Application Brief

AUDIO APPLICATION IDEAS FOR CMOS DAC'S

AD7520's Are Ideal for Signal Generation and Control

by Walter Jung

High-resolution, high-linearity multiplying DAC's that handle both polarities of analog input are naturally quite useful to the instrumentation engineer. They become equally attractive to the designer of audio signal-processing equipment when these benefits are combined with wide bandwidth and low cost.

Monolithic IC DAC's were available for some time before the advent of the 10-bit AD7520,* the 12-bit AD7521,* and the digitally-versatile AD7522,* but with generally less resolution and a limited range of reference variation. The AD7520/21/22 family lack both reference-voltage source and output amplifier, but these are not important limitations in audio use. In fact, the number-one advantage is that the reference-input voltage swing can exceed ±10V, with excellent linearity and bandwidth. Although one would expect a "multiplying DAC" to have this capability, not all types possess it fully.

Thus, not only do the 7520/7521 satisfy classical instrumentation applications with fixed unipolar references; they can also be used with bipolar voltages from volts down to millivolts. Their correct and linear ratiometric operation under such conditions makes them ideal scaling elements for audio signals. They can be viewed as digitally-programmable attenuators, which can marry high-quality audio signal-processing circuits to digitally-based systems under microprocessor control. The recently announced AD7522, with flexible storage registers, achieves interfacing with little external logic circuitry.

AUDIO PERFORMANCE OF CMOS DAC's

Besides the classical DAC specs of conversion linearity, resolution, etc., the special considerations for audio use include distortion, noise, and crosstalk in the "off" state. Interestingly enough, although they are not specifically characterized in this manner, the AD7520/21/22 come off quite well.

For instance, typical measurements of distortion are of the order of 0.05% or less over the audio band. This is due to the linearity enforced by the thin-film R-2R ladder, which ensures a linear summing-point current in the presence of a varying reference (input) voltage at a given digitally-set gain.

Noise is a parameter that can be determined from the data sheet; it is determined by the thin-film network's nominally 10kΩ characteristic resistance. This contrasts favorably with some active types of DAC's, which are noisier.

Reference-input feedthrough is specified on the data sheet as 10mV p-p (max) for 20V p-p input at 100kHz (-66dB). This, being but one point on a curve, doesn't tell the whole story. At lower frequencies, feedthrough is much less, with a floor of ⩽-90dB at 1kHz (Figure 1). Feedthrough is essentially capacitively-coupled crosstalk, it is layout-sensitive.

*Use the reply card to request information on these products, or the new low-cost AD7530.

Control-signal feedthrough is undesirable in audio gain control, since it can cause thumps, pops, or clicks. Because there is no bias current in the AD7520/21/22, the output contains the desired signal current only, avoiding dc level shifts. The narrow switching spikes can be filtered without loss of bandwidth.

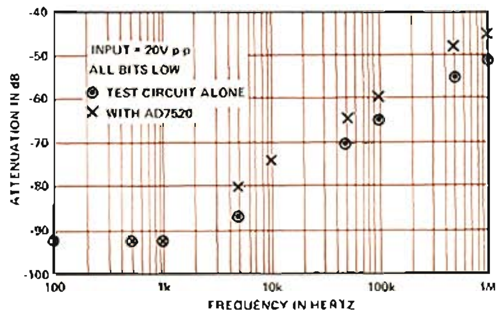


Figure 1. AD7520 feedthrough measurement.

It is interesting to consider the AD7520/21/22 accuracy in relation to the needs of audio level control. Without trim, the full-scale gain error is typically 0.3%, or, in conventional audio parlance, ±0.026dB. Even adding the loosest (conversion) nonlinearity† error, the gain error is still only ±0.043dB, adequate for a great number of audio applications, without trimming or tweaking. Remember that 1dB is close to the threshold of human perception of gain changes.

For applications where it is desirable to trim the DAC gain exactly to unity, given the possibility that it may be either high or low, resistance may be added in series with either the input (V_{REF}) terminal or the feedback terminal. Figure 2 shows a way of dealing with either contingency with one pot.

