Massachusetts Institute of Technology
Department of Electrical Engineering and Computer Science

Lab 4: Design project, Part 2

6.117 Introduction to Electrical Engineering Lab Skills (IAP 2020)

Introduction

In this lab, you will continue construction of the design project and assemble the audio amplifier and infrared (IR) receiver sections. The audio amplifier is identical to the audio amplifier you built in Lab 2, with the exception that the circuit is mounted on the project PCB. The IR receiver section contains circuits for decoding the amplitude-modulated (AM) signal produced by the IR transmitter which you will construct in Lab 5.

This handout follows the same reference designator conventions as used in Lab 3, reproduced here in Table 1.

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

Additionally, this handout follows the same power net naming conventions as used in Lab 3, reproduced here 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

As a reminder, completion of the IR receiver section is optional and is not required for functionality of the project. If you have not already completed both the power supply and digital lock sections of the design project, you must do so **before proceeding to the following exercises**.

Exercise 1: Audio amplifier

This section makes extensive use of the schematic handout. The audio amplifier components can be found on page 2 of the schematic.

The audio amplifier used in the design project is the same circuit as the audio amplifier you breadboarded in Lab 2. The amplifier is a two-stage Class AB amplifier designed to output 1 watt of power into a 16Ω nominal load. Q503 is a common-emitter preamplifier that provides voltage and current gain to the input of the amplifier. Q501 and Q502 form a push-pull Class AB output stage that provides the necessary current gain to drive a low-resistance load.

Input to the audio amplifier is provided by a 3.5mm tip-ring-sleeve (TRS) jack. The TRS jack is commonly used to transmit stereo audio signals. Stereo refers to an audio signal that contains both left and right channels. The pinout of a TRS jack can be seen in Figure 1. As the input contains two channels, but the amplifier only has one output channel, the two channels must be combined to produce a single signal. This is accomplished by R506 and R507, which form a simple audio "mixer." The mixer simply adds equal portions of each input channel to produce the input to the amplifier.

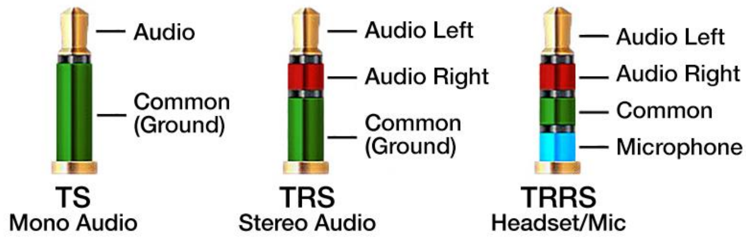

Figure 1: 3.5mm audio jack pinout diagrams

The audio amplifier is enabled and disabled by switching the input signal with a relay. A relay is an electromechanical device that uses an electromagnet to actuate a switch. A diagram of a typical relay can be seen in Figure 2. X501 is a dual-pole, dual-throw relay: it has two sets of contacts, each of which can be switched between two positions. One set of the contacts switches the combined audio signal, and the other set switches the sleeve connection of the TRS connector (audio ground). The "normally closed" contacts are both connected to ground so that the amplifier is disabled in the "inactive" state when the coil is de-energized.

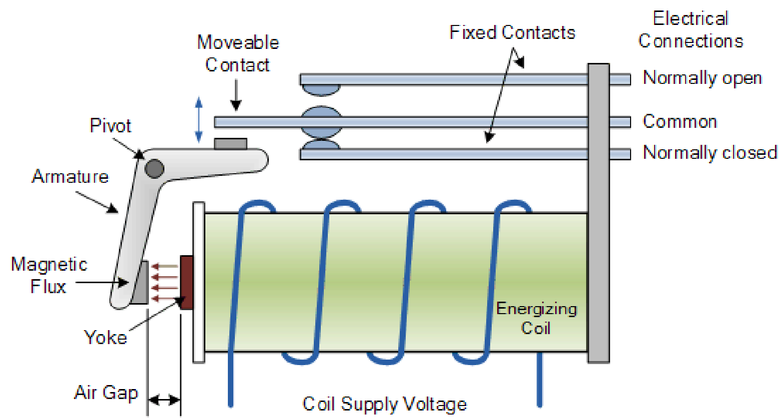

Figure 2: Electromechanical relay construction

D503 is used as a "snubber" diode to prevent the effects of "back-EMF" from damaging Q504. Back-EMF is caused when the current through an inductor is made to change rapidly. Recall the constitutive relation between voltage and current in an inductor:

$$v_L = -L\frac{dI}{dt}$$

When the current through an inductor drops rapidly, the energy stored in its magnetic field causes a high voltage to appear across the inductor for a short time. In the case of a relay, this occurs every time the coil is de-energized. Since the voltage appears opposite in polarity to the current used to energize the coil, placing D503 opposite in direction to the energizing current causes the back-EMF to be dissipated by forward-biasing D503.

