# Audio Volume Control

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## Introduction:

This document details a volume control circuit intended for audio applications. The circuit consists of 2 resistors and one potentiometer; the latter acts as the knob which the user rotates to set a desired volume. One key feature of the circuit design is that that the audible sound intensity should vary approximately linearly versus rotation of the control knob; in other words, it provided smooth, not touchy, volume control over the entire range of the dial.

## Design and Measurements:

The volume control circuit design is shown in Figure 1, left. (adapted from Elliott Sound Productions).

For initial tests measuring Vout/Vin, we used 5V DC power supply for the input (Vin). The DC output (Vout) was measured across R3 (in parallel with a fraction of R2, depending on the pots setting) with a standard multi-meter. We measured the output voltage for 10 different potentiometer settings, approximately equally spaced over its full range ($\alpha = 0 - 1$), judging by eye and feel alone. The pot setting is indicated in Figure 1 by the variable $\alpha$. For proof-of-concept demonstration we connected an audio source (laptop computer) as the input source. The output was connected to an audio amplifier. We turned the knob and subjectively judged the corresponding volume level.

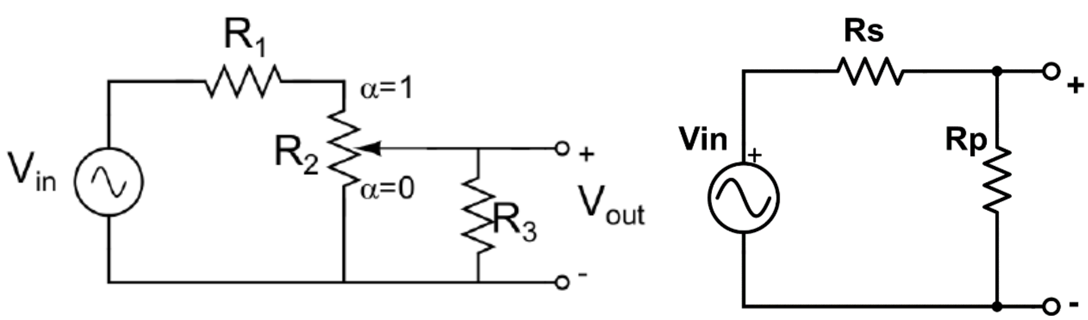


*Figure 1. Left: Audio volume control circuit design. R1 (4.7kΩ) and R3 (15 kΩ) are standard resistors. R2 is 100k potentiometer. The potentiometer's setting is indicated by α, which varies between 0 (wiper terminal at 'bottom') and 1 (wiper at 'top'). Right: Equivalent simplified voltage divider model of the volume control circuit.*

The main principle of operation is that the circuit acts as a voltage divider (Figure 1, right). One resistor of the voltage divider model is formed by the by series combination of equivalent of R1 and a fraction of R2. The parallel equivalent is formed by remainder of R2 in parallel with R3. For the simplified voltage divider model the output voltage measured across is Rp is given by:

$$\frac{V_{out}}{V_{in}} = \frac{R_p}{R_s + R_p}$$

When the pot is set to $\alpha = 1$, the parallel equivalent $R_p$ is maximized and $R_s$ is minimized. This condition produces the maximum output voltage of the circuit, hence the loudest volume. By contrast, when the pot is set to $\alpha = 0$, this forms a short circuit across $R_3$, minimizing $R_p$ thus producing minimal sound output.

## Results:

Figure 2 illustrates the measured performance of the circuit (red dots) compared to theory (blue trace). We see that the output voltage increases with $\alpha$ as expected. In general, the relation is approximately exponential. When the knob is maxed out ($\alpha = 1$), we get a value of Vout/Vin of about 0.62, compared to the predicted maximum output ratio of 0.735 (see Appendix I). The average absolute difference between measurement and theory was 16.1 +/- 8.2 % (mean +/- S.D.). This value quoted for % difference neglects the data point at $\alpha \approx 0$; with an expected output of 0, any small measured value produces an artificially high percent difference.

