Massachusetts Institute of Technology
Department of Electrical Engineering and Computer Science

Lab 3: Design project, Part 1

6.117 Introduction to Electrical Engineering Lab Skills (IAP 2020)

Introduction

In this lab, you will begin construction of the design project. The goal of the design project is to demonstrate how concepts from the past two labs can be combined to form a useful system. As such, it will be helpful to think about the remaining exercises from a **systems perspective**. In other words, while it is important that you understand how each circuit works, it will be much more useful when completing the design project to think of each circuit as a “black box.” A specification describing the intended purpose of each circuit will be given, and you are encouraged to think about the interactions *between* different circuits, rather than the behaviors that occur *within* them.

The design project is a fully self-contained, **password-protected audio amplifier**. When the correct 4-bit password is entered via the user input keys, the amplifier will be activated. Optionally, an **infrared (IR) remote** may be constructed and used to implement remote password entry. The block diagram for the design project, as discussed in lecture, can be seen in Figure 1.

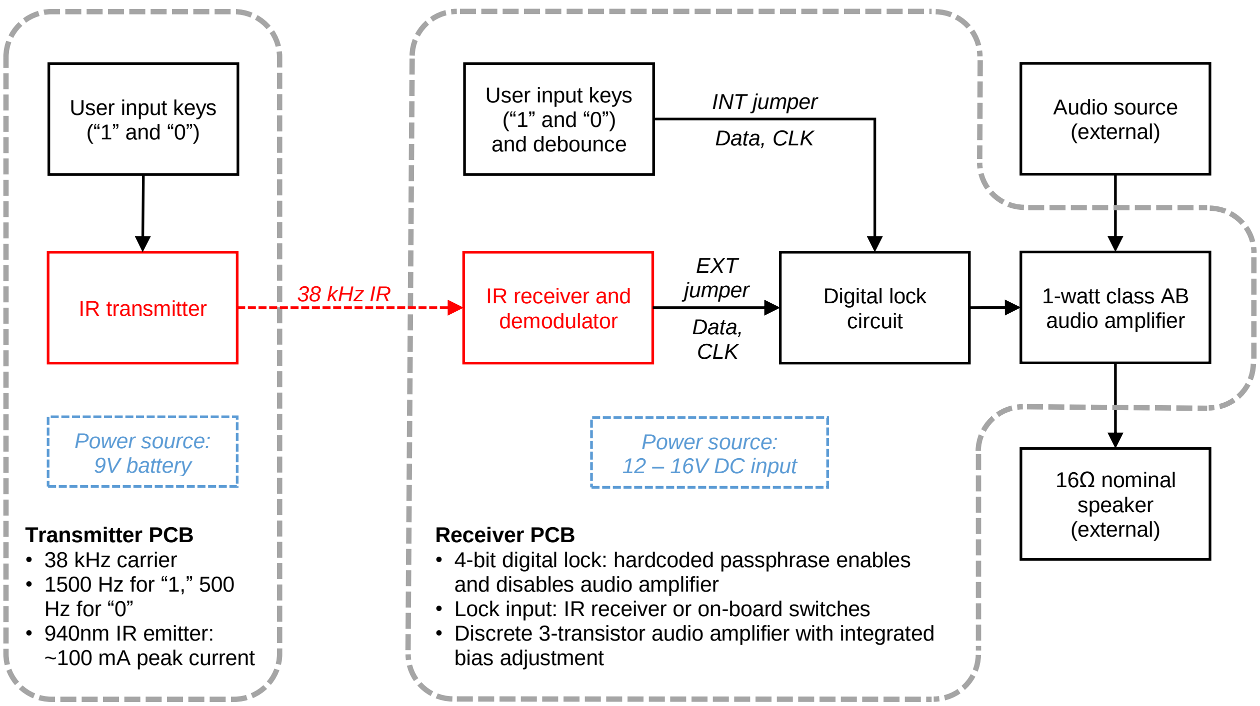

Figure 1: Design project block diagram

The design project is implemented on two printed circuit boards (PCBs): the receiver PCB and the (optional) transmitter PCB. The receiver PCB contains the IR receiver circuit, the digital lock circuit, and the audio amplifier. The transmitter PCB contains the IR transmitter circuit. All sections are powered from onboard power supplies. In this lab, you will complete the **power supply** and **digital lock** sections of the **receiver PCB**.

This handout makes extensive use of the final project schematic, which should have been provided to you as a separate handout (see a member of the course staff if not). Each component in the schematic handout is accompanied by a **reference designator**, a unique identifier used to locate and place components.

The reference designator is composed of one letter followed by three digits. The letter indicates the type of component to which the reference designator refers. Several common reference designator prefixes are listed in Table 3.

