LAB VI : NOISE CANCELING / EAVESDROPPING HEADPHONES*

A) DESCRIPTION OF THE PROBLEM

- BACKGROUND SOUNDS CAN STILL BE HEARD WHEN WEARING HEADPHONES. A MICROPHONE COULD BE USED TO ALSO PICK UP THESE SOUNDS.

- SINCE MICROPHONE OUTPUTS ARE VERY SMALL, WE PROBABLY NEED TO AMPLIFY THEM.

- YOUR EARS ACT AS A SUMMER, THAT IS, WHAT YOU HEAR IS A SUMMATION OF ALL SOUNDS. SO BY CHANGING THE POLARITY SIGN ON THE BACKGROUND SOUNDS, WE COULD CANCEL THEM!

- NORMALLY WE USE HEADPHONES TO LISTEN TO SOME AUDIO SOURCE, SO WE NEED TO ADD THIS TO THE SIGNALS SENT TO THE HEADPHONE.

- SINCE WE WILL NEED TO ADD MICROPHONES TO OUR HEADPHONES, IT WOULD BE NICE IF WE COULD SOMEHOW USE THIS TO LISTEN TO DISTANT SOUNDS.

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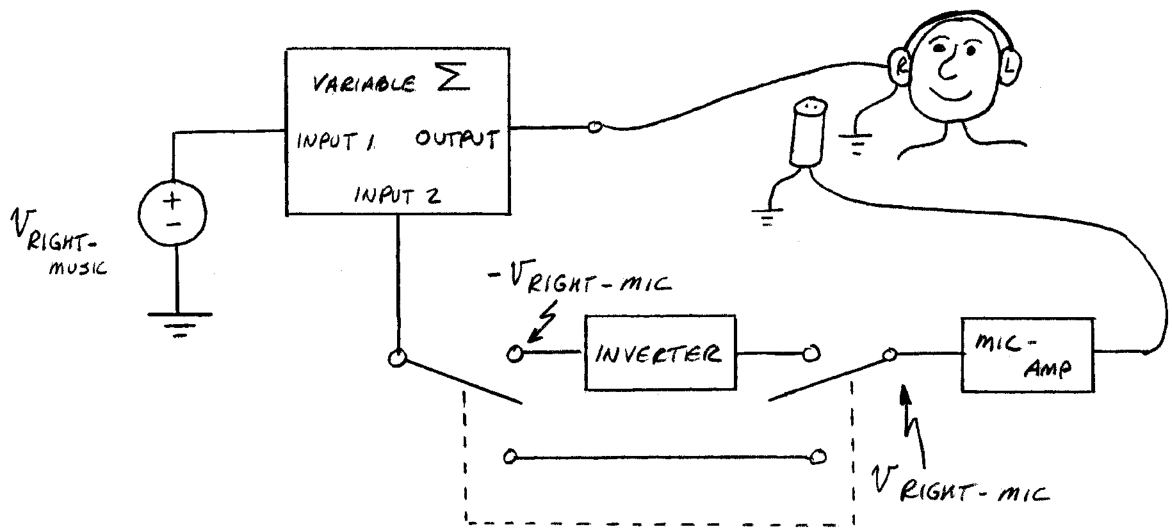
* ARTICLE BY JULES RYCKEBUSH, ELECTRONICS NOW, SEPT 1997, PP 31-37.

B) BLOCK DIAGRAM OF THE SYSTEM

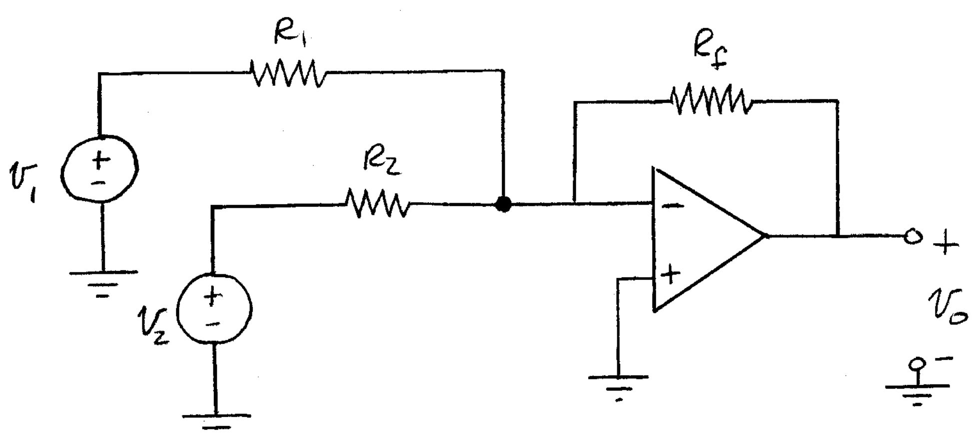
- ONE APPROACH TO DESIGNING A SYSTEM IS TO DRAW WHAT IS CALLED A "BLOCK DIAGRAM," WHICH IS A PICTORIAL MODEL OF THE SYSTEM.