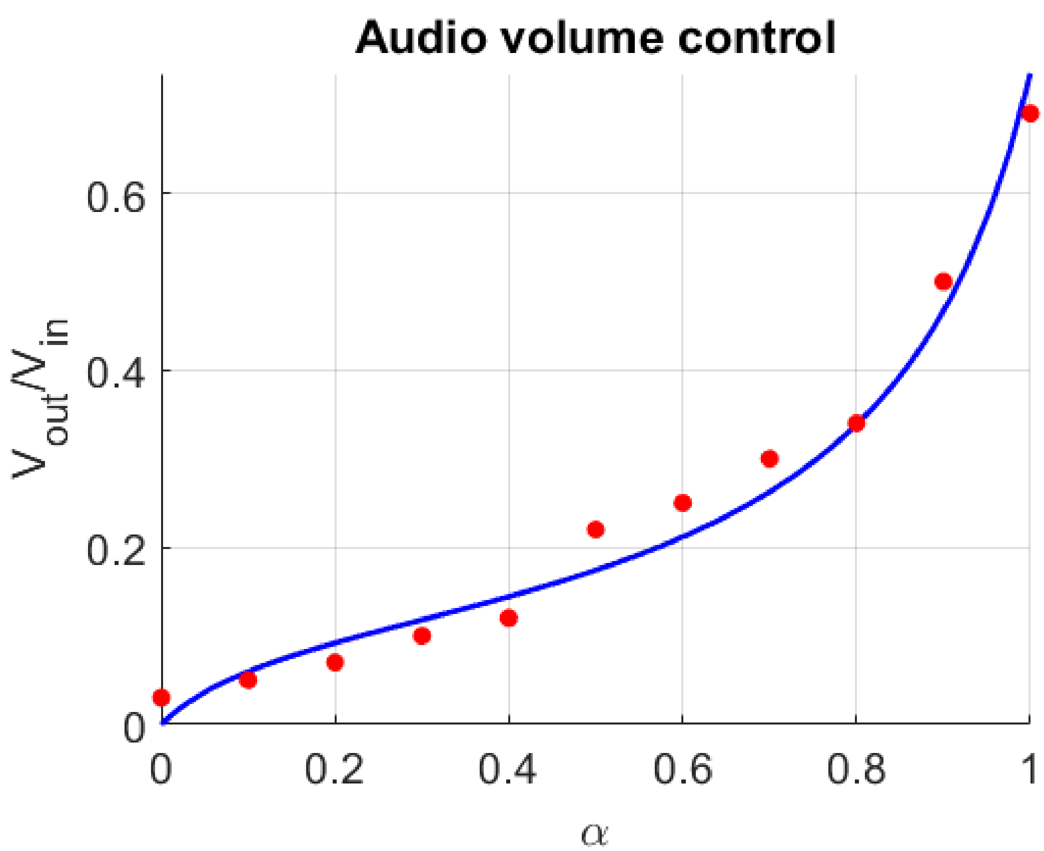


*Figure 2. Measured performance (red dots) and theoretical behavior (blue trace) of volume control circuit.*

The proof-of-concept experiment demonstrated satisfactory performance in a practical scenario. As we turned the knob, we could clearly hear the difference in audible volume, with sound ranging smoothly from loud to soft (no touchy spots), which is highly desirable from a user perspective.

## Discussion:

In general, our circuit worked as expected volume increasing with the variable $\alpha$. The % differences observed may be due to the crude by-eye and by-feel method used estimate pot position. Specifically, if the pot position were underestimated by alpha = 0.05 corresponding about 10 degrees of rotation for the data points alpha = 0.5, 0.6, 0.7, this could shift the corresponding data points in Figure 2 horizontally to more closely match theory to within about 5% (see Appendix I). Of course, this would imply that we would likely need to shift the data point at alpha = 0.8 in the same manner, which would increase the % error noted at higher alpha values. In the future, a more precise method for measuring $\alpha$ would be to measure the pot's resistance at each position tested and dividing that value and dividing by the maximum measured resistance (95.5 k$\Omega$ with the pot knob turned all the way up).

