Experiment No. 6

Audio Tone Control Amplifier

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Purpose

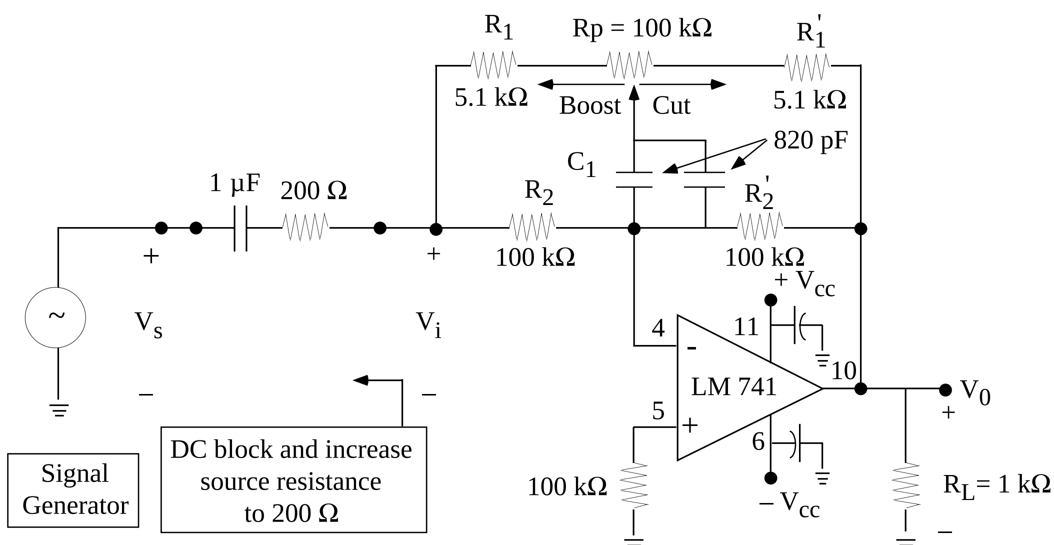
To build and test a tone control amplifier and to study the effect of the capacitor on the corner frequency of an RC circuit.

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

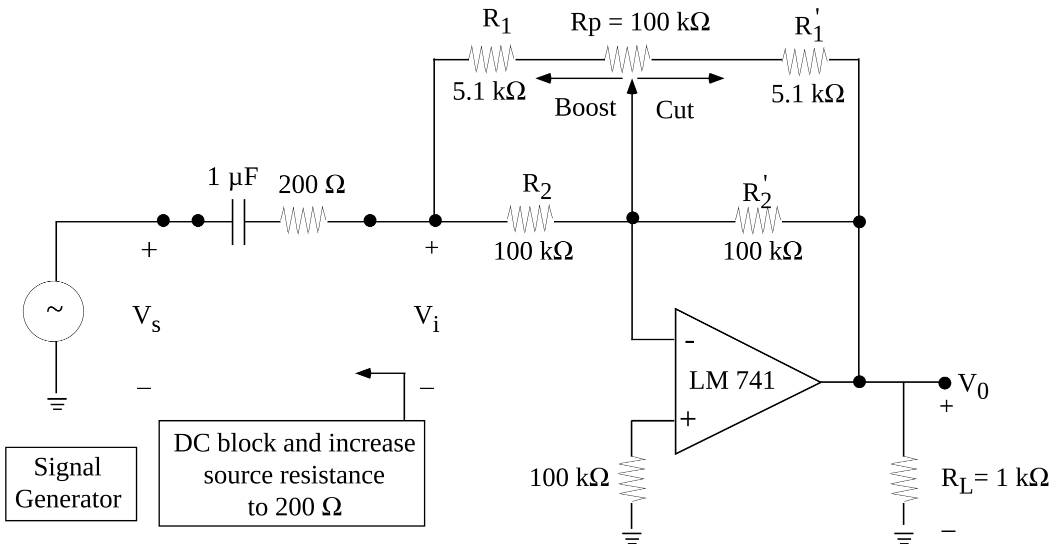
6.1 Treble Tone Control Amplifier:

Equipment: The whole Agilent rack.

