Experiment No. 6.
Audio Tone Control Amplifier

By: Prof. Gabriel M. Rebeiz
The University of Michigan
EECS Dept.
Ann Arbor, Michigan

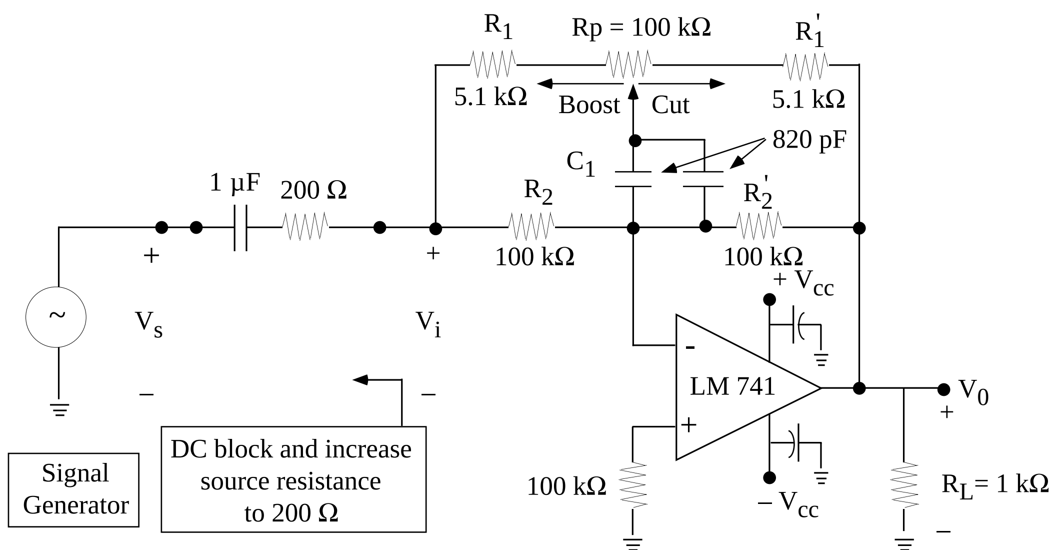
Goal: The goal of Experiment #6 is to build and test a tone control amplifier and to study the effect of the capacitor on the corner frequency of an RC circuit.

❑ Read this experiment and answer the pre-lab questions before you come to the lab.

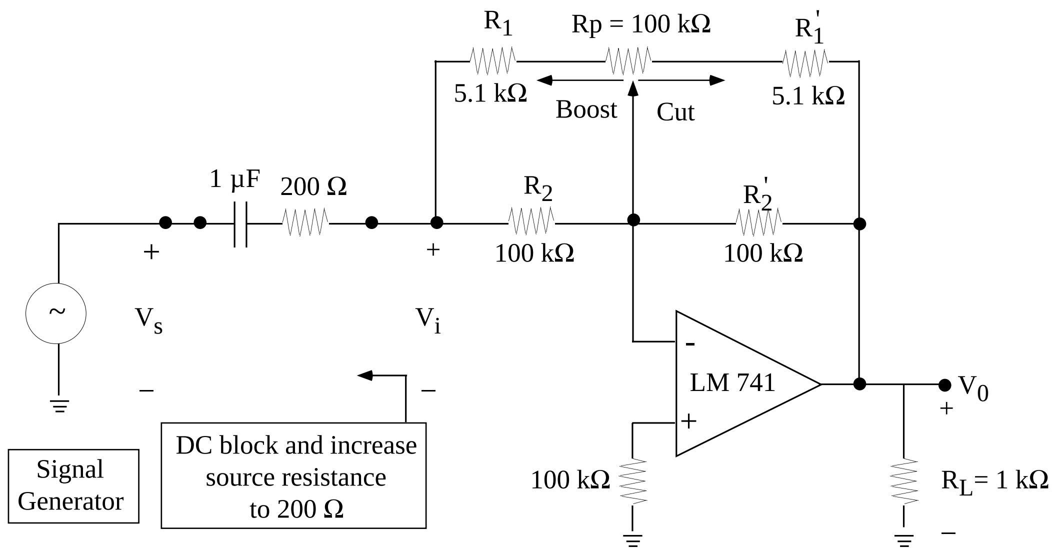
6.1 Treble Tone Control Amplifier:

Equipment:
- Agilent E3631A Triple output DC power supply
- Agilent 33120A Function Generator
- Agilent 34401A Multimeter
- Agilent 54645A Oscilloscope

