SWITCHED-RESISTOR CONTROLS

Close-tracking stereo controls, accurate linear and tapped pots may be made with fixed resistors and a rotary switch.

By **ROBERT K. RE**

ARE YOU tired of looking through component catalogues for those special tapped volume controls, high-linearity potentiometers, and close-tracking dual volume controls for stereo amplifiers? The use of "switched-resistors" can solve most of these special problems quickly and inexpensively. All parts required are readily available and economical. Switched-resistors, shown in Fig. 1A, are merely individual resistors that are controlled by switches to simulate variable resistors.

Applications

The Baxandall feedback tone circuit, which has appeared in many articles in this and other publications, requires a 500,000-ohm linear-taper pot with a tap at 250,000 ohms. The only unit available was one with a tap at 225,000 ohms. Using the switched-resistor technique, this tapped resistor was easily obtained. Another circuit using a tapped resistor control for a compensated loudness control, shown in Fig. 1B, posed quite a problem until the switched-resistor technique was applied.

Stereo sound systems require identical dual controls to provide balanced outputs from the amplifiers. Tracking and tolerance errors of most controls available today are about 5-10%. With switched-resistor methods, the tolerance, tracking, and linearity characteristics can be tailor-made to almost any desired value. Using switched-resistors, the flat positions on tone circuits can be found easily and recorded for future reference. Thus previous settings can be recalled for best sound reproduction from each input.

Some variable resistors have a switch that attaches to the rear of the unit. These are usually s.p.s.t. or d.p.s.t. Using the switched-resistor technique, one or more extra wafers are added to produce the desired switching functions. Sequential switching, as the resistor value is varied, is entirely possible, if desired. Perhaps one needs a four-gang pot with a three-pole, single-throw switch in a particular application. This item is not generally listed in the catalogues and is an unusual requirement. It can, however, be made quite easily with switches and resistors.

Potentiometers are usually replaced when they get noisy or become inoperative. Using switched-resistors, the noisy or defective resistor can be replaced at low cost; no need to purchase a whole new unit. Low noise levels are a "must" for good sound systems; however, the typical potentiometer may become relatively noisy. Low-noise variable resistors can be made using low-noise resistors and switches with double-wiping contacts.

High-wattage potentiometers are usually wirewound units and these, as we know, have an effect on the frequency response because of their inductance. Using carbon resistors (or other non-inductive resistors), high-wattage variables can be assembled which will have little effect on the frequency response of the unit. Dual units can be made to control different power levels with one knob. The wattage of each resistor is determined by the power levels involved. Normally the method of determining the wattage of each resistor is as follows: (1) Determine the maximum applied voltage across the switched-resistors; (2) Compute the current that will flow through the whole string of resistors; (3) Using Ohm's law, compute the power dissipated in each resistor; and (4) If the power level is, say, one watt, use a 2-watt unit for a safety factor. Higher wattage units will give an even greater safety factor.

Circuit design need not be compromised if a special value of variable resistor or taper is required. Thus a 13,000-ohm reverse audio-taper pot is easily constructed. The level changes between steps can be made to conform to decibels, decade, or linear voltage changes by proper choice of the resistor values. The resolution is limited by the number of switch positions used.

Construction

Linear potentiometers are made by taking the total resistance value and dividing by the number of switch positions minus one. Thus a switch with 11 positions and ten 1000-ohm resistors will make a 10,000-ohm linear switched-resistor.

Graphical methods of construction are as follows (see Fig. 2). (1) Draw a graph of resistance (ordinate) as a function of degrees rotation or switch positions (abscissa); (2) At each switch position or degree index, draw vertical lines up to the resistance curve; (3) At the intersection of each vertical line and the resistance curve, draw horizontal lines to the resistance scale on the left. The actual resistance value is found by subtracting one resistance value from the other, thus the fourth resistor value equals Line 4 resistance minus Line 3 resistance (see Fig. 2).; (4) Reversing the order of resistor positions on the switch will reverse the taper of the switched-resistor control (this assumes that clockwise rotation produces increasing resistance for the normal unit).

To illustrate the mathematical method, let us design a 50,000-ohm, 5% tolerance pot with a 24-position switch.

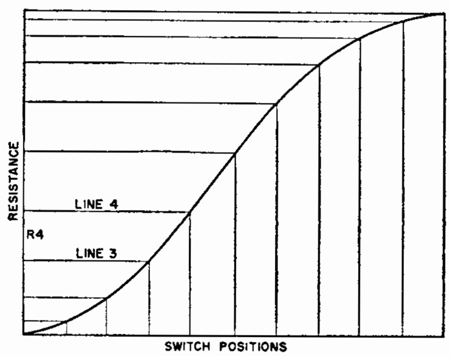


Fig. 2. Graphical method of construction.

