

Power Tips: PWM-controlled Output Adjustment for USB Type-C™ Applications



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Consumer applications often require power supplies to support an adjustable output voltage for different operating conditions such as USB Type-C™. This demand creates the need for a simple and effective method to tune the output voltage. There are many ways to interact with the feedback (FB) pin on the integrated circuit (IC) to set the desired output. One way is to add a trim resistor at the FB pin, and apply a voltage to source or sink additional current at the FB pin's resistive divider. Another approach is to use an I²C bus to program signals to interact with the FB pin. But what if a variable voltage source or I²C bus is not available? In this post, I will show you how to use a simple resistor capacitor (RC) low-pass filter, a trim resistor and a pulse-width modulation (PWM) signal from a microcontroller unit (MCU) to tune the output voltage.

Figure 1 shows the circuit illustration of this approach.

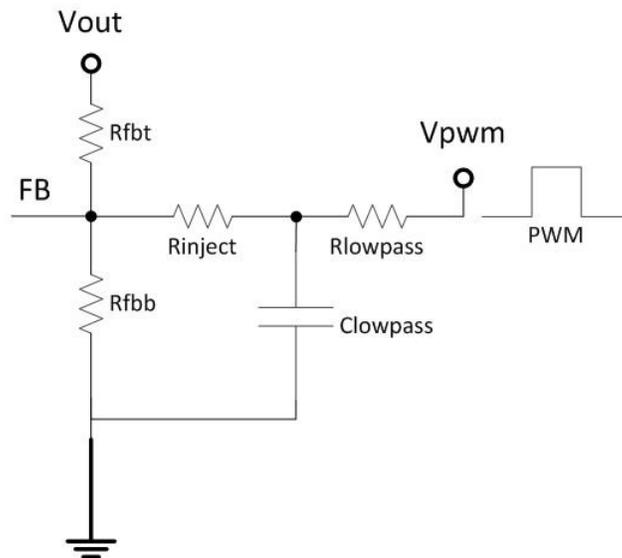


Figure 1. PWM Injection Circuit

The RC low-pass filter will average the PWM signal based on the duty cycle. The Thevenin equivalent of the circuit in Figure 2 and the filter capacitor will create the time constant, which determines the slew rate of the signal injected into the FB pin. Equation 1 shows the calculation:

$$R_{total} = [(R_{fbt} || R_{fbb}) + R_{inject}] || R_{lowpass} \quad (1)$$

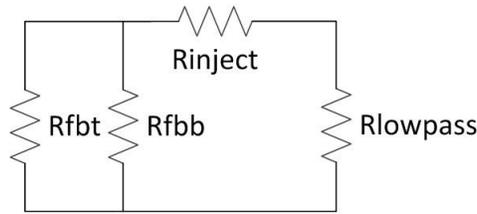


Figure 2. Thevenin Equivalent

Because the added RC filter introduces a pole and zero pair into the overall control loop, you will need to take care when selecting the RC filter. Looking again at [Figure 1](#), at low frequency, when $C_{lowpass}$ is open, the sum of R_{inject} and $R_{lowpass}$ is in parallel with R_{fbb} . When $C_{lowpass}$ shorts at high frequency, only R_{inject} is in parallel with R_{fbb} . Therefore, selecting $R_{lowpass}$ to be much smaller than R_{inject} will ensure that the pole and zero pair is close to each other and will minimize the effect on the controller's control loop.

Equations 2, 3 and 4 calculate how to best select the injection, top and bottom FB resistors, respectively:

$$R_{adj} = R_{inject} + R_{lowpass} \quad (2)$$

$$\frac{V_{outmin} - V_{fb}}{R_{fbt}} + \frac{V_{pwm} * D_{max} - V_{fb}}{R_{adj}} = \frac{V_{fb}}{R_{fbb}} \quad (3)$$

$$\frac{V_{outmax} - V_{fb}}{R_{fbt}} = \frac{V_{fb}}{R_{fbb}} + \frac{V_{fb} - V_{pwm} * D_{min}}{R_{adj}} \quad (4)$$

Equation 3 corresponds to the minimum output voltage, and Equation 4 corresponds to the maximum output voltage.

For example, if the available 3.3V PWM signal's duty cycle varies from 6% to 94%, you would select a 49.9k Ω top FB resistor and a 1k Ω $R_{lowpass}$ to achieve a 1V-to-10V output, and your controller's FB voltage would be 0.8V. Equations 5 and 6 show the calculations of R_{fbb} and R_{inject} :

$$\frac{1V - 0.8V}{49.9k\Omega} + \frac{(3.3V * 96\% - 0.8V)}{R_{adj}} = \frac{0.8V}{R_{fbb}} \Rightarrow \frac{0.8V}{R_{fbb}} = 0.004 + \frac{2.368}{R_{adj}} \quad (5)$$

$$\frac{10V - 0.8V}{49.9k\Omega} = \frac{0.8V}{R_{fbb}} + \frac{0.8V - 3.3V * 6\%}{R_{adj}} \Rightarrow \frac{0.8V}{R_{fbb}} = 0.184 - \frac{0.602}{R_{adj}} \quad (6)$$

Setting Equations 5 and 6 as equal, R_{adj} yields 16.47k Ω and R_{fbb} yields 5.41k Ω when selecting a standard value of 15.4k Ω and 5.36k Ω for R_{inject} and R_{fbb} , respectively.

The controller's duty cycle will be perturbed if a lot of ripple is injected into the FB pin; therefore, you will need to take some care when selecting the low-pass filter's capacitance. As a good design practice, maintain less than 1% ripple on the FB pin voltage – much less. For example, with a switching frequency (F_{sw}) of 200kHz, use a PWM of 1MHz with an RC time constant of 1ms. This will minimize any beat-frequency components appearing on the output voltage. $R_{lowpass}$ and $C_{lowpass}$ will dominate the time constant, since the resistors at the FB divider side have a much higher impedance than $R_{lowpass}$.

Following the design methodologies described in this post will reduce development time and circuit complexity for applications requiring multiple outputs.

Additional Resources

Check out these reference designs:

- [9 to 42VIN 5V/12V/20V at 5A Synchronous Four-Switch Buck-Boost Converter Reference Design.](#)
- [Four-Output USB Type-C™ 100W Buck-Boost Reference Design.](#)

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