CHAPTER 3

# Oncampus Course Lab Week 1.6: Microphone Amplifier Part 1

## 3.1 Study goals

After completing this assignment you should be able to:

1. Identify common electronic components on a circuit diagram and in practice,
2. Identify connections in a circuit diagram,
3. Assemble a simple PCB (printed circuit board) with various components,
4. Experience a self-built electronic circuit,
5. Verify proper functionality of the circuit through measurements.

## 3.2 Introduction

Now that you've had some soldering experience after Assignment 1 you will build a more elaborate circuit. This circuit is a simple microphone amplifier. The microphone amplifier will be used in the measurement assignments, the physics assignment on anti-sound, and the acoustic measurements of the speaker. Since the anti-sound assignment (later on) requires two amplifiers you build and test your own microphone amplifier **individually**.

## 3.3 Circuit Diagram and Components

A circuit diagram is an abstract representation of an electronic circuit. All the components and connections of the circuit are shown in a symbolic representation.

### 3.3.1 Circuit Diagram

The circuit diagram of the microphone amplifier is shown in Figure 3.1.

In the diagram you can see symbols for several different components. These symbols are probably the most common ones, but they represent only a small fraction of all the electronic symbols you might encounter. Figure 3.2 shows these and some other symbols with the name of the component they represent. Circuit diagrams sometimes use different symbols for the same type of component. Figure 3.3 shows several different symbols for resistors and polarized capacitors.

Each component in the circuit diagram has two annotations:

- A unique identifier that consists of a letter or combination of letters followed by a number. The letter(s) represent the type of component: R for resistor, C for capacitor, etc. The number uniquely identifies a component of that specific type. The combination of the letter(s) and the number is used to uniquely identify a specific component in the circuit.
- The value of the component: 10 kΩ in case of a resistor, or 1N4148 to identify a specific type of diode.

The symbols in the circuit diagram are connected with lines, symbolizing conducting wires or tracks on a printed circuit board (PCB). Crossing lines in a circuit diagram only represent an interconnection when there is a dot drawn at the intersection point. Crossing lines without the dot just represent two separate unconnected wires.

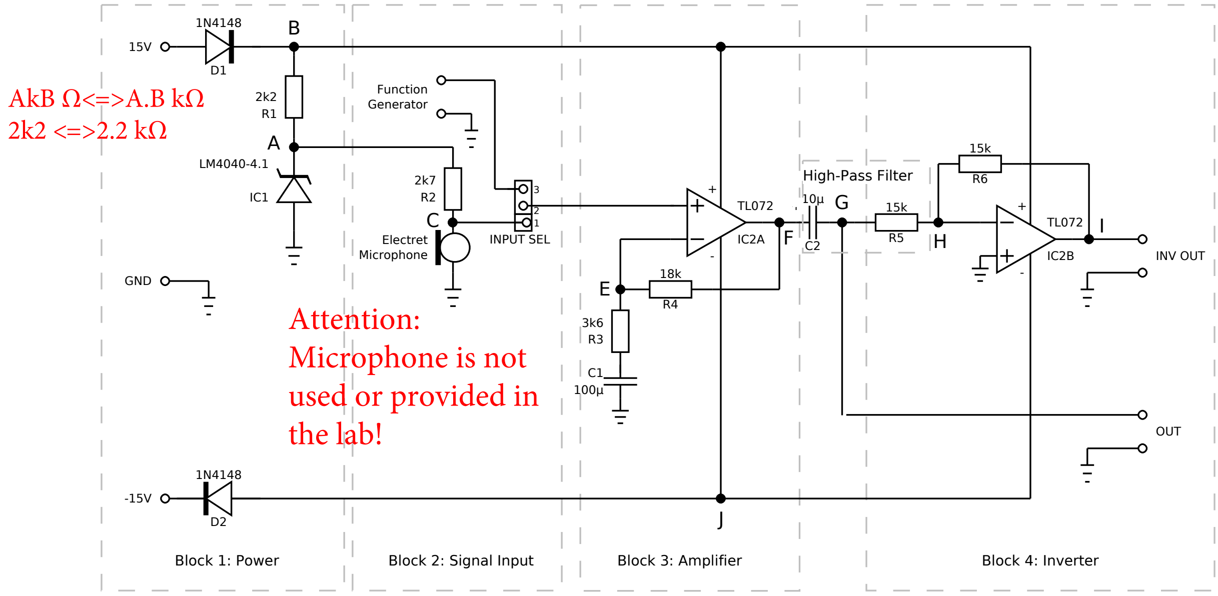



**Figure 3.1:** Circuit diagram of the microphone amplifier.

### 3.3.2 Components

The symbols used in the circuit diagram represent real, physical components. These components can have very different forms, depending on the intended usage. High-power components are usually much larger than their low-power counterparts. Components can be through-hole devices or surface mount devices (SMD). SMD components are usually much smaller than leaded through-hole components. SMD components are very well suited for automated placement and soldering of PCBs. Figure 3.4 shows some realizations of the components from Figure 3.2.