In the design project, C501 is used to block any DC component present at the output of the amplifier from appearing across the load (typically a speaker) and wasting energy. It accomplishes this by acting as a high-pass filter in conjunction with the load resistance. Assuming a constant load resistance of 16Ω[1], we calculate the cutoff frequency of the high-pass filter as described in Lecture 2:

$$f_c = \frac{1}{2\pi RC} \approx 99.47\ \mathrm{Hz}$$

Ideally, the frequency response of the amplifier would cover the entire human audible range (about 20 Hz to 20 kHz). This amplifier is designed primarily to drive small speakers, which generally have poor low-frequency response. While increasing the value of C501 would theoretically increase the low-frequency response of the amplifier, it is not necessary if the speaker cannot accurately reproduce low-frequency signals (lower than about 100 Hz in this case).

Assembly

Assemble the audio amplifier section according to the same steps used to assemble the previous sections. In particular, recall all of the following steps:

1. Always **wear safety goggles** when soldering or clipping leads.
2. If using the tip cleaning sponge to clean the tip of your soldering iron, always **wet the sponge** before use to prevent damage to the tip cleaner.
3. Pay attention to the orientation of components. **Always check with a member of the course staff** if you are unsure about the orientation of a component.

The components you will need for the audio amplifier section are listed in Table 2. Components in *italics* are orientation-sensitive. If you have trouble locating the reference designators, see the assembly diagram provided in Figure 5 (at the end of this handout). As before,

DO NOT SOLDER ANY COMPONENTS WITHOUT APPROVAL.

Testing

The testing procedure for the audio amplifier section is identical to that used in Lab 2. Test and bias your amplifier according to the following instructions:

1. Set the function generator to output a 1 kHz sine wave at 100mV_{pp}.
2. Obtain a 3.5mm audio input cable from the back of the lab. With the output turned off, connect the positive lead of the function generator to the tip of the TRS connector and the negative lead to the sleeve. See Figure 1 if you are unsure of how to do this. Insert the other end of the cable into J502.
3. Connect the oscilloscope to the output of the amplifier (J501).
4. With the variable power supply **turned off**, set the voltage control on the variable power supply to 0 (counterclockwise) and set the current control to about 25% of its maximum value.
5. Turn on the variable power supply and slowly increase the voltage to 12V. **Turn the power supply off immediately if the current exceeds 0.5A**.
6. Adjust RV502 until the current reading on the power supply is at a minimum. **You must do this adjustment quickly** (within 30 seconds) **or else the output transistors will get dangerously hot**.

Once you have verified that the amplifier section is not drawing an excessive amount of current, you must enable the amplifier with the digital lock. To do this, ensure that shorting jumper links are placed between

[1] Typically, the impedance (effective resistance) of a speaker will vary slightly with frequency. High-end amplifiers will often be designed such that the output is biased very close to 0V to eliminate the need for an output capacitor.

the *INT* and *COM* pins of J402 and J405. Next, enter your passcode using SW401 and SW402. The amplifier is enabled if the green LED (D504) is lit and you hear a small "click" when entering the last digit of your passcode (the "click" is the sound made when the coil of X501 is energized).

Table 3: Components for audio amplifier section

Resistors

Reference designator	Value
R501	1kΩ
R502	100kΩ
R503	15kΩ
R504	100Ω
R506	1kΩ
R507	1kΩ

Connectors

Reference designator	Type
J501	*Terminal block*
J502	3.5mm audio jack

Capacitors

Reference designator	Value
C501	*100uF*
C502	1uF
C503	*100uF*

Transistors

Reference designator	Type
Q501	*TIP41C*
Q502	*TIP42C*
Q503	*2N3904*

Relays

Reference designator	Type
X501	EC2-5NU

Diodes

Reference designator	Type
D501	*1N914*
D502	*1N914*
D503	*1N914*
D504	*GREEN*

Potentiometers

Reference designator	Value
RV501	10kΩ
RV502	1kΩ

Now, bias the amplifier according to the following instructions:

1. Adjust RV501 such that the potentiometer is turned to 100% (clockwise).
2. Turn off the output of the function generator. Obtain a speaker from the back of the lab, connect its positive terminal to the positive pin of J501 and connect its negative terminal to the negative pin of J501.
3. Activate the output of the function generator and measure the output of the amplifier with the oscilloscope.
4. Slowly adjust RV502 until the crossover distortion appears to be gone. **Stop as soon as the crossover is gone**.

