Analog voltage input

The final type of output-voltage adjustment uses an analog signal to control the output voltage. This analog signal, fed into the FB pin through a resistor, is usually generated from a voltage reference, either a discrete voltage reference like the TLV431 or an analog output created from the voltage reference inside an MCU, the current or voltage output of a digital-to-analog converter (DAC), or a PWM signal filtered with a simple resistor-capacitor (RC) filter. With an analog voltage, any output voltage is attainable, instead of just discrete settings as with the previously discussed methods. This is critical for analog LED dimming, which requires a gradual change in light output instead of larger step changes. A fully adjustable output voltage also allows fine-tuning of analog-circuit biasing.

The filtered PWM-signal method requires just a single GPIO pin of an MCU, two resistors and one capacitor. Using a DAC instead of a PWM signal gives a cleaner output voltage, with no possibility of a PWM frequency appearing on the output rail. A DAC also eliminates issues arising from variation in the PWM signal's RC filter over temperature or component tolerance.

Reference 2 and Equations 1 through 3 show details of the necessary calculations for basic output-voltage adjustment from an analog voltage. Using the same calculations with the TPS62088 and DAC53608 generates an output voltage between 0.3 V and 1.8 V from a DAC output voltage between 0.3 V and 3 V. Figure 5 shows the tested schematic. Figure 6 shows measured data (with a 3.3-V input voltage and 1-A load) compared to the ideal curve, with nearly perfect matching. Equation 1 gives the transfer function of the analog voltage to the output voltage, while Equations 2 and 3 select the proper resistor values.

Figure 5. The DAC53608 adjusts the TPS62088's output voltage

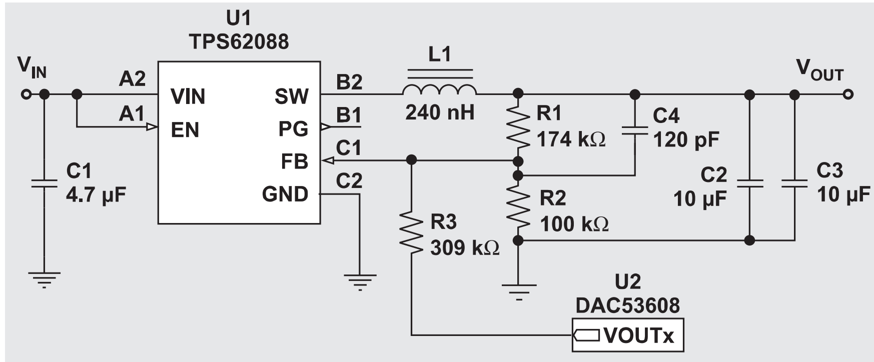
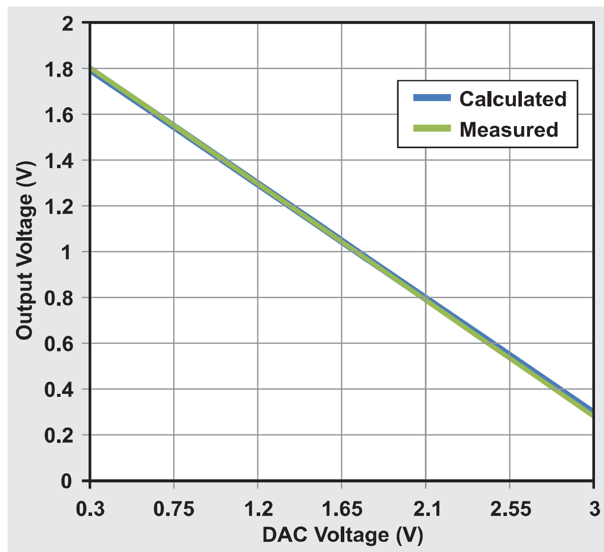


Figure 6. Comparison of measured output voltage adjustment to calculated



$$V_{OUT} = V_{FB}\left(1+\frac{R1}{R2}\right)-\frac{R1}{R3}\left(V_{DAC}-V_{FB}\right) \tag{1}$$

$$R2 = -V_{FB}\times R1\times\frac{V_{DACLOW}-V_{DACHI}}{\left(V_{OUTLOW}-V_{OUTHI}+V_{DACLOW}-V_{DACHI}\right)\times V_{FB}-\left(V_{DACLOW}\times V_{OUTLOW}\right)+\left(V_{DACHI}\times V_{OUTHI}\right)} \tag{2}$$

$$R3 = R2\times R1\times\frac{V_{DACHI}-V_{FB}}{\left(R2\times V_{FB}\right)+\left(R1\times V_{FB}\right)-\left(R2\times V_{OUTLOW}\right)} \tag{3}$$

A further benefit of the DAC53608 is that its disabled outputs have a defined ~10-kΩ pulldown, as Figure 7 shows. This internal pulldown resistor eliminates the disabled-to-enabled power-on glitch from the DAC's output, which can cause transients on the output voltage during startup. Such glitches can potentially have a catastrophic impact on the load.