We will discuss some of these components in more detail.

#### Resistor

The physical resistor is a two-terminal device. Low-ohmic high power resistors often have the numerical value printed on the body, while low power leaded resistors are mostly color coded. This color code is shown in Figure 3.5. Besides the value, the tolerance and optionally the temperature coefficient are specified.

The color code is shown in bands on the resistor. The first two or three bands represent a two or three digit number, the next band represents a multiplier specified as a power of 10. The last band specifies the tolerance.

Resistor values are increasing on a logarithmic scale in several different so-called E series: E12, E24, E48, E96, and E192. See Appendix B for more information on E series. In the lab you have resistors of the E12 series available. In the E12 series a decade (a 1:10 ratio, so 10 Ω – 100 Ω, but also 100 Ω – 1000 Ω) is divided into 12 steps: 1.0, 1.2, 1.5, 1.8, 2.2, 2.7, 3.3, 3.9, 4.7, 5.6, 6.8, 8.2, and 9.1.

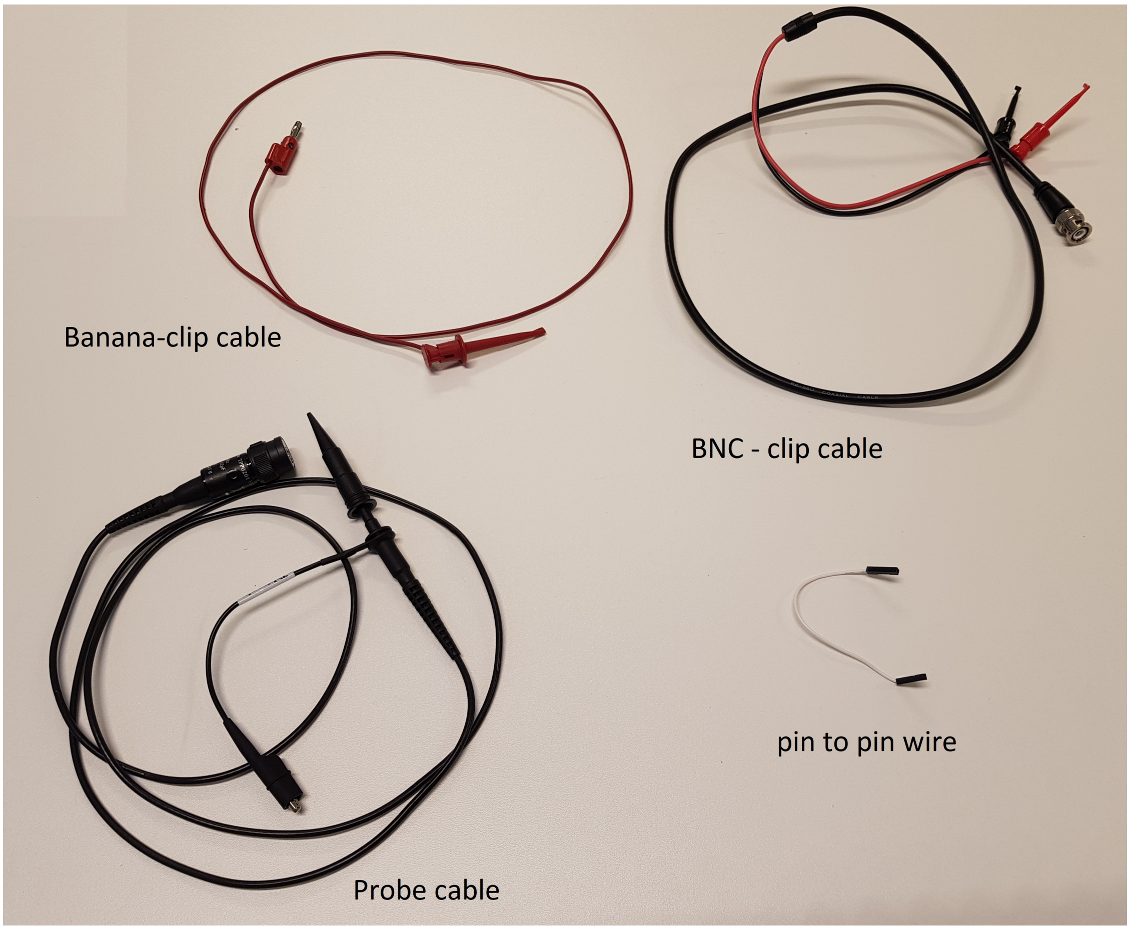
Resistors from the E12 series have two color bands to specify the value. Resistors from the E24 series have three color bands to specify the value. As an example, take a resistor of 100 kΩ, tolerance of 5% from the E12 series. This will be encoded as 1, 0, 4 (from $10^4$), which translates to the colors brown–black–yellow–gold. If the resistor would have been from the E24 series, it would have been encoded as 1, 0, 0, 3 (from $10^3$), which translates to the colors brown–black–black–orange–gold. Of course you can always use a multimeter to measure the actual value.