RIGHT CHANNEL OF A NOISE CANCELING/EAVESDROPPING HEADPHONE

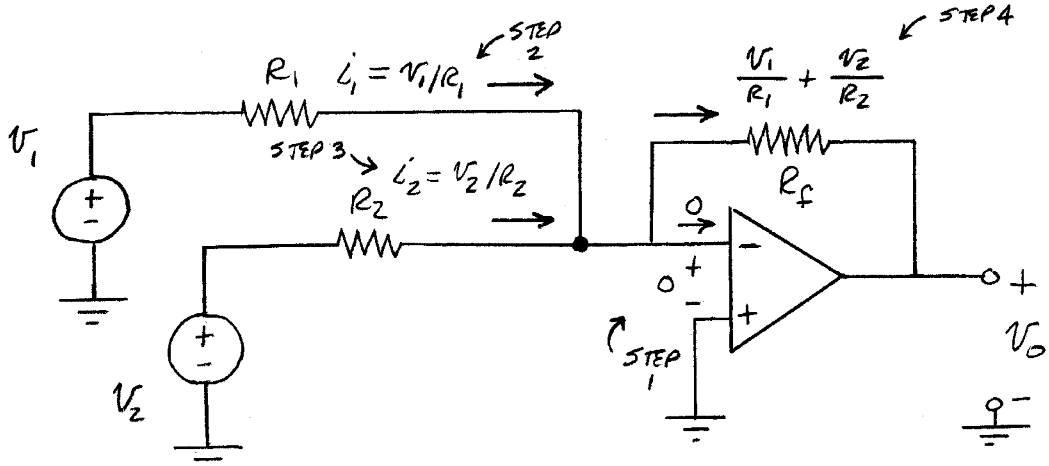
C) SUMMING AMPLIFIER

- FROM ECE 201,* WE ANALYZED AN INVERTING SUMMER:



* SEE ECE 201 e-book, CH 4 SUPPLEMENTAL PROBLEMS p11.

- SOLVING FOR v_o IN TERMS OF v_1 AND v_2



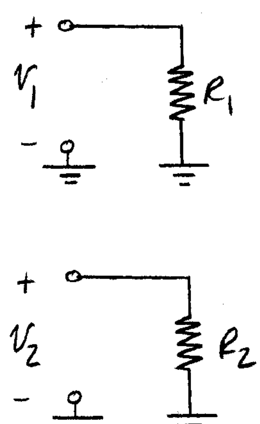
$$v_o = -\left(\frac{v_1}{R_1} + \frac{v_2}{R_2}\right) R_f + 0 = \boxed{-\left(\frac{R_f}{R_1} v_1 + \frac{R_f}{R_2} v_2\right)}$$

