

PUTTING THE LAB TOGETHER

version 1.1

A companion to the book
“A FIRST LAB IN CIRCUITS AND ELECTRONICS”
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TABLE OF CONTENTS

Preface.	3
Overview of a Typical Lab Station.	4
A Turn-key Lab?	5
Fool-proofing	5
Suggestions For Choosing Measuring Equipment	5
Measuring Equipment List	6
Audio Equipment	7
Prototyping Equipment	8
Components	12
Appendix A: More on the Power Amplifier	16
Appendix B: More on the Plexiglass Board	19
Appendix C: More on the Radio Frequency Inductor/Transformer	22
Appendix D: More on the Variable Capacitor	23
Appendix E: More on Cables, Connectors and Adaptors	24

PREFACE

This manual gives suggestions for putting together a lab that uses the book “A First Lab in Circuits and Electronics”. It is meant for those instructors who have adopted the book, as well for those who are considering adopting it, so that they can know what they’re getting into. The lab manager/technician in your department should be able to fully put this lab together based on the material that follows.

I would like to encourage instructors who are considering putting together a lab based on my book to contact me if I can be of any help in this task. My e-mail is tsividis@ee.columbia.edu.

I would like to thank John Kazana for his support in setting up and maintaining this lab at Columbia, and for his photography.

Y. T.

OVERVIEW OF A TYPICAL LAB STATION

An overview of a typical station used in this lab is shown in Fig. PL-1. One such station is used per two-student team. In the background are, from left to right, two function generators; a CD player and a loudspeaker; two digital multimeters; two power supplies; and an oscilloscope. In the foreground you see, from left, a power amplifier (in the small white plastic box); a microphone; behind the microphone, a proto board with a vertical edge plate (front panel) with a potentiometer, a variable capacitor, and a ferrite transformer mounted on it; a plexiglass board; and a wiring kit. This equipment will be discussed in detail below.



Fig. PL-1

A TURN-KEY LAB?

I am in the process of finding an appropriate source that will fully support schools that want to implement this lab, i.e. a source that will make available all required parts and equipment, including the plexiglass board and power amplifier described below. I am talking to several sources, but I do not have a commitment yet and cannot mention them at this point. If you are interested in this possibility, please e-mail me (tsividis@ee.columbia.edu) so that I can notify you as soon as I have a commitment. In the mean time, I have included below detailed instructions for you to put together the lab on your own (as we did), just in case the above effort does not produce results.

The Electronic School Supply (ESS) company has expressed an intention to partly support this lab. They intend to provide most of what is needed, but not the plexiglass board and power amplifier (for now, at least). Their contact information is as follows:

Electronic School Supply
3070 Skyway Dr., Suite 303
Santa Maria, CA 93455
Phone: (805) 922-6383
Toll-free: (800) 726-0084
Fax: (805) 928-0253
E-mail: essinc@lightspeed.net
Web site: www.esssales.com

FOOL-PROOFING

I have made an effort to design this lab so that it is "fool-proof". The ICs used are sturdy types, such as the 741 op amp and the 74LS series of logic gates. These widely available, time-tested chips are perfectly adequate for illustrating the principles, and are less sensitive and with fewer idiosyncracies than some recent chips. In addition, fool-proofing was kept in mind in designing the experiments and in suggestions related to equipment. For example, for those schools that decide to make the 1 W power amplifier (used as standard equipment in this lab) from scratch, an appendix provides suggestions for fool-proofing it, so that it will not burn out if a student connects its supply voltage backwards.

SUGGESTIONS FOR CHOOSING MEASURING EQUIPMENT

Not every instructor will agree with my opinion on this... I am convinced that, for a first lab, it pays to chose equipment as simple as possible. In a beginner's lab our needs are not the same as those of a professional lab: We only need a few basic features, as a vehicle for teaching principles and basic measurement techniques. Students should be able to concentrate on understanding these

basics, with as few distractions as possible.

True, it is tempting to choose equipment with many features, much more so since such equipment is now rather inexpensive and is available from top manufacturers. But if students have to handle complicated equipment, with integrated software, menus, and sub-menus of modes etc., they will be devoting part of their time and attention to the equipment itself, rather than on the principles they are supposed to learn and/or verify. When, for example, a student is trying to understand the features of a waveform, and he/she needs to change, say, the waveform's frequency, there should be one unambiguous knob on the function generator that can be used for doing so. This should not be a double function knob (amplitude/frequency) with another button to select its function, as this can only serve to needlessly interrupt the student's on-going thought process. The same applies when the student wants to change the parameters of a scope's display. If the student has to go through menus and sub-menus of a digital scope for doing so, his/her brain will be dealing with the particulars of the instrument rather than with the general principles being taught. This can interfere with the student's comprehension of the fundamentals, and can make it difficult for the student to see the forest for the trees. Even the face of digital multimeters can be daunting these days.

In short, in my opinion the instruments in a first lab should be the means to an end, not the end, and thus should be as unambiguous and as simple as possible. There is room for sophisticated equipment in more advanced labs, when the students will have the maturity to appreciate their sophistication and why it is needed.

The type of measuring equipment I have found most suitable for this lab is purely analog. Because analog is difficult to program, the manufacturers of such equipment have spared us a dizzying array of features and menus that have no chance of being used in a first lab. And even on an analog scope, some features are likely not to be used in such a lab.

Many dealers will lend you equipment for you to try out for a period, before you commit yourself to it. This is very important, especially if you want to check it out according to what is said in the above paragraphs. One thing you may not be able to check is the equipment's reliability. Here one should proceed with care, and consider the manufacturer's reputation and the warranty they offer.

