Temperature Stabilizing the TI UCC28880 Low-Side Buck Regulator

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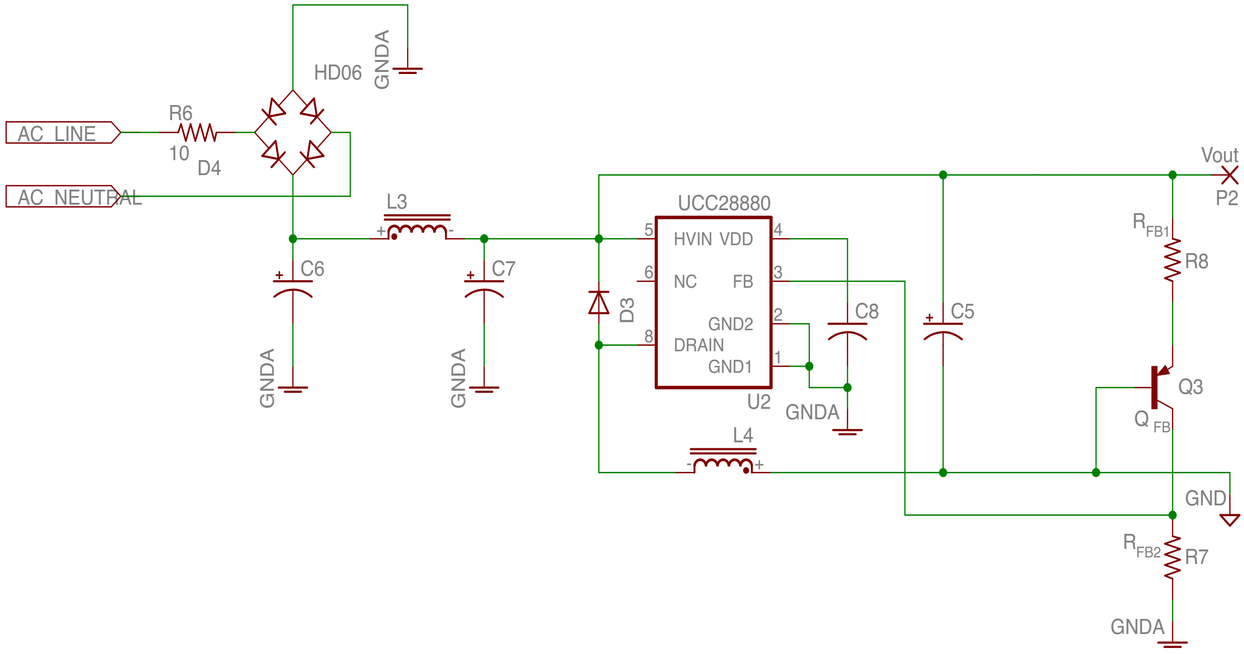
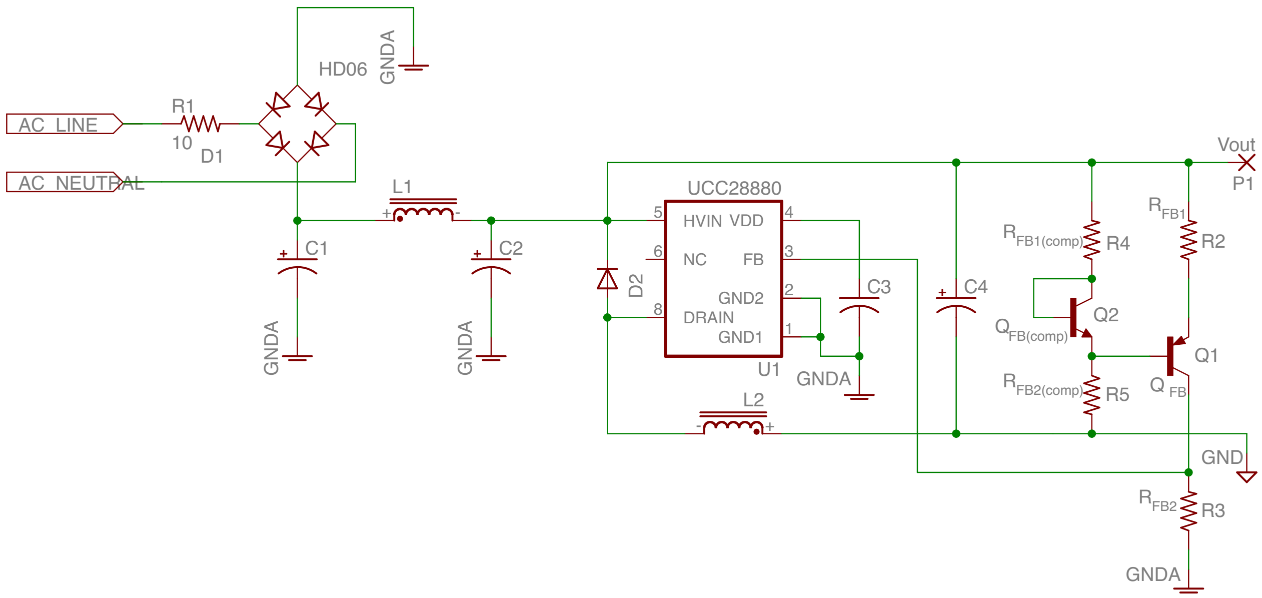
The low-side buck design employed by this regulator requires the use of a transistor level shifter, Q_{FB}, to provide feedback voltage referenced to the regulator's DC ground. While effective, it is unstable over large temperature variations. High temperatures will decrease the channel resistance, increase current, and increase the voltage, V_{FB}, across the feedback resistor. The regulator will respond by reducing V_{OUT} below the intended voltage. The inverse will happen with low temperatures.



