Normal bass and treble tone controls A passive bass and treble tone control without switches was described by Voigt in 1940, though without curves. The circuit, with carefully measured responses, is given in Amos (1977). Subsequently, circuits advantageously employing negative feedback have been widely used, most of these being based on a design which I published in 1952 (Baxandall, 1952).

The exact shape of the response curves obtained depends on the circuit design details; two limiting cases are shown, in somewhat idealized form, in *Figure 2.135*. For adjustment of the general bass and treble musical balance, the type of characteristic shown in (*a*) is usually preferred, but for dealing with background hiss, high-frequency response peaks, or tracing distortion on gramophone records, the adoption of a control with the type of high-frequency characteristic shown in (*b*) enables it to take over the function of a low-pass filter tolerably well in economical equipment not fitted with a separate filter.

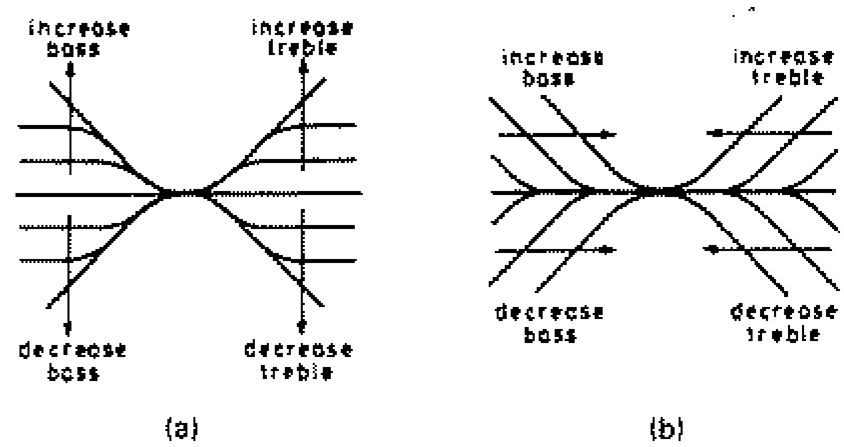

Figure 2.135 *Two basic types of tone-control characteristic.*

My original published design is shown in *Figure 2.136*, although all impedance values have been reduced by a factor of 10 to make them more typical of the semiconductor era. The cheapest versions employ just a single transistor, but lower distortion, more-symmetrical curves and lower output impedance may be obtained by using a transistor pair or an op-amp. In practice it is usually beneficial to add blocking capacitors to prevent the flow of base current, etc. in the control potentiometers, otherwise scraping noises are liable to occur when the knobs are rotated.

The idea of using a centre-tapped linear potentiometer, of adequately low value, to apply variable feed-in or feed-back via a capacitor, thus varying the effective lift or cut corner frequency, did not occur to me until a year or two after the circuit with shelving-type high-frequency characteristics had been evolved. It was pointed out in the original article that by adding a switch in the centre-tap lead, both types of characteristic could be made conveniently available.

The tone-control circuit configuration now most widely used, both in domestic equipment and in mixer desks, is either that the one shown in *Figure 2.136*, with the treble-control centre-tap omitted, or the alternative configuration shown in *Figure 2.137*. This latter version, which I did not publish, is actually the arrangement first used, the change to the circuit shown in *Figure 2.136*, even with no centre-tap, being made largely on the grounds that it saved a capacitor.

