Today we’re going to get some experience studying a relatively large analog system (large compared to 1- or 2- transistor stages): the µA733 of Fairchild Semiconductor. It is a fully differential video amplifier, by which we mean that it has differential inputs and outputs. Let’s pause to remind ourselves of the whole differential vs. common-mode concept.

**CLASS EXERCISE**
Consider the following network:

1) Using superposition, write $v_c$ and $i_c$ in terms of $v_1$, $v_2$, $R$ and $R_c$.
2) Simplify your expressions for the special case of $v_1 = -v_2$.

(Workspace)

So for purely differential drive, we say that the node $v_c$ is a “differential ground.” Linearity allows us to write any $v_1$, $v_2$ as

$$v_1 = v_{cm} + \frac{1}{2} v_d$$
$$v_2 = v_{cm} - \frac{1}{2} v_d$$

where

$$v_{cm} = \frac{1}{2} (v_1 + v_2), \ v_d = v_1 - v_2$$
Our schematic becomes

![Diagram of the µA733 differential video amplifier]

And “half-circuit” analysis is nothing more than an expression of superposition. For the common-mode half-circuit, we set \(v_2\) to zero and calculate responses. For the differential half-circuit, we set \(v_{cm}\) to zero.

Now let’s look at the µA733 differential video amplifier.

“Fully Differential”

![Diagram of the µA733 differential video amplifier]

<table>
<thead>
<tr>
<th>Selectable Voltage Gain:</th>
<th>400</th>
<th>100</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corresponding Bandwidth:</td>
<td>40 MHz</td>
<td>90 MHz</td>
<td>120 MHz</td>
</tr>
<tr>
<td>Corresponding Input Resistance:</td>
<td>4kΩ</td>
<td>30kΩ</td>
<td>250kΩ</td>
</tr>
</tbody>
</table>

How do we do the selection? It’s all done with the input stage…
Input stage:

- Shorting terminals (1) gives highest gain.
- Shorting terminals (2) gives medium gain.
- Leaving both open gives lowest gain.
- Single external resistor across terminals (1) allows continuous selection of gain by user.

Why does this work? The differential half-circuit of this input stage looks as follows:

\[
\begin{align*}
R \quad & \quad r_h \\
& \quad \quad r_\pi \\
& \quad \quad g_m V_\pi \\
& \quad \quad R_L \\
& \quad \quad R_D \\
& \quad \quad v_i \\
& \quad \quad v_0 \\
& \quad \quad v_1 \\
& \quad \quad v_2
\end{align*}
\]

This is a familiar circuit:

\[
a_{vd} \approx \frac{g_m R_L}{1 + g_m R_D} \approx \frac{R_L}{R_D}
\]

In the µA733, shorting out terminals (1) or (2), or connecting a resistor across (1), varies \( R_D \). This is why the gain changes.
What about the input resistance? It’s important to remember that the input resistance is twice the half-circuit input resistance. This is most easily seen by applying a differential test current source:

\[ v_1 = i_t R_{\text{HALF}} \quad \rightarrow \quad v_j = v_1 - v_2 = 2i_t R_{\text{HALF}} \quad \rightarrow \quad R_{\text{IN}} = 2R_{\text{HALF}} \]

Next, let’s look at the bias point calculation. The right place to focus your attention to start this problem is on the “column” that contains \( Q_8 \):

A very reasonable question to ask, when looking at a circuit with this many transistors is: How did I know to start there? The answer, of course, is experience. But one way to get that experience is to try starting a bias point calculation somewhere else in the circuit. See if you can make it work…
There is much more analysis to be done, and the course reader does an excellent job of getting through the details. Here, let’s see if we can get some insight into why the original designers might have gone with this topology:

If we look in the course reader, we’ll see that the gain of the amplifier formed by $Q_3 - Q_4$ is on the order of 100. The data sheet specs the output swing at $V_{p-p}$. What this means is that the differential voltage swing at point (A) is only $47mV_{p-p}$ …it is a low-swing node!

This helps two things:

(1) It allows for a larger common-mode input range.

(2) Since there is no gain from the bases of $Q_1 - Q_2$ to their collectors, the $C_\mu$s of these devices do not get Miller multiplied. This helps to make it a high-bandwidth part.