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:

\[
\frac{V_{OUT}}{V_{IN}} = -\frac{R_f}{R_I(V_B)}
\]

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:

\[ g_m = \frac{qI_c}{kT} \]

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 $\frac{1}{2} g_m R_L$, 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

$$\frac{I_{c2}}{I_c} = \frac{\beta_2}{1 + \beta_2} = \frac{\alpha_2}{1 + \exp \left( -\frac{V_G}{V_T} \right) \left[ 1 + \exp \left( -\frac{V_G}{V_T} \right) \right]}$$

The gain for this circuit is thus

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

\[ V_g >> \frac{kT}{q} (= V_T) \rightarrow a_v \approx g_m R_L \]

\[ V_g << -\frac{kT}{q} \rightarrow a_v \approx 0 \]

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,

\[ I_{C3} = \frac{\alpha_f I_E}{1 + \exp \left( -\frac{V_{\text{CONTROL}}}{V_T} \right)} \quad , \quad I_{C2} = \frac{\alpha_f I_E}{1 + \exp \left( \frac{V_{\text{CONTROL}}}{V_T} \right)} \]

For an emitter follower with resistance \( R_E \) in the emitter, the voltage gain is

\[ a_v = \frac{(\beta + 1)R_E}{r_{e2} + (\beta + 1)R_E} \]
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 $V_{\text{CONTROL}}$:

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 $Q_{14}$