**Pay attention:**

For the oscilloscope, use probes (and not mini-grabbers) and for the function generator, use mini-grabbers (and not probes).

Mini-grabbers

Probe (note: make sure you check attenuation (1x or 10x) on both probe and oscilloscope channel settings)



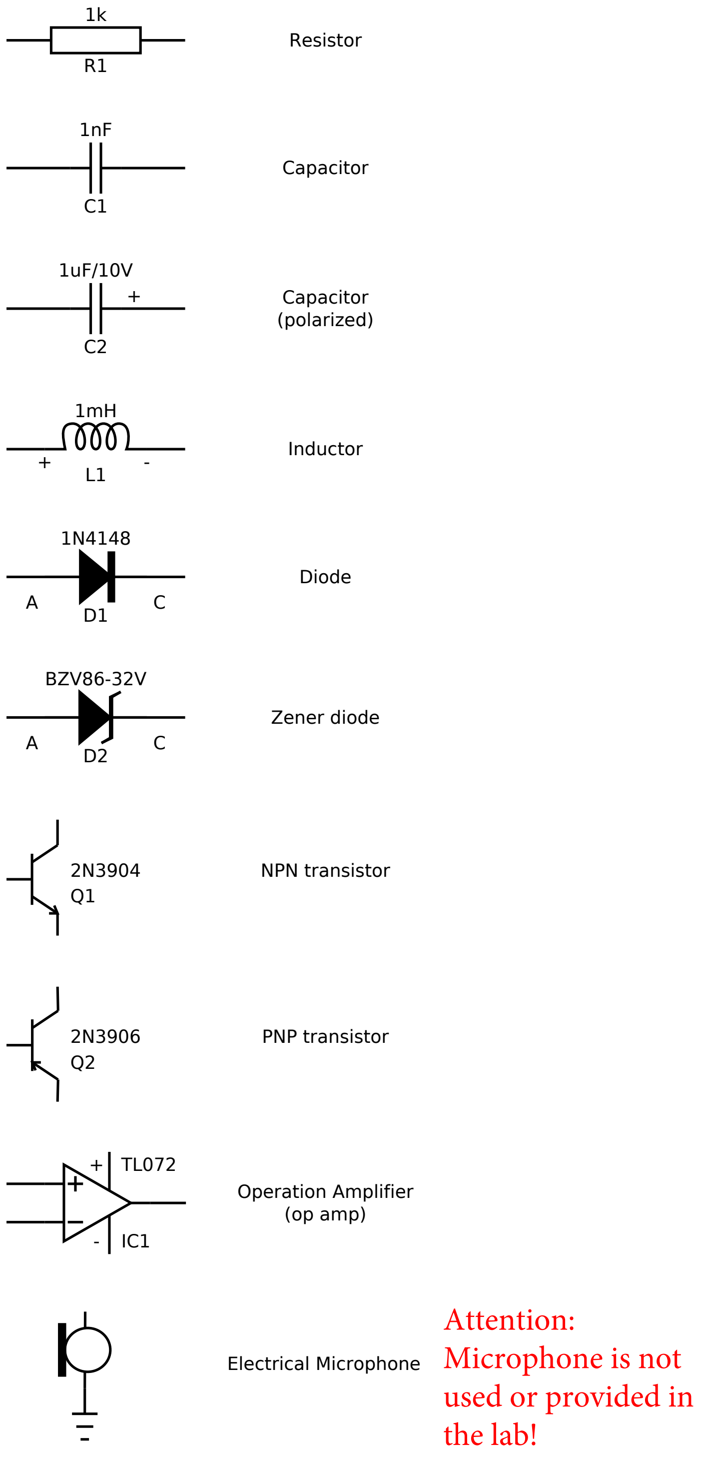



**Figure 3.2:** Some commonly used circuit diagram symbols

## Capacitor

There are two types of capacitors shown in both Figure 3.2 and Figure 3.4: non-polarized and polarized. Most capacitors with a value greater than 10 $\mu$F are polarized capacitors. In contrast to the non-polarized capacitor, a polarized or electrolytic capacitor only works correctly when the

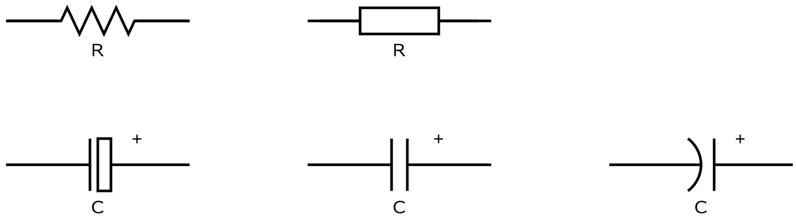



