Dual Digital Pot Creates Accurate, Temperature-Stable Amp

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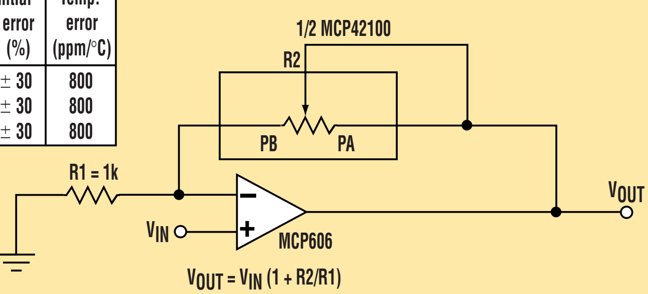
CIRCLE 520

Programmable Gain Range				
Digital Code	R_2^* value (kΩ)	Gain* (V/V)	Initial* error (%)	Temp. error (ppm/°C)
3	1.17	2.17	± 30	800
127	49.6	50.6	± 30	800
255	99.6	100.6	± 30	800

* assuming $R_W = 0$



1. The thermal performance of a simple gain circuit using a digital potentiometer in this configuration is typically 800 ppm/°C.

Digital potentiometers enable systems designers to program resistive values in the circuit during initial calibration or even later on, during normal operation of the circuit. This ability permits the dynamic alteration of the circuit conditions, creating a "smart" analog system that can respond to the surrounding environment. In fact, the programmability feature seems all too promising; as usual, suspicious analog engineers will expect that this advantage is not for free. And, they are right.

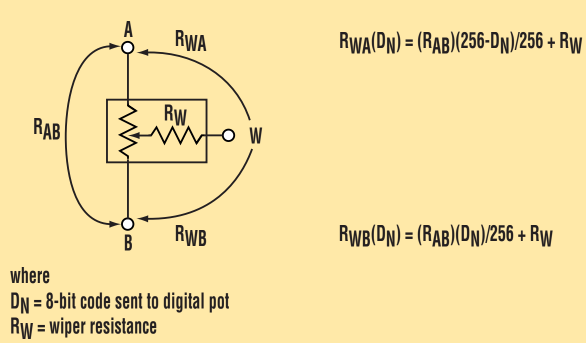
Initial examination of the temperature performance of today's array of digital potentiometers shows that the devices perform with much less accuracy than the standard mechanical potentiometer or discrete resistor combinations. Certainly, the temperature performance of these digital potentiometers is much less than ideal.

But, the clever designer can take advantage of secondary temperature behavior by using the matching characteristics of these devices. The resistive material of current digital potentiometers is predominantly fabricated with the poly-diffusions (soon to be nichrome) of CMOS processes. Because these resistors are manufactured using poly-diffusions, the resistive elements are not trimmed precisely. Consequently, the initial accuracy of the digital potentiometer from part to part at room temperature is ±30% maximum. The thermal-drift specifications for these types of diffusions are either 800 or 500 ppm/°C, depending on the poly level used for the resistive element. With these specifications, it is easy to see that the simple gain circuit shown will have poor performance over temperature *(Fig. 1)*.

In the circuit in Figure 1, the noninverting gain is established using a standard resistor for R1 and a 256-tap, 100-kΩ digital potentiometer (an MCP42100 from Microchip Technology) positioned as R2. The gain of this circuit is determined by the ratio of R1 and R2 as stated in the formula in Figure 1. The amplifier (an MCP606) is a single-supply CMOS amplifier with a low offset voltage (± 250 µV, max.) and high input impedance (1 pA, typical at 25°C). The lower offset of this amplifier allows for gain changes with a minimal increase in offset errors translating to the output of the amplifier.

The key specifications of the digital potentiometer in Figure 1 in regard to this application are the nominal initial resistance (100 kΩ ±30%, max.) and the change in resistance over temperature (800 ppm/°C, typical). Both of these specifications can cause a significant error in the system, limiting the applications for this circuit. The nominal resistor values of this digital potentiometer are easily calculated using the formulas shown in Figure 2.