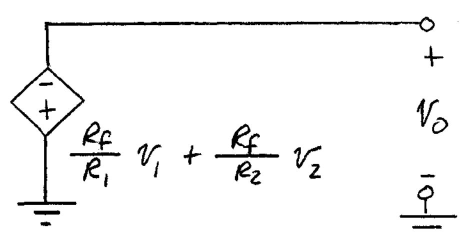
- MODELING

1) $i_1 = \frac{v_1}{R_1}$ & $i_2 = \frac{v_2}{R_2}$

2) $v_o = -\left(\frac{R_f}{R_1} v_1 + \frac{R_f}{R_2} v_2\right)$

3) $R_{TH}\big|_{@ v_o} = 0$



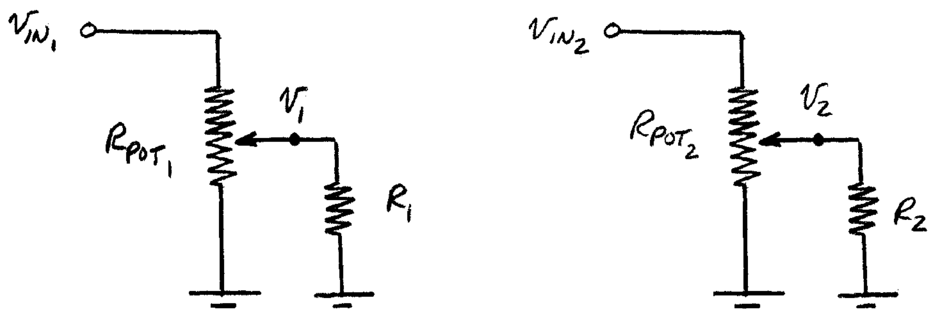


D) VARIABLE GAIN

- WE WILL NEED TO ADJUST THE GAIN OF THE SIGNAL PICKED UP BY THE MICROPHONE TO MATCH THE MAGNITUDE PICKED UP BY THE EAR TO ACHIEVE CANCELLATION.

- IT WOULD ALSO BE CONVENIENT IF WE COULD ADJUST THE VOLUME OF THE MUSIC.

- ONE SOLUTION WOULD BE TO USE A POT. INSERTING POTS BETWEEN $INPUT_1$, V_1 AND $INPUT_2$, V_2



IF WE PICK* $R_{POT_1} \cong 10R_1$ AND $R_{POT_2} \cong 10R_2$ THEN V_1 AND V_2 WILL VARY EXPONTIALLY WITH THE ROTATION OF THE POT. OUR EARS ARE LOGRITHMIC AND THE SOUND LEVELS WILL APPEAR TO BE LINEAR WITH ROTATION.

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* SEE ECE 201 e-book, CH2 SUPPLEMENTAL PROBLEMS pp 19 – 20.

E) Microphone

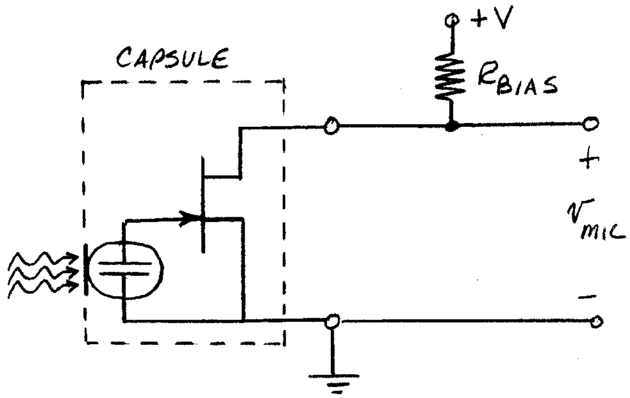
- In this lab, we will be using a set of commercial noise canceling headphones where we have placed a connector between the headphones and the electronics.

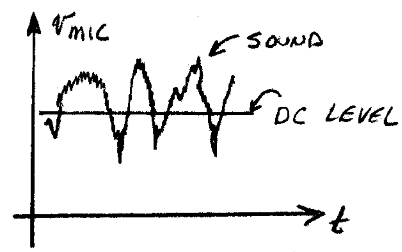
- Mounted in the headpiece is an electret microphone. The name comes from ELECTROstatic and magnET. The microphone consists of a diaphragm and a back plate. This forms a capacitor. The motion of the diaphragm by sound causes a change in capacitance. This is turned into a change in voltage.

- An amplifier is usually built into the microphone. This amplifier will need a battery (DC voltage source) to work properly.

F) DC BIASING

- THE SCHEMATIC SYMBOL FOR THE ELECTRET MICROPHONE IS SHOWN BELOW (DOTTED BOX)





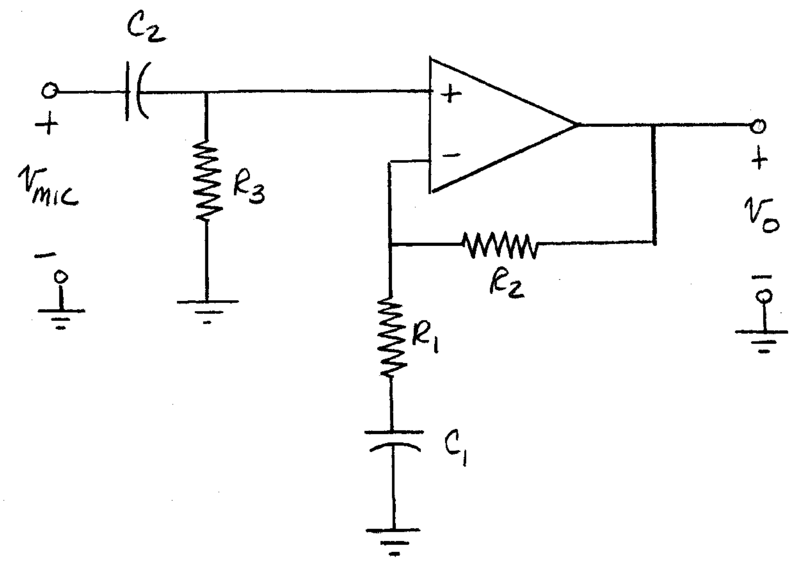
A RESISTOR, R_{BIAS}, AND A DC VOLTAGE ARE ADDED TO POWER THE MODULE.