MEASURING EQUIPMENT LIST

This list is meant to be indicative only, based on what we use at Columbia. It is not meant to suggest a preference for specific equipment types or manufacturers, or to imply that we have found the equipment listed to be reliable. Further, some of the model numbers shown may have been replaced by more recent ones. The quantities given are per lab station.

Two digital multimeters. We have found the Tektronix CDM250 to be one of the simplest digital

multimeters, and a very reliable one.

Dual-trace oscilloscope. 20 MHz bandwidth. In the past we had some reliability problems with scopes (display trace drifting up and down) after a couple of years. We have recently switched to GW INSTEK Model GOS-622G, which so far performs well, but we have not tried it for several terms yet and cannot comment on its long-term reliability.

Two function generators. Range: 0.1 Hz-2 MHz. One generator should have modulation capability (the latter feature is not needed if the first part of Experiment 10 is to be skipped; see Instructor's Manual). The maximum peak amplitude should preferably be at least 5 V. For the generator with the modulation capability, we have been using the Leader LFG-1300S for several years and are generally happy with it. For the second generator, we have been using the Goldstar FG-8002, also with satisfactory results.

A simple function generator may be available on trainer boards. The range of frequencies and amplitudes of such generators may be limited.

Two dual output regulated power supplies. The voltage should be variable from 0 to at least 10 V. A maximum current of 1 A is more than enough. (Much less than that is used in the experiments; the extra room is suggested in case you want to accommodate many types of projects). The power supplies should be short-circuit protected. We have been using HP E3620A and are very happy with them.

Simple power supplies may be available on trainer boards. Their range may be limited.

AUDIO EQUIPMENT

Power Amplifier. Maximum power 1 W, with voltage gain of 1. I am trying to find a source that will make this amplifier for you, fool-proof and contained in an enclosure; see "A Turn-key Lab?" above. In case I do not succeed, I give instructions for making the amplifier (as we did - it's easy!), from scratch or using a kit, in Appendix A. The amplifier can be seen on the left in the foreground of Fig. PL-1. The 1 W power spec is not set in stone (0.5 to 2 W will be fine, but more than 2 W is not recommended; it can be bad for the students' ears and for the noise level in the lab). A voltage gain of approximately 1 is very important. The power amplifier should not have a large voltage amplification, as then power and voltage amplification can be confused by students, and the need for them to make a voltage amplifier themselves (see Experiment 5) will not be present. It's a matter of motivation! The amplifier should have terminals for connections to an external DC power supply, and should preferably be fool-proof to wrong power supply connections. A method for fool-proofing the amplifier is presented in Appendix A.

Loudspeaker. 8 Ohm nominal impedance, with magnetically shielded enclosure. The latter feature

is needed to make sure that the speaker's magnetic field does not distort the scope's CRT display, if the speaker happens to be placed near the latter. The speaker's panel should ideally be removable, if you want your students to do Step 21 of Experiment 3 (which is advisable). We use KLH AV-1001B speakers with good results. The wattage of this speaker is listed as "5 to 100 W", which is much higher than the 1 W the power amplifier can deliver, but this is fine; the speaker cannot be damaged even at full blast, and it can provide good fidelity and a full frequency range (80 Hz to 20 kHz). Many other speaker models can be used. You may want to prefer a speaker that includes '1 W' in its power rating, but make sure it sounds good with your amplifier.

Dynamic microphone. 600 Ohm nominal impedance. A microphone with a plastic casing is preferable, for reasons of safety, and because it will not cause a short if carelessly left to touch a circuit under study. Other than that, the microphone can be just about any 600 Ohm dynamic mike on the market, available for example in stereo stores. In fact, the 600 Ohm impedance is not critical, as long as your mike delivers a signal sufficient for doing Experiment 5. Inexpensive mikes (\$10 to \$20) have a quality more than adequate for the purposes of this lab. Unfortunately, I cannot give you the manufacturer of the mikes we use, as we did not keep records and its logo seems to be designed so that it is totally illegible! (It probably starts with an A...) For what it's worth, I mention the model number: ADM105.

CD player. Just about any model is suitable. If it has a volume control, so much the better, but not many CD players come with volume control. One that does, and which we have used with good results, is the TEAC CD-P1120. The volume control affects the phone output, which can be used as the signal output in Experiment 7. If the CD player lacks a volume control, it is not a big deal; such a control can easily be made, as discussed in Experiment 7.

PROTOTYPING EQUIPMENT

Plexiglass board. If desired, all experiments can be performed using a standard proto board, as described in the following subsection. However, for the first three experiments it makes more educational sense to use a transparent plexiglass board, in which several components are permanently and visibly connected to banana receptacles under the board. See Fig. PL-2. As mentioned earlier, I am trying to find a source that will make available a similar board; see "A Turn-key Lab?" above. In case I don't succeed, simple instructions for making such a board are given in Appendix B, where other information about this board is also provided.



Fig. PL-2

The studentS connect the components on the plexiglass board using cables attached to banana plugs. These banana plugs are of the type that other banana plugs can be inserted into their top, thus making possible the connection of several cables to the same node. In contrast to the proto board, where connections are hidden below white plastic, in the plexiglass board the student can see everything. For a beginner, who may not even have understood what a node is initially, this is important for confidence building; the student knows what he/she is doing. Starting with the fourth experiment, where ICs begin to be used in this lab, one can graduate the students to the proto board. By then they have understood what connections really mean. However, the plexiglass board can still be used for Experiments 6 and 9. Also, some students find it convenient to wire components on it to their circuit on the proto board (e.g., if they want to experiment with different resistor or capacitor values).

Proto Board. Most experiments in the book (starting with Experiment 4) require the use of the

ubiquitous plastic proto board. See Fig. PL-3, behind the front panel.