A treble tone control amplifier is shown below:



At high frequencies, when the C_1 (2 x 820 pF) behaves as a short-circuit, the circuit becomes:



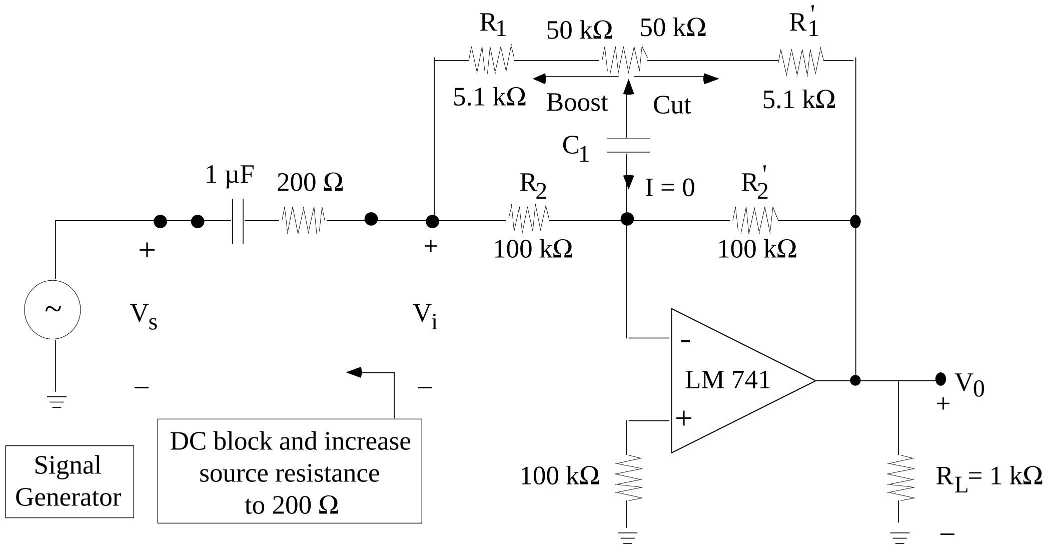
If the 100 kΩ potentiometer is set at maximum boost, the gain becomes:

$$\frac{V_0}{V_i} = -\frac{R_2' \parallel \left(R_p + R_1'\right)}{R_2 \parallel R_1} \approx -10.5\,(20.4\,dB) \text{ at high frequencies.}$$

If the 100 kΩ potentiometer is set at maximum cut, the gain becomes:

$$\frac{V_0}{V_i} = -\frac{R_2' \parallel R_1'}{R_2 \parallel \left(R_p + R_1\right)} \approx -0.095\,(-20.5\,dB) \text{ at high frequencies.}$$

At any frequency, if the 100 kΩ potentiometer is set exactly in the middle, the circuit is perfectly symmetrical and no current passes by C_1 (whatever its value). The capacitor C_1 can therefore be removed from the circuit, and the gain becomes $\frac{V_0}{V_i} = \frac{-R_2'}{R_2} = -1\,(0\,\mathrm{dB})$, which is the flat response over the entire frequency range.



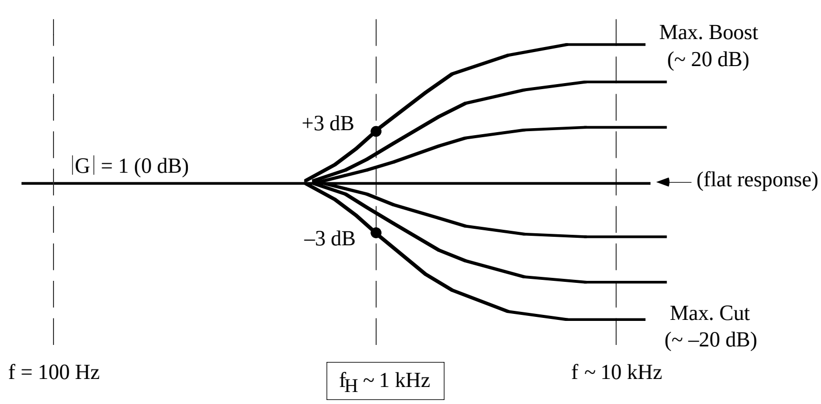
The corner frequency, defined for max. boost/cut positions, is where the transfer function deviates from the flat response by ± 3 dB. It is given by:

$$f_H = \pm \text{ 3-dB frequency } = \frac{1}{2\pi R_2 C_1}$$

f_H ~ 1.0 kHz for C_1 = 2 x 820 pF, R_2 = 100 kΩ

f_H ~ 2.0 kHz for C_1 = 820 pF, R_2 = 100 kΩ

The transfer function for the treble control amplifier and C_1 = 2 x 820 pF "looks" like:



