A Note on Volume Controls

CHARLES P. BOEGLI*

The author shows that it is not always satisfactory to place a high-resistance potentiometer just anywhere in an amplifier circuit if specified performance is to be obtained.

An audio amplifier is generally made up of several stages arranged in cascade so that the input signal is fed through one after the other, being amplified on the way, finally appearing as an output voltage at the loudspeaker terminals. Somewhere in this unit, it is usually necessary to provide a control over the gain of the entire amplifier, so that input signals of the given voltages can be made to yield output voltages of the desired magnitudes. This is most often accomplished in high-impedance locations, by means of a simple potentiometer; the output from the plate of one stage is connected to the top of the potentiometer, the other end of which is grounded, and the grid of the following stage is fed from the slider. The purpose of this note is to mention some considerations that appear to be generally overlooked in providing a "volume" control of this type.

Since hum and noise are most apt to assume noticeable proportions in the input stages of the amplifier where signal voltages are quite low, the volume control should generally be located after the first few stages. In this manner, the signal is maintained at the maximum value compared to the noise through these critical stages and becomes attenuated only when it has reached a value quite large in comparison to noise voltages. On the other hand, should the volume control be located too near the output tubes, the possibility is increased that the signal will attain sufficient magnitude before reaching the control to cause unnecessary distortion in previous stages. Placement of the control at a point where the maximum signal level is from 2 to 4 volts will usually lead to a fairly satisfactory design, suffering neither from distortion nor excessive noise. It goes without saying that the control must not be placed inside the feedback loop, if any are employed in the circuit.

The only disadvantage to locating the control otherwise than at the input to the amplifier is that the voltages of the signal sources used with the amplifier must—to a degree, at least—be controlled. Thus, with the volume control at the input we need concern ourselves only with the minimum input required for full output, but if the control is situated later, the *maximum* input also becomes important. An input stage handling a minimum of 0.5 volt may well be designed to carry a maximum of the order of 1.5 volts; obviously, if a tuner supplying 6 volts is connected to such an input, overloading will result. The best arrangement would therefore seem to be one in which the volume control is placed near enough to the output stages to maximize the signal-to-noise ratio and close enough to the input stages to prevent serious distortion, and in which individual pads are used on the various signal sources to bring their outputs to approximately a uniform level, preferably slightly over the minimum required to drive the amplifier fully.

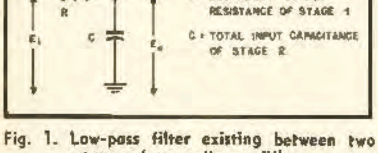

Fig. 1. Low-pass filter existing between two stages of an audio amplifier.

* *Cincinnati Research Company, 6431 Montgomery Road, Cincinnati 13, Ohio.*

Effect on High-Frequency Response

The high-frequency response of an amplifier (utilizing a good output transformer) is largely determined by the cutoff frequencies of the series of low-pass filters incorporated into it and made up of the output resistance of one stage and the input capacitance of the next, as indicated in *Fig.* 1. When one stage feeds directly into the next the problem of attaining good high-frequency response is fairly well defined, and the solution consists simply in keeping the output resistance of each stage as low as possible. Low-mu triodes with plate resistances of the order of 10,000 ohms are excellent in this respect and may be used with plate-load resistances of almost any size without adversely affecting high-frequency response. With high-mu triodes and pentodes the plate-load resistors, as well as the grid resistors of the following stages, must be kept small in order to realize good high-frequency response. But what occurs upon the introduction of a volume control?

Obviously, when the slider is at the top of the control, the situation is the same as if no control were present. When the slider is near the bottom, also, the following stage is fed from a very low impedance so that the high-frequency response is even better than when the slider is at the top. In less extreme positions, however, if the volume control resistance is quite high, there may be a substantial loss of high frequencies—and it is precisely these positions that are most important.

Reference to *Fig.* 2 will make this clear. R_s is the output resistance of the preceding stage and R_t is the volume-control resistance. The symbol a represents the position of the slider and measures the fraction of the voltage appearing at the top of the control that is applied to the following grid. Now R_o, the resistance into which the following grid looks is aR_t in parallel with $R_s + (1-a)R_t$, which is found to be

$$R_o = \frac{aR_tR_s + (a-a^2)R_t^2}{R_s + R_t} \qquad (1)$$

We are interested in the manner in which R_o varies with a. Hence, differentiation of the above expression with respect to a yields

$$\frac{dR_o}{da} = \frac{R_tR_s + R_t^2 - 2aR_t^2}{R_s + R_t} \qquad (2)$$

The resistance R_o is a maximum at the value of a found by setting the right side of Eq. (2) equal to zero and solving for a:

$$R_tR_s + R_t^2 - 2aR_t^2 = 0$$

$$a = \frac{R_s + R_t}{2R_t} \qquad (3)$$

When a assumes this value, the maximum output resistance

$$R_{om} = \frac{R_s + R_t}{4} \qquad (4)$$

For example, if we had a low-mu triode stage with an output resistance of 10,000 ohms connected to the top of a 1-meg. volume control, there would be some point at which the next stage would look back into as much as

$$\frac{10{,}000 + 1{,}000{,}000}{4} = 252{,}500 \text{ ohms}$$

and if the input capacitance of the following stage were sufficient to cause a

[*Continued on page 60*]

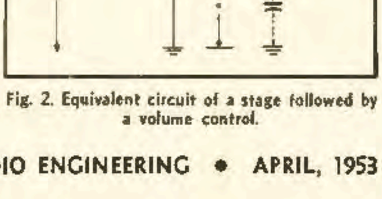

Fig. 2. Equivalent circuit of a stage followed by a volume control.

VOLUME CONTROLS

(from page 40)

3-db drop at 1000 kc without the volume control, there would actually be a drop of 3 db at about 4000 cps at this position of the volume control.

We find, consequently, that the resistance of the volume control is rather stringently limited by the capacitance into which it must work. As an example, suppose we had a 12AY7 stage with an output resistance of 20,000 ohms working into a 6SL7GT with an input capacitance of 100 μμf. At best, there will be a drop of 3 db at 80 kc. Suppose further that we cannot tolerate a drop of more than 3 db at 50 kc in this particular stage. Then the maximum output resistance at any position of the control must be 32,000 ohms. To find the maximum permissible volume control resistance we use Eq. (*4*) with 20,000 ohms for R_s, 32,000 for R_{om}, and solving for R_t we obtain $R_t = 108{,}000$ ohms, and a 100,000-ohm control would be used.

Suppose we are more exacting and state that the high-frequency response with the volume control must never be any poorer than without it. This is the same as saying that R_{om} in Eq. (*4*) must be the same as R_s:

$$\frac{R_t + R_s}{4} = R_s$$

$$R_t = 3R_s \qquad (5)$$

To realize this performance in the case just described we should have to utilize a 60,000-ohm control. That these values are much lower than those commonly in use will readily be recognized.

The installation of a volume control thus appears to be somewhat more involved than simply inserting a 1-meg. potentiometer at the amplifier input. In particular, the use of relatively low values is indicated in cases where the control is working into appreciable capacitance.