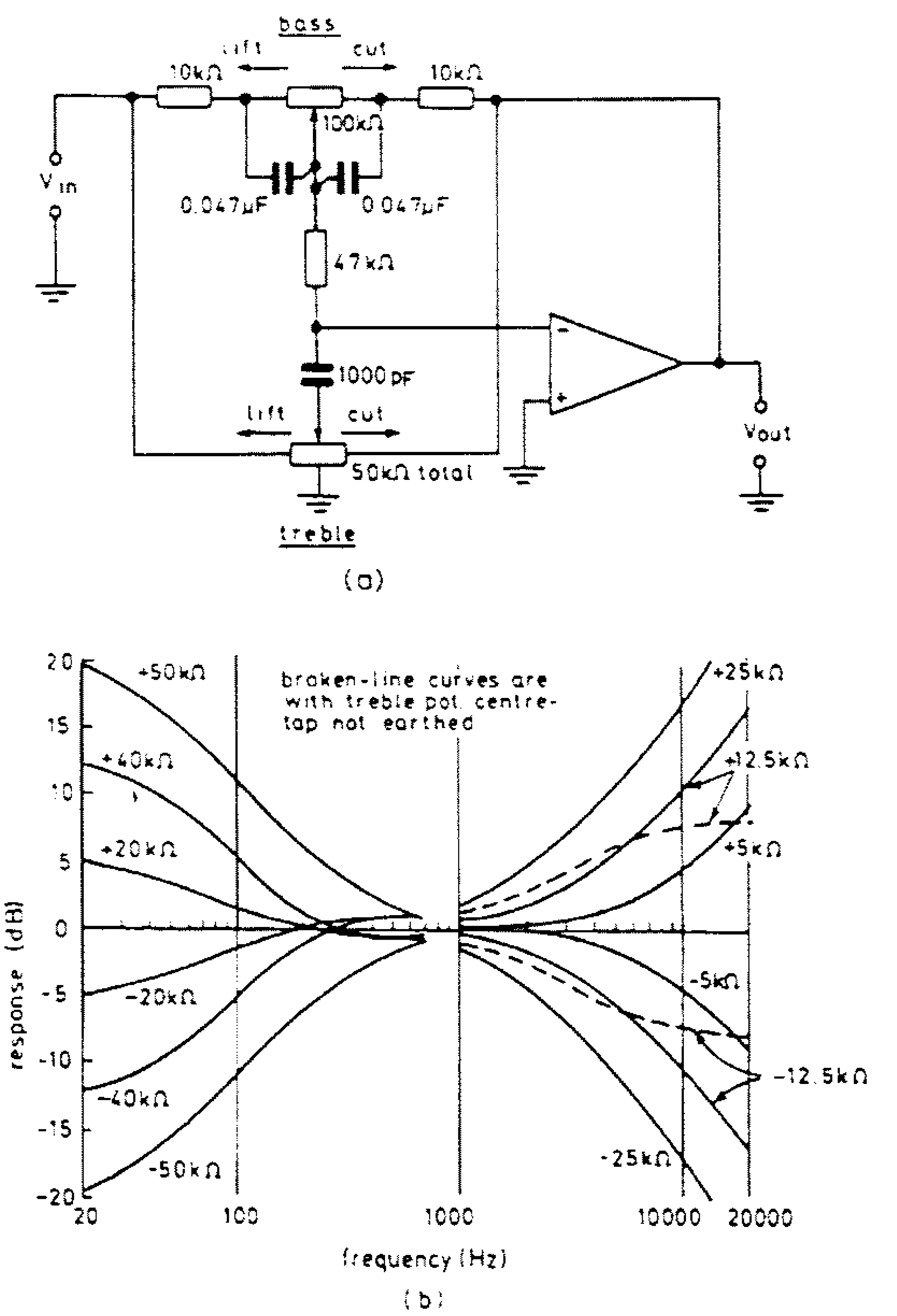

Figure 2.136 *Baxandall tone contol (Baxandall, 1952). To suit solid-state usage, the impedances have all been reduced by a factor of 10 compared with those in the original valve version. A resistor, e.g. 2.2 kΩ in series with the 1000 pF capacitor, may be necessary for high frequency stability when using op-amps.*