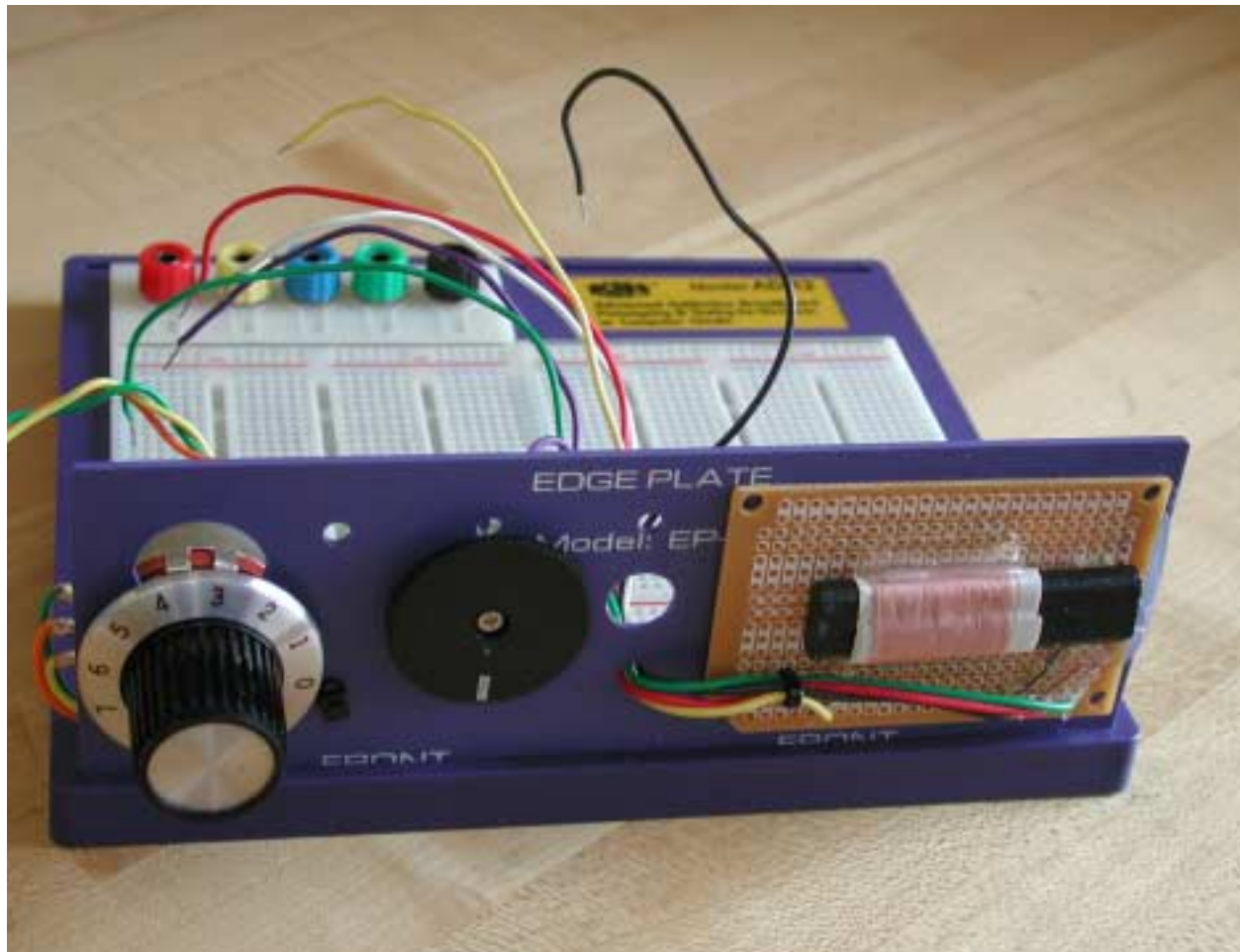


Fig. PL-3

For convenience, and especially if projects are to be included, the proto board should contain 1200 or more tie points (holes). The proto board should preferably be mounted on a supporting board which contains several connecting posts, such as banana receptacles (preferably four or five). Other types of connectors on the supporting board, such as BNC, are welcome; if they are not available, cable adaptors (banana-to-BNC) can be used. Make sure you ask for a proto board known for its high reliability; some of the boards out there are meant mostly for hobbyists, not for heavy use by hundreds of students. We use K and H Products Model AD-12. The K and H product line is distributed by Computronics Technology, Inc. (CTI), 1225 West College Ave., Suite 506, Carrollton, TX 75006, phone (972) 242-8087, fax (972) 242-0395, Web site: www.cti-texas.com, e-mail cti@wtd.net. If they do not have the AD-12, you may try their SB-123 or SB-135.

Wire kit. Such kits contain various lengths of colored, insulated single-strand wire (usually #22 to #24 AWG), with insulation removed at the ends for connections to the proto board. We use K and H Products, model KS350. CTI (see “Proto Board” above) also has other suitable wire kits, such as JP-003 or JP-002. It is important to use wires with diameters as specified for the proto board you use. Some boards may require, for example, #22 wires; thinner wires (larger gage number) may in that case result in unreliable connections.

Edge plate. An edge (front panel) on which certain components can be mounted can be inserted in a slot in the supporting board of some proto boards (e.g., in all proto board models mentioned under “Proto Board” above). One can mount components on this panel, like a potentiometers and a variable capacitor (in our case, we also mount the radio frequency transformer on it); see Fig. PL-3. If I am successful in finding a source that will fully support this lab (see “A Turn-Key Lab?” above, you will probably be able to purchase the edge plate with the components already mounted on it. Single-strand wires, connected to the components mounted on the proto board, must be strapped to the board itself, to relieve the mechanical strain that would otherwise be present if these wires were just "hanging" directly from the solder joints on the component terminals (in which case these wires would break after some use); see Fig. PL-4. We use the EP-3 edge plate from K and H Products, available from CTI (see their whereabouts under “proto Board” above).

