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EECS 210

TA/Professor
Laboratory Manual

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Version I

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General Laboratory Policies and Administrative Issues

Administrative Issues:

a) Email groups: There will be an email group including all EECS 210 GSI's and the 210 professors (tbd by the TAs/professors).

   There will also be an email group including all students and faculty (tbd).

b) Office Hours: Each laboratory GSI is responsible for holding 3 hours of office hours per week in the TA room (EECS). The OH time selection will be discussed/planned with the professor.

c) Keys / Books: GSI's should see Karen Liska (EECS 3300, liska@eecs.umich.edu) for keys to the lab room and the lab cabinet. You can obtain the course books from Karen Merte (3rd floor Southwest wing).

Class Policies:

a) Lab cleanliness: Make sure you stress lab cleanliness and organization to your students. It is their responsibility to keep their area clean and safe. No backpacks are allowed on the work-benches. When the students finish the experiment, they are responsible for turning off all electrical equipment and putting away all components/equipment in the order that they found it.GSI's should prepare the lab prior to the beginning of class arranging equipment and setting up each lab bench.

b) Grading: The laboratory is worth 20% of the overall grade for the class. There will be three sections to each lab report: Prelab, Data, and Postlab. I encourage my students to make comments on what they see (physically and data) and will award an extra points for good comments on trends in data. If a student has wrong data, I'll be more lenient if they comment on their data noting what seems wrong and what the correct data should look like. GSI's should compile grades and send them to the head TA using electronic means.

   i) Prelab: The prelab is worth 25% of the lab grade and should be done prior to the start of class. GSI's should go around the room checking off that the students have completed the prelab once they begin the experiment. If the prelab is partially completed, then make note of the uncompleted portions. If the student has (honestly) attempted a prelab problem but did not complete it, then ask them to finish the problem for the lab report and give them partial credit for that problem when grading it. Use your own discretion for how much credit to give them.

   No late prelab problems will be credited (not even partial credits). However, they will be corrected.

   ii) Data: Lab Data taken during class hours is worth 25% of the lab grade. GSI's should check that all measurements were made and recorded in an organized manner. Also check to see that all questions asked in the manual are answered either in the data section or in the postlab. GSI's will sign the students data section in their lab notebooks before they leave class.

   iii) Postlab: A postlab report worth 50% of the lab grade will completed by each student answering the questions/problems at the end of each lab in the manual. I also encourage them to answer all unanswered questions from the data section and to explain/comment on trends, errors, or discrepancies in the data. Students should list equations used in the postlab in algebraic format with definitions of the variables next to them. All numeric answers should contain units.

Stress that no papers can be attached to the lab notebook. Everything has to be cut and glued to the lab notebook.

c) Missed Lab / Late Policy: Labs are due exactly one week from the start of class. Labs can be handed in early, but must be turned into one of the 210 GSI's or Professor's which should then be dated, signed and put (by the GSI or Prof.) in the lab cabinet. If a lab is handed in late, there is a 25% penalty (deduct 25 points from grade) for the first day late, and a 50% penalty for two days late. If a lab is 3 or more days late, the student will receive a 0/100 for that lab but still must complete the lab. If a lab is missed, the student will receive a 0/100 for the lab and their grade will drop by one full letter (A->B, B+->C+,...). If two labs are missed, the student will fail the course. If a student is unable to attend a lab, then they should contact the professor or the head TA at least 3 days in advance of the lab (unless there are extreme circumstances).

d) Lab Notebooks: Students are required to have two bound notebooks. The notebooks should be such that pages can not be added to them. One notebook will be used for Labs 1,3,5, and the other for Labs 2,4, and 6. All work must be done in either blue or black ink. No work in pencil will be graded. All lab pages should be numbered and dated. Notebooks should be big enough so that large figures can be pasted, stapled, or whatever into them. All figures and tables should be titled and given a figure or table number (e.g. Figure 4-2: Low Pass Filter Frequency Response). Figures should have the axis labeled (with units) and the figure should be understandable without reference lab manual or lab write-up. Equations used during the lab should also be listed in algebraic form and given an equation number. Students should reference data by page, figure, table, or equation number.

e) ALL LABS INCLUDING LAB LECTURES ARE REQUIRED! Just because a lab is not performed that week does not mean attendance isn't required. The same policy will be used if you miss a lab lecture (Your overall grade will by lowered by one letter). So don't miss ANY labs! You also cannot attend any lab you feel like. You must get specific permission by the head TA or Professor to attend another lab section. If you attempt to attend another section without my permission to do so, the TA will not let you in. If you do get my permission, it is best to make a printout of the email stating so and show the TA of the respective lab.

f) Laboratory grades will be normalized at the end of the semester. We understand that different TA's grade differently so grades will be adjusted such that your final lab grade will depend on your relative standing to the other students of your TA. So don't compare your lab grades to another section with a different TA than yours. The head TA (or the assigned TA) will pay attention to this throughout the term and report any large discrepancies.

g) TAs Only: After you read a pre-lab, you should make sure that you put enough clues or writing that they cannot write more and then submit it as a pre-lab. For example, cross all open-spaces (with a nice dash), or make a note with your handwriting that problem # X is missing, then sign at a certain space and do not accept anything below this space for a pre-lab. No late prelab problems will be credited (not even partial credits). However, they will be corrected.

h) TAs Only: Make sure you bring your lab notebooks to class. Document everything out of the ordinary (late lab, student from another lab, absent students). Do not allow any students to attend your class unless they have the head TA permission.

How To Give a Good Lecture

1. *Be prepared*! The best lectures are given when you are very comfortable with the material and have worked it out in your mind.
2. *Be organized* on the board. Always start writing from the left and move in rather small characters (but not too small, since this is a medium room) from left to right. Never start on the right. If you need to draw a circuit, draw it on the far right or far left and keep it there.
3. *Use handwritten notes*. These will help in case you lose your line of thought.
4. Remember to speak *loud and clearly*. Do not mumble! Somebody at the end of the room must be able to hear you. When speaking to the class, face the class and not the board. Look into their eyes...the eyes tell you if they understand the material or not. If someone asks you a question that you do not know, tell them that you will look into it and answer them by email or in office hours. (If you have trouble speaking publicly, practice in front of a mirror at home or with friends, or come and talk to me).
5. You are the teacher and the role model. Dress and behave accordingly. Do not make fun of any question even if it is very simple. Just answer it, or tell them to wait and you will answer it later. Do not allow any bad words in the lab. Also, no food, no drink and surely no chewing gum allowed in the lab.
6. You will see that it takes practice to give a good lecture. At the beginning, life will be tough and you may not be happy with yourself. At the end of the term, you will be a good lecturer!

Lab Schedule

Sept. 7	Week 1	Classes start. Professor-TA Meeting
Sept. 14	Week 2	Lab Lecture 1: Frequencies, Amplifiers, Transfer Function, Bode Plots
Sept. 21	Week 3	Lab 1: Voltage Dividers, DC & AC Signals, Time & Frequency Domains
Sept. 28	Week 4	Lab Lecture 2: Batteries, Telephone Systems and Voice/Music
Oct. 5	Week 5	Lab 2: Batteries, Telephone Systems and Dialing Tones
Oct. 12	Week 6	Lab Lecture 3: Op-Amps, Ideal and Non-Ideal Amplifiers; Part I
Oct. 19	Week 7	Lab 3: Audio Amplifier Frequency Response, Distortion and Clipping
Oct. 26	Week 8	Lab Lecture 4: Differential Amplifiers, Thermocouples Ideal and Non-Ideal Amplifiers; Part II
Nov. 2	Week 9	Lab 4: Differential Amplifiers; Differential Temperature Sensor
Nov. 9	Week 10	Lab Lecture 5: Variable Gain Amplifiers and Summers, AC Power Systems, Electrical Shock and Electrocution
Nov. 16	Week 11	Lab 5: Variable Gain Amplifiers; Summers; Intermodulation Products
Nov. 23		Thanksgiving Week
Nov. 30	Week 12	Lab Lecture 6: Low-Pass and High-Pass Filters, Transfer Functions With Input Signals, Treble/Bass Tone Control Amplifier
Dec. 7	Week 13	Lab 6: Audio Tone Control Amplifier. Classes end.

Week 1
Professor-TA Meeting

Classes start on a Wednesday (or a Tuesday) of Week 1.