**Figure 3.3:** Different symbols for resistors and polarized capacitors

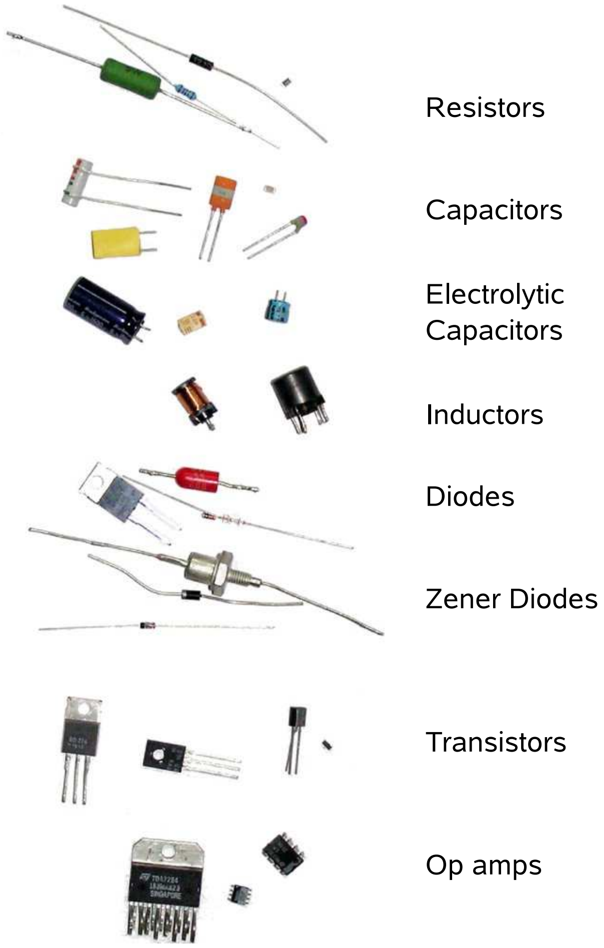
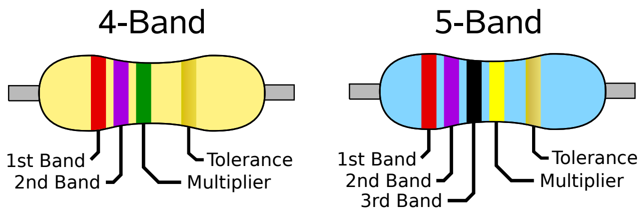



**Figure 3.4:** Physical realizations of commonly used components

voltage at the + terminal is higher than the voltage at the − terminal. If polarity is reversed, a DC current will flow through the capacitor, leading to increasing temperature and potentially the (often violent) destruction of the capacitor. It is thus imperative to observe polarity when handling polarized capacitors.

Besides polarity, the maximum allowed voltage is always specified. When the electrolytic capacitor is exposed to a voltage higher than the specified maximum, it can also be destroyed.