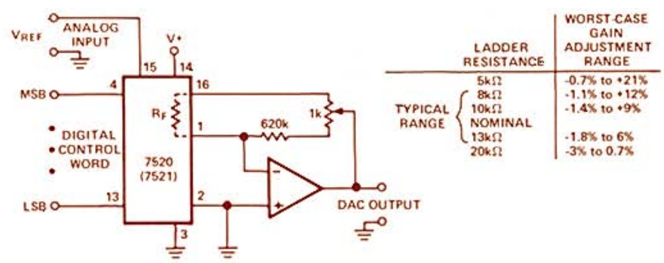


Figure 2. Single-control trim for gain calibration, allowing for a large range of absolute ladder-resistance variation.

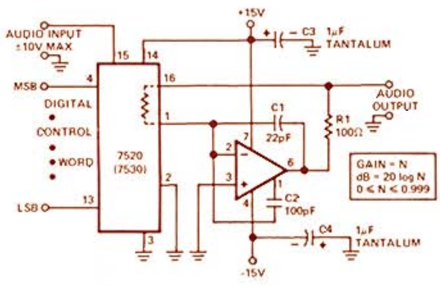
AUDIO CIRCUITS USING THE CMOS DACS (AD7520/21/22)

Figure 3 shows a basic circuit using the AD7520 as an audio gain control. A low-cost AD301A, used as the output buffer, is operated in the feedforward mode, for a gain-bandwidth of 30MHz and a 10V/µs slewing rate. This combination, using the lowest-cost "J"-suffix DAC, provides perhaps the most cost-effective, high-performance combination for an audio gain-

†Conversion-linearity errors affect only gain, not analog linearity.

control of this class. It can of course also be used as a general-purpose DAC, with device choice tailored to desired performance. Settling time to ½LSB (10 bits) is 6μs.

In general, the application of high-speed-DAC circuits to audio use can give rise to some serious problems. For instance, if the channel gain is to be manipulated while signals are present, large instantaneous gain changes in the presence of signal peaks will almost guarantee annoying audible switching-transients due to the abrupt change in level.



DIGITAL INPUTS FOR TYPICAL ATTENUATIONS

dB ATTEN.	N: INPUT NUMBER – VALUE 1 STAGE	2 STAGES
0	0.999	0.999
-1	0.891	0.944
-2	0.794	0.891
-3	0.708	0.841
-4	0.631	0.794
-5	0.562	0.750
⋮		
-10	0.316	0.562
-15	0.178	0.422
⋮		
-30	0.032	0.178
-40	0.010	0.100
-50	0.003	0.056
-60	0.001	0.032
-70	–	0.018
-80	–	0.010
-90		0.006

Figure 3. Inexpensive, high-performance gain control.

As a remedy, one might restrict gain-switching to times when the signal is near zero. A more-pleasing and satisfactory approach is to spread the gain change over about 50ms or more by digitally "ramping" it, using a clock and preset counter. If sufficient resolution exists, the staircase effect should be imperceptible. With an 8-bit converter, this permits 48dB of staircasing. Avoid slew-limiting in the DAC output amplifier; it can cause noxious distortion for sufficiently large gain steps, another reason for using controlled-gain steps and fast amplifiers.

Additional gain range can be obtained by cascading decade blocks of gain, or by cascading DAC's, with common digital input. If you wish to obtain the natural benefits of equal-dB gain steps, the digital number applied to the DAC(s) should vary exponentially. For m cascaded DAC's with -k dB of attenuation, the value, N, of the common digital input, should be

$$N = (10)^{k/(20m)} \qquad (1)$$

This can be achieved via software instructions in a computer system; it can also be achieved by means of programmable read-only memory (PROM), between the counter output and the DAC(s). Note that only about 2 significant digits are needed for accuracy to within 1dB, from the examples in the table (Figure 3).