G) MICROPHONE AMPLIFIER

- WE NEED AN AMPLIFIER WITH A VERY LARGE INPUT RESISTANCE TO PREVENT REDUCING THE AMPLITUDE OF THE SOUND. SO A NONINVERTING AMPLIFIER IS A LOGICAL CHOICE.

- WE ALSO NEED TO BLOCK THE DC LEVEL SHOWN ABOVE. AMPLIFYING THIS WOULD JUST PUSH THE HEADPHONE SPEAKER TO ONE EXTREME END AND DISTORT OUR AUDIO SIGNALS.

1) AUDIO FREQUENCY NONINVERTING AMPLIFIER



$$V_o = \frac{Z_1 + R_2}{Z_1} \; \frac{R_3}{Z_{C_2} + R_3} \; V_{mic}$$

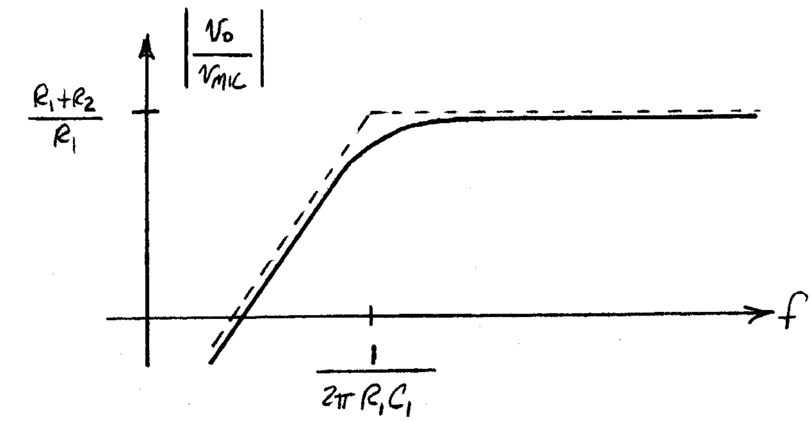
$$\frac{V_o}{V_{mic}} = \frac{\frac{1}{sC_1} + R_1 + R_2}{\frac{1}{sC_1} + R_1} \; \frac{R_3}{\frac{1}{sC_2} + R_3}$$

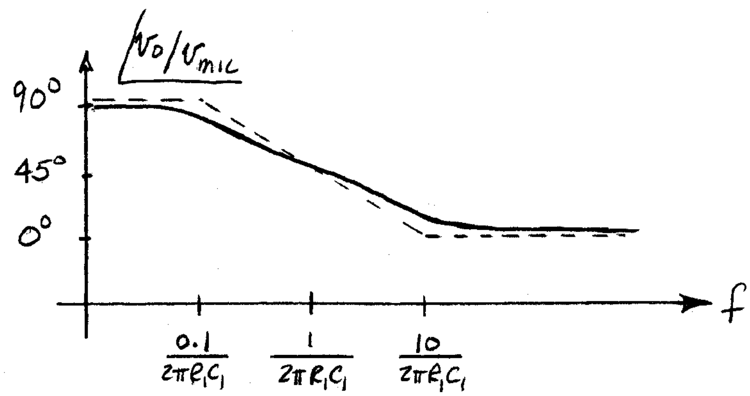
$$= \frac{1 + sC_1(R_1 + R_2)}{1 + sC_1R_1} \; \frac{sC_2R_3}{1 + sC_2R_3}$$