1. “Trainer” boards: Several manufacturers make trainer boards, consisting of a proto board, connecting terminals, power supplies, simple function generators, LED indicators, and some times other features such as a tiny loudspeaker. Using such trainer boards is an inexpensive way to start a first lab. However, the features of the supplies and function generators may be too limited; the tinny loudspeaker certainly is not appropriate for the audio experiments in this lab, and its tinny sound will not be appreciated by the students. Such trainer boards can be useful and are advisable for digital experiments, since they contain pre-assembled de-bounced switches, logic indicators, etc. For experiments 1-13, though, simple proto boards and stand-alone equipment is preferable. If you are considering using a trainer board, make sure to inquire as to its reliability in heavy school use and its warranty. It is best to get a model on loan and test it as much as possible.

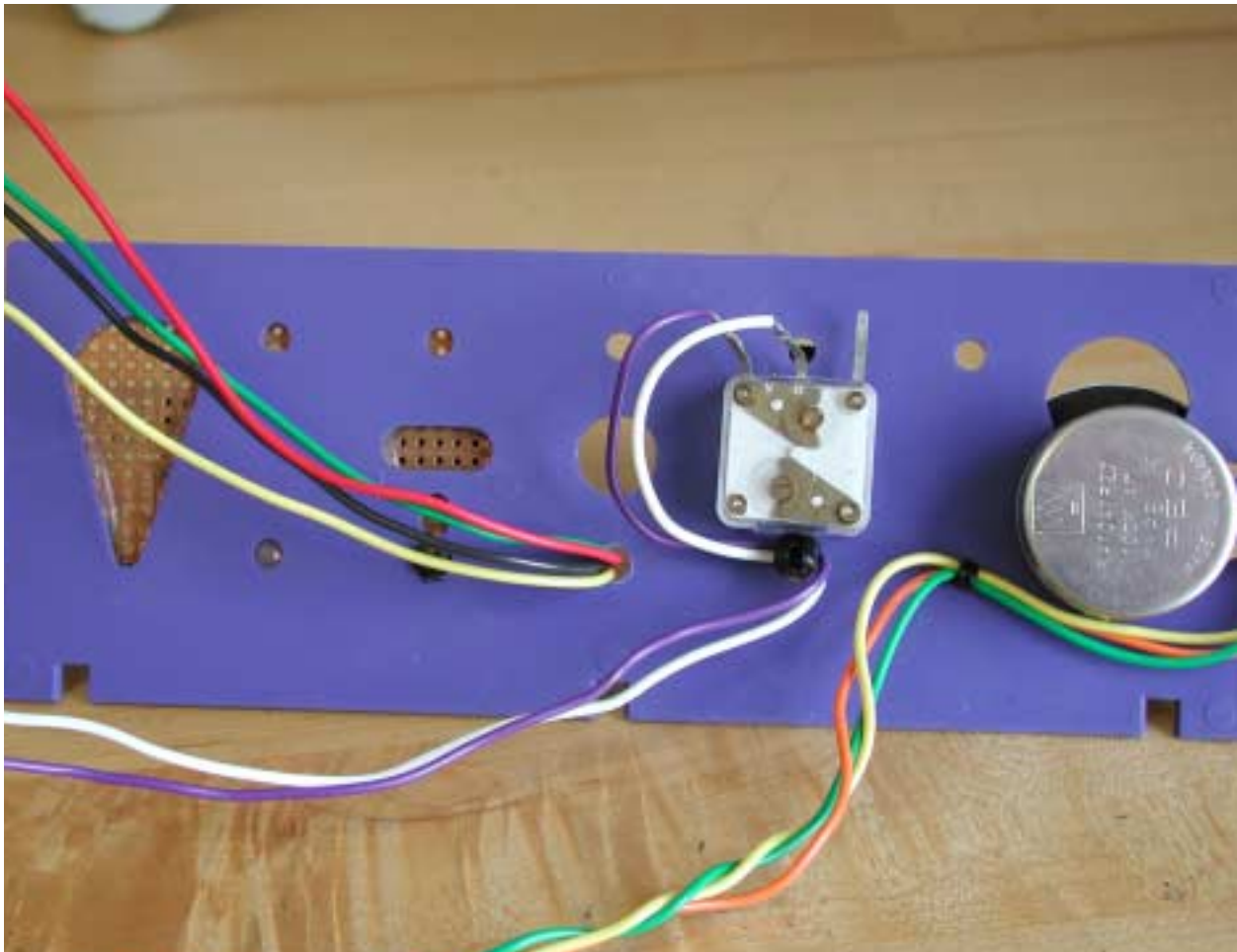


Fig. PL-4

Long-nosed pliers. These can be used for easy insertion of wires into proto board holes, for straightening out chip pins, etc.

IC extractors. Some people like them; some don't.

COMPONENTS

Resistors. 1/2 W, 5% or 10% tolerance; standard values from 10 Ohm to 10 MOhm.

Capacitors. 10% tolerance, 35 V; standard values from 100 pF to 100 uF. We prefer ceramic caps for low values. The reader is warned that there are some pretty bad quality capacitors out there. I have seen caps with tolerances worse than 100% (no matter what the lettering on the cap says), as

well as ones that are open-circuited. Make sure you demand quality caps from your dealer. Capacitors in the μF range will have to be electrolytic ones.

Potentiometers. 10 k Ω , linear. You need two of those; for example, one can be on the plexi-glass board and the other on the edge plate (see above). Normally, one would prefer to use logarithmic potentiometers for volume control, but linear ones are appropriate for the several purposes we use them for in this lab.