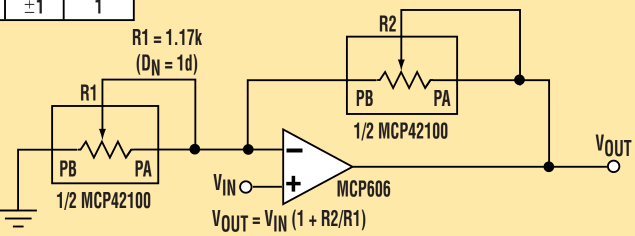
An alternative circuit that addresses both the accuracy and temperature-performance issues of the Figure 1 circuit is shown in Figure 3. In this circuit, a dual digital potentiometer is used to fill



2. The resistance values of the digital pot can be defined as shown.

Programmable Gain Range				
Digital Code	R_2^* value (kΩ)	Gain* (V/V)	Initial* error (%)	Temp. error (ppm/°C)
3	1.17	2.17	±1	1
127	49.6	50.6	±1	1
255	99.6	100.6	±1	1

* assuming $R_W = 0$



3. The intrinsic matching of a dual digital pot is used to achieve an initial gain accuracy of ±1% (max.) and a typical temperature coefficient of 1 ppm/ °C.

both resistor positions in the circuit. Since both resistor elements are on the same IC, their nominal matching and temperature-drift characteristics are closely matched.

Now, instead of an initial gain accuracy of ±30%, the initial gain accuracy of the circuit becomes ±1% maximum. The gain accuracy over temperature is also tightened with this topology from the previous typical performance of 800 ppm/°C to 1 ppm/°C.

With a little attention to circuit design detail, the temperature behavior of digital potentiometers can be optimized using these simple design techniques.

Multiple Serial Devices Interface To The I²C Bus

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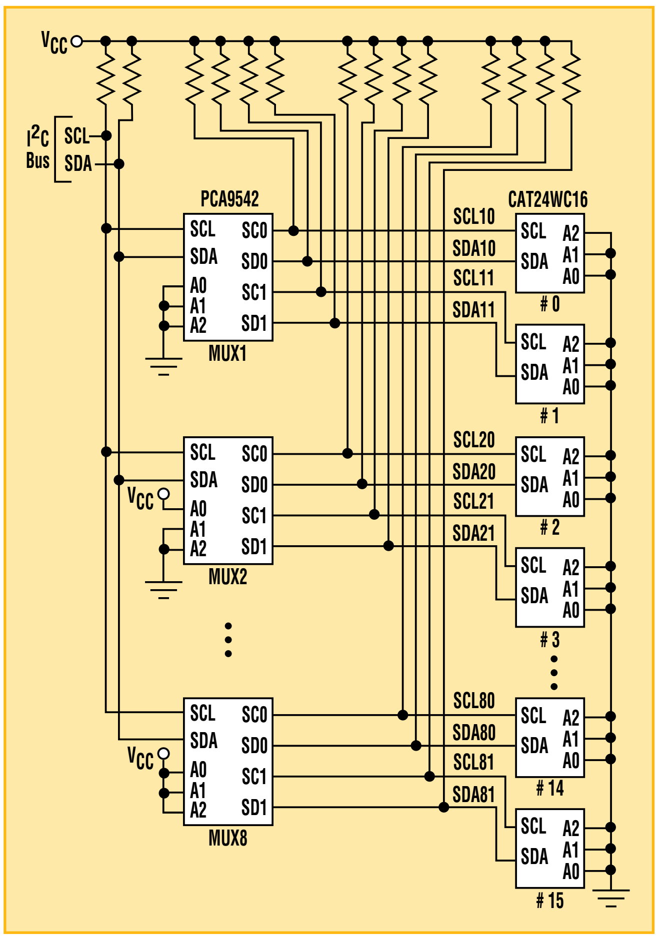
The circuit shown can be used to interface multiple serial devices to the I²C bus, even if they lack the extended-addressing capability required.

Information transfer between I²C devices connected to the I²C bus requires two signals: serial data (SDA) and serial clock (SCL). A device connected to the bus can operate as a transmitter or a receiver. A master device initiates a data transfer on the bus, generates clock signals, and terminates the transfer. A device addressed by the master is considered to be a slave. To connect devices on an I²C multimaster bus, the SDA and SCL lines must be bidirectional and connected to a positive supply voltage through pull-up resistors.

In I²C-bus addressing, the first byte after a START condition determines the slave selected by the master. The slave address (upper 7 bits) is usually made up of a fixed and a programmable part. The eighth bit (the least significant bit) determines the direction of the transfer: read or write. The programmable part of the slave address determines the maximum number of identical devices that can be connected to the I²C bus.



Multiple non-I²C-addressable serial devices, like these CAT24W16 serial EEPROMs, can be interfaced to the I²C bus using Philips PCA9542 I²C multiplexers.

This circuit suits applications in which several devices that lack extended addressing capability (in this case, serial EEPROMs) must be connected over an I²C bus. The circuit also proves useful when there is a need to connect more devices than the maximum number allowed by the devices' address pins.

By multiplexing the SDA and SCL bus lines of connected devices, multiple I²C devices with the same address can be accessed. The figure shows 16 noncascadable CAT24WC16 EEPROMs accessed by using eight, two-channel I²C multiplexers. The Philips PCA9542 is a bidirectional, 1-of-2 multiplexer that is controlled over the I²C bus. It has three address pins.

