# 6.301 Solid State Circuits

Recitation 8: LM172 AGC AM IF Strip
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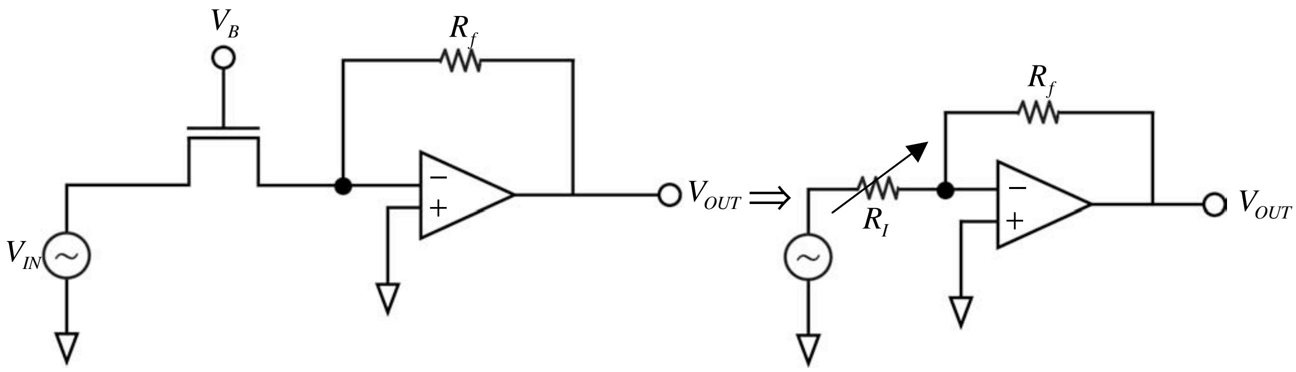
The LM172 AGC AM IF strip gives us a rather rich set of circuit tricks to add to our toolbox. One useful function to be able to realize in analog systems is a variable gain, where the gain is varied by an analog signal. For example, take the following op-amp circuit:



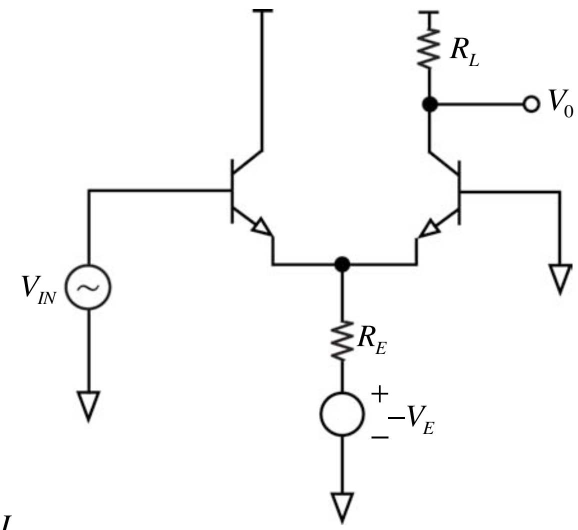

In the small-signal view of the world, the MOSFET looks like a variable resistor (if we bias things right). So the transfer function becomes

$$\frac{V_{OUT}}{V_{IN}} = -\frac{R_f}{R_I\left(V_B\right)}$$

Because $R_I$ is a function of $V_B$.

For our class exercise, let's explore a bipolar-friendly expression of this concept.