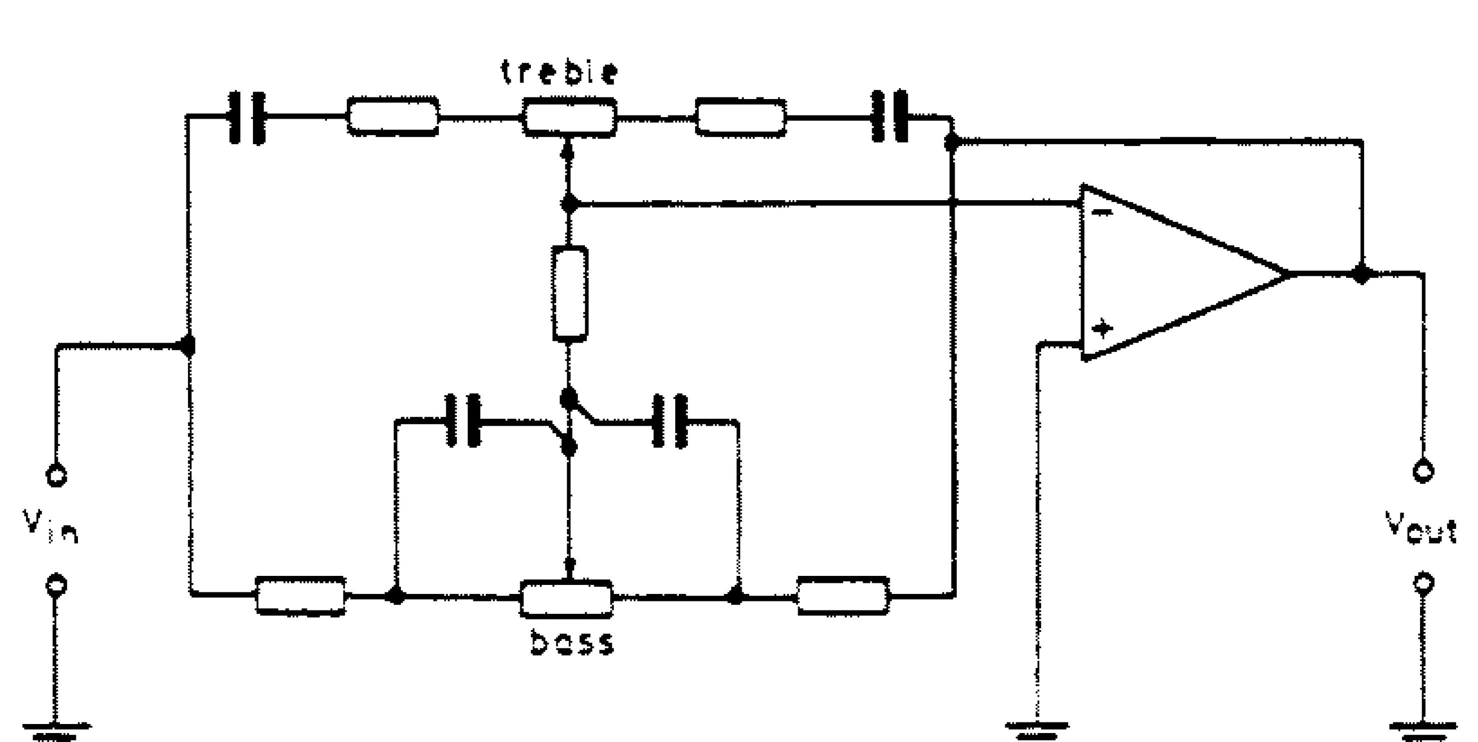

Figure 2.137 *Earlier form of Baxandall tone control.*

The bass-control characteristics given by all these circuits approximate to the type shown in *Figure 2.135(b)*, although the actual curve shapes at intermediate lift and cut settings are more complex, as shown in *Figure 2.136*. Such characteristics have been retained in most contemporary designs. However, bass characteristics of exactly the shape shown in *Figure 2.135(a)* may readily be obtained if preferred, and a bass-only tone-control circuit doing this is given by Amos (1977: Figure 14.26). This could be combined with a treble control in the same circuit, but now that gain has become so cheap, there is a good case to be made for employing separate circuits for bass and treble. This avoids interaction between controls and tends to give better noise performance because large impedance ratios may be avoided. Figure 14.27 in Amos (1977) gives a suitable complementary shelving-type treble circuit.

Accelerated slope tone controls In tone controls of the type described above, simple first-order networks are employed, with the result that, in the case of treble characteristics, the transition from level response at low frequencies to a lifting or falling response at high frequencies is rather gradual, some change in response occurring even at midband frequencies such as 800 Hz. Hence adjustment of the treble control affects the response at these latter frequencies to some extent, and a similar effect occurs on altering the bass control. Although in practice this is not normally found to be objectionable, a recent American contribution (Bohn, 1992) shows how, at the expense of 8 op-amps per stereo channel, this midband gain variation with control settings may be avoided.

The essence of the scheme is that the feed-in and feed-back, mentioned above, take place via low-Q *second-order* C–R circuitry, giving a sharper response transition and an enhanced rate of lift or cut. The much increased internal phase shifts that would normally accompany the use of second-order circuits are prevented from having a highly adverse influence on the shapes of the response curve, owing to partial nulling effects caused by inappropriate phasings, by incorporating additional time-constants to give compensatory phase shifts. A tone control giving virtually zero variation of midband response with knob settings is claimed.