IF WE PICK $C_1(R_1 + R_2) = C_2R_3$ THEN

$$\boxed{\frac{V_o}{V_{mic}} = \frac{sC_2R_3}{1 + sC_1R_1}}$$

2) PLOTTING* ON LOG-LOG SCALES





- NOTE: FOR $f \gg \frac{1}{2\pi R_1 C_1}$, $\left|\frac{V_o}{V_{mic}}\right| \rightarrow 1 + \frac{R_2}{R_1}$ AND $\angle V_o/V_{mic} \rightarrow 0°$. THE SAME IS TRUE IF WE TREAT C_1 AND C_2 AS SHORT CIRCUITS IN THE SCHEMATIC. THE SAME IS TRUE IN THE TRANSFER FUNCTION $\frac{V_o}{V_{mic}} \rightarrow \frac{C_2 R_3}{C_1 R_1}$ WHERE USING $C_1 (R_1+R_2) = C_2 R_3$ WE HAVE

$$\frac{C_2 R_3}{C_1 R_1} = \frac{(R_1+R_2) R_3}{(R_3) R_1} = 1 + \frac{R_2}{R_1}$$

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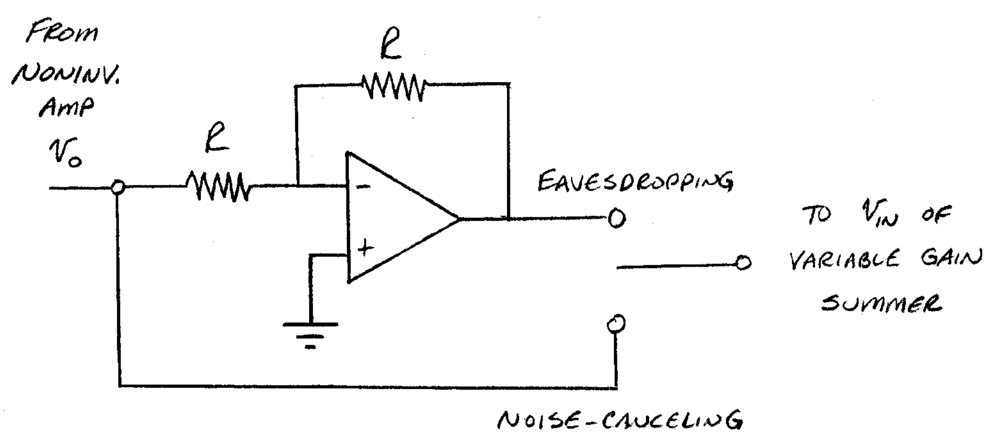
* ECE 202 e-book, CH 12 pp 3-11

H) INVERTER AND SWITCHES

- THE SUMMER AND POTS WILL ALLOW US SUM THE NOISE CANCELING SIGNAL WITH THE MUSIC. SINCE THE SUMMER ALSO INVERTS THE RESULT, WE HAVE THE NEEDED SIGN CHANGE FOR NOISE CANCELLATION. THE SIGN CHANGE ON THE MUSIC WILL REPRESENT A DELAY IN TIME FOR ALL FREQUENCIES. THIS WILL HAVE LITTLE OR NO EFFECT ON THE SOUND.

- WE STILL NEED TO SEND A MICROPHONE SOUND TO THE HEADPHONE WITHOUT SIGN CHANGE FOR THE EAVESDROPPING OPTION. WE COULD DO THIS WITH AN INVERTER TO CANCEL THE SIGN OF THE SUMMER.



I) SELECTING COMPONENT VALUES

- IN GENERAL WHEN PICKING RESISTORS FOR OP-AMP CIRCUITS, IT IS BEST TO USE RESISTORS BETWEEN $1K\Omega$ AND $1M\Omega$. SMALL RESISTORS MAY DRAW HIGH CURRENTS AND BIG RESISTORS GENERATE NOISE.

- SOME SELECTION OF COMPONENTS MAY REQUIRE TAKING SOME LAB DATA BEFORE YOU CAN MAKE A DECISION.

1) MICROPHONE DC BIASING (SEE p6)

- SUPPOSE WE USE A $\pm 9V$ POWER SUPPLY TO OPERATE OUR SYSTEM. WE COULD DO THIS WITH 2 BATTERIES OR OUR LAB POWER SUPPLIES.

- USUALLY ELECTRET MICROPHONES NEED ABOUT $500\mu A_{DC}$ TO OPERATE. ALSO THE MORE DC VOLTAGE ACROSS THE MICROPHONE TERMINALS, THE MORE LINEAR THE RESPONSE OF THE INTERNAL AMPLIFIER. TRYING A RESISTOR OF $\boxed{4.7K\Omega}$ PRODUCED A VOLTAGE ACROSS THE TERMINALS OF ABOUT 7.5V. SPEAKING INTO THE MICROPHONE PRODUCED AC VOLTAGES OF APPROXIMATELY $\pm 1V$.