The professor should meet with the TAs (maybe on Thursday or Friday afternoon), assign the lab sections, the head TA, discuss the rules of the lab, the grading policy, etc. and give the TAs the lab manuals and the TA manual. Most important, the TA's should agree on a time where they will meet to make the lab experiments all together, and understand them well. The experiments are not easy, not even for the TAs, and therefore a lot of effort should be put preparing for them.

There will also be many students who want to switch lab sections, who were on the waiting list, etc. and this should be done also in the first week (and possibly in Week 2).

Finally, the TAs should start reading the Additional Course Notes and the Laboratory Manual. The lab lectures and labs are coming very quickly!

Week 2
Lab Lecture 1: Frequencies, Amplifiers, Transfer Function, Bode Plots

The head TA should make sure that two LM380 amplifiers (one for the lab lecture and one for back-up) are built (as in Exp. #3) and are connected to the small speakers in the cabinet. These amplifiers should be built and fully functioning by Monday morning. The LM 380 amplifier should have a 100KΩ/10KΩ voltage divider at the input and therefore the input voltage can be in the 100 mV-1V_{ppk} range. Also, the output of the LM 380 has a 470 Ω resistor in parallel with the speaker.

Read Chapters 1 and 2 of the Additional Course Notes before you come to the lab.

1) Arrive to the lab 30 min. early. Make sure that the lab is clean and in proper order. Write your name, email and O.H. on the board. Write the section number too.
2) Test the amplifier (already built and in the closet) and the sound pressure meter. Make sure that everything is working well. If the LM 380 is not working, use another amplifier, leave a note in the closet on the non-working unit and tell the head TA.
3) Draw an audio amplifier system on the board (see lab notebook p. 33).

A. Organization Issues

There are some organizational tasks for the TA to do at the beginning of the lab (30 minutes).

Have them sign in (sign-in sheets should be provided on the lab desk) when they enter the lab. Some students are changing labs, so check that they are registered in your section. Talk to the head TA on how to handle student lab changes.

Introduce yourself and make sure to mention the following points:

- your name and ways to contact you
- your office hours
- lab section number (remind them!)
- safety (no messing with electrical outputs!)
- cleanliness (no backpacks/jackets on benches, leave the bench clean)
- lab notebooks (two lab notebooks, one for Exp.# 1,3,5 and the other for Exp.# 2,4,6). They can continue using EECS 210 lab notebooks if they wish to.
- write in ink only
- grading policies
- late/missed lab policies (stress that late students may be denied access to the lab).

– expectations (how to write a lab, units, label figures and tables, also that a lab report is a reflection on yourself and how you understand the material).

– stress that no papers can be attached to the lab notebook. Everything has to be cut and glued to the lab notebook.

– tell them that this is an interactive lab and that their involvement is encouraged. However, this is not Espresso Bar and anyone speaking and disrupting others who want to learn will be asked to leave (and therefore get 0 on the lab!).

– lastly, have them select their partners for the rest of the semester (unless serious problems occur).

B. Lab Demonstration: FREQUENCIES AND TRANSFER FUNCTION

Read Chapters 1 and 2 of the Additional Course Notes before you come to the lab.

1. Talk about frequencies and the human hearing (20 Hz-20 KHz for children, 60 Hz-16 KHz for adults). Talk about the stereo amplifier on the board and what they will do in lab #3 (power amp), lab #4 (Line Level Amp, Summer), lab #5 (Bass and Treble Control). Talk about the voltage levels at the microphone (0.1-10 mV_{ppk}) and at the output of a CD/tape player (10-1000 mV_{ppk}).

2. Talk about SPL and the meaning of the onset of hearing (0 dB SPL= 20 µPascal) and when does the SPL become too high to damage the hearing mechanism (120 dB). Say that a normal conversation occurs at 70 dB SPL and a loud voice is around 80 dB SPL. Show them the table of SPL in the Additional Course Notes.

3. Explain the function of the equipment to the class (the power supply, the waveform generator and the scope). Do not go too much into detail now.

4. Connect the speaker to the amplifier and let them listen to frequencies from 100 Hz to 10 KHz (one at a time and move the freq. quickly using the knob and get a progressing tone). While doing this, show them how the function generator works. Display the output voltage on the scope and play with the vertical scale, horizontal scale (timebase). Also, choose an appropriate voltage level and show them how to measure V_{ppk}, Period and Frequency. (If the sound is loud for a nice voltage on the screen, disconnect the speaker while showing them the use of the scope). Do not cover triggering and V_{rms}. Explain that the LM 380 power amplifier can give up to 2 W of audio power and this is enough for loud sounds!

5. Ask the class if there are any questions. Play a frequency quiz with them: Let them hear something around 500 Hz and ask them to guess the frequency. Move it to 4 KHz and ask them again. Then, use the same frequency (around 800 Hz) but with two different levels (somehow, louder sounds appear as higher frequencies!).

6. Use the SPL meter and measure the sound in the room for absolute quietness and also using a 500 Hz loud sound from the speaker. Involve the students and ask a couple of them to talk to each other and measure the conversation level. This should relax the lab a bit.

7. Go now back to the LM 380 and into the FFT domain on the scope. Measure V_o of the amplifier and show them a bit how to use the FFT knobs (Operand, change timebase to change the center frequency, Ref. Level). Tell them that they will cover this in Lab #1. Show them the spectrum of a

sinewave at around 600 Hz. Move the frequency from 200 Hz to 2 KHz and let them see how the spectrum moves on the screen.

8. Now, talk about the transfer function (V_o/V_i). It is also called the frequency response. Keep a constant V_i and measure V_o at 50 Hz, 2KHz, 20 KHz and 500 KHz. Write your results on the board and explain to them that the gain need not to be constant vs. frequency.

9. Take this opportunity to try to plot the transfer function using LINEAR (f) and show them that it cannot be done. This is why we compress the x-axis and choose a LOG (f) scale. Plot the transfer function from 10 Hz (1) to 1 MHz (6). Do the same with the vertical scale and cover the dB scale (20 log (V_o/V_i)). Stress that the dB scale is a *ratio* scale. Notice that in the (dB, log f) scale, there is no zero frequency and zero response (-120 dB is 10^-6 and it is not zero!). Stress the -3 dB point (V_o/V_i=0.707) which is the half-power point. Also, cover the -6 dB point (V_o/V_i=0.5, quarter power) and the -20 dB point (V_o/V_i=0.1, 1% power).

10. Always be receptive to questions and encourage them. Remember, you have time!

You should take a 10 minute break now. Look at your watch and tell them to return promptly after 10 minutes.

C. Lab Demonstration: FOURIER SERIES, SPECTRUM, CLIPPING

1. Disconnect the LM 380 and connect the waveform generator directly to scope. Talk a bit and write on the board the Fourier Series Representation and how every periodic signal can be decomposed into a sum of sinewaves, a fundamental and harmonics.

2. Talk about V_{pk}, V_{ppk}, V_{rms} and V_{oc} of a signal. Do not explain a lot the V_{rms} concept except that $V_{rms} = V_{pk} / \sqrt{2}$, and it is the equivalent voltage used in powers and in the dB scale. Talk about the dB scale (20 *log* V_{rms}/1V≡ dBV). All spectrum (frequency) readings are taken exclusively in dBV (or V_{rms})

3. Set the waveform generator to a 1 KHz, 2 V_{ppk} square wave and show them the time and frequency domain representation. Make sure to point out the dBV scale in the frequency domain. Stress that there are no harmonics at 2f, 4f, 6f (even if you see a bit on the screen...it is just a sampling error of the scope). Write the levels of the fundamental and harmonics (up to 7 f_o) on the board in dB, and convert them to V_{rms} and V_{pk}.

4. Repeat with a triangular waveform.

5. Connect now the LM 380 and drive it into clipping with a 500-600 Hz sinewave. (As mentioned in our meeting, you may need to reduce the voltage from 10 to 8 V so as not to get a very loud sound). Talk about clipping and why it occurs - i.e. output voltage limit of the amplifier. As you go a bit into clipping, show the small flat portion on the time-domain waveform and how the harmonics are rising in the freq. domain. Increase the input level and drive the amplifier into harsh clipping. Again, show the time domain and then the frequency domain information. Keep the scope on FFT, and increase/decrease the volume to see the rise of harmonics. Then do the same in time domain. Let them hear the undistorted and distorted sound and to the harmonics coming out from the speaker.