'Tilt' controls A negative feedback tone control of an unusual kind was published by Ambler in 1970. In this ingenious 'tone balance' control, the circuit and measured curves for which are presented in Figure 14.28 of Amos (1977), a single knob varies the relative levels of bass and treble. A slightly more elaborate version, which I evolved in 1979, is shown in *Figure 2.138*, and its response curves extend, with nearly constant slope, over a wider frequency range

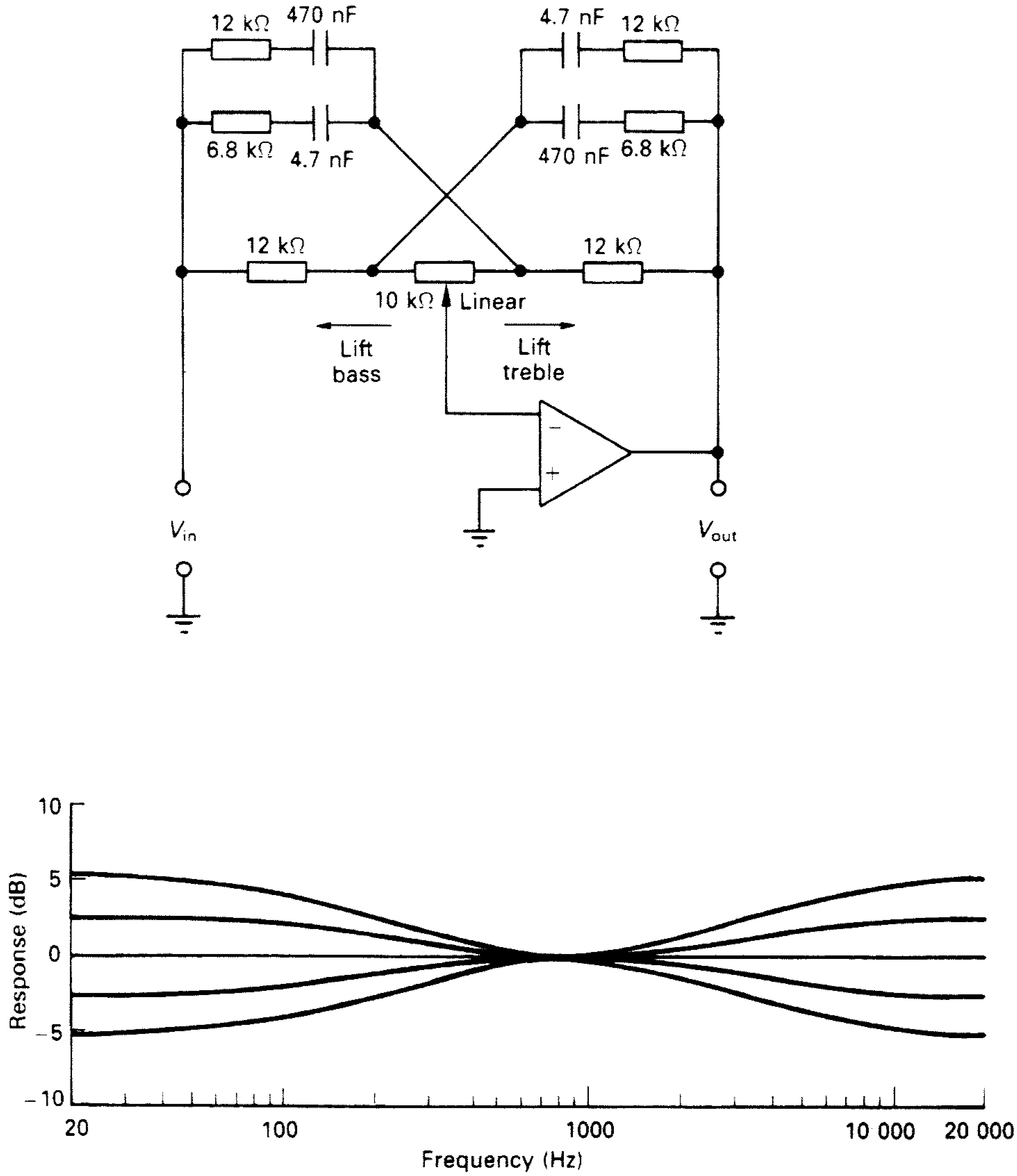

Figure 2.138 *'Tilt' control.*

than for the original design, which used only two capacitors. This type of control has been found very appropriate when pure musical balance is involved, rather than technical shortcomings of a more severe nature.