1. ❏ Draw the circuit in your notebook.
2. Assemble the circuit on the breadboard. Do not forget to connect two 220 µF (or 470 µF) capacitors from $+V_{CC}$ (+12 V) to ground and from $-V_{CC}$ (–12 V) to ground for noise cancellation. Show your completed circuit to your lab instructor before applying the voltage from the power supply.
3. Check the DC voltages at V^-, V^+ and V_0 terminals. They should be in the mV level.
4. Set the Agilent 33120A function generator to 400 mV ppk with a frequency of 20 kHz and connect it to the amplifier.

   Connect V_S to channel 1 and V_0 to channel 2 of the scope.
5. ❏ Vary the 100 kΩ potentiometer and measure V_0/V_S. Make sure that you have a gain around ± 20 dB at 20 kHz. Find the position of the potentiometer which results in a gain of 0 dB (gain = -1) at 20 kHz.
6. ❏ Measure the frequency response (<u>amplitude and phase</u>) from 50 Hz–100 kHz (50, 100, 200, ... Hz) at the three gain settings shown below:

   <u>Gain Settings:</u>

   – Maximum Boost ($|G| \simeq 10$) – Use V_S = 400 mV ppk

   – Maximum cut ($|G| \simeq 0.1$) – Use V_S = 1 V ppk

   – Flat response ($|G| \simeq 1$) (just take few points only). Use V_S =1V ppk.

   <u>Phase Measurement</u>:

   To measure the phase delay between the input and output signals, display both signals on the screen in time domain and use the <u>Phase</u> softkey (phase 1 → 2) under the Measure [Time] menu.

   For the <u>maximum boost</u> and for the <u>maximum cut</u> settings, calculate the 3-dB corner frequency (f_H) from the measured data.
7. ❏ Remove one of the 820 pF capacitors (C_1 = 820 pF now) and repeat 6 for maximum boost setting (amplitude only). What do you notice? Comment.
8. ❏ Put the 820 pF capacitor back into the circuit, C_1 = 2x 820 pF (f_H ~ 1 kHz), set the Agilent 33120A function generator to deliver an 800 Hz <u>square-wave</u> with V_{ppk} = 600 mV. Measure the input waveform (V_S) in frequency domain and note the fundamental and harmonic values (up to 11 f_0 – 6 measurement points).

   Note: Do not measure any <u>even</u> harmonics. These are aliases and you need to check your scope FFT settings.

   Be careful: these measurements should be done on the input signal, thus **Operand** is **1**.
9. ❏ Measure and sketch accurately the output voltage (V_0) in time domain and frequency domain (up to 11 f_0) for the <u>maximum boost</u> and for the <u>maximum cut</u> settings (Make sure that you are not clipping or driving the scope into saturation.).

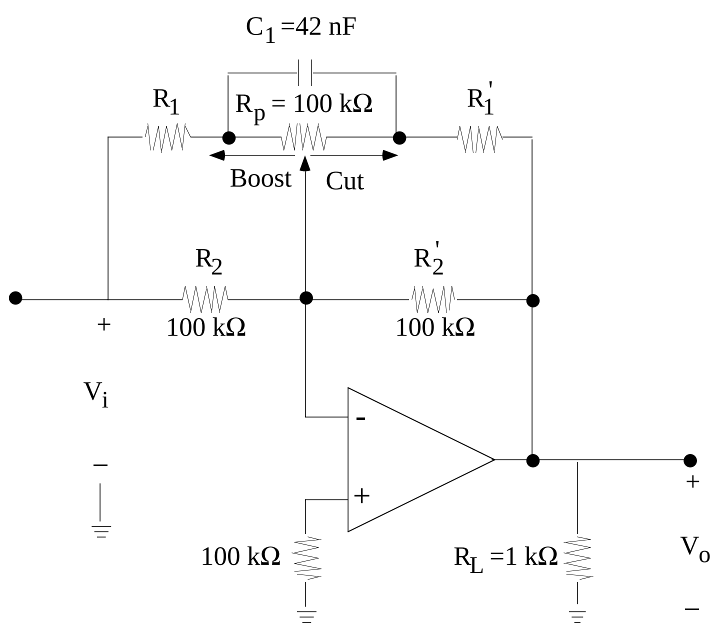
Be careful: these measurements should be done on the output signal; thus **Operand** is **2**.