2) AUDIO FREQUENCY NONINVERTING AMPLIFIER (SEE p7)

- THE FREQUENCY $\frac{1}{2\pi R_1 C_1}$ SHOULD BE AT LEAST 20HZ TO PASS THE LOWER END OF THE AUDIO BAND.

- THE AMPLIFIER BUILT INTO THE ELECTRET MICROPHONE STILL NEEDS MORE GAIN. A GAIN OF 4.5 WOULD PUT A ±1V AC SIGNAL AT ±4.5V. THIS IS ABOUT HALF OF THE FULL RANGE POSSIBLE WITH A ±9V SUPPLY.

a) SUPPOSE WE PICK $R_1 = \boxed{1K\Omega}$ THEN TO GET A GAIN OF 4.5, $R_2 = 3.5K\Omega$. THE NEAREST STANDARD RESISTOR IS $\boxed{3.3K\Omega}$.

b) IF $\frac{1}{2\pi R_1 C_1} = 20\ HZ$ THEN $C_1 = \frac{1}{2\pi(1K)20}$ $= 7.96\mu F$. THE NEAREST VALUE IN OUR PARTS' CABINET IS $\boxed{10\mu F}$.

c) WE ALSO HAD THE CONSTRAINT $C_2 R_3 = C_1(R_1 + R_2) = (10\mu)(1K + 3.3K) = 43m$. IF WE PICK $C_2 = \boxed{0.1\mu F}$ (A STANDARD VALUE) THEN $R_3 = \frac{43m}{0.1\mu} = 430K\Omega$ THE NEAREST STANDARD VALUE IS $\boxed{470K\Omega}$. (THIS ALSO ASSURES A HIGH RESISTANCE SEEN BY THE MICROPHONE.)

3) INVERTER (SEE p 9)

- HERE ANY RATIO OF ONE WILL WORK

PICK $R = \boxed{10K\Omega}$ (A STANDARD VALUE).

4) SUMMING AMPLIFIER WITH VARIABLE GAIN (SEE p 4)

a) PICK $R_{POT} = \boxed{100K\Omega}$ (A STANDARD VALUE) THEN

$R_1 = R_{POT}/10 = \boxed{10K\Omega}$.

b) THE NONINVERTING AMPLIFIER BOOSTED THE LARGEST MICROPHONE SIGNAL TO ABOUT HALF OF THE POWER SUPPLY. SO THIS LAST STAGE OF GAIN SHOULD BE AT LEAST 2. THERE ARE ALSO ISSUES WITH SMALLER LEVELS OF SOUNDS. IN LAB GAINS FROM 2 TO 10 WERE TRIED. AT 10, THERE WAS SQUEALING IN THE HEADPHONE AS A SOUND IN THE MICROPHONE CAME BACK TO THE MICROPHONE BIGGER. GAINS AROUND 3 OR 4 SEEMED TO WORK WELL WITH NOISE CANCELLATION.

LET $R_f = \boxed{33K\Omega}$ (A STANDARD VALUE) THEN THE GAIN OF THE SUMMER IS -3.3.

5) LOW NOISE CONSIDERATION

- NOISE IN ELECTRONIC CIRCUITS IS A SUBJECT THAT IS TREATED IN ECE 402 AND 404.
- HERE WE WILL USE SOME GENERAL GOOD PRACTICE GUILDLINES BUT IN ECE 402 AND 404 WE WILL BE ABLE TO CALCULATE AND MEASURE CIRCUIT NOISE.

a) USE LOW VALUES FOR RESISTORS

- IN MANY ELECTRONIC CIRCUITS RESISTORS OVER $1M\Omega$ ARE A LEADING SOURCE OF NOISE.

b) USE LOW NOISE OP-AMPS

- SOME INTEGRATED CIRCUITS ARE OPTIMIZED FOR REDUCING THEIR NOISE GENERATION. IN THIS LAB, WE WILL USE AN NE 5532 LOW NOISE OP-AMP. THE NOISE VOLTAGE OF THE NE5532 IS $\frac{1}{4}$ OF THAT OF AN LM741.

c) BANDWIDTH

- NOISE IN RESISTORS AND OP-AMPS ALSO DEPENDS ON THE TOTAL BANDWIDTH OF THE SYSTEM. AGAIN WE WILL CALCULATE THIS IN ECE 402 AND 404. BUT FOR NOW LIMITING THE BANDWIDTH TO ONLY WHAT IS NEEDED WILL LOWER SYSTEM NOISE.