Table 1: Common reference designator prefixes

Prefix	Component type
R	Resistor
C	Capacitor
L	Inductor
D	Diode
Q	Transistor
U	Integrated circuit (IC)
J	Connector, jumper

The first digit of the reference designator is the same for all components on a page. For example, R201 and R202 will be on the same page, but R301 will be on a different page. The remaining two digits are used to identify specific components. Some components, particularly in digital circuits, are often separated into **multiple schematic symbols**. For example, U401 (see schematic handout) contains four NAND gates and is separated into four schematic symbols (U401A – D). Since the prefix and digits are the same for all four reference designators, all four gates are contained within a single component.

Occasionally, power pins will be hidden in a schematic symbol. For example, U301 contains four separate op-amps, none of which have schematic symbols showing power pins. In this case, the component is assigned a separate schematic symbol **containing only the power pins** (in this case, U301E). It is important to locate the power pins of each IC when reading a schematic diagram.

Exercise 1: Power supply

This section makes extensive use of the schematic handout. The power supply components can be found on page 5 of the schematic.

In this exercise, you will construct the power supply section of the receiver PCB. There are two main power supplies used on the receiver PCB: an unregulated split power supply and a 5V regulated power supply. The split supply is used to power the analog portions of the receiver. The split supply outputs symmetric positive and negative voltages that are equal in magnitude to **half of the DC supply voltage**, which may range from 12 – 16V DC.

For consistency, each power supply is assigned a unique **net name** in the schematic. Symbols that are accompanied by a three-letter string beginning with V (i.e. VCC) are **power symbols**. All nodes connected to a power symbol are implicitly connected. The power net naming conventions used in this schematic are shown in Table 2.

Table 2: Power net naming conventions

Net name	Power supply
VCC	Positive split supply
VEE	Negative split supply
VDD	5V regulated supply
GND	Floating ground

The unregulated power supply uses an LM741 op-amp (U201) to produce a stable ground point halfway between the positive and negative DC power input voltages. U201 is connected as a non-inverting amplifier with a gain of 1, and its ground reference point is set by two identical resistors (R201 and R202). The output of U201 is connected to a push-pull output stage formed by Q201 and Q202. These transistors provide the current gain necessary to hold GND halfway between VCC and VEE under high load currents.

The regulated power supply outputs a fixed positive voltage of 5V. U202 is an LM7805 regulator that produce a stable DC power supply to drive the digital portions of the receiver. The positive half of the split supply is used as the input to the LM7805.

Assembly

To assemble the PCB, you will be required to solder components in place. Before beginning to solder, review the instructions in the EECS Safety Form you signed on the first day of class. Assemble the power supply section according to the steps below:

1. Obtain a printed circuit board (PCB) from the table near the entrance of the lab.
2. Obtain the parts required for the power supply section. The parts are listed by reference designator in Table 3.
3. Obtain safety goggles from the back of the lab **prior to beginning soldering**.
4. Ensure that your lab station is equipped with a soldering station, a tip cleaner and a fume extractor.
5. Apply water to the tip cleaning sponge to prevent damage to it during the soldering process.

Table 3: Components for power supply section

Resistors

Reference designator	Value
R201	10kΩ
R202	10kΩ

Connectors

Reference designator	Type
J201	2.1mm barrel jack
J202	*Terminal block*

Capacitors

Reference designator	Value
C201	*100uF*
C202	*100uF*
C203	1uF
C204	1uF
C205	*100uF*

Diodes

Reference designator	Type
D201	*1N5402*

Transistors

Reference designator	Type
Q201	*TIP41C*
Q202	*TIP42C*

Integrated circuits (ICs)

Reference designator	Type
U201	*LM741*
U202	*L7805*

The temperature setting of the soldering iron is important to ensure proper connectivity. If the temperature is too low, the solder may not melt completely, leading to a weak connection. If the temperature is too high, the board or the soldering tip may become damaged.

6. Set the soldering temperature between 330 and 350 °C. After this initial adjustment, do **not adjust the temperature yourself**. Ask for assistance before adjusting the soldering iron temperature.

Next, you will populate the PCB with the components for the power supply section. While the order in which you solder the components will not affect functionality, you should populate the PCB **starting with**

shorter components and ending with taller components. This will ensure that the PCB has a relatively flat surface to lay against while you are soldering it. For each component, populate the PCB according to the steps below:

7. Locate the reference designator of the component you wish to populate on the PCB. If you have trouble locating the reference designator, see the **assembly diagram** provided in Figure 2 (at the end of this handout).
8. Insert the component. Components **marked *in italics* in Table 3 are orientation-sensitive**.
9. Fold the leads of the component down on the bottom of the PCB so the component stays in place while the PCB is upside down.

May want to fold several leads under (4-5 parts) to make soldering faster. See assembly diagram if unclear (at the end of this handout).

