Linear pot and op amp provide tapered audio volume control

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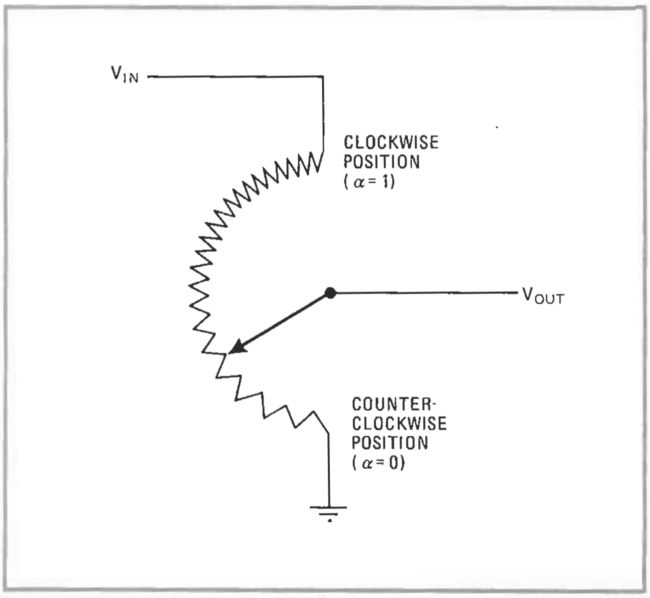
Tapered potentiometers are used in audio amplifiers to compensate for the nonlinear response of the human ear. However, at a lower cost, a linear potentiometer and an operational amplifier can approximate the response of the tapered pot.

The audio taper for potentiometers is described by the gain function

$$V_{out}/V_{in} = f(\alpha) = 10^{2(\alpha-1)}$$

where the potentiometer displacement α can range from



1. Audio taper. Volume-level potentiometer for sound systems has tapered resistivity to compensate for exponential response of human ear. Expensive tapered pot (which should be followed by a buffer stage to prevent loading effects) can be replaced by a linear pot, fixed resistor, and op amp.

$\alpha = 0$ (in the full counter-clockwise position) to $\alpha = 1$ (in the full clockwise position). Signal attenuation through the potentiometer can be expressed in decibels as

$$Attenuation = 20 \log(V_{in}/V_{out}) = 40(1 - \alpha)\ dB$$

This expression shows that the attenuation in decibels is proportional to the potentiometer displacement from the full clockwise position. To obtain this reverse-logarithmic-gain function, special nonlinear potentiometers are usually used.

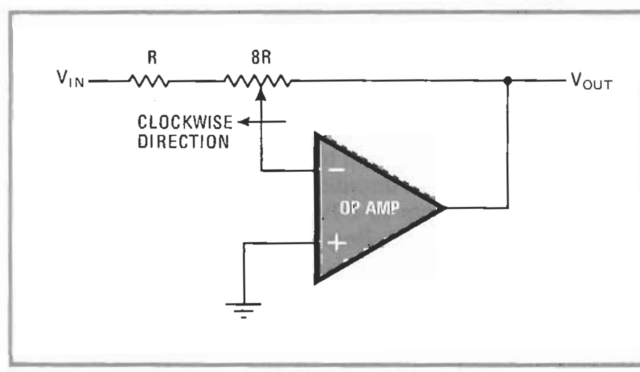
Because these potentiometers cannot be loaded heavily without distorting the gain function, in practical audio applications they are usually followed by a gain stage or a high-input-impedance voltage follower. However, the reverse-logarithmic-gain function can be closely approximated by using a linear potentiometer, a single operational amplifier, and one fixed resistor, as shown in Fig. 2. The operational amplifier adds the capability of voltage gain; in this circuit the maximum voltage gain is 8, or 18 dB. The voltage-transfer function for the circuit of Fig. 2 is

$$V_{out}/V_{in} = (-8\alpha)/(9 - 8\alpha)$$

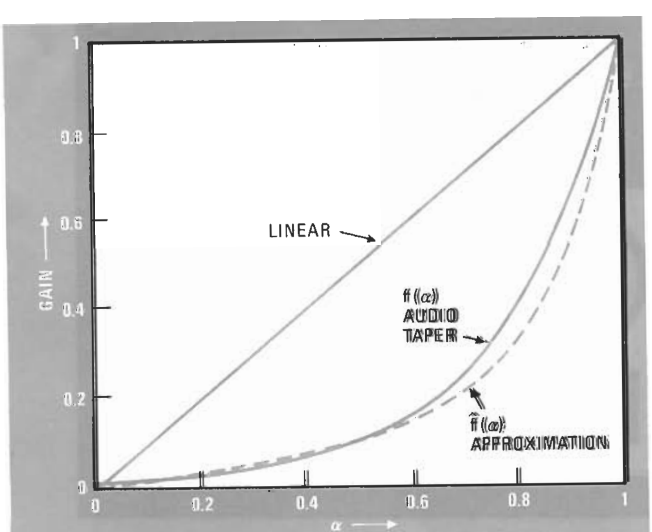
which closely approximates the attenuation function

$$Attenuation = 40(1-\alpha) - 18\ dB$$

over most of the range of α. As a desirable advantage,



2. Replacement. Linear potentiometer, fixed resistor, and operational amplifier, connected as an inverting amplifier, provide transfer function that approximates performance of audio-taper pot plus 18 dB of gain. The minimum input impedance is R.



3. Comparison. Approximation to audio taper is excellent for potentiometer-displacement values α below 0.5 and good everywhere else. The approximation is exact at $\alpha = 0.5$.

the attenuation goes to infinity at $\alpha = 0$.

The transfer function of the circuit in Fig. 2 is normalized to

$$\hat{f}(\alpha) = \alpha/(9 - 8\alpha)$$

and compared to the true audio taper in Fig. 3. The approximation, which is good everywhere, is especially close at the low values of α, where compensation for the reduced hearing sensitivity at low sound levels is most important. The two functions agree exactly at $\alpha = 0.5$.

Because it uses a linear potentiometer, this circuit is less expensive than the normal audio-taper level-control, and it is much more convenient to use in new designs.

The value of R can easily be chosen to suit the op-amp and the circuit impedance; for example, a 100-kΩ pot and a 12.4-kΩ fixed resistor can be combined with a 741 op amp. □

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