Comment on your measurements.

6.2 Bass Tone-Control Amplifier:

DO NOT BUILD THIS CIRCUIT. I AM INCLUDING IT HERE FOR COMPLETENESS.

A bass tone control amplifier is shown below:



– Max. boost = $\dfrac{-R_2' \parallel (R_p + R_1')}{R_2 \parallel R_1}$ = –10.5 f is very low

(capacitor is open-circuited)

– Max. Cut = $\dfrac{-R_2' \parallel R_1'}{R_2 \parallel (R_p + R_1)}$ = 0.095 f is very low

(capacitor is open-circuited)

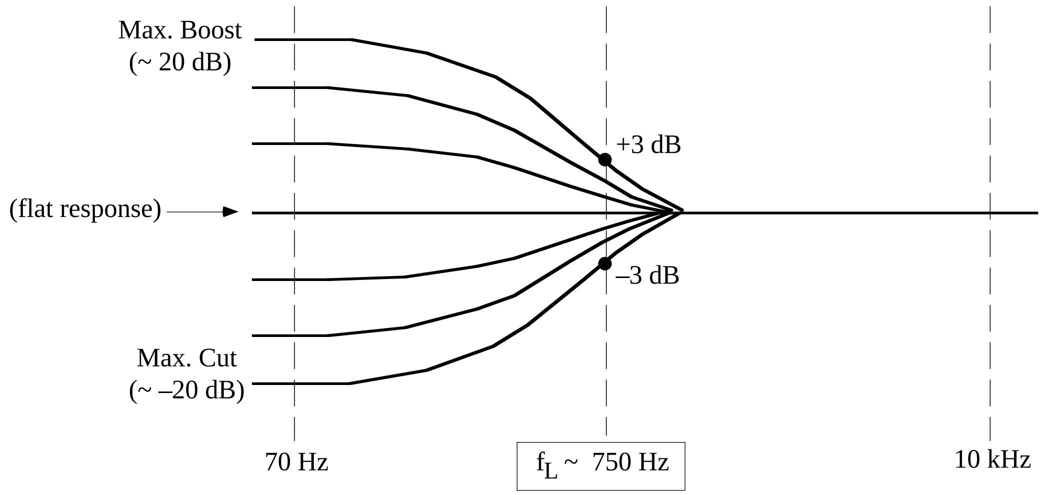
– Corner frequency at max. boost/cut settings: $f_L = \dfrac{1}{2\pi R_1 C_1}$ R_1 = 5.1 kΩ

C_1 = 42 nF

= 750 Hz

– If the potentiometer is set exactly in the middle, then no current passes by C_1 (whatever its value) and we get a flat response ($|G| \simeq 1$) over the entire frequency range.

The transfer function for the bass control amplifier and C_1 = 42 nF "looks" like:

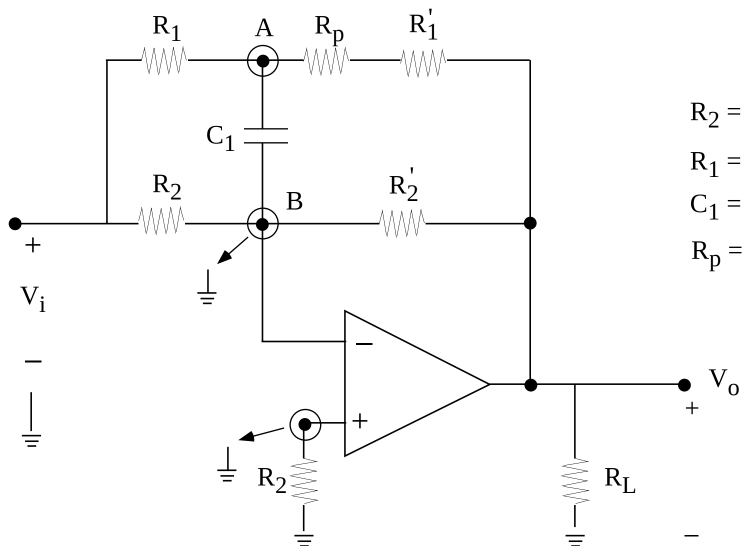


Experiment No. 6.
Audio Tone Control Amplifier

Pre-Lab Assignment

1. Derive V_0/V_i (not V_0/V_S) for the treble control amplifier at max. boost/cut settings and high frequencies (> 20 kHz, capacitor is short-circuited). The answer is given in the lab assignment. Derive now V_i/V_S and then calculate V_0/V_S.