The degree to which this occurs depends on the values chosen for R_{FB1} and R_{FB2}. Larger values make the transistor's variation over temperature proportionately smaller and reduce the effect. However, large R_{FB} values reduce the feedback current available and make the regulator more susceptible to noise. For some applications this may be acceptable.

If tight regulation is required over a wide operating range, say -40C to +85C, temperature compensation is required. This is accomplished with the modification below and works as follows.



$R_{FB1(comp)}$, $R_{FB2(comp)}$ and $Q_{FB(comp)}$, form a complementary voltage divider except that the lower resistor, $R_{FB2(comp)}$ connects to the regulated output ground (instead of the regulator return ground) and Q_{FB}'s base connects to $R_{FB2(comp)}$ along with $Q_{FB(comp)}$'s emitter. The values of $R_{FB1(comp)}$ & R_{FB1} and $R_{FB2(comp)}$ & R_{FB2} are identical. $Q_{FB(comp)}$ must be the NPN complement to Q_{FB}. Because the Vce of $Q_{FB(comp)}$ is less than Vbe of Q_{FB} the majority of the voltage across $R_{FB2(comp)}$ will be due to current flow from $Q_{FB(comp)}$. Current flow from the base of Q_{FB} will be on the order of a few microamps so it's important for the selected transistors to have sufficient gain to properly bias R_{FB2} at the design current.

As temperature increases, Q_{FB}'s resistance will decrease and attempts to increase its bias with more current flow at the base. However, $Q_{FB(comp)}$'s resistance has also decreased and the current flow from its emitter has increased by an equal amount. Since $Q_{FB(comp)}$'s current flow dominates $R_{FB2(comp)}$, Q_{FB}'s bias remains unchanged. The inverse happens with a decrease in temperature. Temperature stability of +/- 100mV over -20C to +70C is possible with this scheme.

Feedback resistor value selection is straightforward. Start with $R_{FB2(comp)}$ and calculate its value per TI's application note for the design. Select the current, in microamps, to use to generate V_{FB} and calculate the resistance value:

$$R_{FB2(comp)} = \frac{V_{FB}}{I_{FB}}$$

A modified formula is used to calculate $R_{FB1(comp)}$:

$$R_{FB1(comp)} = (V_{OUT} - V_{CE(comp)} - V_{FB})R_{FB2(comp)}$$

The values of R_{FB1} and R_{FB2} should equal their counterparts:

$R_{FB1} = R_{FB1(comp)}$

$R_{FB2} = R_{FB2(comp)}$

In-circuit testing should be used to validate & adjust the values as necessary. Accuracy will be determined by transistor tolerances & matching as well as the tolerance of the resistors. The operating environment & PCB layout must be considered to minimize the temperature differential of the transistors. Ensure that both are placed as close to one another as possible and will be subjected equally to temperature effects of the design and environment.

Validation Testing

The formula for $R_{FB1(comp)}$ will tend to set the output voltage high by ~ 200mV so in-circuit validation is required to set the final values.

Testing was done with the aforementioned circuit on a finished PCB for a small consumer appliance. R_{FB2} was set at 12K to provide 83uA of sense current. Vdd for the appliance is 5V so R_{FB1} was calculated 42K but, anticipating a higher voltage, 37.4K was used. This provided a nominal output of 4.9V @ ~ 20C.

The supply was first placed in an oven and taken to approximately 90C. During the early portion of the heating cycle the output voltage dropped precipitously to ~3V. As the heating cycle continued and the oven temperature stabilized the voltage returned to 4.7V – within 200mV of starting ambient temp. This demonstrates a behavior that all current mirrors exhibit: any difference in temperature between the two resistors will yield fluctuating results.

The supply was then placed in a freezer and taken to -21C. The supply started at 4.91V @ ~ 20C. Supply voltage did not vary or oscillate during cooldown. After 15 minutes the output increased to 5.03V and remained there for the duration of the test (45 minutes). At the end of the test, prior to removal from the freezer, the power was cycled, left off for 1 minute, and turned back on. Output returned to 5.03V.

Conclusion

This solution is viable for designs that must work over -40C - +85C and can tolerate ±200mV of output variation. To assure this operating margin the design must adhere to the following:

- Matched transistor pair
- Good thermal coupling between transistors
- Minimize thermal effects from the ambient environment surrounding the transistor that could create a temperature imbalance
- Higher resistor values for R_{FB1} & R_{FB2} so that the resistance change in the level shift transistor is proportionately smaller