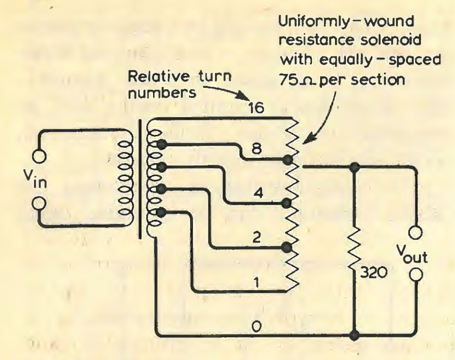

Fig. 29. Multiple-tap linear pot. with transformer-fed taps for precise voltages.

further, providing attenuators of extremely high precision and stability. An interesting example from a different field occurs in the Wayne Kerr B5009 Logarithmic LCR Bridge, in which readings are taken from an approximately 25cm long "slide-rule", which has a logarithmic scale covering a 16 : 1 ratio. The circuit associated with this device is shown in Fig. 29. The use of a tapped transformer winding to energize the tappings on the resistance element ensures extreme precision in the ratios of the voltages at these points, since they are determined almost purely by the turn numbers on the transformer. As the slider is moved down from the top, the attenuation at each tapping position increases by successive factors of 2, or 6.02dB. In the absence of the loading resistor on the slider, V_{out} varies linearly with slider position between tapping points, whereas, for a perfectly logarithmic scale, it is the log of V_{out} that is required to vary linearly. The error amounts to approximately 0.5dB midway between tappings. By adding the right value of loading resistor as shown, this error is reduced to less than ±0.05dB.

By using a transformer, the attenuation characteristic is made almost perfectly independent of production variations or non-uniformity in the resistance element, provided only that the physical positions of the tappings are accurately maintained. With the Fig. 28(a) type of arrangement, variations in pot. resistance do have some effect, but it may be kept small by making the resistance of the resistor-chain connected to the tapping(s) much less than the resistance of the pot. itself.

For high-grade audio control-unit applications, where the use of slider-type controls is considered appropriate, there would seem to be a strong case for using the Fig. 28 arrangement but with two tappings. By using ±2% resistors to feed the tappings, excellent stereo tracking should be obtained with a most desirable shape of control characteristic.

BBC log. attenuator

An interesting and very neat solution to the problem of providing a wide-range gain control having uniformly-spaced decibel scaling was devised in 1946 by C. G. Mayo and R. H. Tanner of the BBC Research Department. It was used in a portable microphone amplifier made by the BBC for acoustic measurements[5], but was unfortunately not taken up commercially.

The principle is given in Fig. 30, and Fig. 31 shows the actual construction. These illustrations are taken from reference 5. A is a block of resistive material, of which the underside is covered by a conductive electrode B. The input is applied between B and another electrode C, the output being taken between B and a slider D. The various series and shunt paths through the resistive material may be regarded as approximately equivalent to the ladder network shown, the output of each successive section of the ladder being a constant fraction of that of the previous section, giving a scaling with uniformly-spaced decibel divisions. The useful range of the model illustrated was about 70dB.

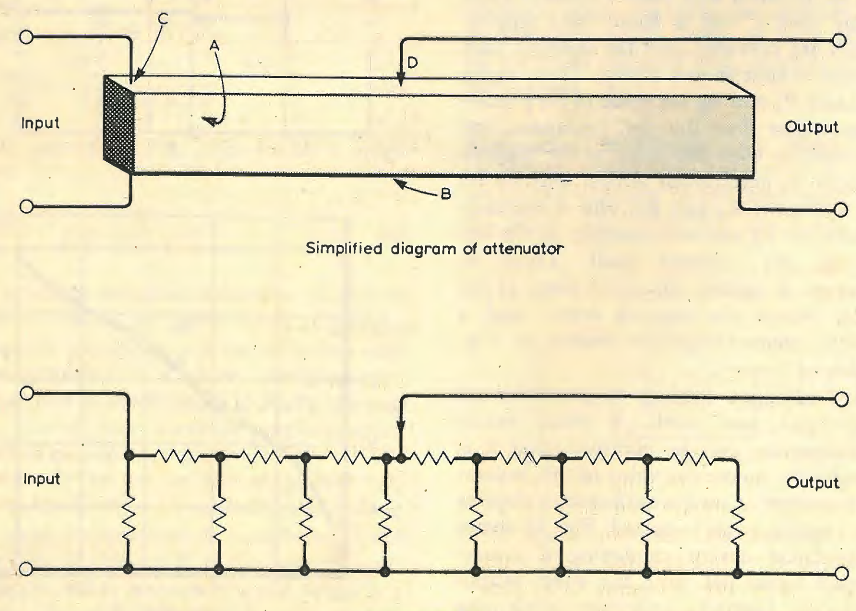

Fig. 30. BBC gain control principle at (a) is 'distributed' equivalent to attenuator network at (b).