2. The circuit at maximum boost setting is shown below. Using nodal analysis at nodes A, B, determine the transfer function $\frac{V_o}{V_i}(\omega)$.



$R_2 = R_2' = 100\ k\Omega$

$R_1 = R_1' = 5.1\ k\Omega$

$C_1 = 2 \times 820$ pF

$R_p = 100\ k\Omega$

Note, in order to get a simple and elegant answer, you should make some "accurate" assumptions (to within a few percent):

$R_p + R_1 \simeq R_p$ since $R_p >> R_1$

$R_p + R_1' \simeq R_p$ since $R_p >> R_1'$

$R_1 \parallel R_2 \simeq R_1$ since $R_2 >> R_1$

$R_2' \parallel (R_p + R_1') \simeq R_2'/2$ since $R_2' \simeq R_p + R_1'$

a. Put the transfer function $\frac{V_o}{V_i}(\omega)$ in the form:

$$\frac{V_o}{V_i}(\omega) = \quad H(\omega) = (A)\,\frac{1 + j\,(\omega/\omega_1)}{1 + j\,(\omega/\omega_2)}$$

A, ω_1, ω_2 = constants to be determined

$\omega_1 \equiv$ zero of transfer function

$\omega_2 \equiv$ pole of transfer function

b. Derive $|H(\omega)|$, the magnitude of $H(\omega)$.

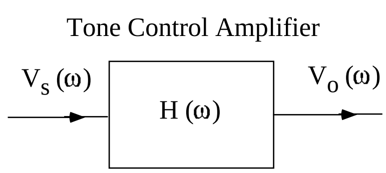
c. Derive the phase of $H(\omega)$.

d. Using the component values given above. Make MATLAB plots of the magnitude $|H(\omega)|$ and the phase of the transfer function from 10 Hz to 100 kHz. Use a log-scale for the frequency axis, and a dB scale for the transfer function magnitude (-10 to +30 dB). Express the phase in degrees.

Experiment No. 6.
Audio Tone Control Amplifier

Lab-Report Assignment

1. Using MATLAB, plot the magnitude in dB and phase in degrees of the transfer function $H(\omega) = (V_O/V_S)$ from 50 Hz to100 kHz for C_1 = 2 x 820 pF and the 3 measured treble gain settings ($|G| \simeq 10$, $|G| \simeq 0.1$, $|G| \simeq 1$). For each case, determine the 3-dB corner frequency. (You may use the subplot command in MATLAB to get two plots vertically on the same page). On the same plots, show the theoretical curves for magnitude and phase which you derived in the pre-lab (you may use the hold command in MATLAB). Comment on the agreement between theory and experiment.
2. Using MATLAB, plot the magnitude of the transfer function $H(\omega) = (V_O/V_S)$ for max. boost setting (only) from 50 Hz to 100 kHz for C_1 = 820 pF and C_1 = 2 x 820 pF. Determine the 3-dB corner frequency of each case. Comment on the difference between these frequencies.
3. The tone control amplifier can be represented as a block diagram with a transfer function, $H(\omega)$ in frequency domain.



$$\frac{V_0}{V_s}(\omega) = H(\omega)$$

$V_O(\omega) = H(\omega) \cdot V_s(\omega)$ (Phasor multiplication)

Which means: Amplitude: $V_O(dB) = H(\omega)(dB) + V_S(dB)$

Phase: $\angle V_0 = \angle H(\omega) + \angle V_s$

$V_S(\omega)$ = Input signal (in frequency domain).

$H(\omega)$ = Measured transfer function of the treble control circuit (in frequency domain, dB and degrees).

$V_O(\omega)$ = Output signal (in frequency domain).

3.1 Calculate the input spectrum (up to $11f_O$-amplitude and phase) of an 800 Hz square wave with V_{ppk} = 600 mV_{ppk} (you know how to calculate this using Fourier Series).

