

## APPLICATION NOTE 1956

## Tips to Remember When Designing with Digital Potentiometers

*Abstract: This article discusses some of the key issues and common questions that arise when designing with digital potentiometers. Topics include wiper current (and how it affects dynamic range), wiper voltages, and temperature coefficients. Tips on how to reduce or eliminate unwanted errors are also included.*

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This article highlights some of the key issues to address when designing with digital pots.

### Configuration

One of the biggest issues when using a digital pot is whether to use it in a true potentiometer (three-terminal) or in a variable resistor (two-terminal) configuration. The circuits for these configurations are shown in **Figures 1** and **2**. There are pluses and minuses involved with each of these circuits.

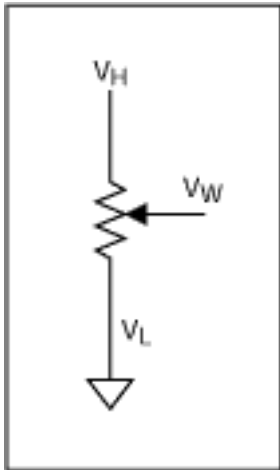


Figure 1. Three-terminal configuration.

First, if possible, it is usually better to use the device in the true potentiometer configuration. There are several advantages to this, not least of which is the control that the designer has over the load on the wiper. When connected as a potentiometer, the device is used in a three-terminal configuration as shown in Figure 1. By connecting the wiper to a high impedance node, the current flowing through the wiper can be kept very low.

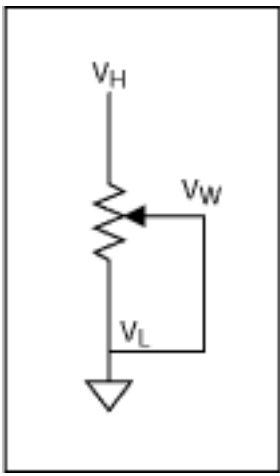


Figure 2. Two-terminal configuration.

In contrast, looking at the variable resistor, or two-terminal, configuration the wiper may now be required to carry significant currents. This is especially true when the wiper is near the high side of the pot with the low side of the pot grounded and connected to the wiper, as shown in Figure 2. Depending on the voltage applied to the pot and the wiper resistance, the designer must be careful not to exceed the maximum current ratings into/out of  $V_H$  and  $V_W$  under these conditions.

## Wiper Current

Once that problem has been taken into account, there are a few other issues involved with drawing significant currents through the wiper in either of the above-mentioned configurations. For reference, talking about "significant" currents refers to values of hundreds of microamps and up to 1mA. Depending upon the potentiometer chosen, the wiper may have a resistance anywhere from tens of  $\Omega$  to over 1Kohm. If 1mA of current is drawn through a 1Kohm wiper, the resulting voltage drop across the wiper is 1V! This may severely limit the dynamic range of the desired output signal, so design wisely.

## Wiper Voltage and Temperature Coefficients

Another design complication involving the wiper is output error due to the voltage coefficient of the wiper. The wiper is made up of CMOS switches and therefore exhibits the same characteristic of a varying resistance with respect to the applied voltage. This means that as the voltage on the wiper varies, either due to a change in wiper position or from an applied AC signal, the resistance of the wiper itself varies nonlinearly. As a result, any significant current flowing through the wiper will then cause distortion and output error due to the voltage drop across the wiper's nonlinear, varying resistance.

One more characteristic of the wiper that may cause subtle errors in precision applications is its associated temperature coefficient. Digital pot data sheets usually state a temperature coefficient relative to the resistor string itself. This specification, however, does not give any indication of the temperature coefficient associated with the wiper resistance. This particular specification is usually not listed in the data sheet. However, since the wiper is made up of CMOS switches, a rough estimate of about 300ppm/C can often be assumed for its temperature coefficient. Since the wiper resistance is usually small in comparison to the overall pot resistance, this error is minor but may still be noticeable in some applications if high wiper currents exist.