2.8.15.6 Filters

With inferior quality sources a low-pass filter is sometimes advantageous. Third-order Butterworth response is usually appropriate, and the design procedure for Sallen and Key active filters of this type, using a single op-amp, is presented in Figure 14.21 of Amos (1977) in the easiest possible form to use. The design procedure for third-order Butterworth high-pass filters is also given.

2.8.15.7 Parametric equalizers

So-called 'parametric equalizers' are frequently provided in mixer desks to allow the response over one or more relatively narrow frequency bands to be raised or lowered. They may be either separate circuits, or incorporated as a modification to the circuitry of bass and treble tone controls to permit variation of the midband response independently of bass and treble. A similar facility may be provided in domestic control units.

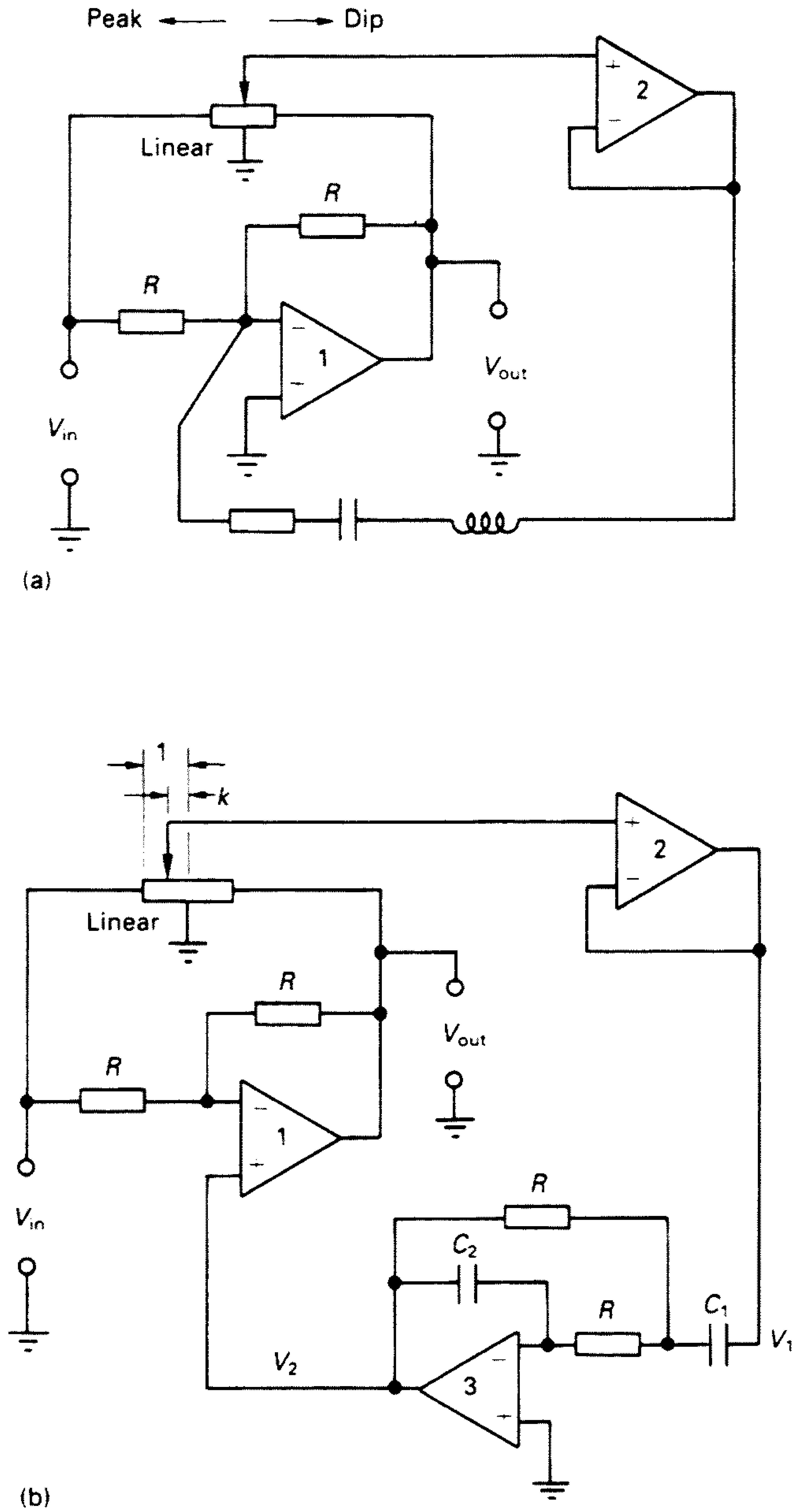

Figure 2.139 *Parametric equalizer circuits. In (b), a resonance frequency of 1.00 kHz may be obtained with* R = 10 kΩ, C_1 = 45.0 *nF,* C_2 = 5.63 *nF. The theoretical* Q *value is then 1.414, giving a one-octave bandwidth and maximum peak and dip magnitudes of 19.1 dB.*