The circuit MUXi connects the I²C bus lines, SDA/SCL, to either the SDAi0/SCLi0 or SDAi1/SCLi1 channel (where i = 1 to 8). No false conditions are generated at the time of connection because the channel becomes active when the I^2C bus lines are in a high state.

The I^2C bus commands used to control the hardware are:

1. Send the multiplexer slave address, 1110 xxx (where xxx = 000 to 111) with R/W = 0.
2. Send multiplexer command code to select the channel: xxxx x100 for channel 0; xxxx x101 for channel 1.
3. Send or read data to/from the EEPROM connected to the selected channel.

C++ Program Offers Versatile Waveform Spectral Analysis Tool

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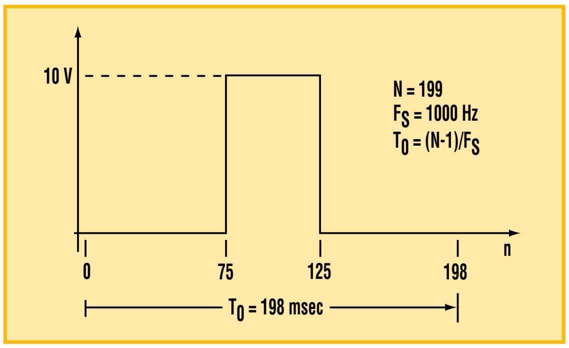
CIRCLE 522

This idea presents a C++ program that uses the complex class, which enables complex arithmetic. The Discrete Fourier Transform (DFT) is applied to the waveform stored in a disk file—a real sequence of double-precision floating-point binary values. (The program listing is available at *www.PlanetEE.com*. Follow the Ideas for Design link.)



1. **To demonstrate the program, an input 50-ms pulse was created and fed into the program.**

The function dft( ) performs a DFT on the real sequence of N samples in Datain(n) and outputs the resulting spectra in the complex array Dataout(k). The program is set up for a 1024-point DFT; however, this can be altered by revising MAXPTS.

The transform is given by:

$$\text{Dataout}(k) = \frac{1}{F_S}\sum_{n=0}^{N-1}\text{Datain}(n)e^{-j2\pi\frac{kn}{N}}$$

for k = 0 to N – 1 and F_S = sample frequency in Hertz.

The real frequency, F, is related to the index k by $F = kF_S/N$, where the frequency spacing is F_S/N. The DFT generates both real and image frequencies. From the Nyquist sampling criterion, $kF_S/N < F_S/2$, where the real frequencies are $k < N/2$ and the image frequencies are $k \geq N/2$. The real and image frequencies have conjugate symmetry—i.e., Dataout(k) = conjugate[Datain(N – k)] for real sequences.

An example 10-V, 50-ms pulse waveform is shown in the figure. Three *for( )* loops will generate this waveform:

```
for(n = 0; n < 75; n++) a(n) = 0.0;
for(n = 75; n < 125; n++) a(n) = 10.0;
for(n = 125; n < 199; n++) a(n) = 0.0;
```

To test your program, in the main( ) function, block out the disk operations and add the for( ) statements. The representative waveform characteristics of power, energy, and voltage are shown in Figure 2. In addition to amplitude, the spectra, power, energy, and voltage spectral densities of the example pulse waveform are shown. The frequency band (k_low, k_high) is user-selectable, allowing calculation of in-band characteristics.

Note that the program is set up to handle odd values of N, which generates the same number of real and image frequencies. However, the program will accept even values of N and will make the required adjustment in the value of N.

A 1024-point DFT was run on the 120-MHz Pentium I and a 350-MHz Pentium II. The respective run times were approximately eight and two seconds. For slower platforms, a run indicator is included.

POWER, ENERGY, AND VOLTAGE
k_low = 0 to k_high = 99 (497.48 Hz)
P_{DC} = 6.313 watts; E_{DC} = 1.256 joules; V_{DC} = 2.513 volts
P_{TOT} = 25.126 watts; E_{TOT} = 5 joules; V_{RMS} = 5.013 volts

AMPLITUDE SPECTRA AND DENSITIES
k = 1 (5.025 Hz)
complex-amplitude spectra = (-0.450, 0.0)
magnitude = 0.450 volt-secs; angle = -3.142 radians
PSD = 1.016 watts/Hz
ESD = 0.202 joules/Hz
VSD = 1.008 volts/$\sqrt{\text{Hz}}$

2. **The DFT results of the sample pulse waveform in Figure 1 are shown.**

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