Capacitors are available in values according to the E12 series or the E6 series.




| Color | 1st Band | 2nd Band | 3rd Band | Multiplier | Tolerance | Temp. Coefficient (optional) |
|---|---|---|---|---|---|---|
| Black | 0 | 0 | 0 | X $10^0$ | | |
| Brown | 1 | 1 | 1 | x $10^1$ | ± 1% | 100 ppm |
| Red | 2 | 2 | 2 | x $10^2$ | ± 2% | 50 ppm |
| Orange | 3 | 3 | 3 | x $10^3$ | | 15 ppm |
| Yellow | 4 | 4 | 4 | x $10^4$ | | 25 ppm |
| Green | 5 | 5 | 5 | x $10^5$ | ± 0.5% | |
| Blue | 6 | 6 | 6 | x $10^6$ | ± 0.25% | |
| Violet | 7 | 7 | 7 | x $10^7$ | ± 0.1% | |
| Grey | 8 | 8 | 8 | x $10^8$ | ± 0.05% | |
| White | 9 | 9 | 9 | x $10^9$ | | |
| Gold | | | | | ± 5% | |
| Silver | | | | | ± 10% | |
| None | | | | | ± 20% | |

**Figure 3.5:** Resistor color codes (modified version of github.com/zeroping/reference-posters/)

## Diode

The diode is a semiconductor. Figure 3.6 presents the current-voltage characteristic of a diode. A diode only conducts when the voltage at the anode (A) is higher than the voltage at the cathode (C) (this is called forward bias). In Figure 3.6, an example for the break point voltage (BPV), at which the diode starts to conduct, is shown approximately around 0.7 V. Note that in the forward bias, the current increases exponentially with the voltage. If the voltage at the cathode is higher than the voltage at the anode (reverse bias), only a very small current will flow through the diode, essentially making it behave as an open circuit.

This selective conducting behavior of the diode is used in the microphone amplifier to prevent damage to the circuit when the +15V and -15V cables are reversed (see D1 and D2 in Figure 3.1).

## Zener Diode

A zener diode is a special type of diode. The current-voltage (I-V) characteristics of the zener diode are shown in Figure 3.7. Under forward bias conditions, it behaves like a normal diode. Under reverse bias conditions, however, the zener diode can conduct when the reverse voltage $V_R$ is higher than the zener voltage or breakdown voltage $V_Z$. The voltage drop over a zener diode can thus never be higher than this zener voltage. The zener voltage can be accurately controlled in the fabrication process. This enables the use of the zener diode as a voltage reference. Zener diodes are available with zener voltages according to the E24 series.