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:



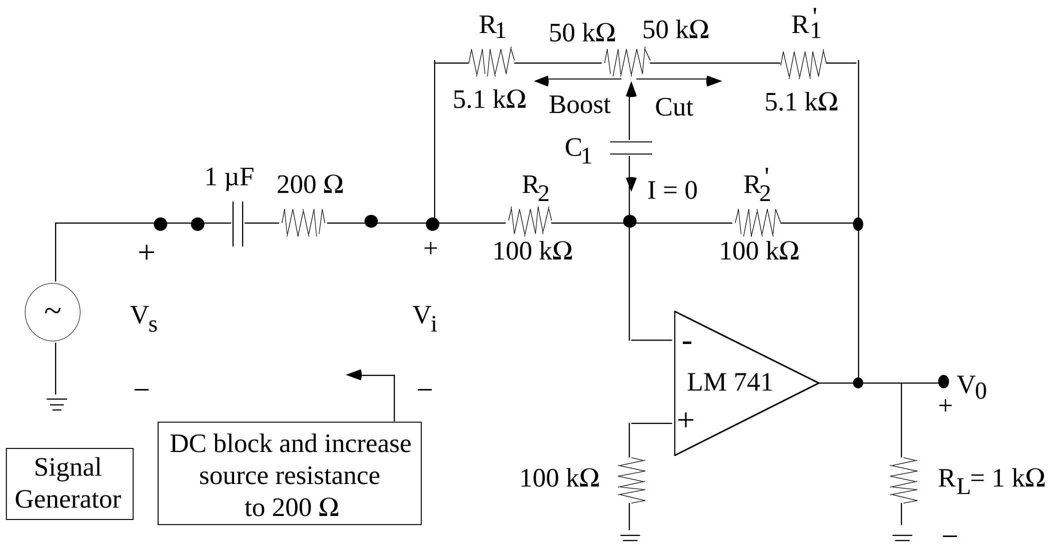
If the 100 kΩ potentiometer is set at maximum boost, the gain becomes:

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

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

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

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 $\frac{V_0}{V_i} = \frac{-R_2'}{R_2} = -1\ (0\,\text{dB})$, which is the flat response over the entire frequency range.



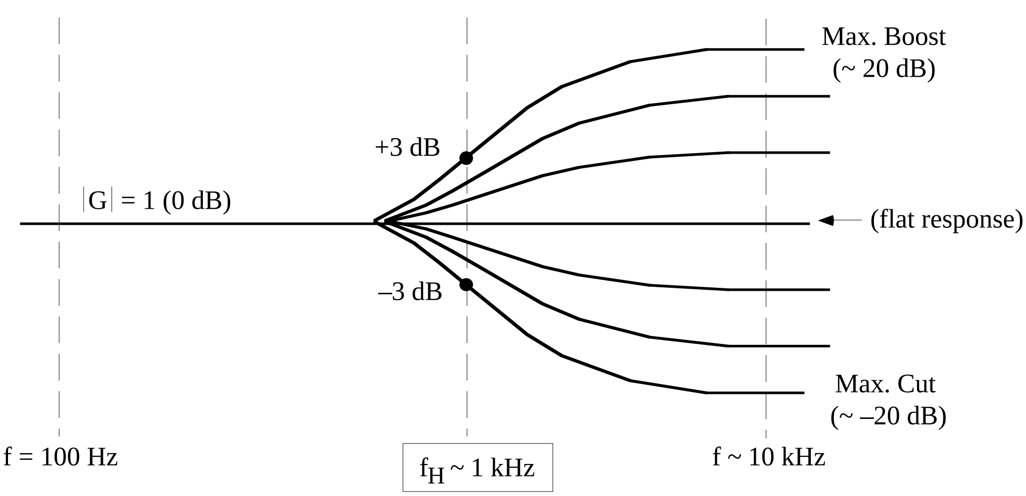
The corner frequency, defined for max. boost/cut positions, is where the transfer function deviates from the flat response by $\pm$ 3 dB. It is given by:

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

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 200 µF capacitors from $+V_{CC}$ (+12 V) to ground and from $-V_{CC}$ (–12 V) to ground for noise

cancellation. Show the T.A. your completed circuit before connecting it to the Agilent 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_0 to channel 1 and V_S 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 $\pm$ 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 (amplitude and phase) from 50 Hz–100 kHz (50, 100, 200, ... Hz) at the three gain settings shown below:

Phase Measurement:

Remember, you need to do this measurement in time domain so as to measure the time delay and hence the phase. To measure the phase delay between the input and output signals, display both signals on the screen and measure the time difference (Δt) between the signals. As mentioned in class, phase = $(\omega)t = (2\pi f)t$. Therefore, the phase delay between the input and output signals is $\Delta\phi = (\omega)\Delta t$.

Alternatively, you can use the phase delay setting softkey (phase 1-2) under the measure [Time] menu.

Gain Settings:

– 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.

For the max. boost/cut positions, 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 square-wave with V_{ppk} = 600 mV. Measure the input waveform (V_S) in frequency domain and note the fundamental and harmonic values (up to 13 f_0 – 7 measurement points).

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

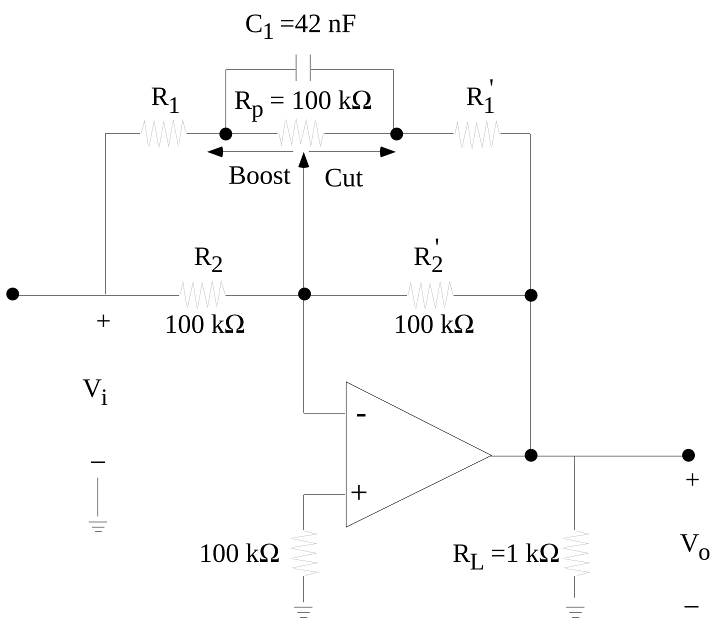
9. ❑ Connect the function generator to the treble circuit. Measure and sketch accurately the output voltage (V_0) in time domain and frequency domain (up to 13 f_0) for the maximum boost/cut settings. (Make sure that you are not clipping or driving the scope into saturation.).

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)