Exercise 2: Infrared (IR) receiver

This section makes extensive use of the schematic handout. The IR receiver components can be found on page 4 of the schematic.

The following section contains an overview of the operation of the IR receiver architecture. While you are not required to understand this section, it is recommended that you read through it to become familiar with common techniques used in wireless data transmission.

The IR remote control circuit uses amplitude-shift keying (ASK) to transmit binary data. ASK is accomplished as shown in Figure 3. A 38 kHz **carrier wave** is **modulated** with a low-frequency signal to transmit a 0 or a high-frequency signal to transmit a 1. In this case, a modulation frequency of 500 Hz represents 0 and 1500 Hz represents a 1. The operation of modulation can be seen as the result of logically multiplying the carrier wave with the modulating signal. If both signals are square waves, the transmitted signal will only be nonzero if both inputs are nonzero. For now, you may assume a transmitter exists that produces this signal; we will cover the transmitter architecture in detail in Lab 5.

When compared to transmitting the 500 Hz and 1500 Hz signals directly, this modulation scheme has two main advantages. First, using ASK reduces the effect of DC and low-frequency interference on the received signal. By introducing the high-frequency carrier component, the majority of the energy in the transmitted signal is concentrated around 38 kHz rather than around 0 Hz (DC). Second, using a modulation scheme allows the receiver to distinguish between other nearby IR sources. If another remote control is transmitting near the receiver, it will not be detected as long as it is transmitting using a different carrier frequency.

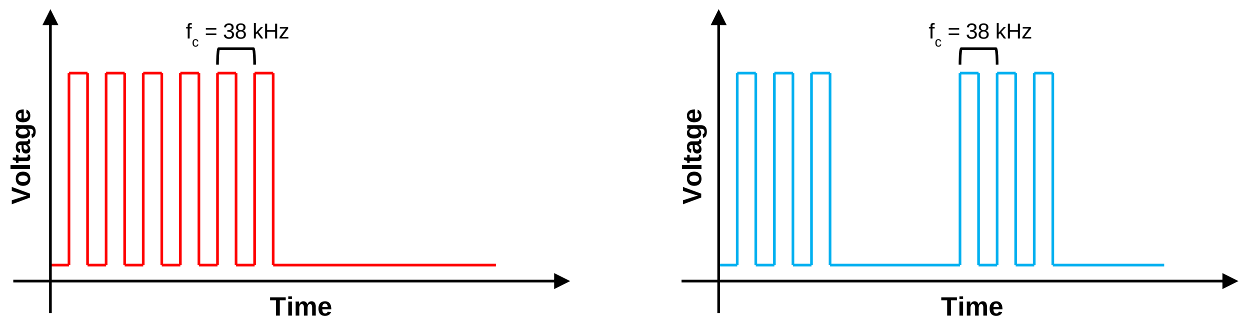

Figure 3: IR transmission scheme for 0 (left) and 1 (right)

The goal of the receiver circuit is to amplify the IR signal detected by a photodiode, distinguish the code for a 0 from the code for a 1, and produce a data and a clock output for use by the digital lock. A block diagram of the receiver circuit is shown in Figure 4.