To obtain symmetrical 'bell-shaped' lift and cut curves, the circuit used should involve the notion of adjustable feed-in or feed-back via a constant-Q tuned circuit. The simplest version is shown in *Figure 2.139(a)*. The L–C tuned circuit may, however, be replaced by an active circuit, as in (*b*). Because this very simple selective circuit, unlike the L–C one, is phase inverting, its output is fed to the non-inverting input of the op-amp.

The response of the selective circuit itself is:

$$\frac{V_2}{V_1} = -\frac{2QpT}{1 + (pT/Q) + p^2T^2} \qquad (2.17)$$

where $T = 1/\omega_o = R\sqrt{C_1 C_2}$, $Q = 1/2\sqrt{C_1/C_2}$, and $p = j\omega$. (Comparably simple non-phase-inverting circuits can be made, with C_1 equal to C_2 and positive feedback, but they are less desirable because the sensitivity to component tolerances is much greater.)

The response of the complete circuit shown in *Figure 2.139(b)*, for lift settings of the control, i.e. with the slider to the left of the centre-tap, is:

$$\frac{V_{\text{out}}}{V_{\text{in}}} = -\frac{1 + \left[\frac{1}{Q} + 4kQ\right] pT + p^2T^2}{1 + pT/Q + p^2T^2} \qquad (2.18)$$

The on-tune gain is $-(1 + 4kQ^2)$, where k is as shown on the circuit diagram. The sharpness of the peak is constant for all settings and is determined by the Q value of the denominator.

With the slider moved to the right, the response is given by the reciprocal of equation (2.18), and the constant sharpness of the dip is now determined by the Q value of the numerator.

2.8.15.8 Graphic equalizers

A graphic equalizer, sometimes incorporated in control units, may be regarded as the most versatile of all tone controls, though practical versions vary greatly in their effectiveness.

The best graphic equalizers are of the one-third-octave constant-Q type, and when optimally designed produce a frequency-response curve almost free from ripples which conforms well with the 'graph' depicted by the positions of the vertical slider-type potentiometers (Bohn, 1986).

A series of separate parametric equalizer circuits of the type shown in *Figure 2.139* connected in cascade is one way to make a good graphic equalizer, and one-octave spacing and bandwidth is a reasonable compromise to adopt. The caption to *Figure 2.139* gives values for this condition.

However, the almost universal practice is to associate several, sometimes all, controls with a single main op-amp. (To minimize ripples in the response curves at some control settings, it is preferable not to have the selective circuits for adjacent frequency bands connected to the same main op-amp). When this is done broadly in accordance with *Figure 2.139*, the tuned-circuit-stimulating circuits must be replaced by ones of the non-phase-inverting kind, so that their outputs may be added by feeding them to the inverting input (virtual earth) of op-amp 1. This non-phase-inverting requirement can of course be satisfied, if preferred, by retaining the circuitry associated with op-amp 3 in *Figure 2.139(b)* and adding a phase-inverting stage to it.

The most refined technique for producing active tuned circuits and filters, which is capable when necessary of giving very high Q values with low sensitivity to component tolerances and active device parameters, is based on the two-integrator-loop principle, to which the rather curious term 'state variable' is nowadays often applied. This technique was originated in Britain in the early 1950s by two of my colleagues (Girling and Good, 1970a,b), who designed many two-integrator-loop filters of high precision for use in radio astronomy and other applications. These used valve op-amps.

References

AMBLER, R., Tone-balance control, *Wireless World*, **76**, 124–126 (1970)

AMOS, S.W., *Radio, TV and Audio Technical Reference Book*, Newnes-Butterworth, London (1977). (See Chap. 14 by P.J. Baxandall)

BAXANDALL, P.J., Negative-feedback tone control, *Wireless World*, **58**, 402–405 (1952)