CMOS DACs act as digitally controlled voltage dividers

John Wynne and Liam Riordan, Analog Devices, Limerick, Ireland

Digital potentiometers, such as Analog Devices' (www.analog.com) AD5160, make excellent digitally controlled voltage dividers in applications in which 8-bit resolution is acceptable. This Design Idea shows how to use a CMOS DAC as a voltage divider in applications requiring higher resolution.

Millions of CMOS R2R (resistor/two-resistor)-ladder DACs have found use in attenuator applications in which an external op amp acting as a current-to-voltage converter forces one current-output terminal to a virtual ground. The reference input to the DAC can be ac or dc as long as the op amp can produce the desired output voltage. A phase inversion is normal between input and output, so the circuit requires dual power supplies.

Figure 1 shows a way to rewire this simple circuit to avoid the phase inversion and to operate with a single supply. In this configuration, the DAC acts as a digitally programmable resistor, and the DAC's code changes the effective resistance between the input voltage and the I_{OUT1} output-current terminal of the DAC. **Figure 2** shows a practical implementation using one-half of an Analog Devices AD5415 dual 12-bit current-output DAC operating as a voltage divider. This **figure** omits the DAC's control lines for clarity. Op amp A_1 forces the voltage on the I_{OUT2A} output-current terminal to follow the voltage on the I_{OUT1A} output-current terminal. This approach prevents a voltage differential from developing between these two bus lines, which would result in the application of different gate-source voltages across the internal DAC switches and a deterioration in the DAC linearity.

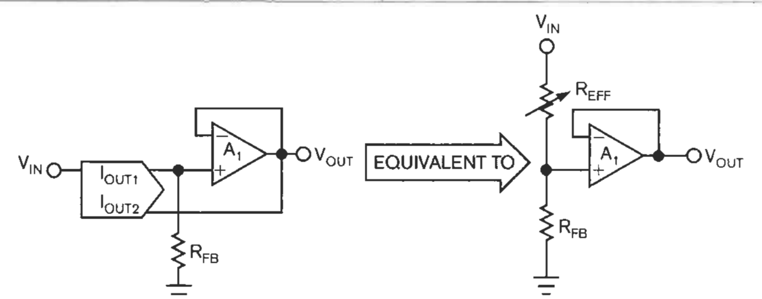

Figure 1 This simple circuit avoids a phase inversion and operates with a single supply. In this configuration, the DAC acts as a digitally programmable resistor.

Wire the split-feedback resistors, R_{FB} and R_1, to produce a composite-feedback resistor equal in value to the DAC's ladder impedance, R. For this arrangement the circuit-transfer function is $V_{OUT}/V_{IN}=(R)/(R_{EFF}+R)$, where R_{EFF} is the effective DAC resistance that is under digital control. Its value is $R(2^n)/N$, where n is the resolution of the DAC and N is the binary equivalent of the digital-input code. Substituting the second **equation** into the first and assuming zero DAC gain error, the circuit-transfer function for a 12-bit DAC reduces to $V_{OUT}/V_{IN}=1/(1+4096/N)$. With all switches off, the effective impedance between the reference voltage and the I_{OUT1A} terminal is infinite, so the output voltage starts at 0V when you load zeros into the DAC. The output voltage increases linearly with increasing code, ideally to approximately half the input with all ones applied to the DAC.

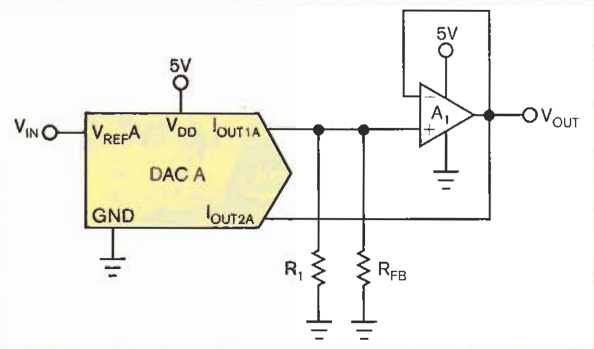

Figure 2 This practical implementation of the circuit in Figure 1 uses one-half of a 12-bit-current-output AD5415 dual DAC that operates as a voltage divider.

The threshold voltage of the DAC's internal N-channel-CMOS switches limits the maximum value of the output voltage, so not all configurations can achieve the full code range. The switch-gate voltage remains at the V_{DD} voltage, and the switch-source voltage rises with the voltage on I_{OUT1A}. As this voltage increases, the on-resistance of the switches becomes large and indeterminate, leading to a flattening of the output voltage and the cessation of the circuit as a predictable voltage divider. For proper operation, the V_{DD} voltage must be a few volts higher than the maximum output voltage—that is, half the input voltage. Otherwise, the input voltage must be less than two times the V_{DD} voltage minus 3V. With a V_{DD} voltage of 5V, the AD5415 operates linearly to approximately a 3.33V output but then flattens. If a wider output-voltage range is necessary, you could use Analog Devices' AD7541A, which uses a 15V power supply, in place of the AD5415. This substitution extends the usable output-signal range to approximately 7V. EDN