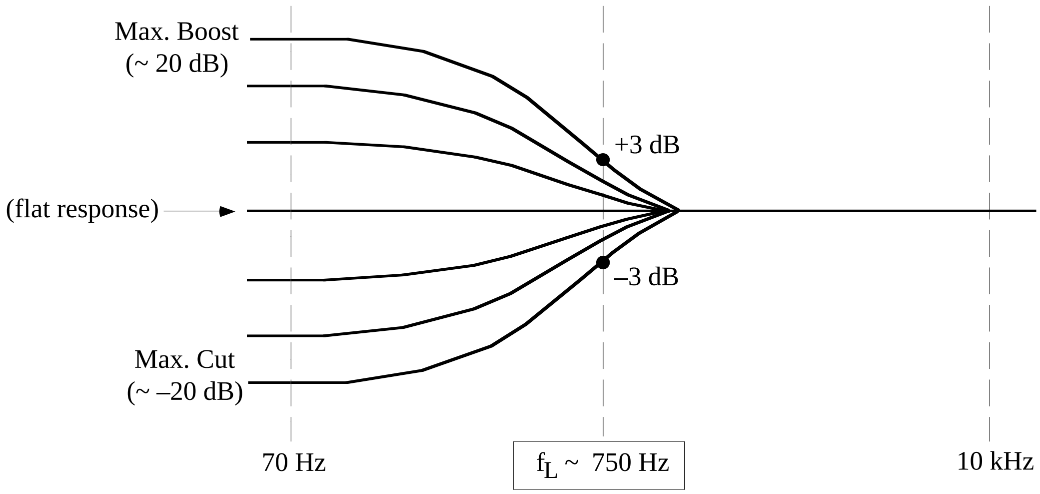
– Corner frequency at max. boost/cut settings: $f_L = \dfrac{1}{2\pi R_1 C_1}$ R_1 = 5.1 kΩ

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:



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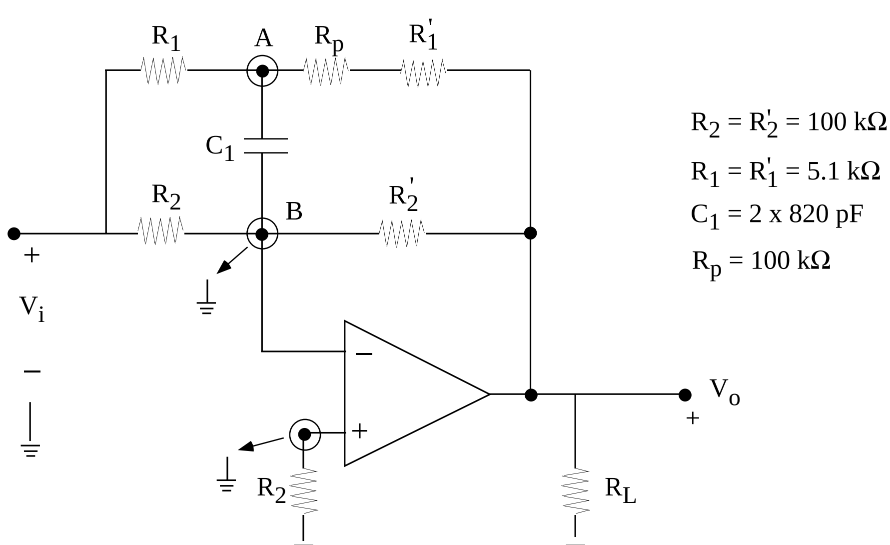
Pre-Lab Assignment

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 V_0/V_S, <u>paying attention to the input impedance of the amplifier</u> at the max. boost/cut positions and very high frequencies (capacitor is short-circuited).

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



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

$$R_p + R_1' \simeq R_p \quad \text{since} \quad R_p >> R_1'$$
$$R_1 \,||\, R_2 \simeq R_1 \quad \text{since} \quad R_2 >> R_1$$
$$R_2' \,||\, \left(R_p + R_1'\right) \simeq R_2'/2 \quad \text{since} \quad R_2' \simeq R_p + R_1'$$

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

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

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, plot ($H(\omega)$) on a Bode-plot (dB, *log f*) from 100 Hz to 100 KHz (dB: -10 to +30).

e. Also, plot the phase of $H(\omega)$ over the same frequency range.