6. Ask if there are any questions. Be receptive. Remember, you have time.

D. Lab Demonstration: MATLAB

Use the Matlab handout given by the head TA and follow its instructions. Concentrate on the commands used to plot a function f(t) vs. (t). They will need this for lab #1, to do the summations of the different sinewaves.

Week 3
Lab 1: Voltage Dividers, DC & AC Signals, Time & Frequency Domains

Arrive early, turn on all of the equipment, make sure that the lab is clean (no paper on benches, chairs in their correct places, etc.). Make sure that each bench has the correct components for this experiment (placed in a small dish).

When the students arrive, check their name in the log-in sheet and ask them to take a seat.

After they sit down, explain to them that this is a serious lab and that they should not waste time. Make sure that their bags are on the floor and their jackets are on the hanger in the corner or their chairs.

Tell them where the components are (but they will not need them) and where the cables are.

Before The Lab:

1) Explain to them the following:
    a. The Banana-Coax adapter and how there is this little black notch which shows where the ground connection is. This is important so that they do not short the input or output by connecting the banana-coax adapter in the wrong direction.
    b. Explain again how to make a VOLTAGE measurement and how everything is between Node A and Node B. Show them a voltage measurement using the multimeter. Explain to them that the scope is basically a voltmeter but can look at different in time frequency and domain.
    c. Explain the Proto-boards and how you do the node connections.

During The Lab:

1) Let them start the experiment, and while the experiment is going on, pass one by one and check their pre-lab. Do not correct the pre-lab, just check that it is done. Make some kind of check mark to indicate what the final answer is for each question and mark incomplete questions.
2) Take attendance while checking pre-lab. Immediately report to the head TA anyone who missed a lab. You should have an email list, which you can use as an attendance. Please indicate any unusual circumstances to the head TA, i.e. student shows up in section to make up a lab, student wants to be in lab that he/she isn't in, student does not show up for lab, etc…
3) Be receptive to questions and always walk and see what is happening at the scopes. Do not sit down for a long. Pass by the stations and ask questions. If you see a group that is advanced and is nearly finished, teach them some tricks on the scope (such as the STOP/RUN feature on the scope, Trace 1 and Trace 2, etc.).

Send an email to the TA group and tell them how the lab went. This is especially true for the Monday section TA to set the tone for the rest of the group (how long it took, what did they find difficult, etc.).

Week 4
Lab Lecture 2: Batteries, Telephone Systems and Voice/Music

The head TA should make sure that a set-up consisting of the microphone, the mic. pre-amplifier, the small packaged audio amplifier and the small speaker is properly connected. Also, a T-connection for the oscilloscope input should be placed at the output of the amplifier (or at the output of the mic. pre-amplifier). This is needed for part B of this lab lecture.

Arrive 20 min. early to the lab and make sure that the lab is clean. Also, test the Audio system with all the necessary connections. When the students arrive, check their name in the log-in sheet and ask them to take a seat.

A. Batteries

Read Chapter 3 of the Additional Course Notes before you come to the lab. This is very important.

1) Start the lecture by covering batteries and DC vs. AC voltages and currents. Explain the unit of Power (VI) and Watts, and that you pay of the Energy that you use (J) or W.s. However, we consume so much W.s that we are billed in KWH ($0.085). Now, move to DC power and talk about the rating of small batteries, mAH, and large batteries such as car batteries (AH). Give some examples where batteries are common (portable CD player) and where they are not (microwave oven - 1000 W, etc.).
2) Give few examples of the time it takes to discharge a small battery for different discharge currents (p. 38 of Additional Course Notes). This is due to the ionic exchange, which is happening in the battery and is less efficient for large currents.
3) The ionic exchange inside a battery is very dependent on the temperature and is very slow and inefficient for low temperatures. Draw Fig. 3.9a on the board and explain that at 0F, the battery can only deliver around 30% of its rated AH. (This the reason why climbers and photographers in cold condition tie the battery packs around their waist - To keep them warm!)
4) Talk about the different battery technology available. The list is on page 41. We use Alkaline-Manganese batteries the most (Duracell and Energizer brands) and the Lead-Acid batteries (cars). Talk a bit about the Nickel-Cadmium rechargeable batteries and the Lithium-Carbon watch batteries.
5) *Important*: Talk about the open-circuit voltage. This voltage is the voltage across the battery with no current flowing in the battery and is around 1.55 V. However, when the battery is connected to a load with a current of 100-200 mA, the voltage across the battery drops to around 1.3 V. The drop can be modeled as a series resistance (IR = 0.25 V drop), which is around 0.5-2 Ω for a normal battery. If the battery is discharged, the series resistance can be 3-10 Ω, leading to a large voltage drop and the battery becomes useless.
6) Draw the batter circuit on the board (as in lab #2). Remember, the series resistance, called the Battery Resistance, is a model and cannot be physically accessed! This means that you cannot measure the voltage drop across the terminals of this resistance. You can only calculate it by

measuring the battery open-circuit voltage and the battery voltage under operation with a discharge current, I.

7) Cover now the battery voltage vs. discharge time. Tell them that the rating of 1.5 V is only when the battery is brand new, and that the voltage will drop quickly to 1.3 V and stay there for a long time (for an Alkaline battery). A battery is considered “empty” when its voltage is below 1 V. Draw Fig. 3.7 on the board. This is the battery voltage and not the open-circuit voltage.

8) *Important*: As the battery discharges, the battery voltage decreases. This is modeled by the open-circuit voltage, which remains nearly the same, but the battery resistance increases.

9) Finally, talk about series and parallel connections and how they either increase the output voltage or the output current. Also, they can be combined together (put Fig. 3.13 as an example). Talk about the mAH rating which effectively doubles for parallel connections (for the same load current). Talk about the series connection which has the same mAH for the same load current but now can deliver more voltage and therefore more power.

This section should take around 35-45 minutes. Take a 10 minute break.

B. Telephone Systems and Voice/Music:

1. Ask the students to come closer and to form a semi-circle around the equipment.
2. Get a telephone dialer from the lab closet and show it to the class. Talk about the frequencies associated with the numbers (draw the dialer on the board and label the frequencies). Tell them why there are related by irrational numbers (so that no harmonics or outside noise can result in a mis-dial). Tell them that they will measure the frequencies in the coming lab.
3. Now, turn on the microphone pre-amp and connect the output to the scope and the amplifier. Set the time span to 5 or 10 msec and choose the appropriate voltage scale. Talk into the microphone in clear tones and use the STOP/RUN feature to freeze the display and show them your sound. Also, run the scope back again and look at the frequency domain information (span 1.22 KHz or 2.44 KHz).
4. Make sure that there is no feedback between the microphone and the speaker. If there is, reduce the gain or separate them from each other.
5. Ask the students to talk into the microphone and do the same things. You might search for the "highest" and “lowest” voices in the class.
6. Do the same with music. Show them music in time and frequency domain.

This section should take around 30 relaxed minutes

Week 5
Lab 2: Batteries, Telephone Systems and Dialing Tones

Arrive to the lab 20 min. early. Make sure that the lab is clean and in proper order. Make sure the equipment is working well. Put a battery tester, two batteries and a telephone dialer on each bench.

When the students arrive, check their name in the log-in sheet and ask them to take a seat.

After they sit down, explain to them that this is a serious lab and that they should not waste time. Make sure that their bags are on the floor and their jackets are on the hanger in the corner or their chairs.

Tell them where the components are (but they will not need them) and where the cables are.

Before The Lab:

1. Remind them of the lab rules (cleanliness, etc.).
2. Give the students an overview of what they will be doing in the lab. Draw a battery circuit on the board or use a battery circuit. Show them where to place the alligator clips to measure V_{oc}, V_b, I in the battery tester set-up.
3. *Note*: It is important to tell them not to connect the + and **-** terminals of the batteries to the multimeter when measuring *current*. This can blow the fuse of the multimeter because too much current will go into the multimeter. The multimeter is effectively a short-circuit in the current measurement mode.
4. Explain again the banana-coax adapter with the small black notch on the side (location of ground connection).

