A digital-to-analogue converter is hardly a cheap alternative to a potentiometer. However, some readily pay the price, only to get rid of the "dirty" mechanical contact, while others are prepared to pay for remote control and repeatable settings. Erik Margan describes an ingenious design using a single D-to-A back to front.

Single D-to-A equalisation

In contrast with other digitally controlled equalisation circuits, which use either a D-to-A to set the analogue voltage for driving two VCAs, or use two D-to-As to provide the required boost-cut function, the circuit described below exploits the available complementary outputs of some cmos D-to-As, like *AD7524*, to achieve the same result with only one D-to-A.

Actually, the D-to-A is connected backwards; the complementary outputs function as inputs and the voltage reference input is used as output. This is possible due to bidirectional cmos switches in the D-to-A and the symmetrical ±7.5Vdc power supply for the D-to-A and control logic. Since the voltage swing capability of D-to-A outputs is limited, two resistive dividers level the signal down and an op-amp is used to restore gain and compensate for filter losses.

This op-amp also serves as a low-impedance driver for the filter section, thus preventing filter transfer function variations with boost/cut setting (a weak point of many equalisers using gyrators).

The second op-amp boosts or cuts the filter output by

$$G = 2 + \frac{R_m}{R_n} = 4$$

multiplied by the 4-bit digital code in symmetrical offset-binary format (0111 = 1000 = 0dB).

For the band-pass filter I have used a series-shunt R C network. Its transfer function is:

$$F(j_\omega) = \frac{\dfrac{R_b}{j_\omega C_b R_b + 1}}{R_a + \dfrac{1}{j\omega C_a} + \dfrac{R_b}{j\omega C_b R_b + 1}}$$