Thermistor. Several k Ω ; the type is not critical at all.

Photoresistor. Several k Ω ; the type is noncritical.

Inductor/transformer. Radio frequency transformer wound around ferrite core, used in Experiments 8 and 10; several hundred μH . (The exact value is not important, as long as it resonates in conjunction with the variable capacitor below over the AM radio band). You can see this part on the right in Fig. PL-3. An example of an appropriate ferrite transformer is ELENCO 484004. I am told that this transformer will be made available by Electronic School Supply (see “A Turn-Key Lab?” above). In case this doesn’t happen, you will find much information about this part in Appendix C. Information for mounting and connecting this part, as well as other information on it, is provided in the same appendix.

The transformer should be handled with care, so that its ferrite core does not fall off; if it does, it is likely to break. Students should be cautioned about this. (Broken cores will partially work when glued back together - a temporary solution until new ones are ordered.)

Variable capacitor. This should be in the several hundred pF range, and should tune the AM band (approximately 530 to 1700 kHz) in conjunction with the larger winding of the above transformer. For use with the ELENCO transformer suggested above, an appropriate variable capacitor is ELENCO 211677. It is expected that this variable capacitor will be made available by Electronic School Supply. In case you need to look for this part yourself, or in case you want extra information, much more about this part is given in Appendix D.

Semiconductor devices:

Two silicon power diodes (1N4148 or 1N4007). The former type has thinner leads, more appropriate for inserting into proto board holes.

Germanium small-signal diode (1N34A or equivalent). There are many replacement types, for example NTE109, ECG109, SK3090. Whatever the part number, make sure this is a small-signal diode of the germanium type, not a silicon one; the low forward voltage drop of a germanium diode is appropriate for radio detection in Experiment 10.

MOS transistor. We prefer to use the MOS transistors found inside a CD4007 complementary pair/inverter chip (listed below).

Bipolar transistor (2N2222A or equivalent).

LEDs of various colors. These should be low-current (a few mA); the reverse breakdown voltage should be at least 5 V. The type is noncritical.

Integrated circuits:

741 op amp¹. Made by various manufacturers. A dual-in-line 8-pin package is preferable.

CD4007 complementary MOS pair/inverter.

CD4066 Quad bilateral analog switch.

74LS00 Quad NAND gate.²

74LS175 Quad D flip-flop.

74LS112 Dual JK negative edge-triggered flip-flop.

Switches:

Single-pole single-throw (on-off) switch.

Single-pole double-throw switch.

Two single-pole double-throw push-button switches.

The first two switches should be of the spring-loaded variety, clicking as they are moved to either of two positions. We use C&K switches.

Cables, Connectors And Adaptors:

-
- ¹ If you prefer to use other op amps, make sure they are internally compensated and well-behaved. Some op amps have non-monotonic DC transfer characteristics which can needlessly confuse beginning students. While modern op amps can have better performance than the 741, such performance is not needed in order to teach the principles in this lab. The robust, time-tested 741 is perfectly adequate for our purposes.
 - ² Other logic families can be used if you want, with appropriate instructions to students. I prefer the 74LS TTL family and have written the last three experiments in the book accordingly. As far as teaching the principles is concerned, it does not matter that this family is not “modern”. For our purposes, this family is ideal since it is robust, can handle some abuse on the part of the students, and has good driving capability allowing it to drive LED/resistor indicators directly.

A variety of connecting cables with appropriate end connectors and adaptors, depending on the equipment used. Remember, you can never have enough of those... We use ones made by Pomona, and are very happy with them. I am told that Electronic School Supplies will make available sets of cables, connectors and adaptors for this lab. If not, you may want to consider the list given in Appendix E as a starting point.

APPENDIX A: More on the Power Amplifier

The 1 W power amplifier mentioned under “Audio Equipment” above is meant to be standard equipment available to the students, and not to be constructed by them. It is hoped that you will be able to purchase the amplifier ready-made and fool-proofed (see “A Turn-Key Lab?” above). If this is not possible, you may have to have a number of amplifiers made locally before the lab begins. The instructions below should be helpful in this task.

Fool-proofing the power amplifier. If the amplifier you purchased is not fool-proof, or if you decide to make it at your school (see below), it is advisable to add diodes inside its enclosure as shown in Fig. PL-A-1, to fool-proof the amplifier. These diodes are meant to protect the amplifier in case a student connects the power supply with the wrong polarity. A is the positive supply terminal and B is the negative supply terminal of the amplifier. The 100 μF capacitor is used for bypass purposes, and may not be necessary with some amplifier circuits. Some power amplifier kits may have a floating speaker output, rather than a grounded one as shown in Fig. PL-A-1.

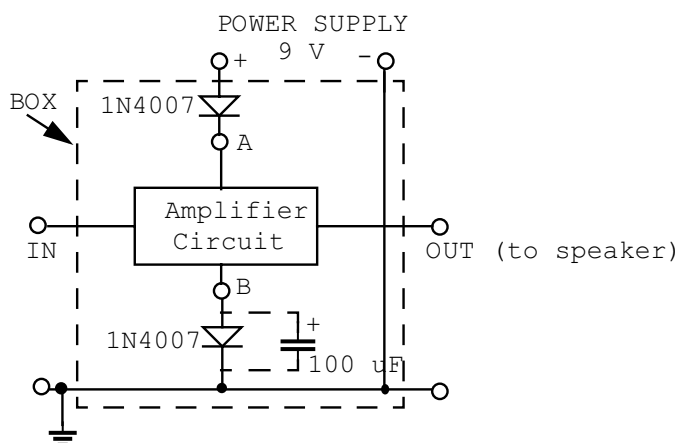


Fig. PL-A-1

The power amplifier circuit should be placed in a plastic enclosure with input, output, and power supply connections as shown in Fig. PL-A-1. We use one measuring 5 in W \times 5.25 in D \times 1.5 in H, with terminals placed as shown in Fig. PL-A-2.

