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Keywords: power supply, calibrate, calibration, voltage reference, digital potentiometer, digipot, mechanical potentiometer, resistive feedback

APPLICATION NOTE 4936

Calibrating a Power Supply with a Digital Potentiometer

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Apr 20, 2012

Abstract: A resistive feedback network is often used to set the output voltage of a power supply. A mechanical potentiometer (pot) conveniently solves the problem of adjusting a power supply. For easier automatic calibration, a mechanical pot can be replaced with a digital pot. This application note presents a calibration solution that uses a digital pot, because digipots are smaller, do not move with age or vibration, and can be recalibrated remotely. This proposed solution reduces the susceptibility of the system to the tolerance of the digital pot's end-to-end resistance, making the solution optimal for designers. This application note also explains some of the equations required to calculate the resistor chain values and to use a digital pot in this way. A spreadsheet with standard resistor values is available for easy calculations.

A similar version of this article appeared on [Power Management DesignLine](#), February 2012.

Introduction

A resistive feedback network is often used to set the output voltage of a power supply, since fixed resistors are simple to use and low cost. However, because a fixed network is not adjustable, the output voltage cannot be accurately set. Therefore, many power supplies use a mechanical potentiometer (pot) in the feedback network to set the output voltage. For easier automatic calibration, a mechanical potentiometer can be replaced with a digital potentiometer. Digital potentiometers are smaller, do not move significantly with age or vibration, and can even be recalibrated remotely. This application note explains some of the calculations required to use a digital potentiometer in this way and also provides a spreadsheet for easy calculations.

Conventional Power-Supply Feedback

A power supply often uses resistive feedback to set the output level. However, because there are many device tolerances that can affect the output voltage, a fixed resistor-divider is often insufficient. In these situations, a variable-resistor ratio is used so the system can be calibrated in final testing.

Although a mechanical potentiometer would have traditionally been used, those components have been replaced by digital potentiometers in many applications. Digital pots do not suffer from significant aging effects and are far simpler to adjust automatically in final tests.

Fixed-resistor and mechanical-potentiometer schemes are shown in **Figures 1 and 2**.

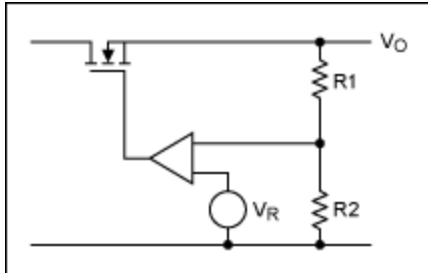


Figure 1. A conventional fixed-resistive feedback.

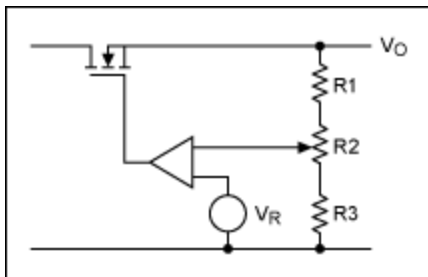


Figure 2. A conventional variable-resistive feedback.

Take the typical example of a 12V supply with a 2.5V reference voltage. The reference voltage and all other devices in the system will have a tolerance. Conveniently, all tolerances can be represented as additional tolerance on the reference. For this example, we will use a $\pm 5\%$ typical total tolerance for the reference.

Calculating the values for a fixed resistive feedback is based on an easy equation:

$$V_O = V_R \times \frac{R_1 + R_2}{R_2} \quad (\text{Eq. 1})$$

Since in this example, V_R will have a tolerance of $\pm 5\%$, this leads to a tolerance in the output voltage of 5%. If this is not acceptable in the application, the resistive-divider needs to be made variable. Replacing R_1 and R_2 with a mechanical potentiometer is not normally done, since it would result in a wide range of output voltages and would be very sensitive to adjustments. Over time and temperature, any drift in the pot's position would create an unacceptable amount of output voltage drift. Therefore, Figure 2 illustrates a scheme that reduces the output range, which is now easier to adjust and is more stable.

Hypothetically, we should be able to replace R_2 with a digital pot, and we should have an electrically adjustable system. However, it is not as simple as that. First, some explanation of digital pots is required.

