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An Easy Way To Roll Your Own Programmable Power Supply

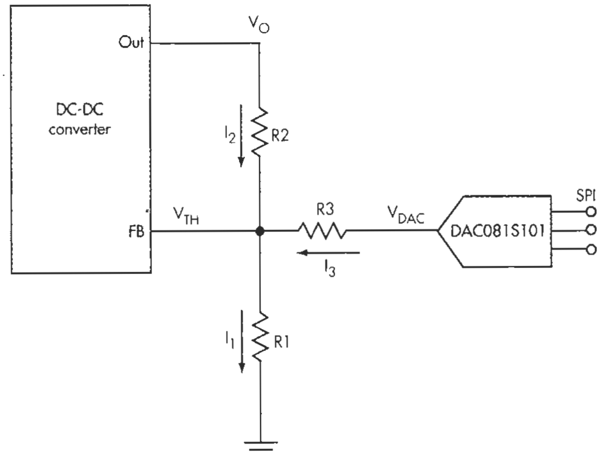
Adjusting the output voltage of a power supply is a feature typically reserved for highly integrated handheld power-management units (PMUs) with multiple integrated power supplies. You can implement this feature, however, with any power supply by adding a single resistor and an inexpensive digital-to-analog converter (DAC) *(Fig. 1)*. While this technique isn't new, the equations to select appropriate resistor values are rarely published.

Using nodal analysis on the circuit in Figure 1 provides the fundamental equations:

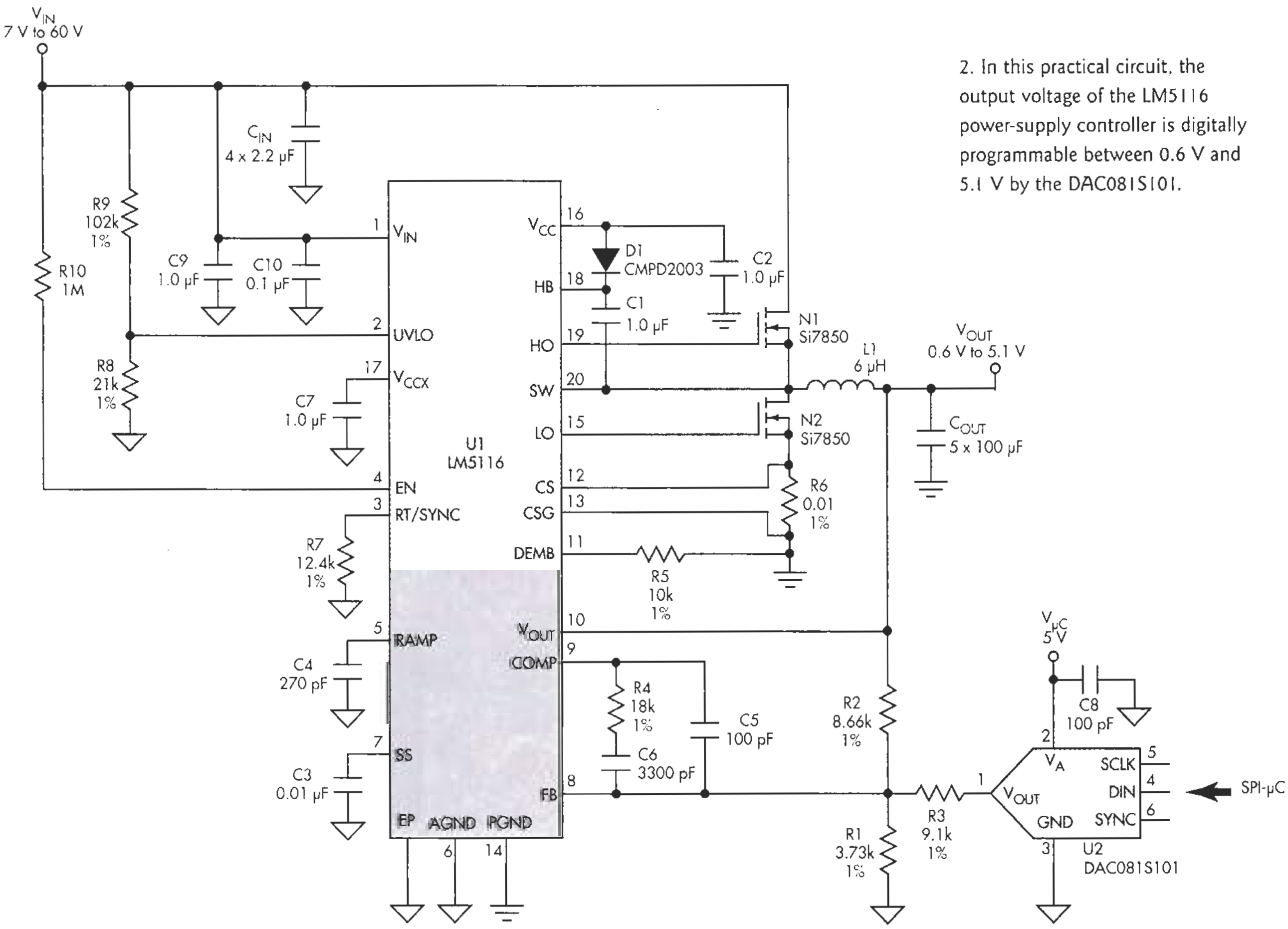
$$\frac{V_{TH} - 0}{R1} = I_1$$

$$\frac{V_O - V_{TH}}{R2} = I_2 \qquad (1) \qquad\qquad I_1 = I_2 = I_3 \qquad (2)$$

$$\frac{V_{DAC} - V_{TH}}{R3} = I_3$$



1. An extra resistor, a DAC, and a little bit of math can make any power supply with external feedback components programmable.



2. In this practical circuit, the output voltage of the LM5116 power-supply controller is digitally programmable between 0.6 V and 5.1 V by the DAC081S101.

You can easily derive the equations for the three resistors using these fundamental equations and the knowledge that the DAC voltage is inversely proportional to the output voltage. For example, when $V_{OUT} = V_{OL}$, then $V_{DAC} = V_{DACH}$, where V_{OL} = the power supply's lowest output voltage and V_{DACH} = full-scale DAC voltage.

Then, using Eq. 1 and Eq. 2:

$$\frac{V_{TH}}{R1} = \frac{V_{OL} - V_{TH}}{R2} + \frac{V_{DACH} - V_{TH}}{R3} \quad (3)$$

So, when $V_{OUT} = V_{OH}$, then $V_{DAC} = V_{DACL}$, where V_{OH} = highest output voltage and V_{DACL} = zero-scale DAC voltage.

Again, using Eq. 1 and Eq. 2:

$$\frac{V_{TH}}{R1} = \frac{V_{OH} - V_{TH}}{R2} + \frac{V_{DACL} - V_{TH}}{R3} \quad (4)$$

Substituting and solving for R1, R2, and R3 yields:

$$R1 = \text{fixed} \cong 10\ k\Omega \quad (5)$$

$$R2 = \frac{R1}{V_{TH}} \times \left[\frac{\left(\begin{array}{c} V_{DACH} \times (V_{OH} - V_{TH}) + V_{DACL} \times \\ (V_{TH} - V_{OL}) - V_{TH} \times (V_{OH} - V_{OL}) \end{array} \right)}{V_{DACH} - V_{DACL}} \right] \quad (6)$$

$$R3 = \frac{R1 \times R2 \times (V_{DACL} - V_{TH})}{R1 \times (V_{TH} - V_{OH}) + R2 \times V_{TH}} \quad (7)$$