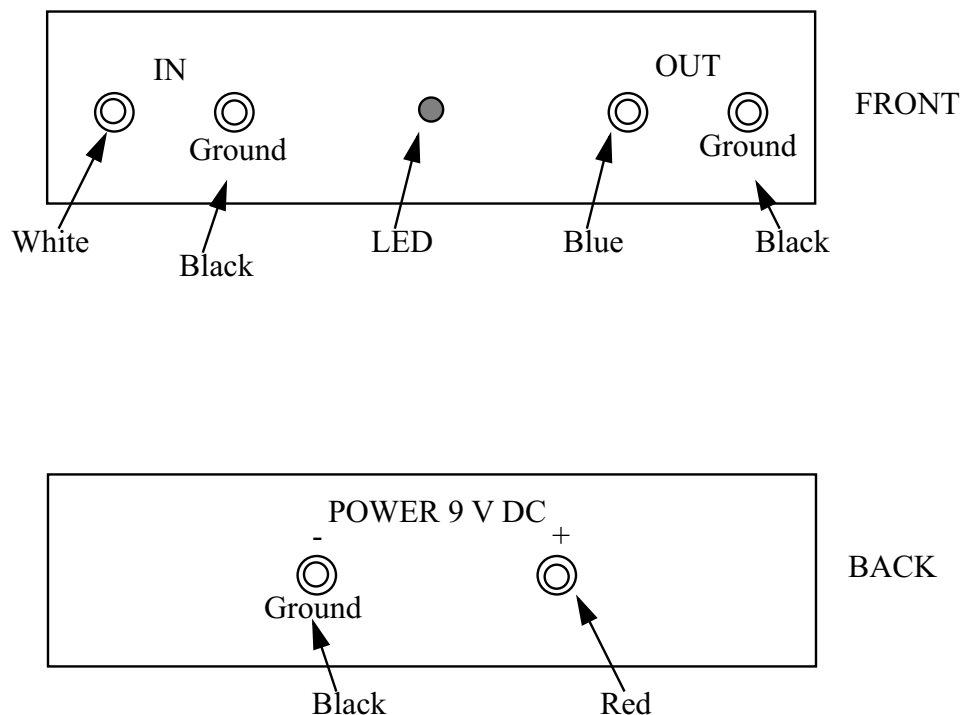


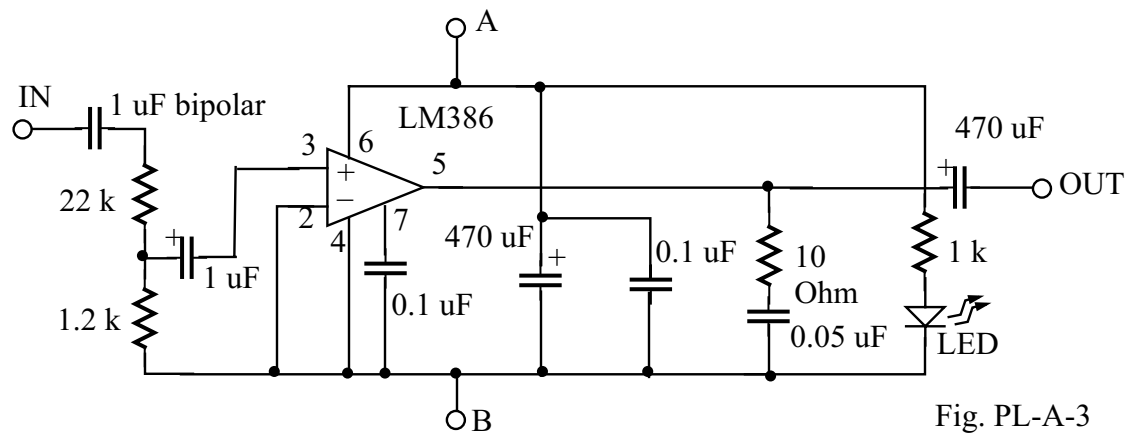
Fig. PL-A-2

Making the power amplifier from a kit. This amplifier can be purchased in kit form [for example 6017-KT from Marlin P. Jones & Associates, P. O. Box 12685, Lake Park, FL 33403-0685, Phone: (561) 848-8236, Fax: (561) 844-8764, e-mail: mpja@mpja.com, web site: www.mpja.com]. If a trim pot is provided as part of the kit, it should be set so that the voltage gain is 1. Otherwise, an input voltage divider can be used as shown in the input of the circuit in Fig. PL-A-3 below. For fool-proofing and enclosure considerations, see above. Some power amplifier kits may have a floating speaker output, rather than a grounded one as shown in Fig. PL-A-1.

Making the power amplifier from a scratch. If you prefer to have the power amplifier made in your department's electronics shop, as we did, you can use the schematic shown in Fig. PL-A-3. This circuit is based on National Semiconductor's application notes for the LM386 chip.¹ The number of components in the circuit shown is not the minimum possible, but this is how we have used it for historical reasons, and it works. The two input resistors reduce the voltage gain inherently available in the LM386, so that the overall voltage gain of the power amplifier is approxi-

¹. Thanks are due to Nagi Krishnapura for breadboarding the prototype.

mately 1. The power supply terminals are A (positive) and B (negative). For fool-proofing and enclosure considerations, see above.