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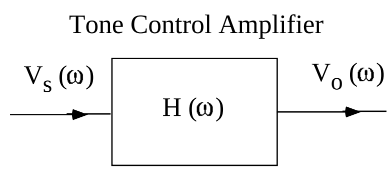
Lab Report Assignment

1. Plot the Bode plots (amplitude and phase) (V_0/V_S) from 50 Hz - 100 kHz for C_1 = 2 x 820 pF and the 3 measured treble settings (|G| = 10, |G| = 0.1, |G| = 1) on the same (*log f*, dB) Bode-plot and the same (*log f*, degrees) phase graph. For each case, determine the 3-dB corner frequency. (Use the subplot command in MATLAB to get two plots vertically on the same page).

2. Plot the transfer function (V_0/V_S) for max. boost setting (only) from 50 Hz - 100 kHz for C_1 = 820 pF and C_1 = 2 x 820 pF on the same *log f,* dB graph (amplitude only). Comment on the 3-dB corner frequency of each case.

3. The tone control amplifier can be represented as a block diagram with a transfer function, H(ω) in frequency domain.



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

V_0 (ω) = H (ω) . Vs (ω)

Amplitude: V_0/dB = H (ω)/dB + V_S/dB

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

V_S (ω)	=	Input signal (in frequency domain).
H(ω)	=	Measured transfer function of the treble control circuit (in frequency domain, dB and degrees).
V_0 (ω)	=	Output signal (in frequency domain).

3.1 Calculate the input spectrum (up to $13f_0$-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(ω) and the spectrum of V_i (calculated in 3.1), calculate the output spectrum (up to $13f_0$ – amplitude and phase) at max. boost/cut settings.

3.3 Compare the calculated output spectrum (up to $13f_0$-amplitude only) for max. boost/cut positions with the measured values in the lab.

3.4 This part should be done in MATLAB:

Knowing the amplitude/phase information of V_0 (ω) (calculated in 3.2), and using Mat-Lab for the sine-wave addition, calculate V_0(t) for the max. boost/cut positions. (Do not ignore the phase, it is very important!). Compare your results with the time-domain measurements of V_0(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.

NOTE: This is really not hard. You have some similar sine-wave additions in Lab #2.

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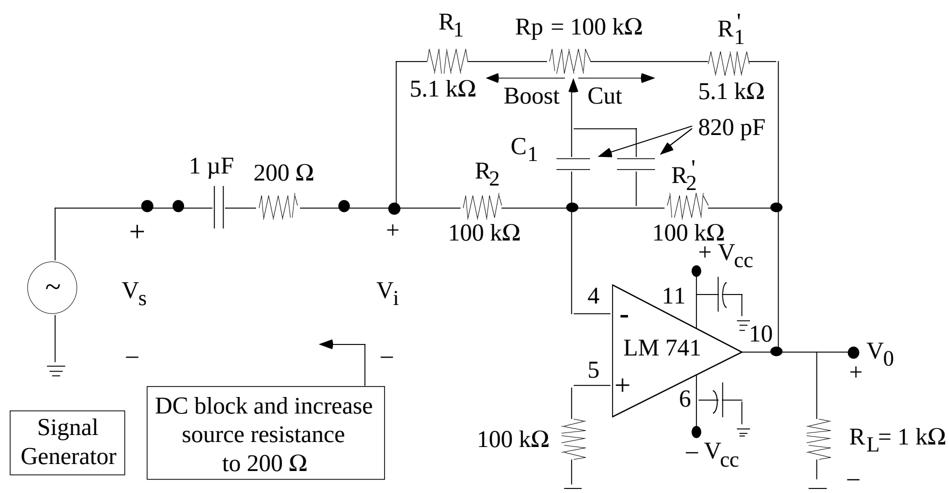
Worksheet/Notes