3.2 Using the *measured* transfer function $H(\omega)$ (plotted in problem 1) and the spectrum of V_i (calculated in 3.1), calculate the output spectrum (up to $11f_O$ – amplitude and phase) at max. boost and max. cut settings.

3.3. Compare the calculated output spectrum (up to $11f_O$ – amplitude only) for max. boost and max. cut positions with the measured values in the lab.

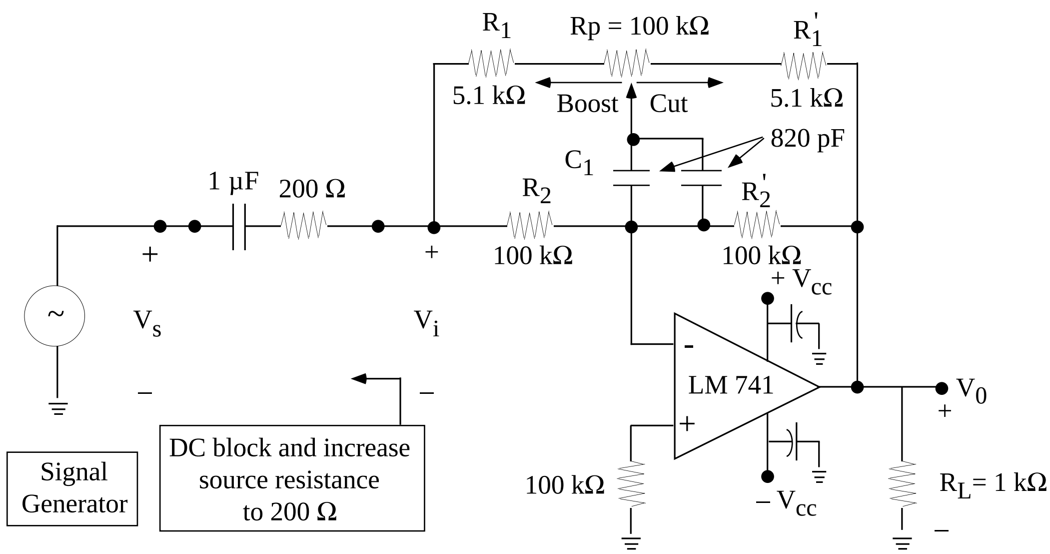
3.4 Knowing the amplitude and phase information of $V_O(\omega)$ (obtained in 3.2), and using MATLAB for the sine-wave addition, calculate $V_O(t)$ for the max. boost and max. cut positions. (Do not ignore the phase, it is very important!). Compare your results with the time-domain measurements of $V_O(t)$ done in the lab.

Explain why at max. boost there are sharp peaks in the output waveform, and why at max. cut, there are slow rising edges in the output waveform.

