Introduction

For this lab, you will be developing the background and circuits that you will need to get your final project to work. You should do this with your project group. The results should go into your powerpoint design document, and will be presented to your TA as a team.

Objective

The goal is to design and simulate several reference circuits and compare their performance. The circuits are: Figure 4.30b, 4.36b, and (possibly a variation of) Figure 4.47. In each case, you will vary the supply voltage $V_{BAT}$ from 0.9V to 1.6V (corresponding to an alkaline battery), and vary the temperature from -40 to +85 Centigrade (the typical industrial temperature specification). For this lab we won’t be exploring process variation.

![Figures 4.30b, 4.36b, and 4.47 from the textbook.](image)

The simple resistor-biased current mirror in 4.30b is included as a reference to see how bad things can be. The $V_{T}$ referenced source in 4.36b is a step in the right direction, and is good enough for some applications. Design both circuits to have a nominal minimum output current $I_{OUT}$ of 10uA. Note that you will need to pick a voltage for the bias of $I_{OUT}$. Since this current will be used in your regulated analog circuits, you can pick a stable, lower voltage, e.g. 0.8V, for that bias point.

Plot the output current and gate bias voltage on M1 and T1 vs. temperature and battery voltage. Tabulate the worst-case variation.

Now make either the bandgap circuit from the book above, or the bandgap reference labeled “Figure 6” below (from Mok&Liang, CICC 2004). This is similar to Figure 4.47 from the textbook, but uses a pair of PMOS transistors as an output stage to avoid loading the output of the op-amp. With your two-stage op-amp from homework 6 you can probably just use the
circuit from the book – just be careful to make sure that your resistors don’t load the op-amp too much.

- Your op-amp may be the single-stage op-amp or the two-stage op-amp that you made from Homework 6. It needs to run off of $V_{BAT}$ because at this point you don’t have any other voltages to work from.
- The bipolar PNP transistors are actually diodes. Use “pdio” from the gpdk90 toolkit. For the larger diode, set $m=8$ (or whatever you like, as long as it’s an integer greater than 1)
- The resistors should have a temperature coefficient. You can use “resnsnpoly” for your resistors, from the gpdk90 toolkit. You should be able to use “tc1=1e-3” to get a reasonable temp coefficient.
- Design the MOS transistors to source 10uA or so with a small overdrive voltage
- Design $R_1$ so that the voltage across it will be $V_T \ln(N)$ with roughly 10uA flowing through it.
- $R_2$ should be something like 20 times bigger than $R_1$. When you sweep temperature and plot the bandgap voltage ($V_{REF}$ in the figure) you should see curves that look like Figure 4.45 in the book, and you can use that to guide your choice of $R_2/R_1$.

![Diagram](image-url)

**Fig. 6: A CMOS bandgap voltage reference using error-amplifier-based current mirror.**

**Bandgap reference voltage generator and a circuit to convert that voltage to a stable current.** Note that $V_{DD}$ in the figure is actually $V_{BAT}$. (from Mok&Liang, CICC2004)

Use another op-amp to generate a reference current from your reference voltage, as in the figure above. What supply should this op-amp use?

Now simulate vs. temperature and battery voltage, and compare to your results for the simple circuits above. Note that the bandgap circuits aren’t going to work very well below 1.3V – that’s fine for now.