Treble Control Amplifier



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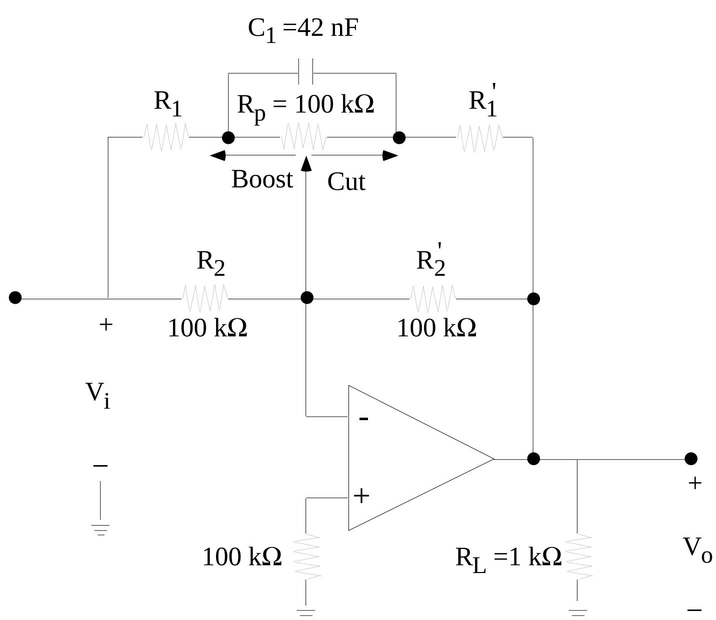
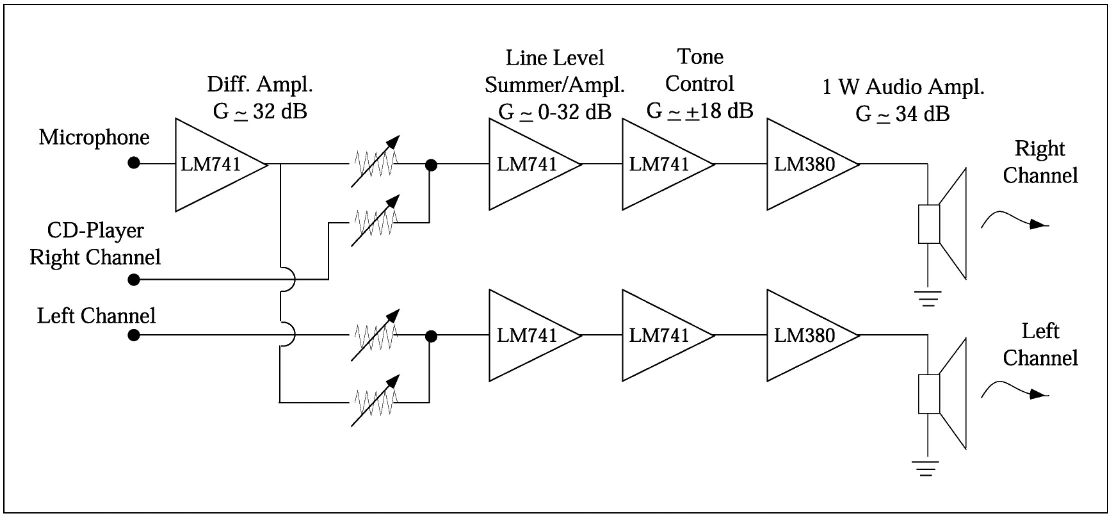
Worksheet/Notes

<u>Bass Control Amplifier</u>



Open Audio Lab

You are welcome to show up in the lab and test a complete audio amplifier assembled from the components which you built and tested during the term. You can talk into a microphone or use a CD-input. The output will be in stereo mode. BRING YOUR FAVORITE CD and listen to it, mix your voice with music and create weird sound effects. The audio system is:

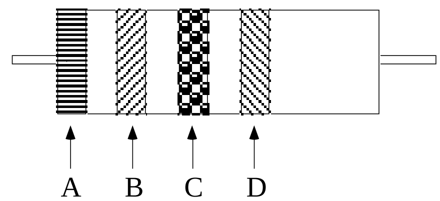


☺ Enjoy ☺

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	–	–



$R = AB \times 10^{C}$ %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%.

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