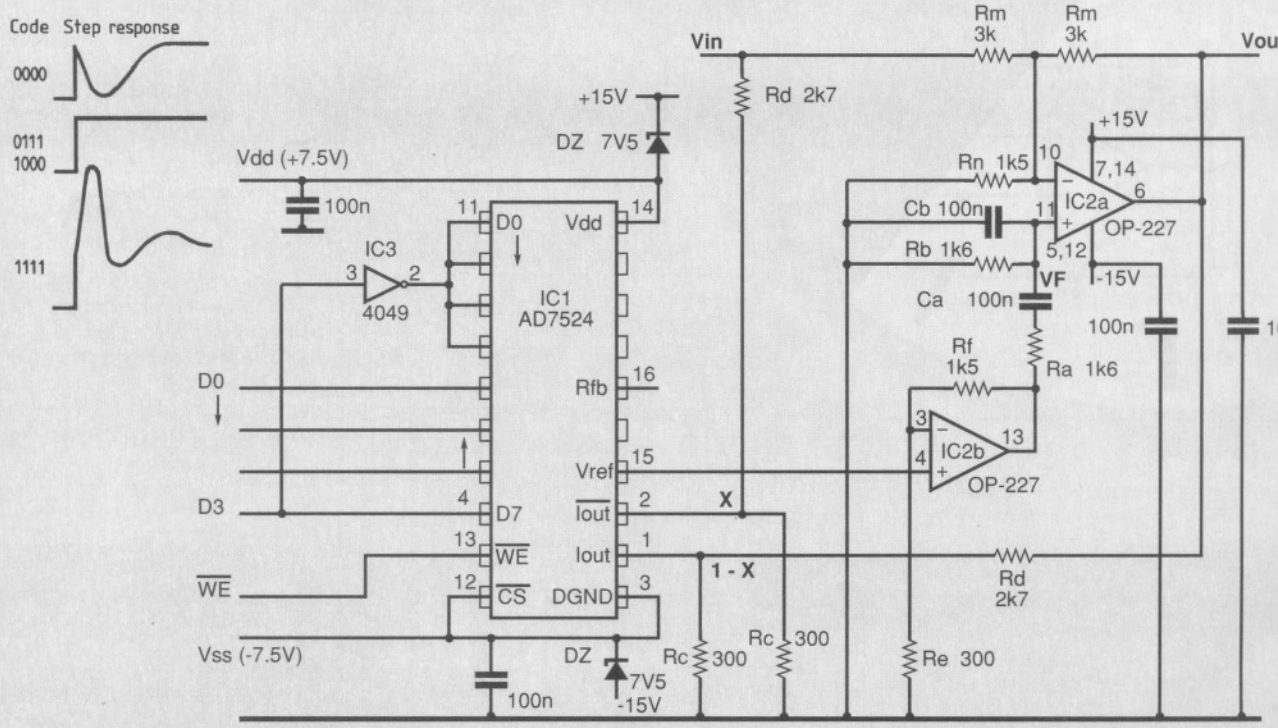

Fig.1. Circuit diagram. Note the ±7.5V DC power supply for the D-to-Aand the data control logic.

With little rearrangement, it may be rewritten as:

$$F(j\omega)=\frac{\frac{1}{R_aC_b}j\omega}{(j\omega)^2+j\omega\left(\frac{1}{R_aC_a}+\frac{1}{R_bC_b}+\frac{1}{R_aC_b}\right)+\frac{1}{R_aC_aR_bC_b}}$$

If we compare this to the normalized biquadratic form:

$$H(s)=A_0\frac{\frac{\omega_0}{Q}s}{s^2+\frac{\omega_0}{Q}s+\omega_0{}^2}$$

we find the filter centre frequency at:

$$\omega_0=\sqrt{\frac{1}{R_aC_aR_bC_b}}$$

From the last three equations we may calculate the filter Q-factor:

$$Q=\frac{\sqrt{\frac{1}{R_aC_aR_bC_b}}}{\frac{1}{R_aC_a}+\frac{1}{R_bC_b}+\frac{1}{R_aC_b}}=\frac{1}{\sqrt{\frac{R_bC_b}{R_aC_a}}+\sqrt{\frac{R_aC_a}{R_bC_b}}+\sqrt{\frac{R_bC_a}{R_aC_b}}}$$

and the attenuation at the centre frequency:

$$A_0=\frac{1}{R_aC_b}\cdot\frac{1}{\frac{1}{R_aC_a}+\frac{1}{R_bC_b}+\frac{1}{R_aC_b}}=\frac{1}{\frac{C_b}{C_a}+\frac{R_a}{R_b}+1}$$

If $R_a=R_b=R$ and $C_a=C_b=C$ then

$$\omega_0=\frac{1}{RC}\qquad Q=\frac{1}{3}\qquad A_0=\frac{1}{3}$$

and this results in one-octave band-width. The filter output voltage is:

$$V_F=\left(xV_{in}+(1-x)V_{out}\right)a_1A_1F(j\omega)$$

where:

$$0\geq x\geq 1\quad a_1=\frac{R_d}{R_c+R_d}=\frac{1}{10}\quad A_1=1+\frac{R_e}{R_f}=6$$

The system output voltage is then:

$$V_{out}=-V_{in}+a_1A_1GV_F$$

So the system transfer function will be:

$$\frac{V_{out}}{V_{in}}=-\frac{1-xa_1A_1GF(j\omega)}{1-(1-x)a_1A_1GF(j\omega)}$$

Of course, x is digital code dependent:

$$x=\frac{D_3 2^7+D_2 2^6+D_1 2^5+D_0 2^4+\overline{D_3}\left(2^3+2^2+2^1+2^0\right)}{2^8-1}$$

Figure.1 shows the circuit schematic diagram and **Fig.2** shows the frequency responses for various settings. To make the settings symmetrical, I used a 4-bit code with the MSB inverted and tied to the lower four bits. Due to the *x/(1-x)* law, the increment at the filter centre frequency is 1.5dB around code 1000, rising up to 2.2dB at extremes. Of course, up to 8-bit control is possible.

Other equalizing sections are connected serially. It is possible to use two separate virtual-earth summing junctions for a parallel connection of sections and the D-to-A is then connected in the usual way, but the result is much more noisy. The serial system single-stage noise gain is low (G = 4, with no boost or cut), the noise of other stages is passed unaffected and the D-to-A noise (the dominant noise source) is filtered in one-octave bands, so a 10-band system will be as noisy as a single wideband stage. Use low impedances wherever possible and low-noise op-amps like the dual *OP227*.

