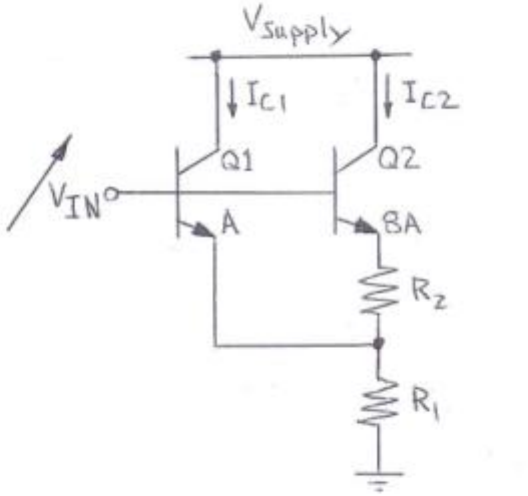
Circuit Challenge 5

Consider the circuit shown below.



Core Circuitry for a Voltage Reference

Observation
Practitioners of the electronics arts (particularly those who design and use voltage references) will recognize the schematic as a basic building block for bandgap references. (Note: The circuit could have been inverted, thus permitting the use of PNPs.)

Assumptions
- Assume V_{BE1}=0.6V at the design center.
- Assume I_{E1}=I_{E2}=100µA at the design center.
- Assume V_{IN}=1.25V at the design center.

The Challenge
- Determine the approximate value of R_1.
- Determine the approximate value of R_2.
- Sketch the transfer characteristics of I_{C1} & I_{C2} versus V_{IN} above & below 1.25V.

For a comparison of your results with the author's results, scroll down to the analysis.

Analysis for Circuit Challenge 5

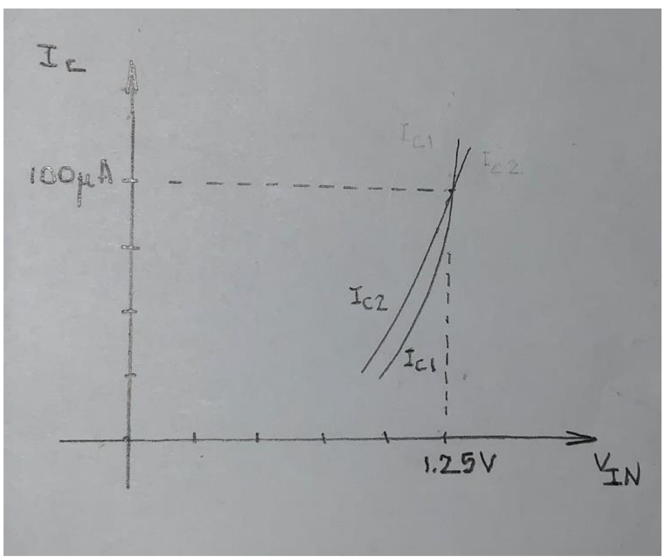
It was stated that the design center is I_E 100µA for each transistor. We here assume that $I_C \sim I_E$. Thus the two collector currents are also approximately 100µA at the design center. Both emitter currents flow through R_1. Because the design center is 1.25V, and because V_{BE} was declared to be 0.6V, we have

$$R_1 = (1.25V - 0.6V)/200\mu A$$
$$R_1 = 3250\ \Omega$$

Please notice that Q_2 is 8 times larger than Q_1. Assuming identical emitter currents (and wafer processing, etc.), a general rule of thumb is that Q_2's V_{BE} will be reduced by 18mV for each factor of 2 size increase (see the note at the end of this section). 8X therefore implies a 54mV V_{BE} reduction. R2 "sees" this ΔV_{BE}, and we can write

$$R_2 = 0.054V/100\mu A$$
$$R_2 = 540\ \Omega$$

And here is a sketch of the transfer characteristics:



The key (the intuitive observation that must now be driven home) is this: I_{C1} and I_{C2} *cross over* at the design center. It is the dynamic circuit evaluation of these two currents at crossover that allows completed reference circuits to find their respective design centers with the use of negative feedback.

Note 1: The 18mV/octave rule can be derived from the Ebers-Moll model.

Note 2: It was stated that that $I_C \sim I_E$. They are not actually equal because each bipolar transistor has base current. The input will generally come from a voltage divider. Non-zero base currents will affect the accuracy of the divider. Paul Brokaw developed a solution for cancelling the effects of base current by introducing a resistor between the bases of Q1 and Q2. It is a closed-form solution dependent only on the value of the resistors in the divider and the values of R_1 and R_2.

For Additional Information

- Paul Brokaw's analysis is found here (see particularly Figure 3. and Section C.).
- Put "bandgap reference" into a search engine.

Want to Simulate This Challenge, But You Don't Have a Simulator?

- Try this one —> http://www.5spice.com/