Figure 7. The DAC53608 has a ~10-kΩ resistance to ground at startup

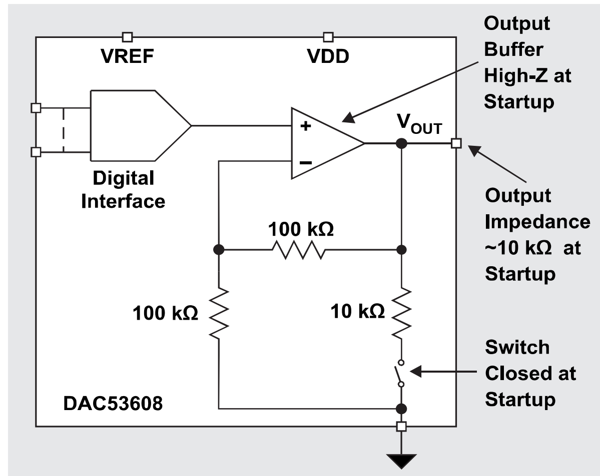
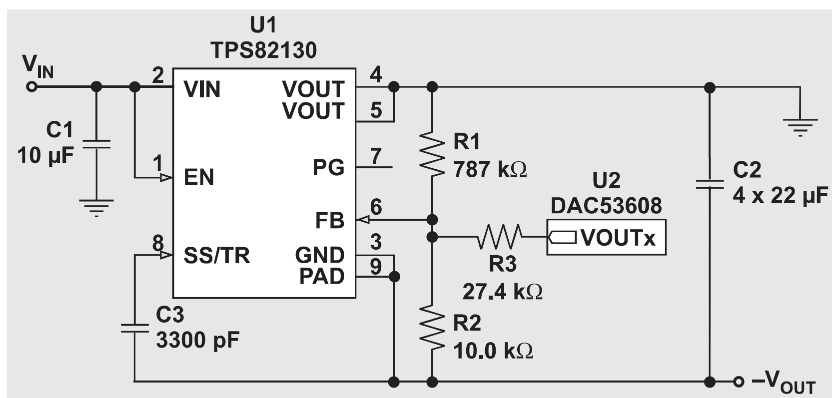


Figure 8 uses this same analog voltage-margining technique for a negative voltage, based on Reference 3. Using the TPS82130 power module in the inverting buck-boost configuration creates a variable negative-output voltage, useful for optical circuit biasing. Figure 9 shows very good matching until the lowest output voltages.

Equation 4 gives the transfer function from DAC voltage to output voltage.

$$V_{OUT} = \frac{\frac{-V_{FB}}{R2} - \frac{V_{FB}}{R1} - \frac{V_{FB}}{R3} + \frac{V_{DAC}}{R3}}{\frac{1}{R1} + \frac{1}{R3}} \quad (4)$$

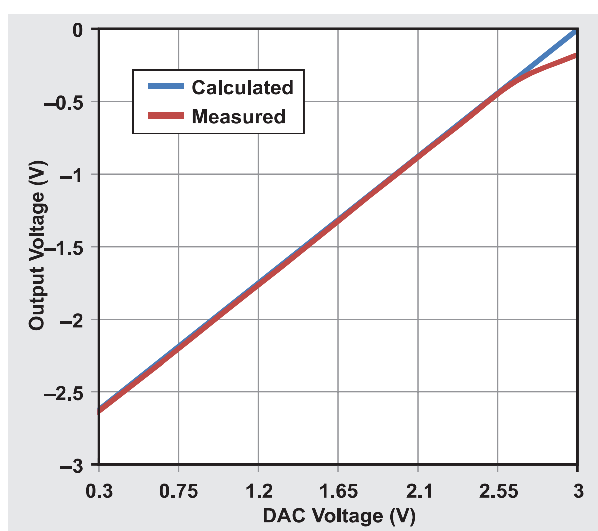
Figure 8. DAC53608 adjusts the TPS82130's negative output voltage



Figures 6 and 9 also show a hidden benefit of analog voltage margining: adding a voltage into the FB pin achieves output voltages below the converter's FB pin voltage. The margining circuit shown in Figure 5 achieves a 0.3-V output voltage even with the TPS62088's 0.6-V FB pin voltage, while Figure 8 achieves voltages below –0.5 V even with the TPS82130's 0.8-V FB pin voltage. Such circuits can also be used with a fixed analog voltage instead of an adjustable DAC. Reference 4 uses this method to increase LED driver efficiency.

