Programmable Gain Amplifier with Arbitrary Attenuation Step Size

The R/2R ladder is a popular resistor topology often used to implement a current or voltage 6 dB step attenuator. However, if the resistors are appropriately scaled, the network can be modified to provide any desired attenuation step.

A programmable gain amplifier (PGA) can be made with a attenuating ladder network followed by CMOS multiplexer and a fixed gain amplifier, as in Figure 6-166. This circuit has several advantages (see Reference 12).

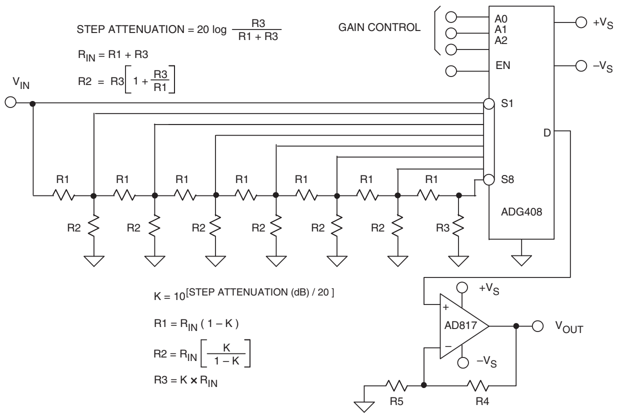

Figure 6-166: Programmable gain amplifier with arbitrary attenuation step size

First, as stated previously, the attenuation step size doesn't have to be 6 dB. Manipulating the resistor ratios, as described below, can easily change it. Second, the bandwidth of the circuit is always the same, regardless of the attenuation, due to the fact that the op amp buffer operates at a fixed gain. Third, the circuit is flexible, because practically any CMOS multiplexer and op amp can be used. The bandwidth of the circuit is determined primarily by the output op amp. Switching time between gain settings is determined by the multiplexer switching time and the op amp settling time.

The resistor ladder as shown uses three different resistor values: R1, R2, and R3. The step attenuation in dB is given by

$$\text{Step Attenuation}\ (\text{dB}) = 20\log\left[R3/(R1+R3)\right] \qquad \text{Eq. 6-37}$$

Also, the following relationships apply:

$$R_{IN} = R1 + R3 \qquad \text{Eq. 6-38}$$

$$R2 = R3\left[1 + R3/R1\right] \qquad \text{Eq. 6-39}$$

If R1 = R3, then R2 = 2 × R1. In this case, the R-2R network provides 6 dB step attenuation.

To determine the resistor values for a specific step attenuation and input resistance, use the formulas as follows:

$$K = 10^{\left[\text{Step Attenuation (dB)}/20\right]} \qquad \text{Eq. 6-40}$$

where the step attenuation is entered as a negative number.

Then, the following equations complete the design:

$$R1 = R_{IN}(1-K) \qquad \text{Eq. 6-41}$$

$$R2 = R_{IN} \times K/(1-K) \qquad \text{Eq. 6-42}$$

$$R3 = K \times R_{IN} \qquad \text{Eq. 6-43}$$

For example, to implement a resistor ladder with a –1.5 dB step attenuation and a 500 Ω input impedance: K = 0.8414, R1 = 79.3 Ω, R2 = 2653 Ω, and R3 = 420.7 Ω using the above equations.

The gain of the op amp is equal to 1 + R4/R5. The overall gain of the PGA is equal to the op amp gain minus the attenuation setting.

Finally, it is interesting to note that the AD60x-series of X-Amps discussed in the previous "Communications Amplifiers" section of this chapter uses the same basic approach described above. In the AD60x X-Amp series however, attenuation is continuously variable, because an interpolation circuit rather than a multiplexer is used to connect the individual taps of the network to the op amp input.