During The Lab:

1) When the students are testing the telephone dialers make sure that they use only 4**-** 4.5 V DC Voltage from the power supply.
2) Explain the telephone dialer circuit to the students and where each of the wires are to be connected:

   Black wire = ground of DC Supply. Red wire = positive 6 V terminal of DC supply.

   Blue Wire = Positive terminal of Scope. Yellow or Green wire = Ground of the oscilloscope.
3) *Important*: Make sure the black and Red wires of the dialer are not touching. This will short the DC supply. Another point is that the negative speaker wire (usually yellow wire) of the dialer should be connected to ground of the oscilloscope and the + (usually blue wire) is connected to the positive terminal of the oscilloscope. If they are connected backward you will not here a sound or output from the dialer. This is because the oscilloscope is grounding the output signal.

Send an email to the TA group and tell them how the lab went. This is especially true for the Monday section TA to set the tone for the rest of the group (how long it took, what did they find difficult, etc.).

Week 6
Lab Lecture 3: Op-Amps, Ideal and Non-Ideal Amplifiers; Part I

Arrive early, make sure that the lab is clean (no paper on benches, chairs in their correct places, etc.). When the students arrive, check their name in the log-in sheet and ask them to take a seat.

A. Op-Amp Power Consumption and Power Delivery:

1. Draw an Op-Amp on the board. Explain the Golden Rules. Say that these are ideal rules based on infinite gain, but that they apply quite well since the gain of the op-amp is 10^4 to 10^6 (and let us take it 10^5).

2. Now, introduce the power supply and that an op-amp is composed of many transistors and needs a +12 and a -12 V supply to bias all the transistors/resistors and operate the op- amp. The current from each supply may well be around 8.5 mA (2*12V*8.5 mA= 200 mW) so as to operate the op-amp (see p. 34 in the Lab Manual).

3. Also, introduce the DC supply capacitors, which are there to reduce the noise pick-up on the lines. Do not talk much about capacitors, except that they charge to +12 or -12 V, and that they must be careful when they put them in the circuit since they are polarized!

4. Draw an op-amp follower. This is easy and V_o=V_i. Set Vi= 1V and therefore, V_o= 1V. Now take the gain of the op-amp to be 10^5. Therefore, the input voltage difference is 10 uV (microvolts) and V_o= 0.99999 V, which is very close to 1 V. This is the reason why we can safely assume the ideal op-amp rules (Fig. 1a).

5. Now, put a 100 Ω load at the output of the op-amp follower with V_i= 1 V (DC). The power delivered to the load is 10 mW (P=VI, V_o=1V, I=10 mA, R=100Ω). The power from the input source is 0 mW since there is no input current (V*I=0). Therefore, it is the op-amp that delivers the current to the load from the +12 V supply. The input voltage controls the op-amp but does not deliver any power. Repeat with Vi= -1 V (DC) and show that it is the op-amp that sinks the current from the load to the -12 V supply (Fig. 1b).

6. At this point, talk about the current from the supply. The current from the supply (+12 V in the case of the V_o= 1V) will be around 9.3 mA, with 8.5 mA going to the op-amp and 0.8 mA going to the load! How is this possible? THINK OF THE POWER! This 0.8 mA is at 12 V and will be converted by the op-amp to 10 mA at V_o=1 V (Fig. 1c). Talk about the rule that the power delivered from the DC source is equal to the power consumed in the op-amp plus the power delivered to the load. Consider the single supply and the dual supply case (p. 34).

7. Repeat the above with an inverting op-amp configuration (V_{cc}= +/-12V), with a gain of -10, R_1= 10 KΩ, R_2= 100 KΩ, R_L= 100 Ω, V_i= +/-0.2 V (and V_o= +/-2 V). Notice that the input contributes only 0.2 V/10KΩ= 20 µA of current to the load, and that the op-amp delivers/sinks 20 mA (Fig. 2).

B. Voltage and Current Clipping:

1. Use the same circuit as the inverting amplifier above. The output voltage cannot exceed +/-10.5-11 V since there is a | 1-1.5 | V drop in the op-amp. If V_i= +/-1 V, then V_o= +/-10 V and everything is good. For V_i =+/-1.5 V, V_o cannot be +/-15 V and the op-amp will clip at +/- 11 V. Same for V_i = +/-2 V, the output cannot be +/- 20 V and the op-amp will still clip at +/- 11 V. This is called voltage limiting (clipping).

2. Now, assume that the op-amp cannot deliver/sink more than 50 mA. At this point, with a 100 Ω load, the output voltage cannot be more than +/-5 V before it is *current limited*. This means that V_i cannot be more than +/-0.5 V. If Vi is larger, the op-amp current clips at +/- 5 V and stays there. Now, if the load resistor is 1 K, then current limiting occurs at V_o= +/-50 V! However, the op-amp will voltage limit at V_o= +/-11 V before current limiting occurs.
3. Demonstrate this on the oscilloscope by turning up the input V_s from the function generator until clipping is seen. The LM 380 op-amp with V_C=+12V, which will be used to amplify the signal from the function generator and output it to the speaker and scope has a voltage clipping level of ~10 V (or whatever voltage is supplied by the power supply up to 25 V) and a current clipping level of 1.3 A. Since a nominal output impedance of 8 Ω is used the op amp will current clip at 8 Ω*1.3 A = 10.4 V. So depending on the voltage supplied to the op amp the opamp can either voltage clip or current clip.

C. Bandwidth of the Op-Amp:

1. Again, using the same inverting configuration, draw a transfer function of the op-amp with a pole at 100 KHz (remember, the gain is 10). Tell them that the Gain*Bandwidth product of this amplifier (the LM 741) is around 1 MHz. The bandwidth is the -3 dB value of the transfer function from the midband flat gain. Explain how the -3 dB pt is found in dB vs. freq. as compared with (V_o/V_{in}) vs. freq. In dB vs. freq the –3 dB pt is 3 dB's below the midband gain. In gain (V_o/V_{in}) vs. freq., the -3 dB pt is found where V_o/V_i is equal to $1/\sqrt{2}$ *(V_o/V_{in}) at Midband.
2. If the gain is increased to 100, then the bandwidth will become 10 KHz and draw the transfer function. If the gain is decreased to 1, then the bandwidth will become 1 MHz and draw the transfer function. Say that this is a fundamental property of amplifiers and they will study it in EECS 311.
3. Show the bandwidth of the opamp by plotting the transfer function for 3 different gain levels (gain=1w/ f=1 Hz, G=10 w/ f=100 KHz, G=100w/ f=10 KHz). Notice, the graphs will meet together in the –20 dB/dec range high frequencies. Tell them that the gain can be measured in two different ways: One way is to look at the frequency domain and measure the amplitude of V_o as frequency increases (with constant V_i). Another good way is to measure the V_{oppk} output in the time domain (with constant V_i) as frequency increases.

   Take a 10 minute break.

D. The LM 380 Amplifier:

1. Draw the LM 380 amplifier circuit with all the components. Explain that this is a single supply op-amp operating from +9 to +12 V, with an internally set gain of 50 (can vary a bit) and that it consumes internally up to 4 W of power for very high output voltages/powers (normally it consumes around 0.2-0.5 W for medium power outputs). It can drive an 8 Ω load with a peak output current of 1.3 A! It has a bandwidth of at least 200 KHz, which means that its Gain*Bandwidth product is at least 10 MHz.
2. The 5 µF capacitor is for stability and the 2.7 Ω/0.1 µF capacitor is to help the op-amp under high current conditions (these are required by the manufacturer). The 10 KΩ input resistors is to set the input impedance of the circuit to 10 KΩ. The input impedance of the op-amp from the (+) and (-) terminals is very high, around 1-2 MΩ.

3. Perhaps the most tricky part to explain is the series 1 µF capacitor at the input, which is the DC block. Since they do not know much about capacitors now, just say that the 1 µF capacitor is there to block any DC voltage from the source and to ensure an AC voltage (sinusoidal) input.
4. The same for the 500 µF capacitor at the output. The op-amp is a self-centering op-amp with V_o(DC)= V_{cc}/2=5V. Therefore, the 500 µF blocks the 5 V DC output and makes sure that only the AC part is transmitted to the load (speaker).