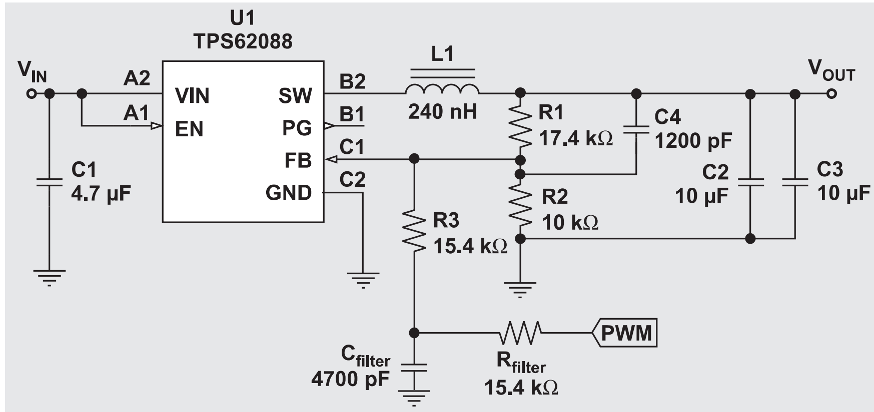
If no available analog voltage exists, an RC filter can create one by filtering a PWM signal. The frequency is held constant, while the duty cycle varies to adjust the resulting analog voltage. Reference 5 explains such a circuit for LED dimming applications. For DC/DC converters, the PWM frequency should be above the control-loop bandwidth, to allow easier filtering and to prevent the control loop from gaining up the frequency of the PWM signal and appearing on the output voltage.

Figure 9. Comparison of measured negative output voltage adjustment to calculated



A 1-MHz PWM signal replaces the DAC shown in Figure 5 to create Figure 10, which shows that the RC-filtered PWM signal creates an analog voltage to adjust the TPS62088's output voltage. Figure 11 shows the margining performance. As the PWM signal's duty cycle increases, the analog voltage created by the RC filter increases and the output voltage decreases. To adapt Equation 1 to use with a PWM signal, replace V_{DAC} with $[D \times V_{PWMHI} – (1 – D) \times V_{PWMLOW}]$ and R3 with $(R3 + R_{filter})$.

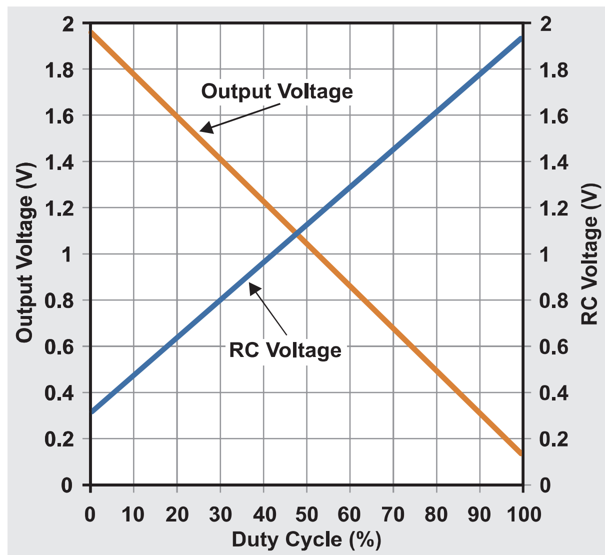
Figure 10. RC-filtered PWM signal controls the output voltage



Any of these three methods—DAC output, analog voltage or filtered PWM signal—generate an analog output that adjusts the output voltage. Simple systems use a filtered PWM signal or spare MCU analog output to adjust the voltage on one rail. As the number of voltages needing adjustment increases, a multichannel DAC becomes a more cost- and space-effective solution, since it's possible to control more DAC outputs on the same interface bus without an increase in MCU pins or additional circuitry. With the filtered PWM-signal method, every extra rail requires an additional MCU pin and RC filter.

Reference 6 is a calculator spreadsheet which aids in the design and analysis of both the positive- and negative-output voltage circuits shown in Figures 5 and 8.

Figure 11. Output voltage margining by a PWM signal



Conclusion

Changing the output voltage can optimize power delivery, reduce power consumption, or properly bias analog circuits such as LED drivers and optics. Three basic techniques—a digital communication interface, digital input and analog input—adjust the output voltage differently to match specific requirements. The examples shown in this article demonstrated common adjustment techniques that are transferable to your specific system and design challenges.

References

1. "Voltage-Margining Power Supply for USB Type-C Ports in Docking Stations," Texas Instruments reference design (TIDA-01567).
2. Will Hadden, "Dynamically Adjustable Output Using TPS63000," Texas Instruments application report (SLVA251), August 2006.
3. "3- to 11.5-VIN, –5-VOUT, 1.5-A Inverting Power Module Reference Design for Small, Low-Noise Systems," Texas Instruments reference design (TIDA-01457).
4. Jeurgen Neuhaeusler, "Different Methods to Drive LEDs Using TPS630xx Buck-Boost Converters," Texas Instruments application report (SLVA419B), January 2012.
5. Matt Guibord, "How to Use Analog Dimming with the TPS6116x," Texas Instruments application report (SLVA471), July 2011.
6. Design Tool for Output Voltage Adjustment using a DAC (SLVC780), Texas Instruments, 2019

Related Web sites

Product information:

TPS62866, TPS40428, TPSM82480,

TPS62136, TPS62802, TPS62745,

TLV431, TPS62088, DAC53608, TPS82130