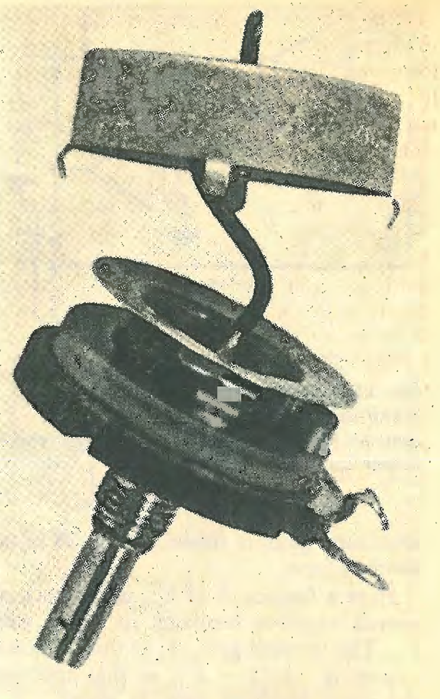

Fig. 31. Attenuator whose principle is shown in Fig. 30. Note screen round output. Photograph by courtesy of Electronic Engineering

It is pointed out that the output impedance of this type of attenuator does not become low when the attenuation is large, so that it is very important to avoid appreciable stray-capacitance coupling between input and output. The output connexion is therefore brought out coaxially, with a screening plate as shown in the photograph.

It has occurred to me that there is no essential need to employ a thick block of resistive material, and that an attenuator based on the same broad principle could be made using carbon-coated s.r.b.p. sheet material of the type commonly used in ordinary carbon pots. To test this idea, a quick experiment was done with the set-up shown in Fig. 32, and yielded the rather impressive result shown in Fig. 33. The very first graph obtained was somewhat inferior, apparently because of unsatisfactory contact between the steel vice jaw and the carbon coating. This was overcome by interposing a strip of polished copper foil between the carbon coating and the vice jaw.

Though an attenuator having a very extended range of operation as in Fig. 33 may fulfil some requirements, it is not ideal for use in control units etc., for the range of control needed in practice covers far less than 100dB, except that an "off" position coming soon after the position giving 40 or 50dB attenuation is really desirable. The Fig. 32 type of construction could readily be modified to provide such a characteristic, by shaping the conductive electrode, or metallic coating, somewhat as shown in Fig. 34. Halving the width of the carbon track, for example, would double the slope of the graph.

It is relevant to consider the suitability of attenuators based on the above principle for stereo purposes, i.e. whether sufficiently accurate tracking would be readily obtainable. Since the slope of the attenuation characteristic depends, to a first order at least, on nothing but the width of the resistive track, it would be important, for stereo use, to adopt a form of construction in which production variations in this width are minimized. The Fig. 34 construction does not appear to be ideal, for it relies on cutting the edge of the carbon material accurately in relation to the position of the metallized coating. The arrangement shown in Fig. 35 would seem much preferable, since accuracy of cutting is no longer involved and the metallized coating could be deposited by some form of printing technique with a very high degree of consistency.

The lower impedances usually used in transistor equipment, compared with earlier valve equipment, ease the problem of keeping the input-to-output stray capacitance sufficiently small, but it is still important to adopt a constructional arrangement which aims to minimize such capacitance. Working at 1kΩ impedance, with a control giving up to 100dB attenuation, the stray capacitance must be kept to less than 0.1pF. The connexion "rail" on which the slider moves must therefore be positioned away from the carbon surface and screened from this and the input connexion by an earthed screening plate.

Another advantage of the Fig. 35 arrangement is that, because of its symmetry, unwanted slight lateral movements of the slider during its traversal would be expected to have less effect on the attenuation than with the Fig. 34 form of construction – though it has been found that even with the latter, movements of about 1mm at right-angles to the direction of traversal produce only a small fraction of 1dB change in output provided the slider contacts the carbon track within 2 or 3mm of its edge.

