In this lab we will build a band gap reference and compare its performance to simpler references. The learning goals are listed below:

- Observe bias fluctuations with power supply variation.
- Observe bias fluctuations with temperature variation.
- Practice calculations for band gap references.

## Build and Measure References

1. Build three references: a voltage divider on $V_{cc}$ with a division ratio of two, a diode connected NPN device pulled up to $V_{cc}$ by a 1 kΩ resistor, and a band gap reference. You may refer to Figure 1 for a schematic of the band gap reference. Use a 2N3904 for the diode reference and a BCM847DS matched NPN pair and an MCP601 op-amp for the band gap.

You will need to select the gain $M$ for the band gap reference and then use that value of $M$ to select $R_1$, $R_2$ and $R_3$. Recall that $M$ depends on the temperature sensitivity of $v_{be}$ (-2 mV/K) and the temperature sensitivity of $\phi_T$ (+3300 ppm/K = +0.086mV/K). You can calculate the expected $V_{OUT}$ of the band gap based on your value of $M$, make sure you produce that output.

2. Vary $V_{cc}$ from 2.7 V to 6 V and observe $v_{out}$ for each of the three references.

3. Use the cold spray and heat gun to vary the temperature of the three circuits and observe the maximum excursions of $v_{out}$ while they are heated or cooled. Be sure to keep scope probes far away from the area being heated or cooled and try to avoid damaging breadboards.

When applying heat/cold to the bandgap, focus on the NPNs rather than the rest of the circuit. Ensure that the two transistors are in close thermal contact and far from the rest of the circuit for best results.

4. Which circuits are temperature insensitive? Which are supply insensitive? Why?