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## **Add Programmable Gain, Attenuation**

by James Wong

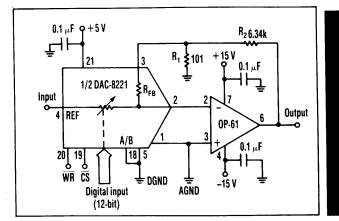
y adding two resistors to the output-amp feedback loop of a current-output digital-to-analog converter (DAC), both gain control and attenuation control can be achieved (Fig. 1). This digitally programmable amplifier produces gain and attenuation in the range of 1/64 to 64. The circuit gets its range from a 12-bit CMOS DAC.

The design works because the transfer function from the DAC's input to its output is purely voltage attenuation. Connecting  $R_1$  and  $R_2$  in a "T" configuration inside the output amp's feedback loop produces a voltage gain from the resistor junction to the output. If  $R_1$  is much less than  $R_{\rm FB}$  (11 k $\Omega$  in this example), the gain produced nearly equals  $1+(R_2/R_1)$ , or 64. The result is a programmable gain amp with a transfer function of

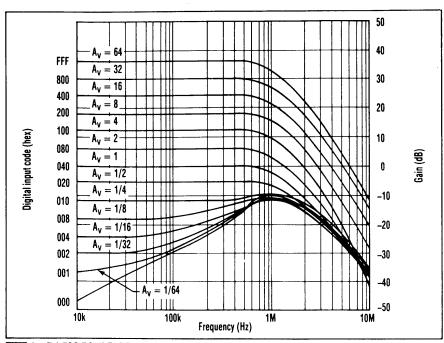
$$A_V = -(D/4096)(64),$$

where D represents the DAC's binary-weighted digital code. Of course, the added gain of the T-network increases the circuit's noise gain. Therefore, it's important to choose first a low-noise amplifier.

By using a low-noise, high-frequency op amp, such as the OP-61, the circuit will have a wide bandwidth performance even at high gain settings. The circuit's frequency response can be plotted at different gain settings (Fig. 2). At high gains, the amp has a 1-MHz bandwidth.



1. BY adding R<sub>1</sub> and R<sub>2</sub> in the feedback loop around a DAC, the circuit functions as a digitally-programmable amp. The gain or attenuation is variable over the range of 1/64 to 64. The resistors are connected in a T-configuration.



2. GAIN IS PLOTTED versus frequency for various digital inputs of the DAC. The amplifier has a 1-MHz bandwidth at high gains, but it drops for gains below 1/4.