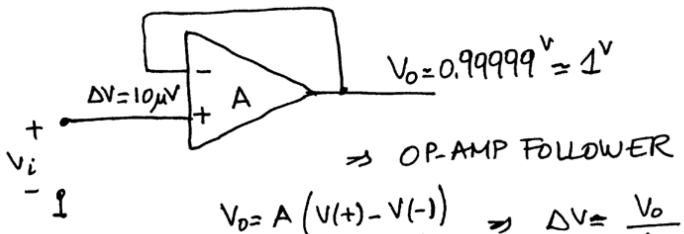
Remember that 10 LM380 audio amplifiers need to be built and tested for Lab 3. Choose a DC bias voltage of 10 V. The circuits should be well assembled and act as an example of good layout to the students. Clearly label the V_{cc}, Ground and Input/Output nodes. Make sure to test them at 1 KHz and 100^+ KHz. Make sure to test that they are clipping at $V_i \approx 140$ mV_{ppk}.

E. Total Harmonic Distortion:

1. This is the last part of the lab lecture. Explain the THD concept which arises when you have a non-linear transfer function (V_o/V_i) and that higher frequency components show up. (The THD equation is defined on page). The most obvious reason for the non-linearity is clipping, and therefore making the sine-wave output look like a square wave.
2. Show them the figure at the bottom left of the LM 380 data sheet. The THD is around 0.2% up to 4 W of output power (for V_{cc}=22 V) and then rises very sharply when clipping starts. Look also at the center figure with THD vs. frequency for 1 and 2 W outputs, and it is around 0.2-0.3% from 20 Hz to 15 KHz.
3. Tell them that the human ear cannot hear a THD below 0.5% at 2 KHz and below 2% at 200 Hz, and demonstrate this in class with the small amplifier and the large speaker (the good one). Use a frequency between 200 Hz and 2 KHz and ask them to close their eyes. Increase the voltage until one of them says that they clearly hear a distortion. See the level of the higher frequency harmonics (in dBV) on the scope, convert it to voltage and calculate in front of them the THD (bring a calculator).

WEEK 6:

Fig 1a:

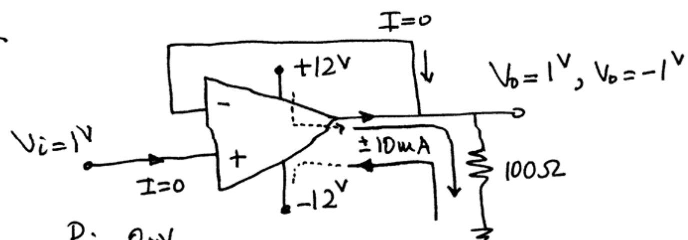


→ OP-AMP FOLLOWER

$V_0 = A\underbrace{(V(+) - V(-))}_{\Delta V} \Rightarrow \Delta V = \frac{V_0}{A} \approx 10\mu V$

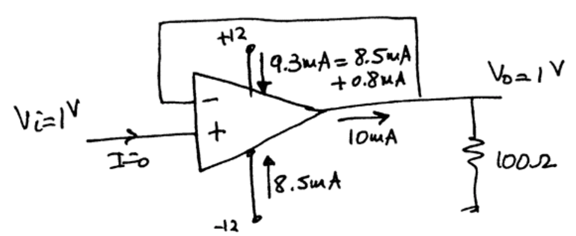
$A = (10^5)$

Fig 1b:



$P_i = 0 mW$

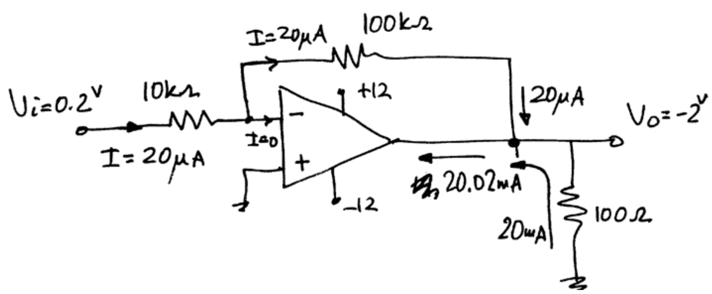
Fig 1c:



→ 8.5mA is needed to power the op-Amp

→ 0.8mA is needed to deliver 10mA to the 100Ω load.

Fig 2:



$\frac{V_o}{V_i} = \frac{-100k}{10k} = -10$

Week 7
Lab 3: Audio Amplifier Frequency Response, Distortion and Clipping

Arrive early, turn on all of the equipment, make sure that the lab is clean (no paper on benches, chairs in their correct places, etc.).

When the students arrive, check their name in the log-in sheet and ask them to take a seat.

After they sit down, explain to them that this is a serious lab and that they should not waste time. Make sure that their bags are on the floor and their jackets are on the hanger in the corner or their chairs.

Tell them where the components are (but they will not need them) and where the cables are.

Before The Lab:

1. Stress that several groups will be using the same LM380 amplifier boards. Therefore, please handle them well and tell the TA if anything is missing or incorrect. Show them the V_{cc}, Ground, and input/output nodes on the photo-board.
2. Connect an LM380 amplifier to the power supply and show them how to measure the DC current supplied by the power supply.
3. Stress that they should write/plot neatly the measured data in the lab notebook.

During The Lab:

1. Part 1, voltages at Pins 2 and 6 should be in the mV levels. The output nodes Pin 8, should be around 5 V.
2. If a circuit does not generate considerable clipping at 140 mV_{ppk} input, then increase the input voltage to 150 mV_{ppk} (but not more).
3. Check that the students are correctly measuring the frequency response, especially at high frequencies. Point out the cross-over distortion on the scope at f > 100 KHz.
4. Remind the students to take accurate measurements of the harmonics. They used them for the THD calculations.

Send an email to the TA group and tell them how the lab went. This is especially true for the Monday section TA to set the tone for the rest of the group (how long it took, what did they find difficult, etc.).

Week 8
Lab Lecture 4: Differential Amplifiers, Thermocouples
Ideal and Non-Ideal Amplifiers; Part II

Arrive early, make sure that the lab is clean (no paper on benches, chairs in their correct places, etc.). When the students arrive, check their name in the log-in sheet and ask them to take a seat.

A. Ideal and Non-Ideal Amplifiers, Part II

1. Cover the main points of the non-ideal amplifiers: Part II. Mainly, the input bias currents and how an op-amp will *never* work without DC input currents. Give some examples of these non-working circuits. Cover the input offset voltage and how it is the limiting spec. in most op-amp designs. Then talk about the input resistance and the CMRR. Give a numerical example for the CMRR (as in the lab workbook).
2. Go to the data sheet of the 741 op-amp and show them the input bias current, the input offset current, the input offset voltage, the input resistance and the CMRR. Also, cover "old" topics too such as the output voltage swing, output short-circuit current, the gain•bandwidth product, and the op-amp power consumption (all of these are in the data sheet).

B. Differential Amplifiers and Thermocouples

1. Talk about experiment #4 and why do we use Differential amplifiers. The reason is noise and there is a lot of electrical noise around us (the atmosphere and the galaxy are the largest noise producers in the world on a global scale). On a closer scale, car ignition systems with spark plugs, large motors requiring hundreds of amps, etc. are all noise producers. Tell them that all sensors in a car with µV-mV levels use diff. amps to amplify the signals. Also, all microphones with µV-mV levels and long lines use diff. amps, otherwise you will pick up the 60, 120, 180 Hz and translate it into a Hummmmm!
2. Go over Prelab 4 question 1. Tell them to calculate V_o/V_i using *superposition*, by first taking V_1 at the negative input and calculating V_{o1}, then taking V_2 at the positive input and calculating V_{o2}, and then taking the input as $V_i=V_1-V_2$ and calculating the output as $V_o=V_{o1}-V_{o2}$. Do not solve it.
3. Talk more about microphones and show them a microphone and the mic. pre-amp. that we have in the lab. Most high quality microphones have a 600 Ω source impedance, and therefore the input of the pre-amp must have a high impedance (p. 65). Otherwise, the input circuit may result in a large resistive divider drop. For example, if the input of the amplifier is only 1 KΩ, you lose around 1/3 of your input voltage signal. This is the reason why the input resistance of the diff. amp is 10 KΩ or higher.
4. Talk about the thermocouple and that it is made of two different metals which generate a voltage which is linearly proportional to the temperature between the *cold* junction and the *hot* junction. Take a thermocouple and show it to them (with the cold and the hot junctions). This is the same thermocouple used in cars to measure engine temperature and in hospitals to measure body temperature (with the right teflon insert). The output voltage is mV levels and this is the reason why we need to connect it to a differential amplifier.