Table 1. Resistors used for a 50,000-ohm, 5%, 24-position potentiometer control.

Step	Computed Values	5% EIA Values
1	12.5 k	12 k
2	9.38 k	9.1 k
3	7.04 k	6.8 k
4	5.28 k	5.1 k
5	3.96 k	3.9 k
6	2.97 k	2.7 k
7	2.23 k	2.2 k
8	1.67 k	1.6 k
9	1.25 k	1.2 k
10	938	910
11	704	680
12	528	510
13	396	390
14	297	270
15	223	220
16	167	160
17	125	120
18	93.8	91
19	70.4	68
20	52.8	51
21	39.6	39
22	29.7	27
23	22.3	22
Total Res.	51.0 k-ohms	48.2 k-ohms

Note: values rounded off to three places

Fig. 1. (A) Basic switched-resistor circuit. (B) Special tapped loudness control.

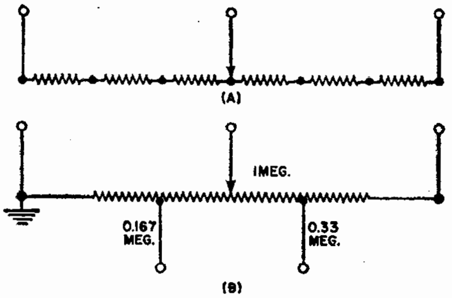
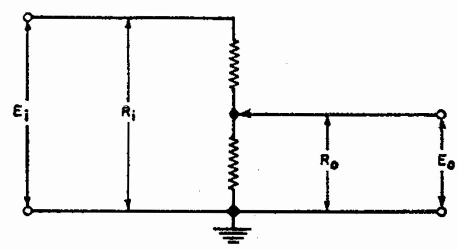


Fig. 3. Circuit constants used in formulas.



The level changes per step are to be equal and should be 2.5 db. This will allow us a 60-db range of control over the input signal. Equations 1, 2, and 3 show that the resistance ratio is proportional to the voltage ratio, if the current is constant. The loading of the succeeding circuit will change the current, but usually not enough to seriously affect the attenuation ratio. With reference to Fig. 3 the following equations apply:

$$\textit{Attenuation (db)} = 20 \log (E_o/E_i) \quad \text{.......... (1)}$$

where: E_o = output voltage and E_i = input voltage, but

$$E = I \times R \quad \text{.......... (2)}$$

therefore,

$$\textit{Attenuation (db)} = 20 \log (R_o/R_i) \quad \text{.......... (3)}$$

where: R_o = resistance from slider to ground and R_i = total resistance of the unit. If full output (maximum resistance from the slider to ground) is assumed as 0-db attenuation, then the first step must attenuate -2.5 db. Thus, using Eq. 3:

$$-2.5\ db = 20 \log (R_o/R_i)$$

or,

$$\log (R_o/R_i) = -2.5\ db/20 = -0.125$$

The number whose log is -0.125 is 0.75, therefore:

$$R_o/R_i = 0.75$$

or,

$$R_o = 0.75 \times R_i \quad \text{.......... (4)}$$

Thus, $R_o = 0.75 \times 50{,}000$ ohms $= 37{,}500$ ohms. This means that the first resistor equals:

$$R_i - R_o = 50{,}000 - 37{,}500 = 12{,}500$$

ohms.

The value of the next resistor can be found by using the first value of R_o as the new R_i in Eq. 4, and subtracting the new value of R_o from the new value of R_i. Thus the second resistor equals:

$$R_o = 0.75 \times 37{,}500 = 28{,}100 \text{ ohms}$$

Second resistor = 37,500 − 28,120 = 9380 ohms.

The other resistors are calculated in a similar manner. However, a simple method will produce the same results quickly. Just multiply the value of the first resistor (12,500 ohms) by 0.75 to find the value of the second resistor. Multiply the value of the second resistor by 0.75 to find the value of the third resistor, and so on. Table 1 lists the values obtained and the 5% EIA values chosen to construct the control. The exact values are shifted to the closest EIA value. If one resistor is shifted down to the closest EIA value, shift all of them down so that the relative ratio among them is about the same as before.

Either the graphical or mathematical method can be used to determine the resistor values. Curves of most any resistance-rotation characteristic can be duplicated quickly using this method. Normally ½- or ¼-watt resistors are sufficient if more than ten resistors are used for the control. Thus ten ¼-watt resistors will make a variable resistor with a 2.5-watt rating. Increasing the wattage rating of each resistor will produce less noise, less resistor drift with time, and insure longer life. ▲