

From (2) it can be observed that for a constant g_m the W over L ratios of the P -channel and the N -channel input pair have to obey the following relation:

$$\frac{\mu_N}{\mu_P} = \frac{\left(\frac{W}{L}\right)_P}{\left(\frac{W}{L}\right)_N} \quad (3)$$

If the ratio μ_N over μ_P differs from its nominal value because of process variations, the g_m will have an additional variation. For example if μ_N over μ_P changes about 15%, the additional variation will be approximately 7.5%.

It can be concluded that the g_m is approximately constant over the common-mode input range except for two take-over ranges, i.e., common-mode input voltages between $V_{SS} + 1$ V and $V_{SS} + 1.3$ V and common-mode input voltages between $V_{DD} - 1.3$ V and $V_{DD} - 1$ V, where the g_m varies only 15%, as is shown in Fig. 3. In the take-over ranges the current through one of the current switches changes from 0 to I_{ref} , or vice versa.

The offset of the rail-to-rail input stage changes over the common-mode input range because the N -channel input pair and the P -channel input pair have, in general, a different offset. This change in offset limits the CMRR of the input stage, since it is defined as the change of offset relative to the change in common-mode input voltage. To maximize the CMRR the change of offset should be spread out over a large part of the common-mode input range. In this circuit, the change of offset is spread out over the two take-over ranges of the current-switches. This allows a relatively large CMRR for these types of input stages.

At supply voltages below 2.9 V both current switches might conduct at the same common-mode input voltage. To prevent the positive feedback loop, $M_5 - M_{10}$, from becoming active, $M_{29} - M_{31}$ are added to the circuit. Each side of the differential pair, $M_{29} - M_{30}$, is connected via a voltage source, V_{b5} or V_{b6} , to either one of the supply-rails. The differential pair, $M_{29} - M_{30}$ measures the supply voltage. If the supply voltage is larger than 2.9 V the gate-voltage of the current switch, M_8 , is biased by M_{31} . At supply voltages lower than 2.9 V, the differential pair gradually turns off M_8 . Thus, the gate-voltage of the N -channel current switch moves towards the positive supply rail. This means that the current switch is always off at supply voltages below 2.9 V. In this way the positive feedback loop can never become active.

The current mirror, $M_{11} - M_{14}$, together with the folded cascodes, $M_{15} - M_{16}$, form a summing circuit. This summing circuit adds the signals coming from the complementary rail-to-rail input stage.

III. RAIL-TO-RAIL CLASS-AB OUTPUT STAGE

To make efficient use of the supply voltage and supply-current, an opamp requires class-AB biased output transistors connected in a common-source configuration. Moreover, the class-AB control should be compact to efficiently use die area.

The compact class-AB output stage is shown in Fig. 5 [7]. It consists of two common-source connected output transistors, M_{25} and M_{26} , which are directly driven by two in-phase signal currents, I_{in1} and I_{in2} . The floating class-AB control is formed by M_{19} and M_{20} . The stacked diode-connected transistors,

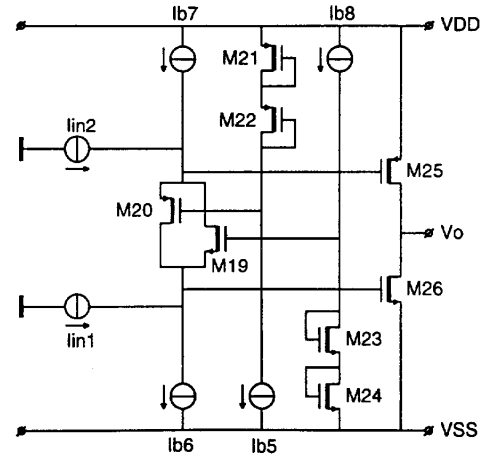


Fig. 5. Rail-to-rail output stage with floating class-AB control.

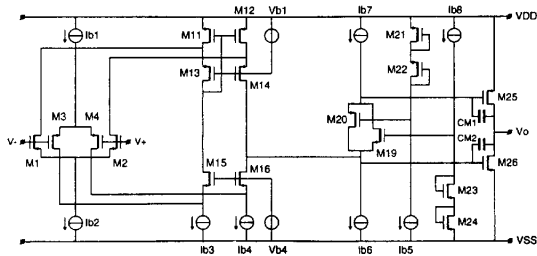


Fig. 6. Two-stage cascaded operational amplifier.

$M_{23} - M_{24}$ and $M_{21} - M_{22}$, bias the gates of the class-AB transistors M_{19} and M_{20} , respectively. As was shown in the previous section the minimum required supply voltage is limited by the demand for a fully rail-to-rail common-mode input range. Therefore, two stacked gate-source voltages are allowed in the class-AB output stage.

The floating class-AB control transistors, the stacked diode-connected transistors and the output transistors set up two translinear loops M_{20} , M_{21} , M_{22} , M_{25} and M_{19} , M_{23} , M_{24} , M_{26} , which determine the quiescent current in the output transistors. The class-AB action is performed by keeping the voltage between the gates of the output transistors constant. Suppose the in-phase signal current sources, I_{in1} and I_{in2} , are pushed into the class-AB output stage. As a result, the current of the P -channel class-AB transistor, M_{20} , increases while the current in the N -channel class-AB transistors, M_{19} , decreases by the same amount. Consequently, the gate-voltages of both the output transistors move up. Thus the output stage pulls a current from the output node. This action continues until the current through the P -channel class-AB transistor is equal to I_{b7} . Now, the current of the P -channel output transistor is kept at a minimum value, which can be set by W over L ratios of the class-AB control transistors. Note that the current through the N -channel output transistor is still able to increase. A similar discussion can be held when input signals are pulled from the class-AB output stage.