Other methods of log. control and stereo tracking

● Perfect tracking of stereo channel gains at all settings, without the need for precision gain-control circuits, may be obtained by first producing, from the incoming L and R signals (L + R) and (L – R) signals. If the (L + R) signal is fed to one half of a ganged gain-control circuit, multiplying it by a factor α, and the (L–R) signal is fed to the other half of the gain-control circuit, which multiplies it by a factor β, then the sum of the gain-control circuit outputs is given by:

$$\text{sum} = (\alpha+\beta)L + (\alpha-\beta)R \qquad (10)$$

and the difference of their outputs is given by:–

$$\text{difference} = (\alpha+\beta)R + (\alpha-\beta)L \qquad (11)$$

Thus, though the balance as such is perfect, it is obtained at the price of introducing some cross-talk when α is not quite equal to β. The effects of stereo cross-talk are discussed in detail in reference 6.

● Perfect tracking without the introduction of crosstalk can be produced if a single gain-control circuit is used to control both channels. This can be done, for example, by first making the L and R audio signals modulate two different r.f. carrier frequencies, the two amplitude-modulated carriers being fed to the same gain-control circuit and being subsequently demodulated in phase-sensitive detector circuits. Though this technique could give virtually perfect results, it would not seem to be very attractive economically.

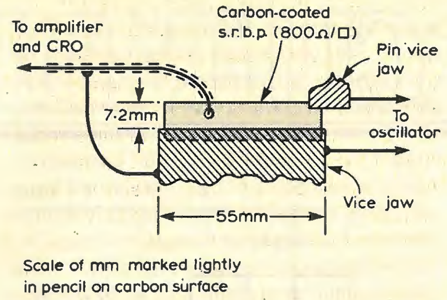

Fig. 32. Experiment using sheet instead of block in Fig. 30.

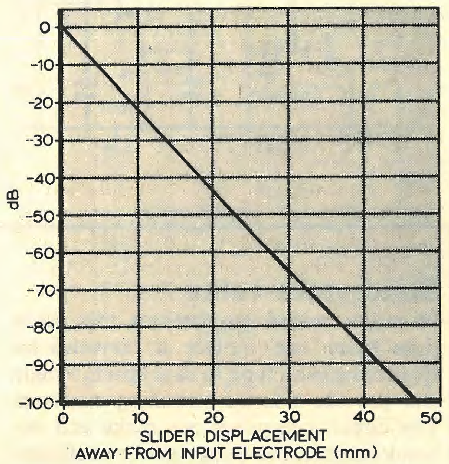

Fig. 33. Measured result obtained with Fig. 32 arrangement.

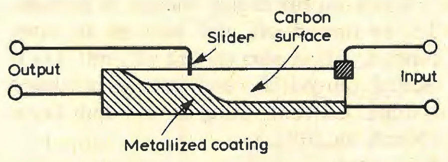

Fig. 34. Suggested form of control using Fig. 32 principle. Characteristic steeper at low-gain settings.

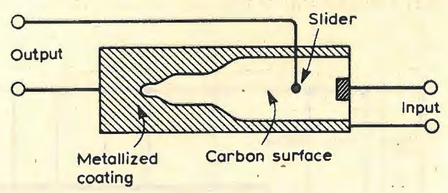

Fig. 35. Symmetrical version of Fig. 34 for improved consistency of performance.

● Various simple gain-control circuits give a nearly linear relationship between attenuation in decibels and control position over a range of several dB. If a sufficient number of such circuits are put in cascade, and the controls are ganged, an approximately linear relationship may be obtained over any required range. While this technique is not usually very attractive when carried out literally with mechanically-ganged pots., it would appear to be worth bearing in mind as a possible technique for providing electronic gain control with a logarithmic characteristic. The idea is quite old.

● At the present time the most satisfactory technique for wide-range electronic gain control is that which exploits the fact that silicon planar transistors follow with high accuracy the relationship:–

$$I_c = I_0 e^{qV_{be}/kT} \qquad (12)$$

where I_c is the collector current and V_{be} is the base-to-emitter voltage. (The other quantities are constants.)

Circuits can be designed in which the gain in decibels is linearly related to the control voltage over a range of about 100dB, and by using the "log-antilog" or predistortion technique, a performance sufficiently good, with respect to distortion and signal-to-noise ratio, to justify the use of such circuits in very high-quality audio systems, can be obtained. A very sound and clear treatment is given in reference 7.

This type of circuit is at the heart of compander systems of the dbx type. It could be used to provide gain control in audio control units, a single pot. varying the control voltage to a pair of such circuits in the two audio channels. The distortion and noise performance, though good, is not quite up to the highest standards sometimes demanded, maybe unnecessarily, in expensive control units, but some further refinement of i.c. versions of these gain-control circuits, including the reduction of residual even-harmonic distortion by the use of more fully balanced arrangements, may take place.

● In a fully digital audio system, gain control with perfect stereo tracking and any desired control law may be carried out on a purely numerical basis.

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