   Take a 10 minute break.

5. Review of lab #3: Linear and Non-Linear Response. Finally, talk about the last lab, and the two things that they should have learned are:

   a. All amplifiers have a certain bandwidth (i.e., transfer function).

   b. Linear vs. Non-Linear behavior of amplifiers: Linear is V_o= A(f)*Vi where A(f) is the gain (which can change with frequency ≡ transfer function). In this case, if we put a sinewave at f_1, we get a sinewave at f_1 times a certain amplitude (larger or smaller than the input). If we put f_1, f_2, f_3, … then we get f_1, f_2, f_3, each one with a different amplitude depending on the transfer function. However, in non-linear circuits, we have the V^2 and the V^3 terms ($V_o = AV_i + BV_i^2 + CV_i^3 +...$) and if we put f_1, we get f_1, $2f_1$, $3f_1$, etc. which are called the harmonics of a signal. A good example of non-linear behavior is clipping as we saw in lab #3. A sinusoidal wave starts looking like a square wave with a lot of non-linear behavior (clipping)!

6. Then, cover what is linear. Everything has a non-linear component, but the question is how small? The practical limit is that if 0.1% or less of your power is in higher harmonics, then it the system is pretty linear. This means that the harmonics in the output voltage should be -30 dB or less compared to the fundamental. However in communication systems, it is typical to ask for -60 dB harmonic levels, which means that 99.9999% of your power is in the fundamental frequency, and 1/million of your power is in the harmonic components.

C. Automotive Electrical Systems

Read Chapter 4 of the Additional Course Notes before you come to the lab.

1. Talk about the car as an electrical system and the power load on the battery. Use Fig. 4.1 as a guide. The battery cannot handle all this power and alternators are used to charge the battery and supply the car with power.
2. Talk about alternators and how they are mini-generators (driven by the shaft and belt). Talk about the construction (Fig. 4.4) and the current output of alternators vs. rpm (Fig. 4.5).
3. Talk a bit about the starter (Fig. 4.9), and most important, its immense current draw from the battery (100-120 A for 1-3 sec for a 4-cylinder car). Mention the Cold Cranking Amps Rating of batteries.
4. Talk about fuses (Fig. 4.10) and relays and why they are used. A typical car may have more than 20+ fuses and 10 relays. Talk about the wiring of the car and cover tables 4.1 and 4.2.

Week 9
Lab 4: Differential Amplifiers; Differential Temperature Sensor

This is the first lab where the students have to build the circuits themselves. This lab might take the whole 3 hours depending on the students skills in building circuits on protoboards.

Arrive early, turn on all of the equipment, make sure that the lab is clean (no paper on benches, chairs in their correct places, etc.).

When the students arrive, check their name in the log-in sheet and ask them to take a seat.

After they sit down, explain to them that this is a serious lab and that they should not waste time. Make sure that their bags are on the floor and their jackets are on the hanger in the corner or their chairs.

Tell them where the components are (but they will not need them) and where the cables are.

Before The Lab:

1. Explain how to connect and use the +/- 12V supplies.
2. Emphasize the polarity of the capacitor and the proper way to connect it to the circuit.
3. Draw a potentiometer on the board and explain how to make connections to it.
4. Tell the students to connect everything and wait until you have checked their circuits before turning on the supply. This helps reduce students burning up the chips by wrong connections. It also reduces your diagnostic time to find what is wrong with their circuits.
5. Draw on the board the pin connections of the particular op-amp chip that you are using.
6. Write down the temperature of the room and explain to them that the thermocouple can only make relative measurements. Therefore the room temperature is used as a reference temperature for all the measurements. The room temperature is about 22 degrees Celsius.

During The Lab:

1. Make sure that they measured R_1, R_2, R_3, R_4. This is needed for the lab report.
2. Check off students circuits before they turn on the power supply on.
3. For part 8: V+ and V- should be in the millivolt range, but V_o will vary from 0.5–4 Volts depending on the offset voltage in the op-amp.
4. Make sure that the students remove the short between the inputs for the thermocouple part.
5. Explain how to calculate body, cold water, and hot coffee temperatures from the data.

Send an email to the TA group and tell them how the lab went. This is especially true for the Monday section TA to set the tone for the rest of the group (how long it took, what did they find difficult, etc.).

Week 10
Lab Lecture 5: Variable Gain Amplifiers and Summers, AC Power Systems, Electrical Shock and Electrocution

Arrive early, make sure that the lab is clean (no paper on benches, chairs in their correct places, etc.). When the students arrive, check their name in the log-in sheet and ask them to take a seat.

There are three parts, which should be covered in this lecture. 1) Material for Lab 5, 2) The AC Power system, and 3) Electrical Shock and Electrocution.

A. Variable Gain Amplifiers and Summers

1. Draw a variable gain/summer amplifier on the board. Explain to them the function of the input capacitor (it allows high frequencies to pass and blocks low frequencies). For the prelab, the students are to assume that V_s is at midband frequencies (gain is flat).
2. Show that a summer amplifier basically allow the superposition of two signals on one another. This can be used as an audio mixer (karaoke etc.). The output in the frequency domain will consist of each signal, together with the harmonics of both signals and their intermodulation products (if non-linearities occur and generate these components).
3. Review some of the non-idealities of the op amp such as the maximum output current, voltage clipping, and the input bias current.
4. Explain the role of the 100 KΩ resistor connected to the (+) input terminal.

B. AC Power system

Read Chapter 5 of the Additional Course Notes handbook.

1. Introduction: Describe different types of ways electrical energy is used in our daily lives. The AC systems we use provides a 120V rms 60 Hz signal. More than 90% of the US economy GDP is based on electrical equipment of some sort.
2. Emphasize the economics (efficiency!) of why AC power is used and not the DC power. One major advantage is transformers which allow efficient AC voltage step-up or step-down (this is not possible in DC systems) and therefore results in low currents on the long power distribution lines. Explain transformers (Fig. 5.1). Using the example in the handbook to compare the power delivered using a DC vs. AC distribution system, and the efficiency of the AC system.
3. Power Consumption: Go over different home devices and their power consumptions (p. 82). Show the daily usage of power in a home (Fig 5.4). Go over the power consumption at UM. Give numerical figures.
4. Wiring and Circuit Breakers: Emphasize the necessity for different size wires, which is. needed for the amount of current used. Show why a circuit breaker is needed and how it works (Figs. 5.5 and 5.6).
5. Describe the typical power distribution system of Detroit Edison. Show the voltage step-up and step-down transformers (Fig. 5.9a and b), and the different levels/steps encountered in a typical distribution system.

   Take a 10 minute break.

C. Electrical Shock and Electrocution

Read Chapter 6 in the Additional Course Notes handbook.

1. You may want to go over a little about the neural system of the human being just so the students have a little background before you talk about electrical shock and electrocution. For example you could talk about the 4 types of excitable tissues: Sensory Receptors, Neuron Cell Bodies, Axons, Muscle Fibers. Also you can stress that the signals are digital pulses in the mV levels. They are emitted about 20 – 100 times a second and are regenerated (i.e. amplified) as they propagate along the axons.
2. Emphasize that a human's nervous system is affected by current transmitted through the body and not by voltages. Also the current itself does not kill a human, but rather, it is the human nervous system acting in an uncontrollable reaction to the external current that kills the human being.
3. The internal body resistance is 10-100 Ω and therefore can potentially pass large amounts of currents in a 120 V system. Dry skin is the major protection to prevent large currents from passing through the human body. Therefore, dry skin resistance is in the 50 KΩ to 1 MΩ level. However, when the skin is wet the skin resistance is only 1 – 5 kΩ, and therefore it is easier to pass large current and get an electric shock (or be killed).
4. Emphasize that the AC current at 60 Hz is a very bad frequency because it is close to the frequency of which normal pulses are generated in the body. Therefore, the 60 Hz system confuses the body quite a bit and results in a quick cardiac arrest.
5. Go over the different current levels and how they affect the body. A current of 10-20 mA at 60 Hz is considered dangerous, while a current of 40-100 mA (at any frequency) will kill a person! Go over the let-go current value (i.e., you cramp hard enough that you cannot let-go of the "hot" wire).
6. Talk about ventricular fibrillation, which is the case of the heart pumping out of rhythm due to an electrical shock.
7. Finally go over how the electrical chair is used. Provide details of voltage and current values.