6) BANDWIDTH

- AS SHOWN ON p8 AND p11, THE LOWER END OF OUR SYSTEM BANDWIDTH IS ABOUT 20 Hz.

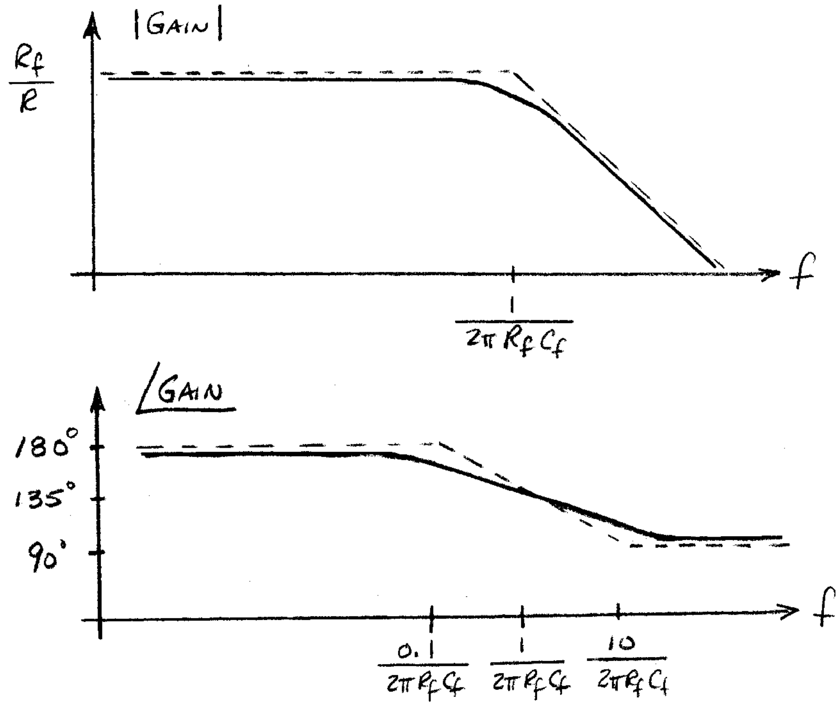
- IF OUR OP-AMPS WERE IDEAL THE UPPER END OF OUR SYSTEM BANDWIDTH WOULD BE VERY HIGH. ACTUALLY THE NONIDEAL OP-AMP WILL LIMIT THE UPPER END OF USEABLE BANDWIDTH TO ABOUT 2.3 MHz. (AGAIN WE WILL LEARN HOW TO CALCULATE THIS IN ECE402).

- SINCE OUR HEADPHONES ARE ONLY USEABLE IN THE AUDIO BAND, WE SHOULD LIMIT THE UPPER BANDWIDTH FREQUENCY TO 20 KHz. SO WHAT WE NEED TO DO IS TO LOWER THE SYSTEM GAIN WITH FREQUENCY. WE COULD DO THIS WITH A CAPACITOR. THE SUMMING AMPLIFIER IS COMMON TO BOTH THE MICROPHONE AND THE MUSIC. LET'S TRY PUTTING A CAPACITOR C_f IN PARALLEL WITH R_f ON p3. THEN THE GAIN FOR V_1 IS

$$-\frac{Z_f}{R_1} = -\frac{\frac{1}{\frac{1}{R_f}+sC_f}}{R_1} = -\frac{\frac{R_f}{1+sC_fR_f}}{R_1} = \boxed{-\frac{R_f}{R_1}\frac{1}{1+sC_fR_f}}$$

LIKEWISE THE GAIN FOR V_2 IS $\boxed{-\frac{R_f}{R_2}\frac{1}{1+sC_fR_f}}$

- PLOTTING* ON LOG-LOG SCALES WITH $R_1 = R_2 = R$



LET $\frac{1}{2\pi R_f C_f} = 20\,KHz$ THEN

$C_f = \frac{1}{2\pi(33K)(20K)} = 241\ pF$. THE

NEAREST STANDARD VALUE IS **240 pF**

J) FINAL DESIGN

- THE TOTAL DESIGN IS SKETCHED ON THE FOLLOWING PAGE.