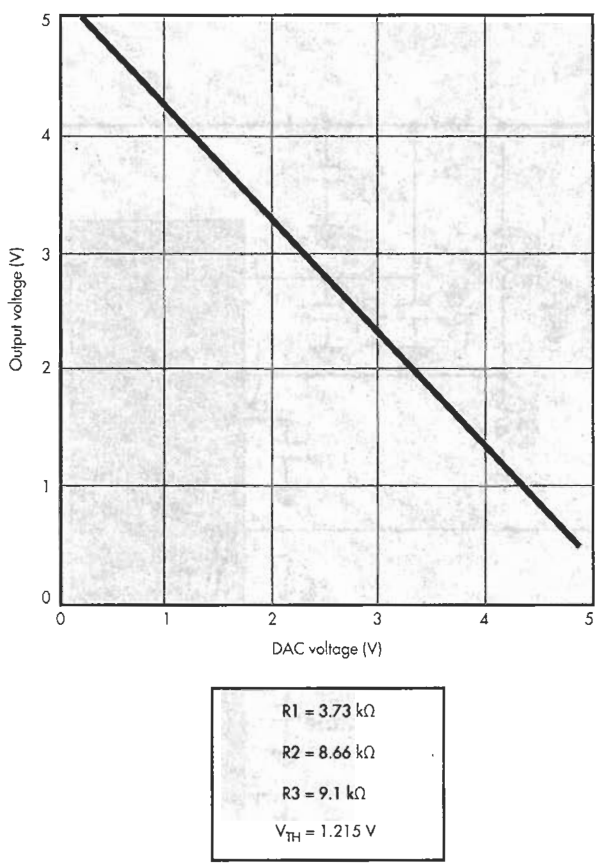
The circuit in Figure 2 uses the LM5116 power-supply controller, which has a threshold voltage of 1.215 V, to generate an arbitrary dynamic output voltage ranging between 0.6 V and 5.1 V. The output voltage is adjusted by the DAC081S101, which swings between 0 V and a reference of 5 V. The calculated resistor values for this example are R1 = 3.73 kΩ, R2 = 8.66 kΩ, and R3 = 9.1 kΩ.

Returning to the fundamental equations, you can calculate V_O as a function of the DAC voltage, V_{DAC}:

$$V_O = R2 \left[\left(\frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3} \right) \right] \times V_{TH} - \frac{1}{R3} \times V_{DAC} \quad (8)$$

The format of Eq. 8 is y = mx + b, which proves that the output voltage is a linear function of the DAC voltage. Figure 3 plots the measured output voltage versus the DAC voltage for the example resistor values calculated above.

When using this method to control your output voltage, ensure that the DAC can drive the chosen resistor values. A unity-gain operational amplifier may be needed to buffer the DAC output. Alternatively, choosing resistor values in excess of 10 kΩ allows just about any DAC to meet this requirement. If you plan to program the output voltage to a value below that of the controller threshold voltage, the DAC must be able to drive a voltage higher than the threshold voltage.



3. The output voltage of the power converter with respect to the DAC voltage is a linear function and thus easily controlled with a general-purpose microcontroller.

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D-a converter controls programmable power source

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The output of an integrated-circuit regulator can be digitally controlled to generate any number of voltages for use in testing components or equipment. A digital-to-analog converter transforms the digital value into a current, and the current is converted to a linearly proportional voltage.

As shown in the figure, the Analog Devices' MDA-10Z-110 converter generates an output current of 0 to 2 milliamperes with a resolution determined by its 10-bit digital input. This current is transformed to an output voltage of 0 to 6 volts by the following 741 operational amplifier. The 723 is adjustable over a wide voltage range (7 − 37 volts), and for use as a 2-to-22-v regulator it requires a linear controlling voltage.

The 2N4351 field-effect transistor operates as a voltage-controlled resistor to produce voltage V_{REF}, which is essentially equal to the voltage across resistor R_6 and is linearly proportional to the digital input to the d-a converter.

The 723 was designed so that its output voltage is equal to an input voltage times a factor determined by gain-controlling resistors placed in a feedback loop. Thus, its characteristic equation may be expressed by:

$$V_o = KV_{REF}$$

where K is equal to $1 + R_1/R_2$.