APPENDIX B: More on the Plexiglass Board

I hope that I will succeed in finding a source that will make a plexiglass board similar to the one in Fig. PL-2 (see “A Turn-Key Lab?” above). Alternatively, the board of Fig. PL-2 can be made out of 1/4 in thick plexiglass. In our case, this was done by our electronics shop in collaboration with the machine shop. The dimensions of the board are about 11 in \times 9 in. Four legs, one attached to each corner, are 1.5 in tall and are made of 0.75 in cylindrical plexiglass; stick-on rubber feet are used. Fig. PL-B-1 shows the components connected to the board. The horizontal distance between two neighboring banana posts is 1.25 in; the vertical is 1 in.

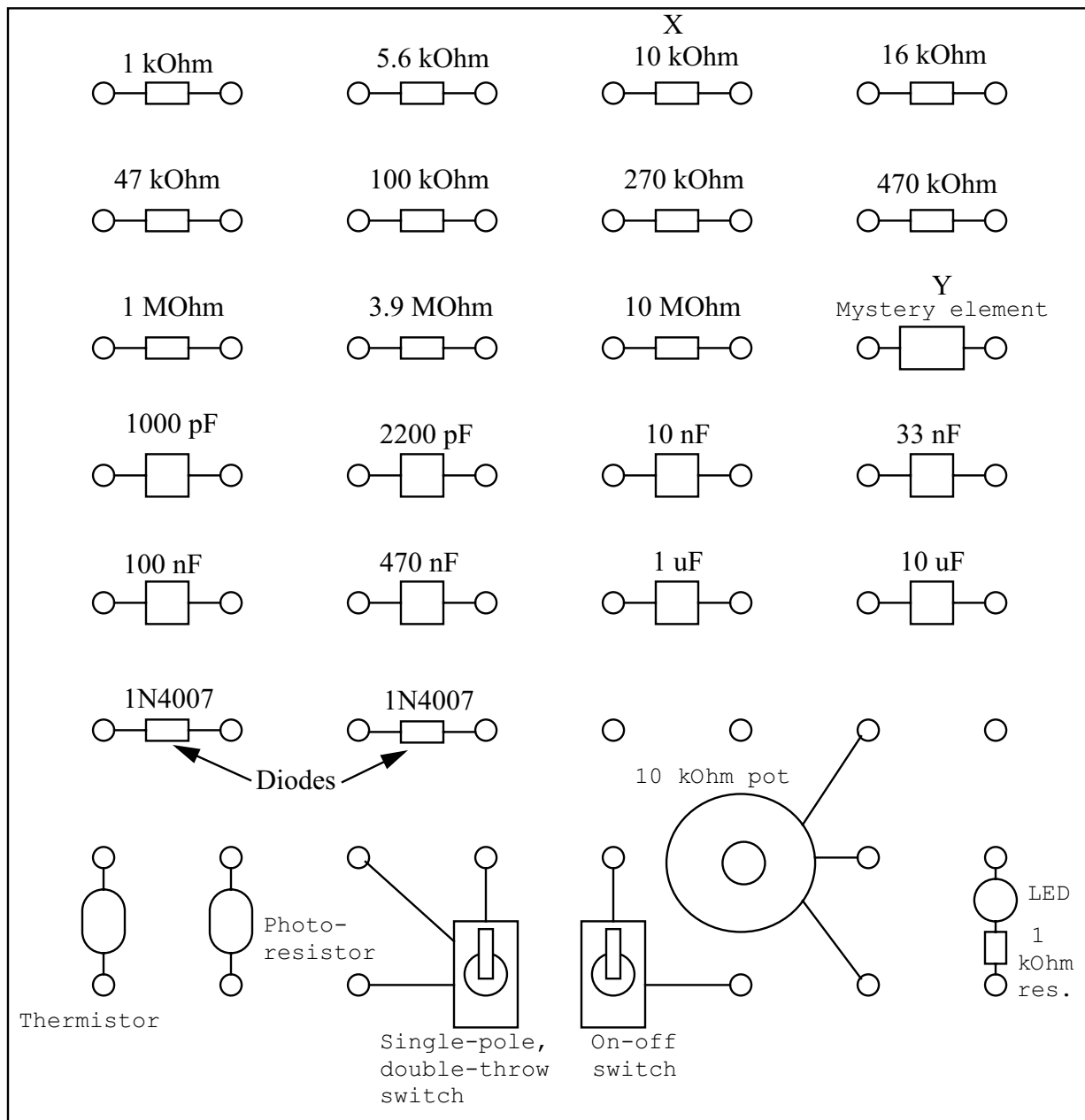


Fig. PL-B-1

The resistor marked "X" is used in Experiment 1. The "mystery element" Y is the circuit in Fig. PL-B-2 wrapped in plastic tubing, so that the students cannot see (and are not told) what is inside. (Well, if they happen to hit this Web site, they will now what is inside... That's OK - they still have to measure it). This is meant to be a black box, for which the have to obtain the V-I characteristics in Experiment 1. This black box gives a nonlinear characteristic, which helps drive the point home right from the beginning, that not all elements are linear. If the instructor does not want to use this, a resistor can be used instead.

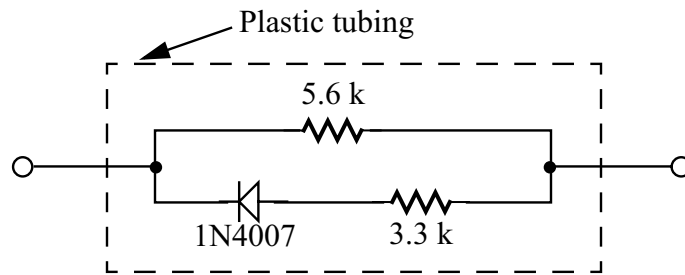


Fig. PL-B-2

It is better to use nonpolar capacitors on the board, just in case a student tries to use them without having read the warning on polarity of electrolytic capacitors.