When assembling the PCB, you may wish to fold the leads of several (4-5) components at a time to streamline the assembly process. Once you have populated several components, ask a member of the course staff to check your PCB. Importantly,

DO NOT SOLDER ANY COMPONENTS WITHOUT APPROVAL.

Once the components are soldered, it is extremely difficult to remove them if they are inserted incorrectly. Something as simple as inserting an IC backwards can cause hours of difficulty if the IC has been soldered and must be removed. Once you have obtained approval to solder,

10. Solder the components. Feed the solder wire into the joint slowly so as not to build up excess solder.
11. Clip the leads of the soldered components. To do this, first position the component lead in the wire cutters, then **cover the lead with your hand**. Clip the lead. Covering the lead will prevent the lead from flying off the PCB and into potentially dangerous areas (eyes, for instance).

Testing

To test the power supply, you must first find **test points** at which to measure power supply voltages. Test points are component pins connected to the signals you wish to test. Use the schematic to find test points for each signal in the following steps. Test your power supply according to the steps below:

1. Connect the variable power supply to the screw terminals on the PCB. The negative input terminal is marked by a minus ("–") symbol.
2. Set the voltage control of the variable power supply to 0 (counterclockwise). Turn the power supply on and **slowly** bring the voltage up to **12V**. If the current display on the power supply exceeds 0.1A, **shut the power supply off immediately** and ask a member of the course staff to inspect your PCB. This usually indicates a shorted connection.
3. Find test points for VCC and GND. Using the DMM, measure the voltage between VCC and GND. The voltage should be half of the output of the variable power supply (around 6V).
4. Find test points for VEE and GND. Using the DMM, measure the voltage between VEE and GND. The voltage should be negative one-half of the output of the variable power supply (around -6V).
5. Repeat this procedure for VDD and GND. The voltage should be at most 5V.

Exercise 2: Digital lock

This section makes extensive use of the schematic handout. The digital lock components can be found on page 3 of the schematic.

In this exercise, you will construct the digital lock section of the receiver PCB. The digital lock circuit is responsible for processing the user passcode inputs and controlling activation of the audio amplifier. At a high level, the digital lock circuit has two inputs and one output. The two inputs are the "1" and "0" switches, and the output is an active-high[1] logic signal that is asserted when the received passcode matches the set passcode.

The four NAND gates within U401 form two SR flip-flops. As discussed in lecture, the SR flip-flop requires a low-going pulse on the "set" input to set the output to "1," and a separate low-going pulse on the "reset" input to set the output to "0." When used in conjunction with a dual-pole, dual-throw (DPDT) switch, this circuit acts like a **debouncer**, filtering out noise caused by unintentional multiple switch activations.

U405 is configured as a 4-bit shift register. The shift register holds the most recently received password inputs. U403A compares these against the set passcode, and U403B is configured as an inverter to change the polarity of the output signal.

The passcode is "hardcoded" by soldering four jumper wires into positions J401, J403, J404 and J406. The jumpers select the polarity of each shift register output to feed into U403. If the active-high output is selected for a bit, that bit must be "1" to activate the output of the NAND gate. If the active-low output is selected, that bit must be "0."

Assembly

Assemble the digital lock section according to the instructions in the previous exercise. The list of components required for the digital lock section can be found in Table 4. As before, all components sensitive to orientation are marked in *italics*. Pay special attention to the orientation of the **user input switches (SW401 and SW402):** the switches must be inserted correctly or the circuit will not work as expected. After you have finished soldering all the components, set the passcode according to the steps below:

1. Create a 4-bit passcode.
2. For each digit of your passcode, solder a wire in one of the passcode selection jumpers corresponding to the value of the digit. For example, if your passcode is "1010," you would solder a wire from "0" to "COM" in J401, from "1" to "COM" in J403, and so on.

Testing

Test the digital lock circuit according to the steps below:

1. Set the voltage control of the variable power supply to 0. Turn on the variable power supply and **slowly** bring up the voltage to 12V. **Stop if the current exceeds 0.1A**.
2. Obtain two removable jumpers from the table near the entrance of the lab and select the internal switches as the input source for the digital lock. Do this by connecting pins "COM" and "INT" on both J402 and J405.
3. Push each of the user input switches and ensure your inputs are accurately reflected on the LEDs (Depress – D403).
4. Enter your passcode with the user input switches and ensure the green LED (D504) is activated.

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[1] "Active-high" and "active-low" refer to the polarity of a digital logic signal. An active-high signal is said to be "asserted," or activated, at a high logic level (5V), while an active-low signal is said to be activated at a low logic level (0V).