Week 11
Lab 5: Variable Gain Amplifiers; Summers; Intermodulation Products

Arrive early, turn on all of the equipment, make sure that the lab is clean (no paper on benches, chairs in their correct places, etc.). Make sure that each bench has the correct components for this experiment (placed in a small dish).

When the students arrive, check their name in the log-in sheet and ask them to take a seat.

After they sit down, explain to them that this is a serious lab and that they should not waste time. Make sure that their bags are on the floor and their jackets are on the hanger in the corner or their chairs.

Tell them where the components are (but they will not need them) and where the cables are.

This is another lab where the students build the circuits on their own. It is an easy lab and they should not have any trouble.

Before The Lab:

1. Explain again the function of the input 1 µF capacitor. It allows high frequencies to pass and blocks DC.
2. Explain to them that in this lab they will make a variable gain amplifier. Until now the gains have been fixed. In this experiment, they can change the input resistance and thus change the gain by changing R_a. The application of this is the volume control in an audio receiver.

During The Lab:

Variable Gain Amplifier:

Remember again to check the students' circuits before they turn on the power supplies.

1. Part 3. V+, V- and V_o should be in the mV range.
2. Part 5. V_o/V_s max and V_o/V_s min should be close to their prelab values (if they did the prelab right). I measured V_o/V_s max = 37.5 and V_o/V_s min = 0.975.
3. Part 6. Make sure they have gain vs. frequency response curves for a midband gain at minimum ~1, maximum ~ 37, and also ~10. The 1 KHz frequency is a good estimate of the midband gain.

Summer/Intermodulation Products:

4. Part 3 and part 4. The gains for each amplifier should be set independently (i.e. while the other is disconnected).
5. Part 6. Make sure they graph the frequency spectrum.
6. Part 7. Make sure they verify amplitude of the fundamental and 3rd harmonic frequencies.

Send an email to the TA group and tell them how the lab went. This is especially true for the Monday section TA to set the tone for the rest of the group (how long it took, what did they find difficult, etc.).

Week 12
Lab lecture 6: Low-Pass And High-Pass Filters, Transfer Functions With Input Signals, Treble / Bass Tone Control Amplifier

Arrive early, make sure that the lab is clean (no paper on benches, chairs in their correct places, etc.). When the students arrive, check their name in the log-in sheet and ask them to take a seat.

This is the last lab lecture for EECS 210. You need to cover some filter circuits and do a solid introduction to lab 6.

A. Review of Filter Circuits and Transfer Functions

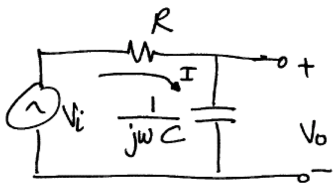
1. Start by covering resistors, inductors and capacitors and their phase equivalent (Z= R, 1/j ωL, 1/j ωC). Stress that a cap is an open at low frequencies (Z=∞) and a short at high frequencies (Z=0). Cover the inductor at low frequencies (short, Z=0) and at high frequencies (open, Z=∞).
2. Cover the low pass and high pass filters (see attached). Do it both using phasors and using simple circuit methods. Talk about the amplitude and phase response.
3. Talk about the transfer function and how $V_0(\omega)= H(\omega). Vi(\omega)$ and give examples in the case of a low pass and a high pass filter (see attached).

B. Treble Tone Control Amplifier

1. Draw the circuit on the board and plot the transfer function (see p. 82). Explain the role of R_p (Max boost, Max. Cut, Flat) and tell them that we will soon analyze the circuit.
2. High-Frequency Analysis: Treat the capacitor (2 x 820 pF) as a short circuit. The reason is that we are working at high frequencies (>10 KHz) when the capacitor is a short. Analyze the circuit as a simple inverting amplifier and derive the transfer function (see attached).
3. Midband Analysis: This is used to derive the transfer function when the capacitor is interacting with the circuit. Write the two nodal equations (nodes A and B) needed to solve the circuit. Do not solve the since this is part of the pre-lab.
4. Low-Frequency Analysis: Treat the capacitor as an open circuit. The reason is that we are working at low frequencies (< 800 Hz) when the capacitor is an open. Analyze the circuit and derive the transfer function (see attached). This is a tricky analysis!
5. Stress that what we learned on transfer functions applies to any circuit and any transfer function, and therefore, applies to this circuit too. This will be done in the post-lab for a square wave at 800 Hz.

Week 12 ; Lab Lecture 6.

Low-Pass Filter:



$$I = \frac{V_i}{R + \frac{1}{j\omega C}} \quad \& \quad V_o = I Z = I \times \frac{1}{j\omega C}$$

$$\Rightarrow \boxed{\frac{V_o}{V_i} = \frac{1}{1 + j\omega RC}} \equiv \text{Transfer function } H(\omega)$$

pole $\omega_0 = 1/RC$

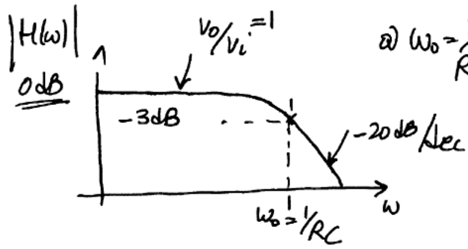
or $\omega \to 0$ Cap $\to$ Open Circuit & $V_o = V_i$

$\omega \to \infty$ Cap $\to$ Short Circuit & $V_o \to \infty$

$\Rightarrow$ Low-Pass Filter

$$|H(\omega)| = \frac{1}{\sqrt{1 + \omega^2 R^2 C^2}}$$

$$\angle H(\omega) = -\tan^{-1}(\omega RC / 1)$$

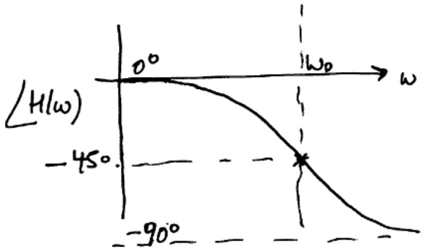


@ $\omega_0 = \frac{1}{RC}$

$$H(\omega = \omega_0) = \frac{1}{1 + j1} = \frac{1}{\sqrt{2}} e^{-j45}$$

$$|H(\omega_0)| = 1/\sqrt{2} \Rightarrow -3\text{dB}$$

$$\angle H(\omega_0) = -45^\circ$$



$\omega \gg \omega_0$ $\quad H(\omega) \to \frac{1}{j\omega RC} \to \frac{1}{\omega}$

$$\angle H(\omega) = e^{-j\omega RC} \to -90^\circ$$

$\rightarrow V_o(\omega) = H(\omega) \cdot V_i(\omega)$

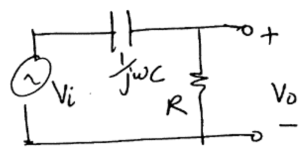
$V_o(\omega) = H(\omega) + V_i(\omega) \,|_{dB}$

$\angle V_o = \angle H(\omega) + \angle V_i$

Give examples with specific frequencies

choose $f_o = 1\text{KHz}$, $f_i = 100\text{Hz}, 1\text{kHz}, 6\text{kHz}, 10\text{kHz}$

High-Pass Filter:



Derive $\frac{V_o}{V_i} = \frac{\overbrace{j\omega RC}^{zero}}{\underbrace{1+j\omega RC}_{pole\ \omega_o = 1/RC}} \equiv H(\omega)$

OR

$\omega \to 0$ Cap ≡ Open Circuit
& $V_o = 0$

$\omega \to \infty$ Cap ≡ Short Circuit
& $V_o = V_i$

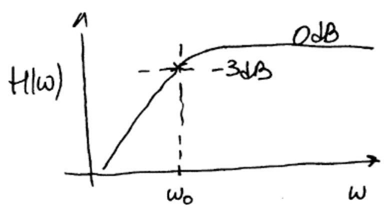
⇒ High-Pass Filter

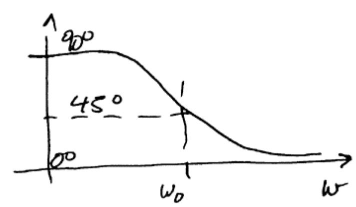
$|H(\omega)| = \frac{\omega RC}{\sqrt{1+\omega^2R^2C^2}}$ $\begin{cases} \omega \to \infty & |H(\omega)| \to 1 \\ & \angle H(\omega) \to 0 \end{cases}$