Basic Structure of Digital Pots

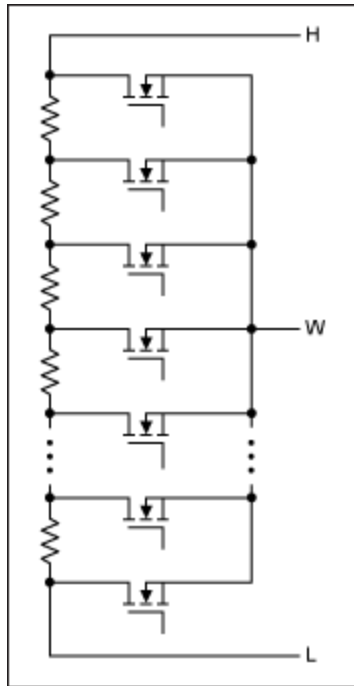


Figure 3. Typical digital potentiometer structure.

A digital pot is normally a string of resistors with a switch at each node, as shown in **Figure 3**. For simplicity, the switches are shown as single MOSFETs. Typically, these switches would be two BiCMOS transistors (one "P" and one "N") to produce low on-resistances.

This structure is commonly used for pots up to 256 taps. When the pot is above 256 taps, it can be more efficient to use a more complex segmented structure. However, that is beyond the scope of this application note.

Since all resistors are manufactured on the same die, they will be very closely matched. Unfortunately, the end-to-end resistance may not be so well defined. A typical digital pot is the [MAX5402](#), a single-channel, 256-tap device with end-to-end resistance of 10k Ω (typ). The end-to-end resistance tolerance, however, is $\pm 20\%$. Ratiometrically, it is far better defined with integral nonlinearity (INL) of 0.5 LSB (max). It is, therefore, well suited to be used as a potential divider.

Using the Digital Pot to Calibrate a Power Supply

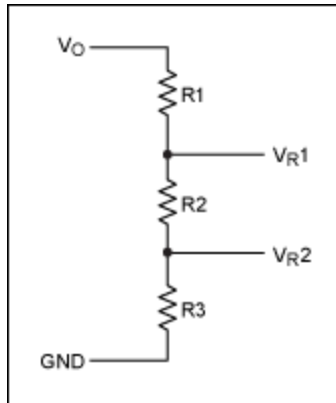


Figure 4. The initial resistor string.

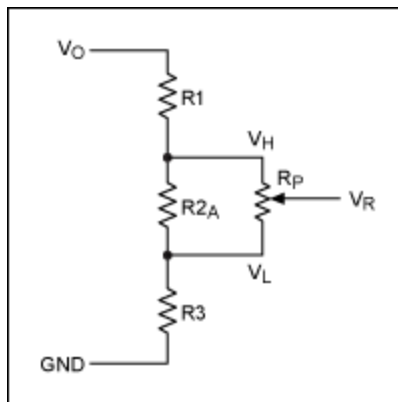


Figure 5. The final resistor string.

The method to calculate the resistor values R_1 , R_2 , and R_3 , is shown in **Figure 4**. We will use the following example:

$$V_O = 12V$$

$$V_R = 2.5V \pm 5\%$$

$$R_T = R_1 + R_2 + R_3$$

The initial equations are simple and defined below:

$$V_{R2} = V_O \times \frac{R_3}{R_T} \Rightarrow R_3 = \frac{V_{R2} \times R_T}{V_O} \quad (\text{Eq. 2})$$

$$V_{R1} = V_O \times \frac{R_2 + R_3}{R_T} \Rightarrow R_2 = \frac{V_{R1} \times R_T}{V_O} - R_3 \quad (\text{Eq. 3})$$

$$R_1 = R_T - R_3 - R_2 \quad (\text{Eq. 4})$$

The first step is to define a total resistance for R_T , using $(R_1 + R_2 + R_3)$. Since this is arbitrary, we'll start with $R_T = 20\text{k}\Omega$. (We can always change it later to give more realistic values for R_1 , R_2 and R_3 if required.) From Equation 2, we find $R_3 = 3.598\text{k}\Omega$. From Equation 3, $R_2 = 417\Omega$, and from Equation 4, $R_1 = 15.625\text{k}\Omega$.

Clearly the ideal resistor values calculated will not generally be available, so standard resistor values need to be used. The closest 1% values are substituted for R_1 and R_3 : $R_1 = 15.8\text{k}\Omega$, $R_3 = 3.92\text{k}\Omega$. (For convenience, we have included standard resistor value charts in the [spreadsheet](#).)

Now we can calculate backward to find an ideal value for R_2 , as shown in Equation 5. R_2 will eventually become variable. Thus, its value is calculated so that V_O will be correct when R_2 is centered and V_R is at its nominal value.

$$R_2 = \frac{V_O \times R_3 - V_R \times R_3 - V_R \times R_1}{V_R - V_O/2} \quad (\text{Eq. 5})$$

Therefore, $R_2 = 646\Omega$.

