and the $V_{in2}$ side, respectively. For $V_{in}$ near zero, $V_o > V_{in}$ or equivalently, $V_{in2} > V_{in1}$, $M_1$ receives more current.
from \( M_p \) than \( M_{1a} \). Because of this and the fact that the p-channel pair is operating at this point, the transconductance seen from the \( V_{in1} - \text{side} \) is larger. For \( V_{in} \) near \( V_{DD} \), \( V_{in1} > V_{in2} \), and hence \( M_2 \) is conducting more current than \( M_{2a} \) and this again results in larger transconductance from the \( V_{in1} - \text{side} \). The second point to be made is that because there is no circuit to maintain \( g_{mT} \) constant we see a significant change in \( g_{mT} \) as \( V_{in} \) is varied from rail to rail. Figure 7.3 shows the open loop small signal frequency response of the opamp 1 with different common mode input voltages and we can clearly see the dependence of both the unity gain frequency and the low frequency differential gain of the opamp on \( V_{CM} \). More detailed simulation results are provided in Table 7.1 which shows the low frequency gain, \( A_{DC} \), the unity gain frequency, \( f_u \), and the phase margin, \( \phi_M \) for \( V_{CM} \) swept from 0.5V to 2.5V. For \( V_{CM} < 0.7V \) and \( V_{CM} > 2.2V \), \( A_{DC} \) drops drastically due to the cascode stage transistors being pushed into the triode region. In the region \( 0.7V \leq V_{CM} \leq 2.2V \), \( f_u \) changes between \( 1.59MHz \) and \( 2.7MHz \) for \( 5pF \) load and between \( 0.275MHz \) and \( 0.474MHz \) for \( 30pF \) load. Next, we will investigate other opamp performance criteria.

**CMRR:** Figure 7.4 and Table 7.2 show the common mode rejection ratio, \( CMRR \), of opamp 1. Simulations were performed with ac signals, \( v_{em1} \), at the positive input terminal and, \( v_{em2} \), connected between the negative input and the output terminals. The common mode dc voltage \( V_{CM} \) was placed.