Table 4: Components for digital lock section

Resistors

Reference designator	Value
R401	10kΩ
R402	10kΩ
R403	10kΩ
R404	10kΩ
R405	470Ω
R406	470Ω
R407	10kΩ
R408	470Ω
R409	470Ω
R505	470Ω

Switches

Reference designator	Type
SW401	*Push switch*
SW402	*Push switch*

Capacitors

Reference designator	Value
C401	100nF
C402	100nF
C403	100nF
C404	100nF
C405	10nF

Diodes

Reference designator	Type
D401	*RED*
D402	*RED*
D403	*RED*
D404	*RED*
D504	*GREEN*

Transistors

Reference designator	Type
Q504	*2N7000*

Integrated circuits (ICs)

Reference designator	Type
U401	*74LS00*
U402	*74LS08*
U403	*74LS20*
U405	*74LS175*

Connectors

Reference designator	Type
J401	
J402	3-pin header
J403	
J404	
J405	3-pin header
J406	

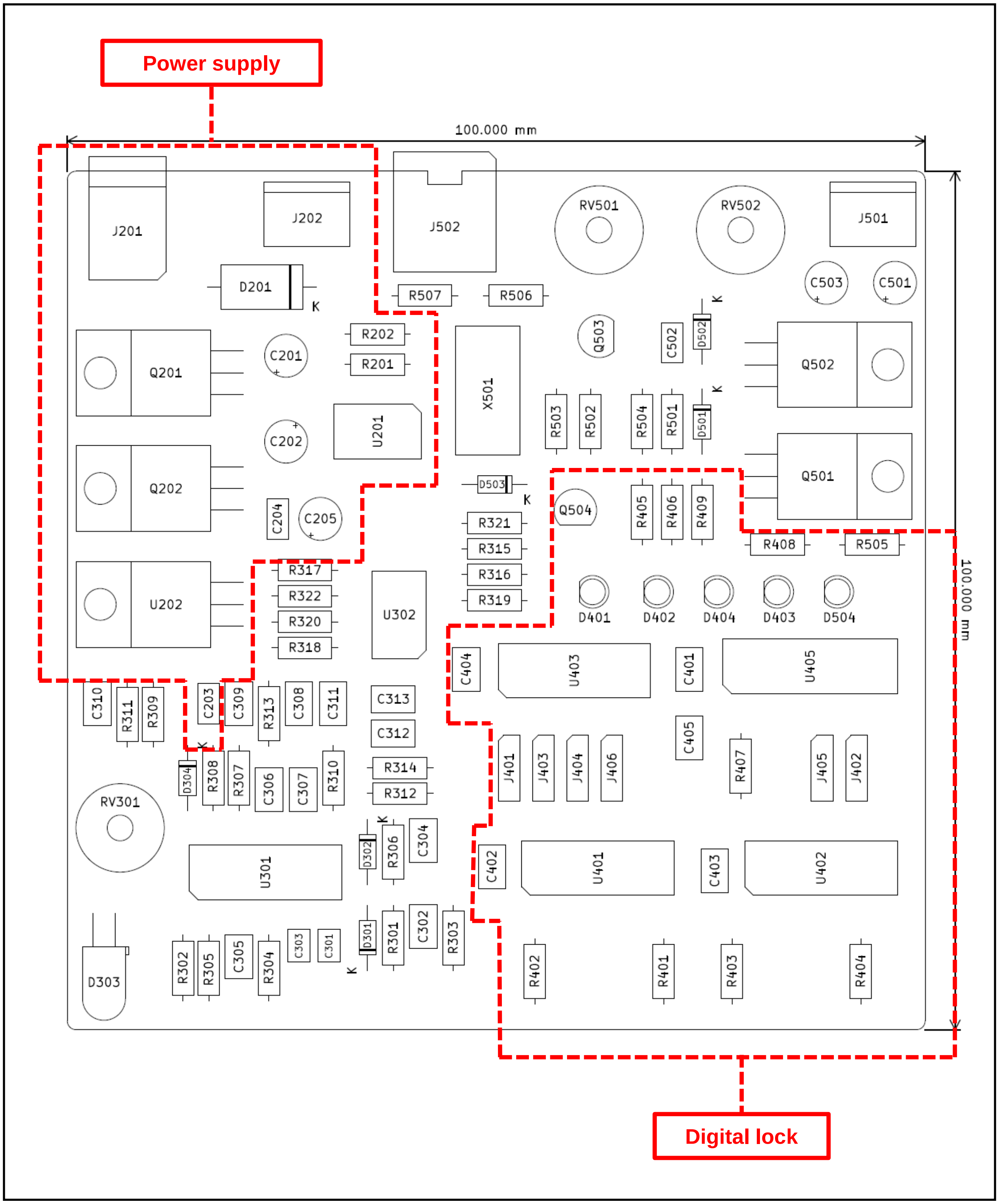

Figure 2: Receiver PCB assembly diagram