$\angle H(\omega) = 90^\circ - \tan^{-1}\left(\frac{\omega RC}{1}\right)$ $\begin{cases} \omega \to 0 & H(\omega) \to \omega \to 0 \\ & \angle H(\omega) \to 90^\circ \end{cases}$

at $\omega = \omega_o = 1/RC$ $|H(\omega)| = 1/\sqrt{2} \equiv -3dB$

$\angle H(\omega) = 90^\circ - 45^\circ = 45^\circ$





Different Design:

$\frac{V_o}{V_i} = \frac{j\omega L}{R+j\omega L} = \frac{\overbrace{j\omega L/R}^{zero}}{\underbrace{1+j\omega L/R}_{pole\ \omega_o = R/L}}$

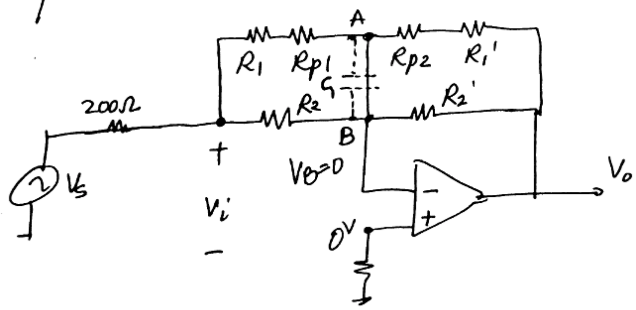
Same as above
but different value pole.

$\omega \to 0$ Ind ≡ Short-Circuit
$V_o \to 0$

$\omega \to \infty$ Ind ≡ Open-Circuit
$V_o \Rightarrow V_i$

Treble Tone Control:

1) High-Frequencies ($C_{op} \equiv$ short). The circuit becomes:



$R_{p1} + R_{p2} = R_p$

Regular inverting Amp: $\dfrac{V_o}{V_i} = \dfrac{-R_2' \,\|\, (R_1' + R_{p2})}{R_2 \,\|\, (R_1 + R_{p1})}$

For $R_{p1} = 0$, $R_{p2} = 100k\Omega$ $\Rightarrow$ $\dfrac{V_o}{V_i} \approx -\dfrac{100 \,\|\, (105)}{100 \,\|\, (5)} \simeq -10$ (+20dB)

$R_{p1} = R_{p2} = 50k\Omega$ $\rightarrow$ $\dfrac{V_o}{V_i} = -\dfrac{100 \,\|\, (55)}{100 \,\|\, (55)} \simeq 1$ (0dB)

$R_{p1} = 100k\Omega$, $R_{p2} = 0$ $\Rightarrow$ $\dfrac{V_o}{V_i} = \dfrac{-100 \,\|\, (5)}{100 \,\|\, (105)} \simeq -0.1$ (−20dB)

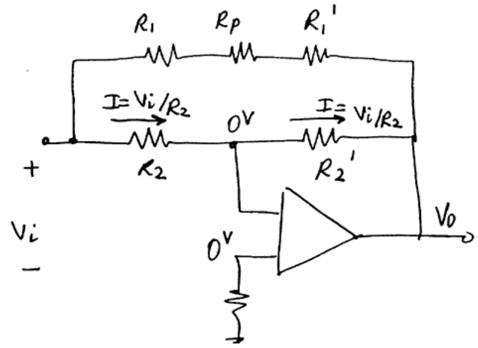
2) Midband Frequencies ($C_{op} \neq$ short, $C_{op} = \frac{1}{j\omega C}$)-

Nodal Analysis at A: $\dfrac{V_A - V_i}{R_1 + R_{p1}} + \dfrac{V_A - V_o}{R_{p2} + R_1'} + \dfrac{V_A - 0}{\frac{1}{j\omega C_1}} = 0$

Nodal Analysis at B: $\dfrac{V_B - V_i}{R_2} + \dfrac{V_B - V_o}{R_2'} + \dfrac{V_B - V_A}{\frac{1}{j\omega C_1}} = 0$

Solve for V_o/V_i —

3) Low-Frequencies (Cap = open). The circuit becomes:



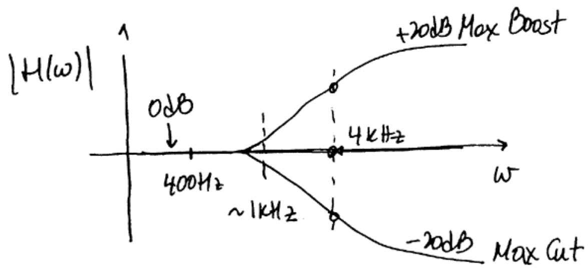
$I = V_i/R_2 \Rightarrow V_o = -I R_2'$

$= -V_i \dfrac{R_2'}{R_2}$

$$\Rightarrow \boxed{\frac{V_o}{V_i} = -\frac{R_2'}{R_2} \simeq 1}$$

Independent of R_1, R_p e R_1'!

Transfer function:



$V_o(\omega) = H(\omega) + V_i(\omega)\Big|_{dB}$

$\angle V_o = \angle H(\omega) + \angle V_i$

Works on this circuit too!

→ Any signal at 400Hz will not be affected
$V_o = V_i$

→ A signal at 4KHz can be boosted or attenuated or can remain the same.

Week 13
Lab 6: Audio Tone Control Amplifier

Arrive early, turn on all of the equipment, make sure that the lab is clean (no paper on benches, chairs in their correct places, etc.).

When the students arrive, check their name in the log-in sheet and ask them to take a seat.

After they sit down, explain to them that this is a serious lab and that they should not waste time. Make sure that their bags are on the floor and their jackets are on the hanger in the corner or their chairs.

Tell them where the components are (but they will not need them) and where the cables are.

This is the last EECS 210 lab for this year. It is a relatively long lab and some students take more than 3 hours to finish it.

Before The Lab:

1. Explain briefly how the treble control amplifier can be used to adjust the gain at high frequencies. Basically adjusting the potentiometer between Max Boost and Max Cut settings allow either amplification or attenuation of high frequencies.
2. Explain to the students that the treble control amplifier can be pictured as a black box with a transfer function that they derived in the prelab. This transfer function modifies the input signal in both amplitude and phase in the following way $V_o(\omega) = H(\omega) * V_s(\omega)$. This can be broken down to magnitude and phase components. $|V_o(\omega)| = |H(\omega)| * |V_s(\omega)|$ or $V_o|dB = H(\omega)|dB + V_s(\omega)|dB$, and $<V_o(\omega) = <H(\omega) + <V_s(\omega)$.
3. Go over how to take phase measurements using the scope. Phase measurements are found by selecting Time measurements, going to the next menu and selecting phase measurements in *degrees* in the menu. The readings will be positive and negative in degrees so have the students convert all their readings to positive by taking 360 + (theta) for any negative phases.

During The Lab:

1. Check off the students circuits before they turn on the power supplies.
2. In part 3, the voltages should be in mV range.
3. For part 5, they should measure 3 different gains -20 dB (0.1 V/V), 0 dB (1 V/V) and 20 dB (10 V/V).
4. Part 6 is critical: The students need to take both amplitude and phase measurements at the 3 different gain settings. They need both V_o and V_s displayed to measure phase difference between the signals.
5. Part 7, the students should remove just one of the 820 pF capacitors.
6. Part 8, Make sure the 820 pF capacitor is back in the circuit. A square wave is used as an input. For part 8, the students need to measure the Fourier spectrum of the input V_s only (only the odd harmonics f_0, $3\ f_0$, $5f_o$, …) .
7. For part 9 the students need to make both measurements in the time domain and frequency domain for the output. They also need to draw the signal in the time and frequency domains. Make sure they

make plots with labeled values in the time and frequency domain. They need to do this for max boost and max. cut settings.

Send an email to the TA group and tell them how the lab went. This is especially true for the Monday section TA to set the tone for the rest of the group (how long it took, what did they find difficult, etc.).