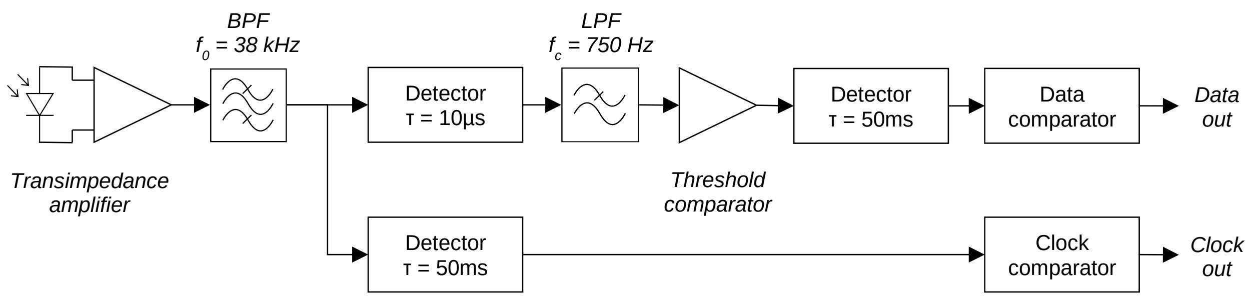

Figure 4: IR receiver block diagram

The intensity of the received light is converted to an electrical signal by a **photodiode** (D303). A photodiode operates identically to a standard diode, with the exception that the current through a photodiode varies with the intensity of light received. The first stage of the IR receiver is a **transimpedance amplifier**. This circuit, implemented with U301A, produces a voltage proportional to the reverse current flowing through D303. The output of the transimpedance amplifier is filtered by a second-order bandpass filter (BPF). The BPF provides the receiver with **selectivity** by only allowing frequencies near the 38 kHz carrier.[2]

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[2] This particular BPF is known as a “multiple-feedback” filter and is used for its ability to admit a very narrow range of frequencies. A detailed analysis of multiple-feedback filters can be found at https://www.analog.com/media/en/training-seminars/tutorials/MT-220.pdf.

Following the BPF, the received signal travels through two **envelope detectors**. An envelope detector takes an amplitude-modulated signal and produces an output that corresponds to the envelope of the input. The envelope detector formed by D302 (the upper detector in Figure 4) has a small enough time constant (τ) that it allows the 500 and 1500 Hz modulating signals to pass through while blocking the 38 kHz carrier. This signal is then filtered by a Sallen-Key LPF (U301C) with a cutoff frequency of 750 Hz.[3] The response of this LPF is steep enough that it only blocks the 1500 Hz signal representing a “1” while passing the 500 Hz signal representing a “0.” This signal is fed through a threshold comparator (U301D) to produce a digital output, then again through an envelope detector to remove the switching component. The result is a signal that is low when the user transmits a “0” and high when the user transmits a “1.” Conveniently, this circuit uses four op-amps, all of which are contained in a single package (the LM324).

The lower signal path is used to generate the clock input to the digital lock. The clock signal must only be high when data is being received, and must be low when no data is being received. This is accomplished by processing the output of the initial BPF with an envelope detector. U302A and U302B are comparators with hysteresis that serve both to reduce noise in the output signals and to convert the ±6V signals used by the analog receiver to +5V signals used by the digital lock.

Assembly

Assemble the IR receiver section according to the instructions in the previous exercise. The list of components required for the IR receiver section can be found in Table 4. As before, all components sensitive to orientation are marked in *italics*.

Testing

Test and calibrate the IR receiver circuit according to the instructions below:

1. With the variable power supply **turned off**, set the voltage control on the variable power supply to 0 (counterclockwise) and set the current control to about 25% of its maximum value.
2. Turn on the variable power supply and slowly increase the voltage to 12V. **Turn the power supply off immediately if the current exceeds 0.5A**.
3. Place shorting jumper links connecting the *REM* and *COM* pins on J402 and J405. This will configure the digital lock circuit for remote operation.
4. Obtain an IR transmitter from a member of the course staff.
5. Adjust RV301 until the threshold of the comparator formed by U301D is at 0V by turning the potentiometer completely counterclockwise. Test both of the user input keys on the transmitter and ensure at least one of them causes the LEDs on your receiver to change state.
6. Adjust RV301 until the receiver can no longer distinguish between a “1” and a “0,” then slightly turn the potentiometer counterclockwise until it can distinguish the input again. This will adjust the threshold of U301D to reduce interference while maintaining sensitivity.

When fully calibrated, the receiver should have an operational range of 2 – 3 feet. The range can be increased by either increasing the power output of the transmitter or increasing the gain of the transimpedance amplifier. Both of these adjustments can negatively impact performance, however: increasing transmitter output power results in shorter battery life, and increasing the gain of the transimpedance amplifier may cause the amplifier to saturate at short ranges, making the circuit unusable if the transmitter is placed too close to the receiver.

[3] The circuit for the Sallen-Key LPF used in the IR receiver is identical to the second-order LPF you constructed in Lab 2.

