ELE339, Electronics I Laboratory

LAB 3 - PN Junction based Voltage Reference

Pre-Lab

Objective:

Voltage references which are independent of supply voltage variations and temperature excursions are of great practical importance. They represent one of the most crucial elements, for instance, in data converter circuits, where an (analog) input needs to be compared to a very stable reference. The circuit we investigate in this lab exploits the (negative) temperature coefficient of the PN junction voltage to counteract the (positive) temperature coefficient of the thermal voltage V_T. As we will find out, this solution yields an output which is (first-order) temperature independent.

Temperature Dependence of PN Junction

The current through a forward biased PN junction (or diode) can be expresses as

$$I_d = I_S \exp[\frac{V_d}{nV_T}] \quad (1)$$

where I_S denotes the reverse saturation current, V_d the junction voltage, V_T=kT/q the thermal voltage (approximately 26mV at 300K) and n the empirical emission coefficient ($1<n<2$). As far as a temperature change is concerned, I_s represents by far the most critical parameter, since it increases exponentially as the temperature rises. In silicon, for example, I_S approximately doubles for a mere 5C increase in temperature. Provided the junction current is kept proportional to temperature (this is the case in most practical voltage reference circuits), we can approximate the temperature coefficient of the junction voltage by

$$\frac{dV_d}{dT} = \frac{1}{T}[V_d - 2V_T - V_G] \quad (2)$$

where T denotes the absolute temperature (in K) while $V_G=E_G/q$ is the material dependent but **very stable** *bandgap voltage* (e.g. V_G(Si)=1.12V, V_G(Ge)=0.66V). Since the bandgap voltage exceeds the typical forward biased junction voltage V_d, the above expression always yields a negative coefficient. By creating a balanced weighted sum of the decreasing junction voltage and the positive thermal voltage gradient (i.e., dV_T/dT), it is possible to obtain an output which is (first-order) temperature independent.

Tasks:

1. Use equation (2) to find approximate values for the temperature coefficients of the PN junction voltage in Silicon and Germanium at T=300K. To obtain reasonable numerical values, assume junction voltages of V_d(Si)≈ 0.65V and V_d(GE)≈ 0.3V, respectively.
2. By how much do you have to amplify the positive temperature gradient of the thermal voltage in order to perfectly balance it with the negative voltage coefficient of the silicon PN junction as described by equation (2)? Assume T=300K and V_d≈ 0.65V.
3. Consider the circuit depicted in figure 1 and express its output voltage V_{bg} as a function of R_1, R_2, R_3 and the diode voltage V_{d1}. To simplify the analysis, we assume the op-amp to be ideal, i.e., it features infinite input impedance and infinite (differential) gain. The latter implies that $V_2=V_{d1}$.

4. Simulate the circuit depicted in figure 1 with PSpice for R_1=R_2=680Ω and your estimated value for R_3 (cf. tasks 1 & 3). Use 1N916 diode model parameters or the best available match. Sweep the temperature in your simulation over a range of 50C (e.g. 20C – 70C) and adjust R_3 such that the output voltage V_{bg} (approximately) remains constant (at what level?). Plot V_{d1} and V_{bg} over the 50C temperature excursion.
5. Repeat task 4 employing 3 Germanium diodes (1N34 or its best available match). You may have to adjust R_3 again to accommodate the Germanium diodes.

Experimental

6. Realize the circuit in figure 1 on your Protoboard using 1N916 silicon diodes. Arrange your elements so that the resistors and the LF356 op-amp reside on a board outside the oven while **only the 3 diodes** are placed inside the heat chamber. Use +/-5V for the op-amp supply. Your initial element values should match the values used in your PSpice simulations. Adjust R_3 as necessary to obtain the proper reference voltage. Does the output voltage V_{bg} change if you increase the op-amp supply to +/-7.5V?
7. Record the voltages V_{d1} and V_{bg} as well as the diode current I_1 over a range of 10 C. Heat the oven very slowly so that the system is in thermal equilibrium when you record the two voltages. How well do your empirical values match your predictions and simulated results?

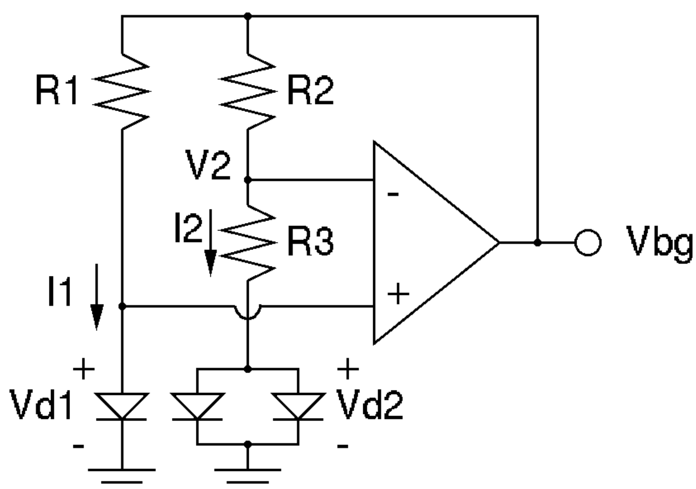

Figure 1: Proposed band-gap reference circuit based on thermal characteristics of a PN junction.