Figure 4 illustrates in principle a variation of the basic gain controller which can be used to steer or "pan" an audio signal between two output channels, another common audio pro-

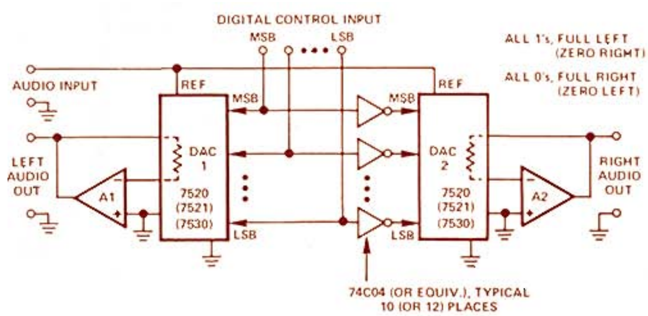


Figure 4. Digitally-programmed audio panner.

cessing requirement. The two gains are simply made complementary. Thus, the signal will be fully *left* for all 1's, full-*right* for all 0's, and deployed equally for just the MSB on.

In a simpler version (Figure 5) a single DAC is used. Here, the I_{OUT2} line of a 7520, normally grounded, is used to drive a second summing amplifier with an external feedback resistor, R_{f2}. Since the current at I_{OUT2} is inherently the complement of I_{OUT1}, the circuit will work as a complementary panner. The drawback is the necessity to trim R_{f2} for equal channel gains (MSB on); since the external resistor will in general not track the network, the panner may not retain its accuracy for wide temperature variations. However, the method is simple and attractive for non-critical applications.

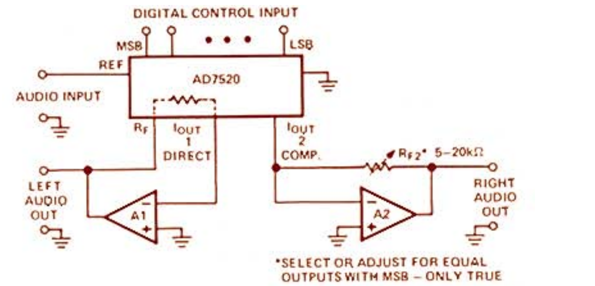


Figure 5. Simplified audio panner.

DAC's are useful for generating, as well as controlling, signals. Figure 6 shows a simple scheme for digitally programming the output frequency of a standard integrator-comparator function generator[1,2]. The timing resistor (the input resistor to the integrator) is replaced by the DAC's R-2R ladder. Since frequency is proportional to the integrator input current, it will be proportional to the digital input to the DAC.

A calibration control with wide latitude is needed because of the loose tolerance on absolute value of the R-2R ladder resistance; also, as noted above, tracking errors with temperature will limit stability. Fast amplifiers, such as the 301A (with feedforward in the integrator) are cost-effective.

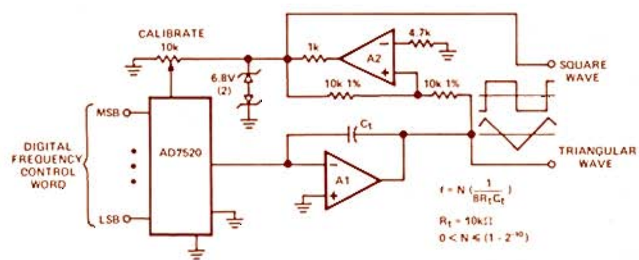


Figure 6. Programmable function generator; p-p amplitude of both waveforms is ≅15V.

There are myriad uses for these versatile DAC's; many have been documented here in the past, and more are sure to come. In audio alone, programmable oscillators, equalizers, filters, etc., may provide the Reader with food for thought.

▶▶▶

[1] *Nonlinear Circuits Handbook*, Analog Devices, Inc., 502pp., $5.95 (soft)

[2] *Audio IC Op-Amp Applications*, W. G. Jung, Howard W. Sams & Co., Inc. Indianapolis, Indiana 46206 (soft)