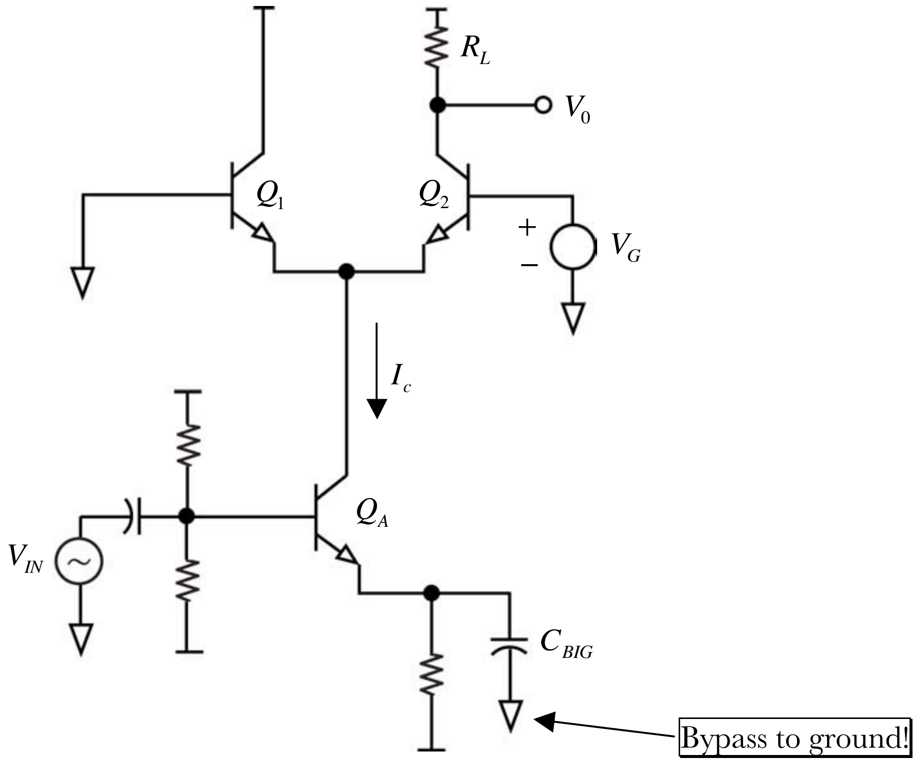
CLASS EXERCISE: Consider the emitter-coupled pair:




Remembering that $g_m = \frac{qI_C}{kT}$, derive the gain of this amplifier as a function of $V_E$.

(Workspace)

There are other ways to implement this variable gain idea. In lecture yesterday, Prof. Roberge spoke of "current stealing" as a way of varying the gain. We can examine that concept here in a simpler context:




When $V_G = 0$, the output current from $Q_A$ gets split evenly between $Q_1$ and $Q_2$ ….the gain is therefore $\frac{1}{2} g_{mA} R_L$, as half of the output signal current is "stolen" by $Q_1$. Looking in Gray and Meyer, we can find the function of $I_C$ that actually winds up going through $R_L$ as

$$\frac{I_{C2}}{I_C} = \frac{\frac{\beta_2}{1+\beta_2}}{1+\exp\left(-\frac{V_G}{V_T}\right)} = \frac{\alpha_2}{1+\exp\left(-\frac{V_G}{V_T}\right)}$$

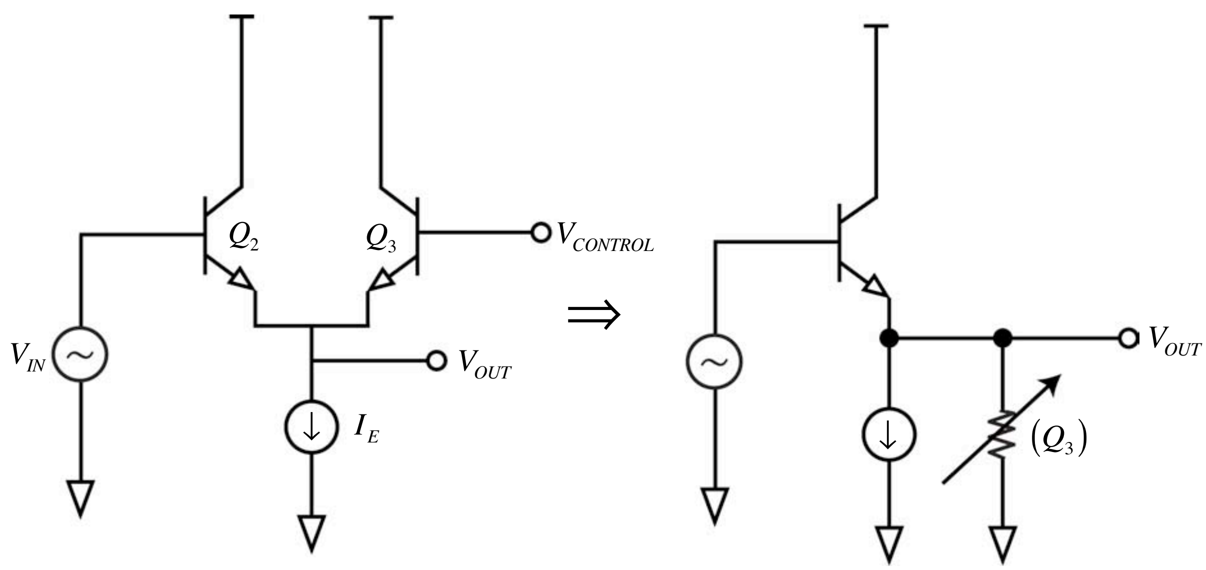
The gain for this circuit is thus

$$a_v = \left( \frac{\alpha_2}{1+\exp\left(-\frac{V_G}{V_T}\right)} \right) g_m R_L$$

which for

$$V_G >> \frac{kT}{q}\left(=V_T\right) \rightarrow a_v \approx g_m R_L$$
$$V_G << -\frac{kT}{q} \rightarrow a_v \approx 0$$