The maximum input signal level is $2V_{pp}$, which should allow for boost on all stages without severe distortion and a good signal-to-noise ratio. With filters one-octave wide, some mutual influence of adjacent bands is inevitable (see **Fig. 3**). If this is undesirable, use more elaborate filters ■

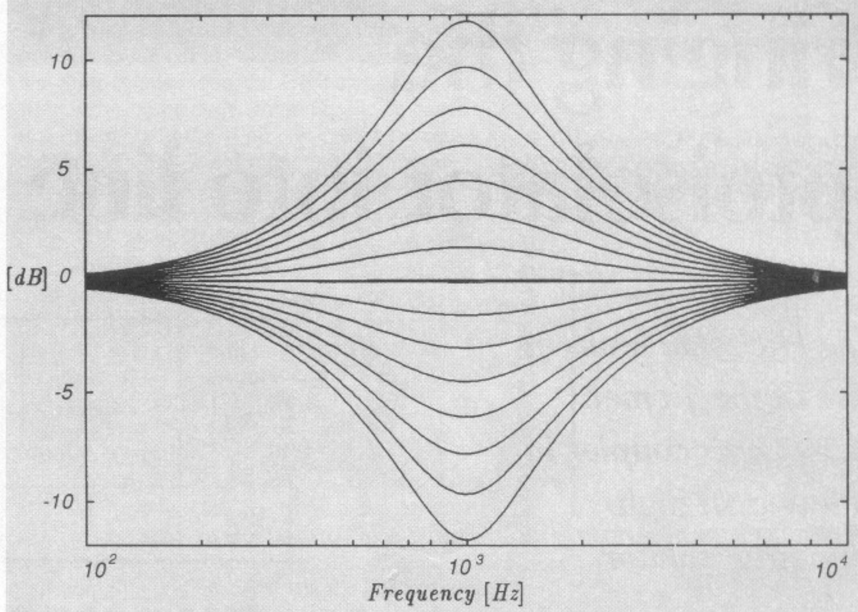

Fig.2. Frequency responses of a single 1kHz equalising section at various code values (0F, 1F, 2F, ..., 7F, 89, 90, A0, ..., F0). Maximum boost and cut is 12dB. Because of the x/(1-x) law, the steps are not equidistant; the lowest is around 1.5dB and the highest is around 2.2dB.

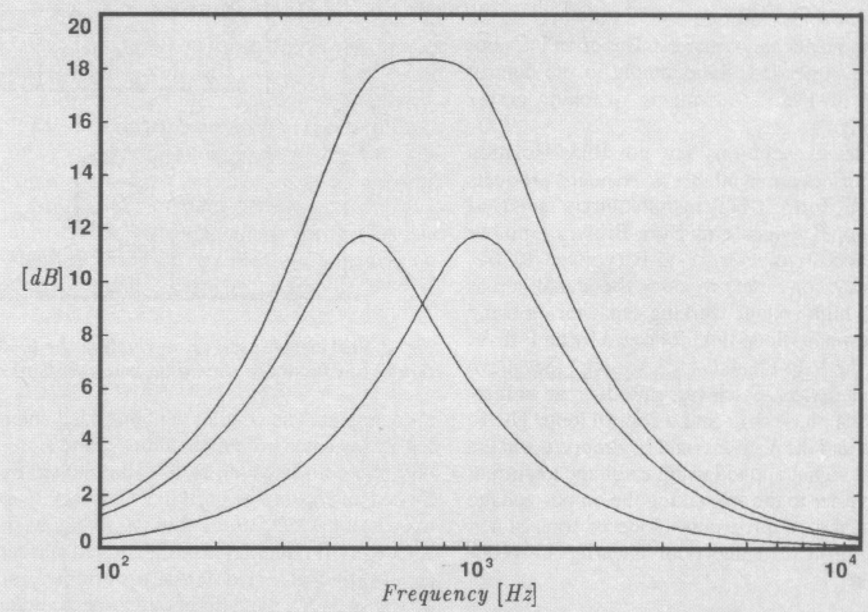

Fig.3. Interaction of two adjacent (one octave apart) sections at maximum boost. The resulting boost is 18dB. If this is undesired, more selective and more complex filter types must be used.