We observed an approximately exponential increase in Vout/Vin vs. alpha. Given that the human ear interprets the sound intensity level on a logarithmic scale, this circuit thus produces an approximately linear relation between sound intensity and pot position, as desired. Applications of this circuit could thus extend to any scenario of a logarithmic sensor.

In theory, this volume control circuit should produce a maximum ratio of Vout/Vin = 0.73. This implies about 27% of the signal is lost across R1. One could modify the circuit to use a value of R1 = 1k. This would lead to a maximum output of Vout/Vin = 0.86 while evidently not sacrificing the exponential behavior vs. alpha (Figure 3).

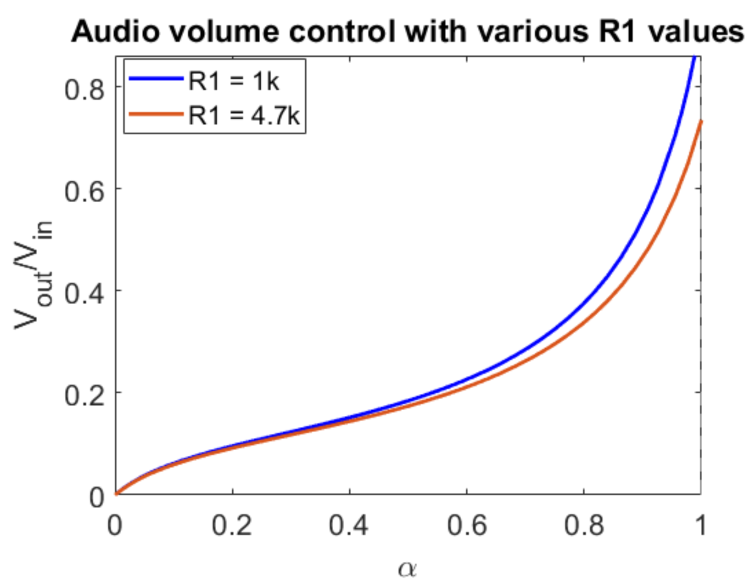


*Figure 3. Comparison of volume control circuits with existing (orange trace) and alternative (blue trace) value for R1. A higher maximum value may be achieved with the smaller value resistor.*

**Appendix I: Detailed Theory and Calculations**

In view of Figure 1, we can define the series and parallel equivalent resistors as follows:

$R_s = R_1 + (1-\alpha)R_2.$

$$\frac{1}{R_p} = \frac{1}{\alpha R_2} + \frac{1}{R_3}.$$

$R_p = (\alpha R_2 R_3)/(\alpha R_2 + R_3).$

Here the quantity $(1-\alpha)R_2$ and $\alpha R_2$represent, respectively, the "top" and "bottom" portions of the pot's resistance, depending on the knob position.

The total current in the circuit is given by $I = \frac{Vin}{Rs+Rp}$. The output voltage is $Vout = IR_p$.

Thus, we have the relation:

$$\frac{V_{out}}{V_{in}} = \frac{R_p}{R_s+R_p} = \frac{(\alpha R_2 R_3)/(\alpha R_2 + R_3)}{(\alpha R_2 R_3)/(\alpha R_2 + R_3) + R_s + (1-\alpha)R_2.}$$

When the pot is set to $\alpha = 0$, this expression clearly becomes 0 because of the factor of $\alpha$ in the numerator, with non-zero denominator. With the pot set to $\alpha = 1$, the expression evaluates to a maximal value of 0.735.

**Effect of uncertainty in alpha – example calculation**

At a value of alpha = 0.5 and 0.6, the expression above for Vout/Vin computes as 0.1775 and 0.216, respectively.

The measured value at an experimental value of alpha = 0.5 was 0.22. This is an absolute % error of:

(0.22 – 0.1775)/0.1775 *100 = 23.9%.

If the true experimental alpha value were 0.6 (instead of 0.5), we would have an absolute % error of:

(0.22 – 0.216)/0.216*100 = 1.85%

This shows the discrepancy between theory and experiment is significantly reduced.

While the change in alpha from 0.5 to 0.6 may be an overcorrection, this still shows that inaccuracy (underestimating) alpha could be a plausible reason for the discrepancy noted.