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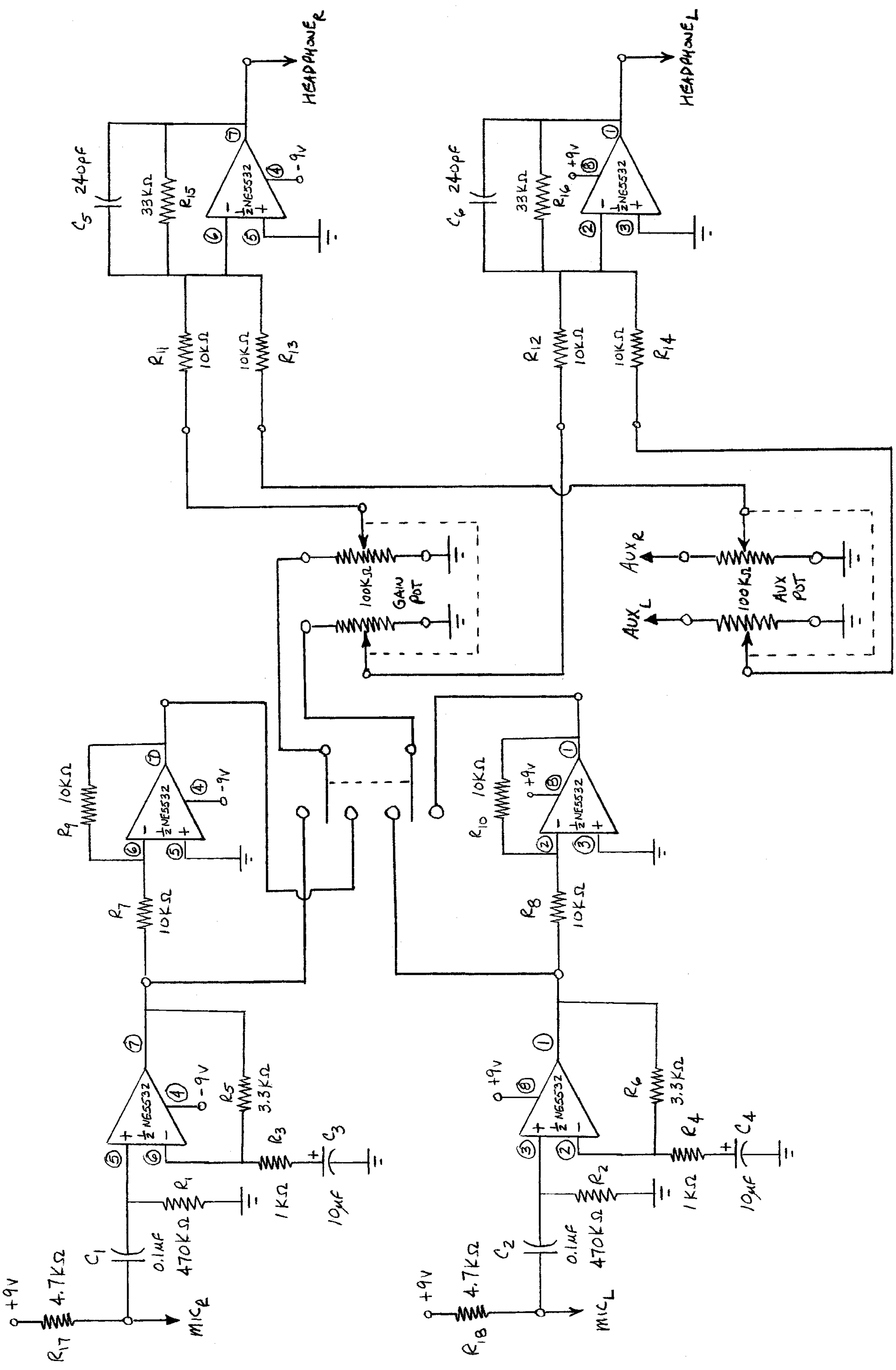
* ECE 202 e-book, CH12 pp 3-11


HEADPHONE R
HEADPHONE L
C5 240pF
C6 240pF
33KΩ
R15
R16
½NE5532
-9V
+9V
R11 10KΩ
R12 10KΩ
R13 10KΩ
R14 10KΩ
100KΩ
GAIN POT
AUX R
AUX L
AUX POT
R9 10KΩ
R10 10KΩ
R7 10KΩ
R8 10KΩ
R5 3.3KΩ
R6 3.3KΩ
R3
R4
C3
C4
10μF
R1
R2
1KΩ
C1
C2
0.1μF
470KΩ
+9V
4.7KΩ
R17
R18
MIC R
MIC L