Replacing Digital Potentiometers with Precision DACs

When Can a Digital Potentiometer (DPOT) be Replaced by a Precision Digital-to-Analog Converter (DAC)?

This seems like a simple question, but to thoroughly understand the trade-offs of replacing a DPOT with a DAC, it is important to understand the difference between the two device types and how they are used.

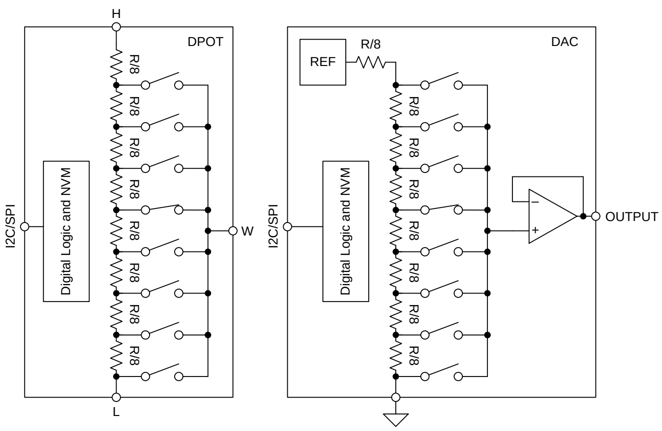

Figure 1.

A DPOT is a digitally controlled IC that mimics a manual predecessor: the potentiometer. It consists of a resistor string and switches that connect the out (also called the "wiper") to the tap points on the string. A controller that interprets digital commands sets the switches, which connect the wiper to the desired tap point. The ends of the DPOT string can be connected to external voltages, and are usually called the H node and the L node. Some DPOTs have additional features, such as non-volatile memory and shutdown controls. DPOTs are used in many applications where a ratiometric voltage bias is created, such as:

- LED biasing in automotive interior lighting
- Stepper motor torque control in multifunction printers
- Calibration trimming in aerospace and defense applications
- Programmable comparators in grid infrastructure
- Industrial transport
- Medical applications.

In some respects, a DAC can be thought of as a DPOT. A DAC also consists of a resistor string (or ladder), and it has switches that connect to various points of the string (or ladder) to the output. It also contains a digital interface that controls the switches. However, a majority of DACs include an output buffer. In addition, some DACs also include a reference, and a reference buffer. The reference buffer ensures that the voltage of the DAC output is known, while the output buffer allows for current drive capability.

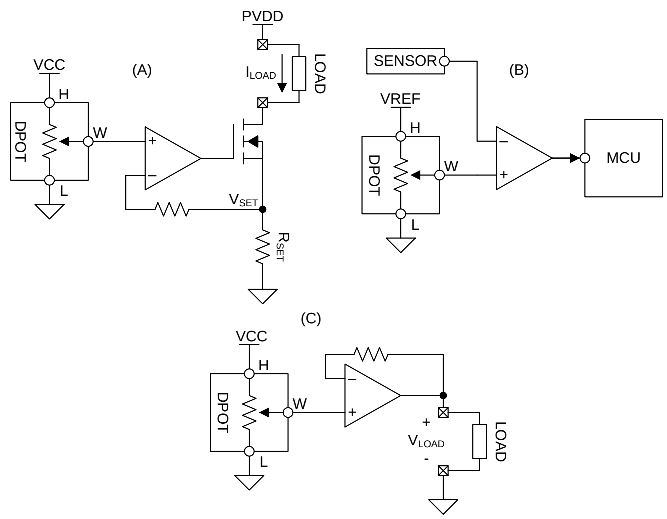

Figure 2.

How are DPOTs Used?

DPOTs have many applications where they are well-suited. For example, they can be used as a resistor divider of a static (or dynamic) voltage resistor divider, or as a variable resistor in an op amp feedback network. But there are some systems where both a DAC and a DPOT offer advantages. For example, when DPOTs are used to provide a programmable bias for a controlled voltage source, a programmable reference voltage for a comparator, or a controlled source (or sink current).

Circuit A in Figure 2 shows the controlled source (or sink current) with a DPOT. These currents can be used to excite a sensor, act as a controlled current for calibration, or even bias an LED for a controlled brightness level. These circuits require an external amplifier to compensate for the gate-source voltage (also called the V_{GS}) of the MOSFET transistors so they can adjust the gate voltage of the MOSFET. This ensures the correct voltage is dropped across the reference resistor, R_{SET}, and the voltage output is converted to the desired load current.