Experiment No. 6.
Audio Tone Control Amplifier

Worksheet/Notes

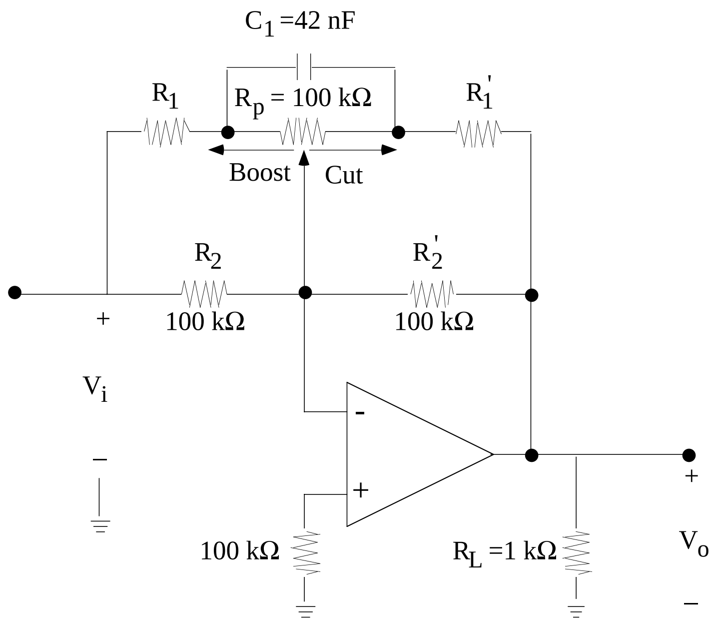
<u>Treble Control Amplifier</u>



Experiment No. 6.
Audio Tone Control Amplifier

Worksheet/Notes

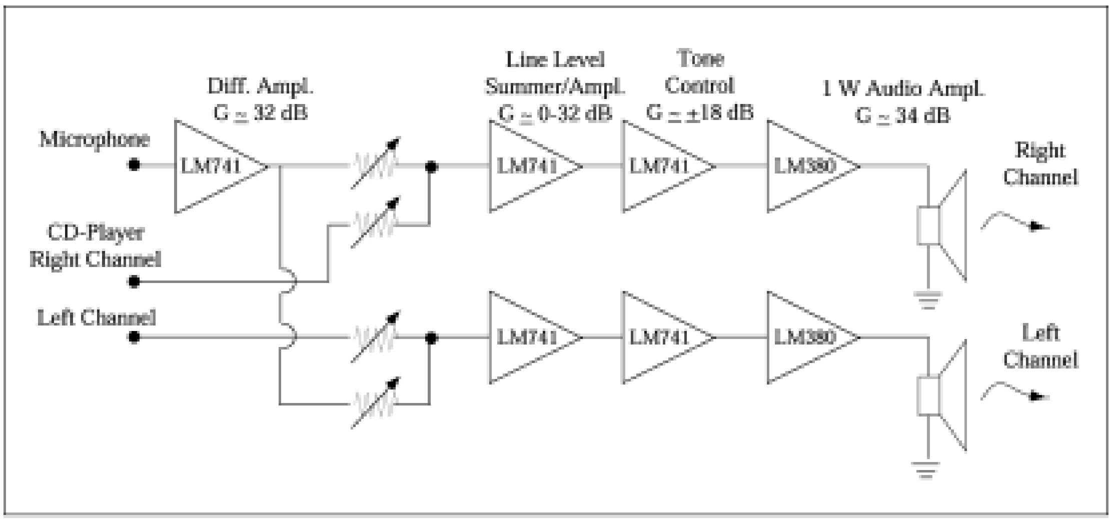
Bass Control Amplifier



Open Audio Lab

In this Open Audio Lab, you'll do some really cool things! From the circuits you've built in Experiments #4 and #6, and the circuit that you tested in Experiment #3, you'll assemble a working audio system and listen to your favorite music from your CD player.

The lab instructor will demonstrate a similar circuit built for the left- and right-channels for stereo sound, as shown in the diagram below:



BRING YOUR FAVORITE CD and listen to it, mix your voice with music and create weird sound effects.

☺ Enjoy ☺

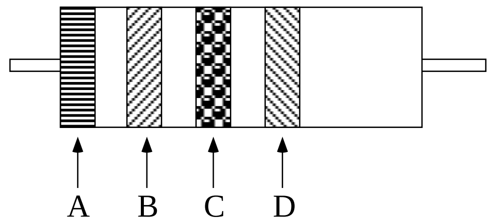
Gabriel M. Rebeiz

December 11, 1997

Appendix A

Color Coding of Resistors/Capacitors

Color	Significant Figure	Decimal Multiplier (10*)
Black	0	1
Brown	1	10
Red	2	100
Orange	3	1,000
Yellow	4	10,000
Green	5	100,000
Blue	6	1,000,000
Violet	7	10,000,000
Gray	8	100,000,000
White	9	1,000,000,000
Gold	–	0.1
Silver	–	0.01
No Color	–	–



R = AB x 10^C %D

Standard Resistance Values
1.0, 1.2, 1.5, 1.8, 2.0, 2.2, 2.4, 2.7, 3, 3.3, 3.6, 3.9, 4.3, 4.7, 5.1, 5.6, 6.2, 6.8, 7.5, 8.2, 9.1

Axial Leads	Color
A	Indicates first significant figure of resistance value in ohms.
B	Indicates second significant figure.
C	Indicates decimal multiplier.
D	If any, indicates tolerance in percent about nominal resistance value. If no color appears in this position, tolerance is 20%. A gold band means a 5% tolerance, and a silver band means a 10% tolerance.

Examples:			
	R = 2.2 kΩ	Red, Red, Red	(22 x10^2)
	R = 1.0 kΩ	Brown, Black, Red	(10 x 10^2)
	R = 100 kΩ	Brown, Black, Yellow	(10 x 10^4)
	R = 560 Ω	Green, Blue, Brown	(56 x 10^1)
	R = 47 Ω	Yellow, Violet, Black	(47 x 10^0)