The 723 yields a load regulation of 0.02% and a line voltage regulation of 0.01% at output currents of up to 150 milliamperes. This excellent performance is made possible by the error-control amplifier in the 723, which compares V_{REF} to the scaled-down voltage derived by the resistor feedback network R_1 and R_2. Resistor R_{sc} is used in a current-limiting capacity. A value of R_{sc} = 30 ohms will limit the output current to 20 milliamperes; a value of R_{sc} = 4 ohms limits the output current to its rated maximum of 150 milliamperes. External transistor circuitry can be added to easily extend the load current capacity. □

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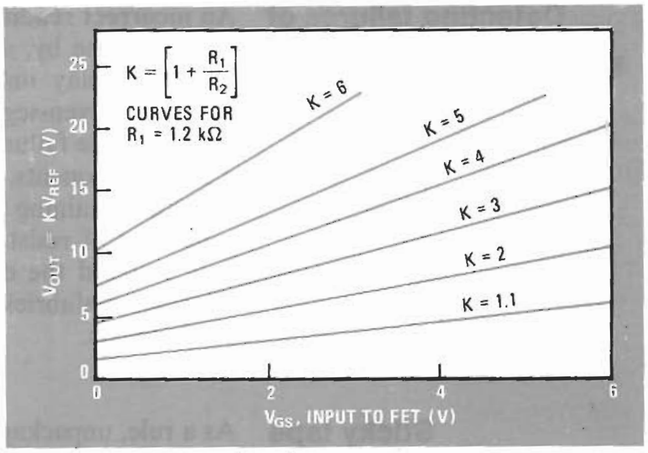
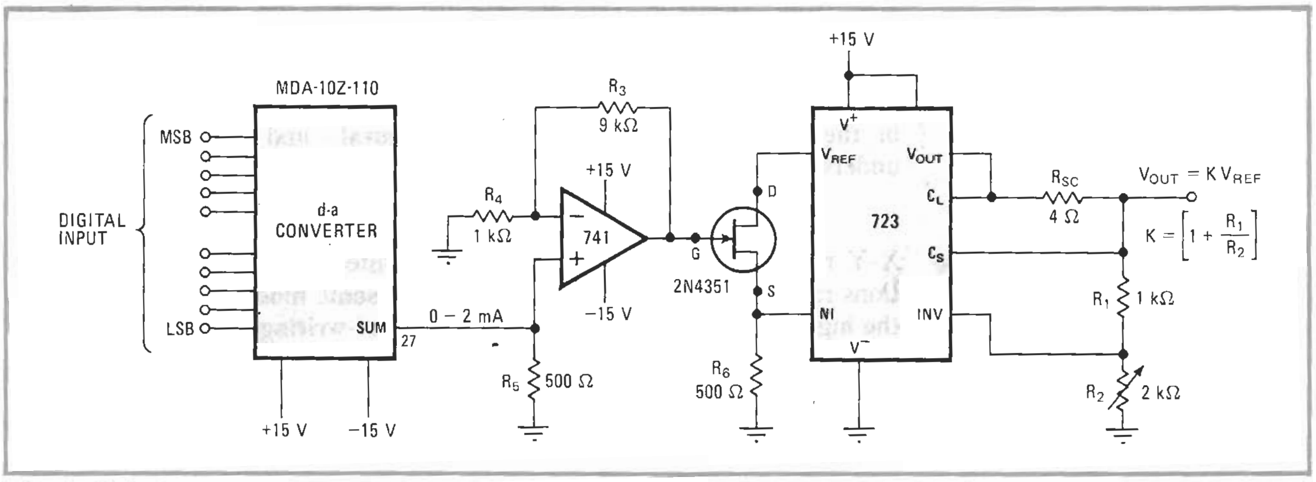


2. Characteristic equation. Relationship of scale factor K to V_{out}, V_{GS} is linear as shown by curves. Scale factor is controlled by resistor feedback network at regulator output. FET, used as voltage-controlled resistor, assures output voltage is proportional to K.



1. Controlled voltage generator. Digital-to-analog converter determines output voltage of regulator when FET is used as a voltage-variable resistor. If digital source is computer, specified voltages may be generated for automatic testing of components.