We need to account for the fact that digital pots have a very poor end-to-end tolerance. Using a large-value digital pot in parallel with a small-value fixed resistor is a simple method of reducing the effect of the pot's poor end-to-end tolerance. This is illustrated in **Figure 5**. Thus, the parallel combination of R_{2A} and R_P makes R_2 .

Using Equation 6, the final step is to calculate the value of the parallel fixed resistor, given a potentiometer nominal end-to-end resistor.

$$R_{2A} = \frac{R_P \times R_2}{R_P - R_2} \quad (\text{Eq. 6})$$

So, using a $10\text{k}\Omega$ pot for R_P , the ideal value for R_{2A} is 690Ω . The closest 1% value is 698Ω . If we calculate the parallel combination of this and the digital pot at its tolerance extremes, we get $R_{\text{MIN}} = 642\Omega$ and $R_{\text{MAX}} = 660\Omega$. This is a tolerance of only 1%, due to the 20% end-to-end tolerance of the pot. We use a 698Ω resistor for R_{2A} , as this is the closest standard 1% value.

The final calculation confirms that with real values, the digital pot can cover the required range of 5% for the reference tolerance. We can use the star-delta transformation, as shown in **Figure 6**. We obviously do not need to calculate R_6 .

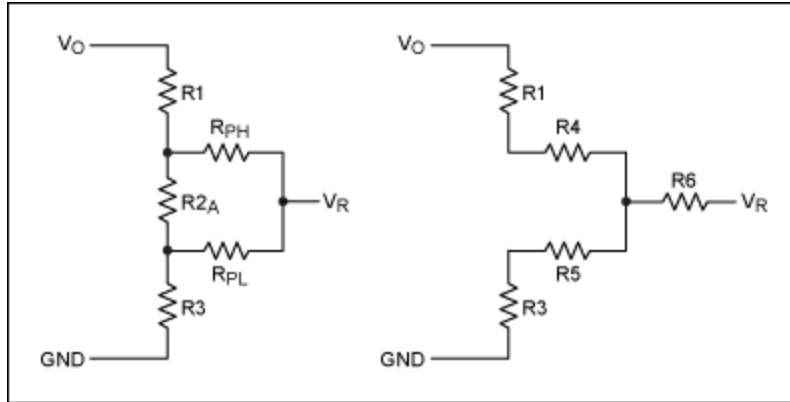


Figure 6. Using the star-delta transformation.

$$R_{PL} = \frac{R_P \times N}{N_{MAX}} \quad (\text{Eq. 7})$$

Where N is the tap position and NMAX is the maximum tap position.

$$R_{PH} = R_P - R_{PL} \quad (\text{Eq. 8})$$

$$R_4 = \frac{R_{PH} \times R_{2A}}{R_{2A} + R_{PH} + R_{PL}} \quad (\text{Eq. 9})$$

$$R_5 = \frac{R_{PL} \times R_{2A}}{R_{2A} + R_{PH} + R_{PL}} \quad (\text{Eq. 10})$$

$$V_O = \frac{V_R \times (R_1 + R_3 + R_4 + R_5)}{R_3 + R_5} \quad (\text{Eq. 11})$$

Using these equations, we confirm that the pot's range will cover the tolerance range for the reference.

To summarize the requirements and the component values selected:

- $V_O = 12V$ (output voltage)
- $V_R = 2.5V \pm 5\%$ (reference voltage)
- $R_1 = 15.8k\Omega$ (upper resistor)
- $R_{2A} = 698\Omega$ (parallel resistor)
- $R_P = 10k\Omega$ (digital potentiometer)
- $R_3 = 3.92k\Omega$ (lower resistor)

The following tap points set the required output voltage at the extremes of reference tolerance.

- $V_R = 2.375V$, tap = 44, $V_O = 11.99842V$
- $V_R = 2.625V$, tap = 210, $V_O = 11.99773V$

It may be possible to optimize this further to reduce the output voltage steps. However, the potentiometer does have some overhead at either end to take account of any further tolerances.

Summary

This application note discussed the problem of adjusting a power supply and how this problem can be solved with a mechanical pot. Additionally, the article explains a calibration solution that uses a digital pot, since digital pots are smaller, do not move with age or vibration, and can be recalibrated remotely. This proposed solution also reduces the tolerance of the digital potentiometer's end-to-end resistance, making the solution optimal for designers. The equations required to calculate the resistor chain values were developed and a spreadsheet is available that contains standard resistor value charts.

Related Parts

[MAX5402](#)

256-Tap, μ PoT Low-Drift, Digital Potentiometer

[Free Samples](#)

More Information

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