As for the overall temperature coefficient of the pot, this specification is usually given as an absolute and ratiometric value. The absolute tempco is much higher than the ratiometric tempco and it is best exhibited in the two-terminal configuration of Figure 2.

Here, the resistance between the high side of the pot and the wiper will vary by the value of the absolute tempco over the rated temperature range of the device. However, in the three-terminal circuit of Figure 1, the resistance between the high side of the pot and wiper will vary over temperature at approximately the same rate as the resistance between the wiper and the low side of the pot. This makes for a much more relatively stable resistive divider and is specified as the ratiometric tempco.

## Summary and Applications

As shown here, there may be multiple factors involved in output signal errors in digital potentiometers. These errors become even more apparent as the wiper approaches the H terminal in a two-terminal configuration. Here the wiper resistance adds directly to the desired resistance and may even be larger than the desired resistance setting depending on the value of the total pot resistance and the resolution of the pot.

There are many applications where the errors contributed by thermal and various wiper characteristics are trivial. When used for adjusting power supplies or the contrast to an LCD display all of these error sources may be unimportant but in some temperature sensitive and precision applications they warrant consideration.

One cure to all of the above issues is to use the digital potentiometer in a three-terminal configuration when possible and to buffer the wiper with an op amp. This circuit will ensure that the wiper current is equivalent to the input bias current of the op amp. By using an op amp with an input bias current spec in the picoamps, any errors due to the value or changes in the value of the wiper resistance are virtually eliminated. Sometimes this solution does not look appropriate, especially in a transimpedance amp where the pot is used as the variable feedback resistor. However, using a Tee network for the feedback resistor, as shown in **Figure 3**, allows the designer to use the pot in a three-terminal configuration and take advantage of its benefits. So, be creative in your designs as there is usually a way to use digital pots in their true, three-terminal form. If the two-terminal circuit is preferred or required just be careful to account any thermal and wiper errors, if warranted by your design criteria.

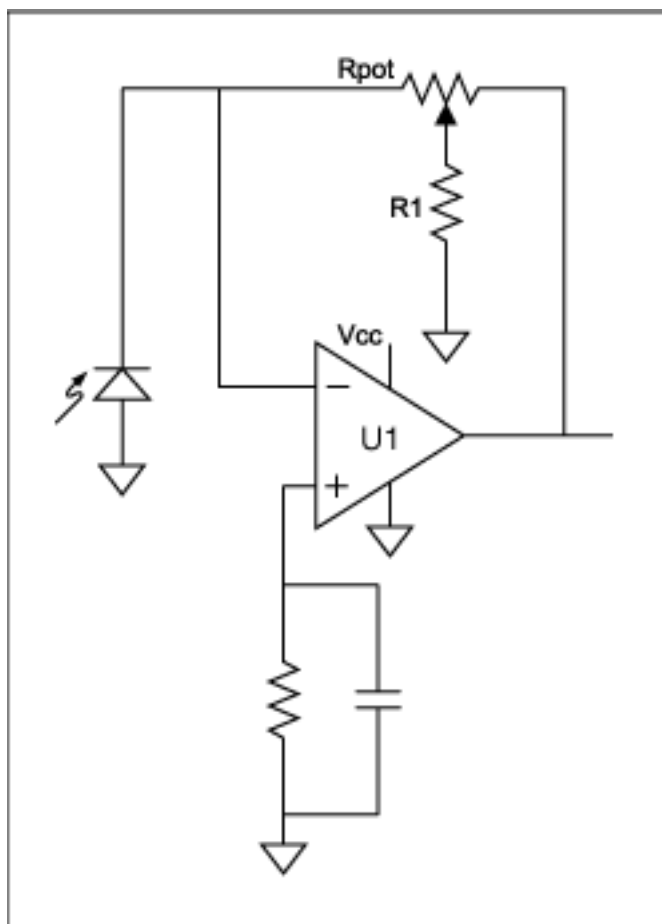


Figure 3. TEE network for PIN transimpedance amp.

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