Table 4: Components for IR receiver section

Resistors

Reference designator	Value
R301	10kΩ
R302	1MΩ
R303	470kΩ
R304	100kΩ
R305	10kΩ
R306	1kΩ
R307	10kΩ
R308	47kΩ
R309	82kΩ
R310	1kΩ
R311	470kΩ
R312	22kΩ
R313	4.7kΩ
R314	10kΩ
R315	10kΩ
R316	10kΩ
R317	10kΩ
R318	10kΩ
R319	56kΩ
R320	56kΩ
R321	3.3kΩ
R322	10kΩ

Capacitors

Reference designator	Value
C301	100pF
C302	100nF
C303	180pF
C304	10nF
C305	100nF
C306	100nF
C307	10nF
C308	100nF
C309	10nF
C310	100nF
C311	100nF
C312	100nF
C313	10nF

Diodes

Reference designator	Type
D301	*1N914*
D302	*1N914*
D303	*Photodiode*
D304	*1N914*

Integrated circuits (ICs)

Reference designator	Type
U301	*LM324*
U302	*LM393*

Potentiometers

Reference designator	Value
RV301	10kΩ

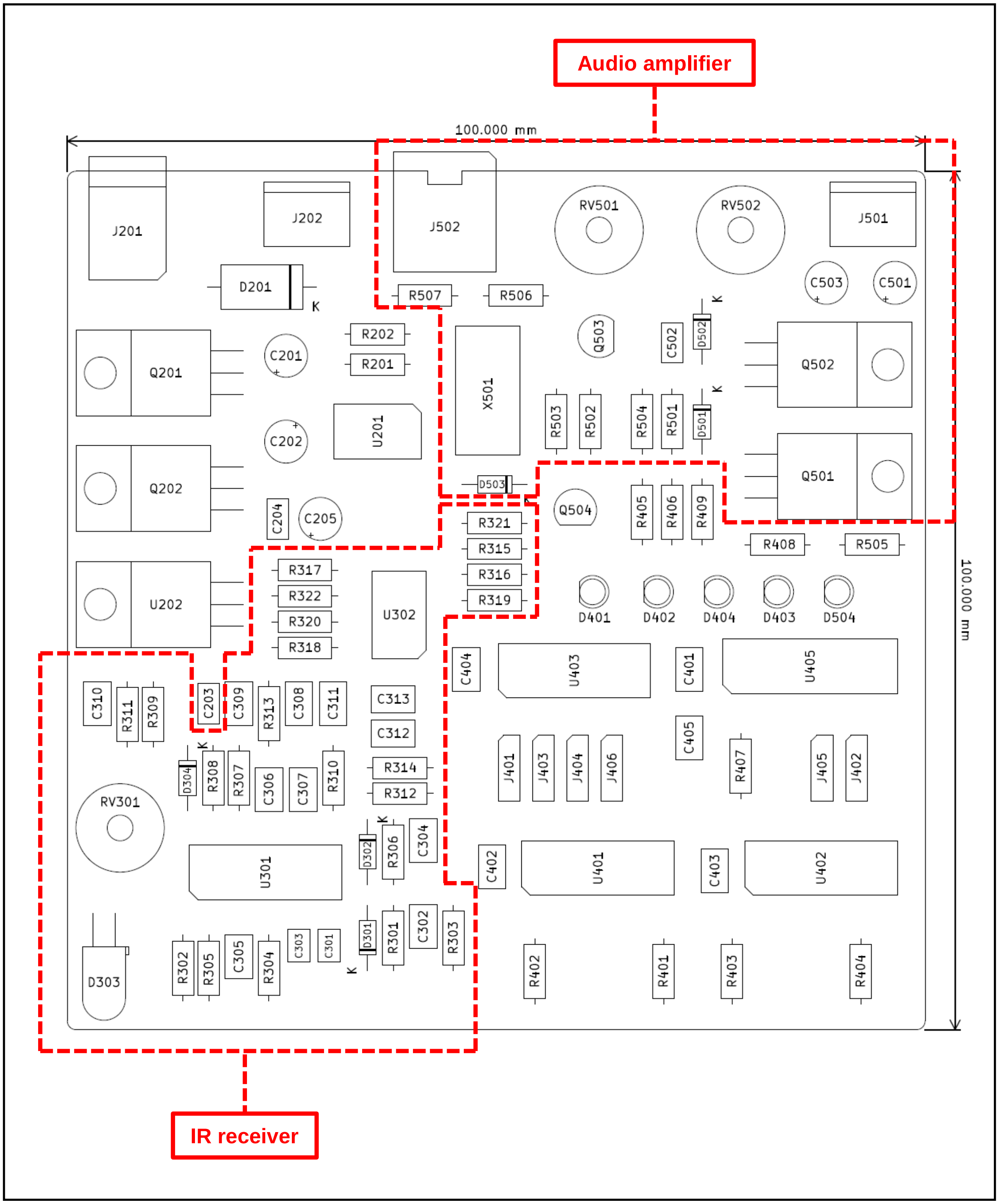

Figure 5: Receiver PCB assembly diagram