The LM172 has yet another approach to solving this problem. Look at $Q_2$ and $Q_3$, and see an emitter follower $(Q_2)$ with a dynamic load (impedance looking into the emitter of $Q_3$).




Now, again consulting Gray and Meyer,

$$I_{C3} = \frac{\alpha_F I_E}{1+\exp\left(-\frac{V_{CONTROL}}{V_T}\right)} \quad , \quad I_{C2} = \frac{\alpha_F I_E}{1+\exp\left(\frac{V_{CONTROL}}{V_T}\right)}$$

For an emitter follower with resistance $R_E$ in the emitter, the voltage gain is

$$a_v = \frac{(\beta+1)R_E}{r_{\pi 2} + (\beta+1)R_E}$$

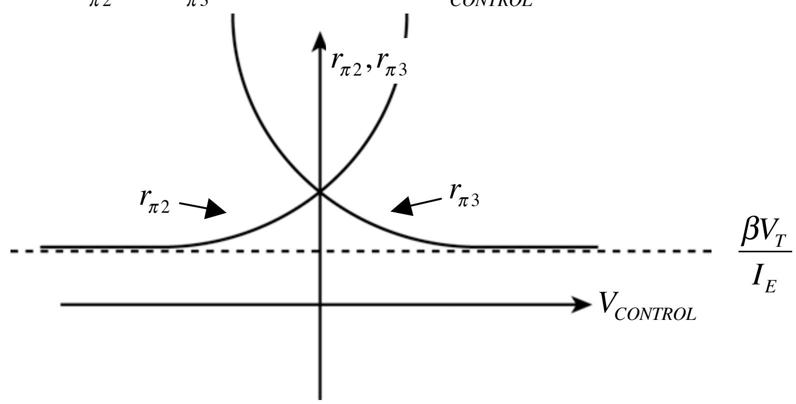
But here, $R_E = \frac{r_{\pi 3}}{\beta + 1}$. Assuming all $\beta$ s are equal,

$$a_v = \frac{r_{\pi 3}}{r_{\pi 2} + r_{\pi 3}}$$

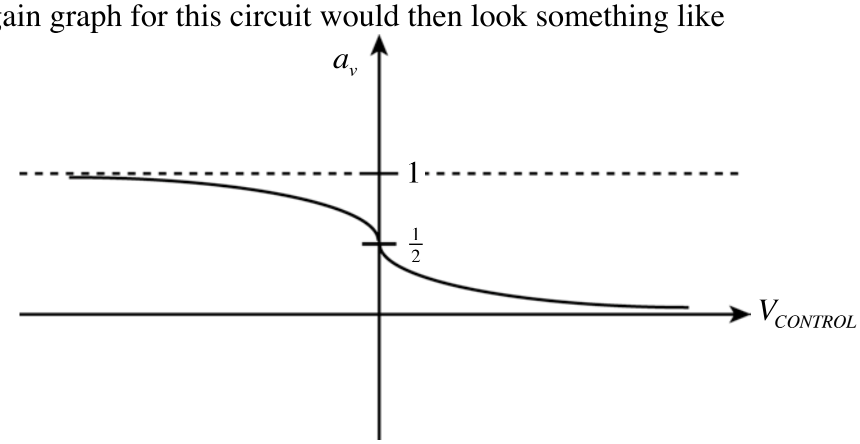
Recalling that $r_\pi$ is inversely proportional to $I_C$

$$r_\pi = \beta \frac{V_T}{I_C}$$

We can qualitatively sketch $r_{\pi 2}$ and $r_{\pi 3}$ as a function of $V_{CONTROL}$:




The corresponding gain graph for this circuit would then look something like




There's also an op-amp hidden in this chip. Can you find it?

Look at $Q_{11}$, $Q_{12}$, and $Q_{14}$