There are several posts left unconnected on the board. These provide extra wiring flexibility and can come in handy in some cases. If desired, they can be used instead for extra components on the board, with values other than the ones given in Fig. PL-B-1.

APPENDIX C: More on the Radio Frequency Inductor/Transformer

This appendix gives more information on the inductor/transformer, in case you need it. This part is standard at the inputs of all AM transistor radios, and you can see it on the right in Fig. PL-3. It has a ferrite core, and is sometimes referred to as “ferrite antenna” or “ferrite loopstick”. Typically, one winding of this transformer consists of a hundred or so turns around the ferrite core, and the other winding contains much fewer turns (e.g., one tenth of those of the larger winding). For the various ferrite transformers available for AM radios, typical values for the inductance of the larger winding (with the ferrite core all the way in) are from 175 μH to 865 μH . The exact value does not really matter, as long as a suitable-valued capacitor is used to tune the AM band (see variable capacitor below). For example, ELENCO 484004 is at the upper end of the range given above. If worse comes to worse and you cannot find this part, you can purchase entire AM radio kits (often in the range of \$10 to \$20), e.g. ELENCO AM-550 K, and use the variable capacitor and RF transformer that come with them; but make sure the ferrite core in the latter can be moved in and out (see below).

You will need to identify the four terminals of the transformer, and code them for easy identification by the students (see Experiment 8). The ferrite transformer terminals often come color-coded; for example, for the ELENCO 484004 the terminals shown in Fig. 2(b) of Experiment 8 are as follows: A: Green, B: Red, C: White, D: Black. The red and black terminals may come already connected to each other. This is fine, as this is how they are to be used; both these terminals are to be connected to ground in Experiments 8 and 10. The reader is warned that the above color code may not be valid for a different model, and that the color code may even be different for two transformers of the same model, manufactured at different times. A way to unambiguously identify the transformer terminals is described in Experiment 8.

We have found it convenient to mount the transformer on the front panel (see Fig. PL-3), in such a way that its core can be easily moved in and out. The smaller winding should be toward the side from which the core is moved in and out (see Experiment 8); in Fig. PL-3, this is the right-hand side. The type of mounting shown does not have to be used; any reasonable solution will do. The inductor terminals should be attached to single-strand wires for easy insertion into the proto board holes. These wires should be strapped to the front panel as shown in Fig. PL-4 for mechanical durability.

APPENDIX D: More on the Variable Capacitor

This appendix provides more information on the variable capacitor. As mentioned, this part is supposed to tune the AM band (approximately 530 to 1700 kHz) along with the larger winding of the ferrite inductor/transformer. With the capacitor at its maximum value, the resonant frequency $f = 1/(2\pi\sqrt{LC})$ should be at about the lower end of the above frequency range, and with the capacitor at the minimum value one should be able to get close to the upper end. This may not be fully possible with the transformer and capacitor at hand, but this is not a problem as long as most of the range can be tuned. Typical (and acceptable) value pairs for the maximum capacitance and the inductance of the larger transformer winding are: 500 pF with 175 uH; 365 pF with 240 uH; 145 pF with 600 uH; 100 pF with 865 uH; and so on.

If you decide to use the transformer found in AM kits, you can use the variable capacitor in them, too. Then the LC product will have the right value for the AM band (see below, though, concerning the loading effect of the scope probe).

Variable capacitors for AM receivers usually come as dual units, one of which might be better suited to the inductance at hand. If the capacitance of either unit is small by itself, you may want to connect both units in parallel. Also, often each unit comes with a small trim cap in parallel with it (e.g., 10 pF), which can be used to provide a desired total capacitance value. We use an ELENCO 211677 variable capacitor. The first unit of this capacitor can be varied approximately from 7 to 67 pF, and the second unit can be varied from 7 to 147 pF, with the trim caps at their minimum value; these values increase by about 11 pF each with the trim caps turned to their maximum value.

All the above capacitors in a given unit have one terminal common, which is usually connected to the unit's metal shaft. This is the ground terminal, and it should so be labelled. The single-strand wires attached to the capacitor should be strapped on the front panel as shown in Fig. PL-3 for mechanical durability.

When an oscilloscope probe is used in parallel with an LC tank, as in Experiment 8, its capacitance (typically 20 pF) will be in parallel with the capacitance of the variable capacitor. In order for this not to upset tunability over most of the AM band, you may want to choose variable capacitor values smaller than what is suggested above by an amount equal to the probe capacitance. Or, you may want to decrease the inductance accordingly, by moving the ferrite core partly outside the transformer, as discussed under in Appendix C.

APPENDIX E: More on Cables, Connectors and Adaptors

Here I list what we use in terms of cables, connectors and adaptors. Included is a very rough number of units per station, as a starting point for you to consider. All part numbers given are for Pomona parts.

BNC-to-BNC cables, 2249-C-36 (three per station).

Minigraber - banana plug cables, one per station for each of 3782-36-0 (black), 3782-36-2 (red), 3782-36-4 (yellow).

Banana-to-banana patch cords, 4-in long: B-4-7 (four per station), 12-in long: B-12 (eight per station), 35-in long: B-36 (six per station).

BNC-to-banana cables, 3073 (four per station).

Coaxial adaptor, BNC (M) to two BNC (F), 3285 02918. One per station.

Phone jack-to-BNC adaptor, 4043. This is used for the mike (or, you can use phone jack to banana). One per station.

Stereo phone jack to banana cable. This is for connecting to the output of the CD player and we put it together ourselves, but I am sure it exists ready-made. One banana, connected to one channel, is sufficient. Alternatively, a combination of adaptors may be used. One per station.