Circuit B in Figure 2 is a sensor voltage being connected to an input of a comparator. The DPOT is used to divide a known voltage reference as the other input of the comparator. This allows the DPOT to provide a programmable threshold for the comparator, which is useful for adjustable alarm or warning flags.

Circuit C in Figure 2 shows a controlled voltage bias. The DPOT wiper output is high-impedance, meaning that any current draw from the load skews the output voltage. An external amplifier is used to buffer the DPOT output to source any required load current.

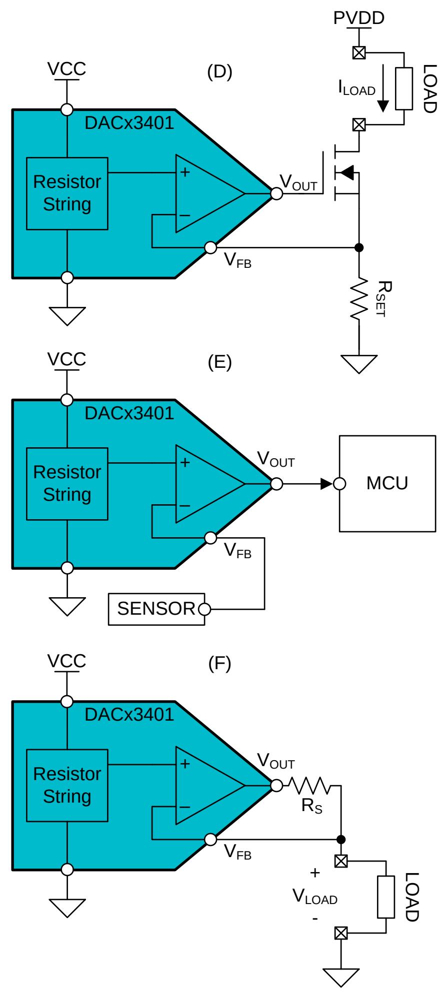

Figure 3.

Replacing a DPOT with a Precision DAC

The main drawback for DPOT circuits is that they require an op amp to act as a buffer. These amplifiers create additional complexity to the circuit, take up additional board space, and add extra cost to the system. The benefit of using a precision DAC in these applications is that the buffer is included with the device, which reduces system cost and complexity.

The DACx3401 family of devices further improves on these advantages by offering an additional feature: access to the feedback pin of the integrated op amp. As seen in circuit D of Figure 3, this additional pin allows for the amplifier to compensate for the V_{GS} voltage of the MOSFET transistor. This same feedback node also allows the integrated op amp of the DACx3401 to replace the comparator in circuit E. Finally, the feedback node enables the buffer to compensate for series resistance by acting as a voltage sense, as seen in circuit F. This is particularly useful for capacitive loads where a series resistor needs to be added to the output to ensure stability.

The inclusion of an internal, non-volatile memory, similar to that of DPOT devices, makes the DACx3401 a very good fit for calibration and biasing applications. The non- volatile memory can store DAC codes. This enables the DAC to start up with the previous settings, and without communication from the micro-controller. For such systems, the DAC codes need to be set only once. Most DPOTs are limited to 64 to 256 tap points, while the DAC43401 and DAC53401 feature 8- and 10-bit resolution, or 256 and 1024 steps, respectively. This higher resolution allows for finer adjustments of the bias voltage, current, or calibration value.

The DACx3401 is available in a tiny 2 mm x 2 mm package, which makes it an ideal choice for space-constrained applications.

Conclusion

In applications where a DPOT is used to provide a static bias for a voltage or current reference, like in most calibration circuits, it can generally be replaced by a precision DAC. The DACx3401 offers an excellent alternative, as it only occupies 4 mm^2 of PCB space and has:

- 10- or 8-bit resolution
- An integrated output buffer
- A reference
- Non-volatile memory
- A feedback pin

Table 1. Alternative Device Recommendations

DEVICE	OPTIMIZED PARAMETERS	PERFORMANCE TRADE-OFF
DAC43401	1-ch, 8-bit, non-volatile memory, 2 mm × 2 mm, feedback pin	Single channel
DAC53401	1-ch, 10-bit, non-volatile memory, 2 mm × 2 mm, feedback pin	Single channel
DAC43608	8-ch, 8-bit, 3 mm × 3 mm	No non-volatile memory, no feedback pin

Related Tech Notes

- Texas Instruments, *DACx3608 Delivers Programmable LED Array Biasing Solution at Ultra Low Cost and Smallest Footprint*
- *DACx3401 Delivers Ultra-Compact Automotive and Commercial LED and LASER biasing Solution*