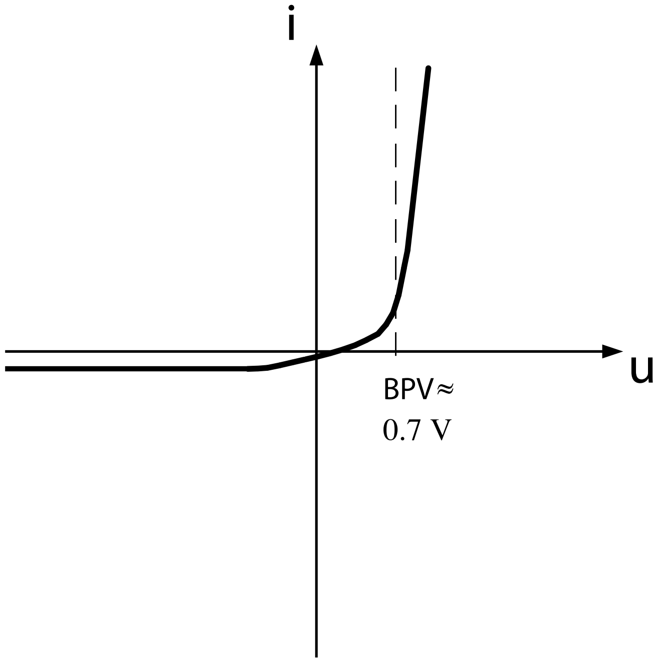



**Figure 3.6:** Current-voltage (I-V) characteristic of a diode.

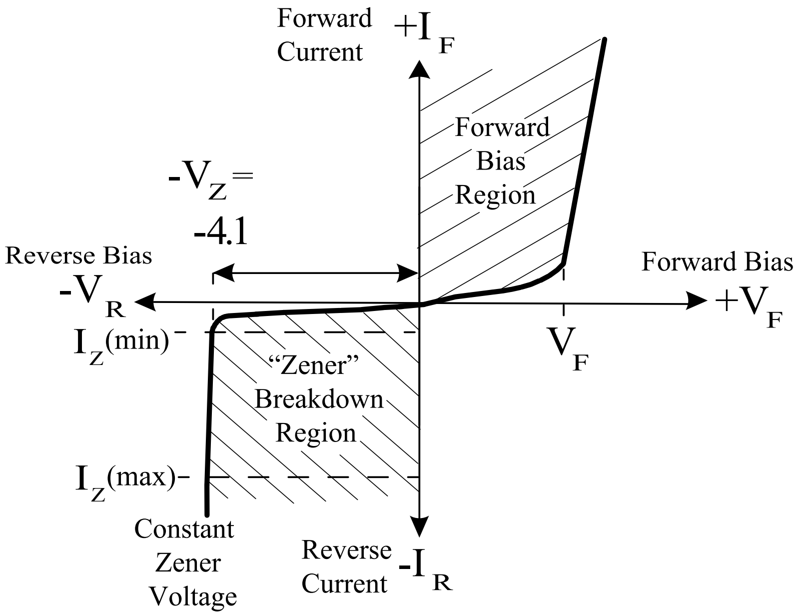



**Figure 3.7:** Zener diode current-voltage (I-V) characteristics.

## Op amp

The op amp or operational amplifier can be used to build amplifier circuits. The ideal op amp is treated in Linear Circuits A (EE1C11) and later on in more detail in Amplifiers and Instrumentation (EE1C31). The provision of the detailed operation of the op amp is outside the scope of this assignment, however for your future use in the EPO-1 project, they are provided to you in Appendix E (see also Chapter 5 of [1]). You can see the op amps IC2A and IC2B in Figure 3.1.

### 3.3.3 Datasheets

Data on the different components can be found in the datasheets. If you know the manufacturer of a specific component, you can find the datasheet on that manufacturer's website. Of course, you can also use a search engine, in most cases the term 'datasheet' followed by the component number will lead you to the correct datasheet.

## 3.4 Functional Description of the Circuit

Now that you've seen the building blocks of a circuit, it is possible to analyze the microphone amplifier circuit. The circuit diagram of the microphone amplifier is split in four blocks:

- Power
- Signal input
- Amplifier
- Inverter

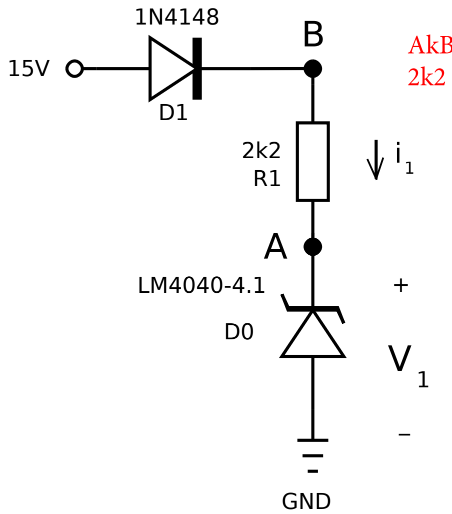
Each of the blocks performs a specific function.

### 3.4.1 Block 1: Power

Block 1 is the power block and provides energy at the correct voltage levels to the other blocks of the circuit. The +15V (node B in Figure 3.1), GND, and -15V (node J in Figure 3.1) headers can be connected to a so-called symmetrical power supply. The diodes D1 and D2 protect the circuit against reverse polarity.

The resistor R1 and the voltage regulator IC1 form the power supply of the electrical microphone. The supply voltage of the microphone needs to be stable and is thus stabilized at 4.1 V by voltage regulator LM4040-4.1. This voltage regulator is an active component that behaves like a normal zener diode, except it has much better characteristics.

1. What is the function of D0 and D1 in the circuit shown in Figure 3.8?
2. What is the approximate value of voltage $V_1$?
3. What is the approximate value of current $i_1$?




AkB Ω<=>A.B kΩ
2k2 <=>2.2 kΩ

Attention: Microphone is not used or provided in the lab!

**Figure 3.8:** Block 1: Power.

### 3.4.2 Block 2: Signal Input

The microphone amplifier can use two different input devices: a microphone or a signal generator (see INPUT SEL in Figure 3.1). The signal input block makes it possible to switch between these input devices. By placing a jumper cap over pins 1-2, the microphone input is selected, whereas by placing the jumper cap over pins 2-3, the signal generator input is selected.

The microphone itself is connected to the board with the 3.5 mm jack socket (node C in Figure 3.1). Bear in mind that the microphone needs bias to operate properly. The signal generator can be connected to the pin header SIG GEN.

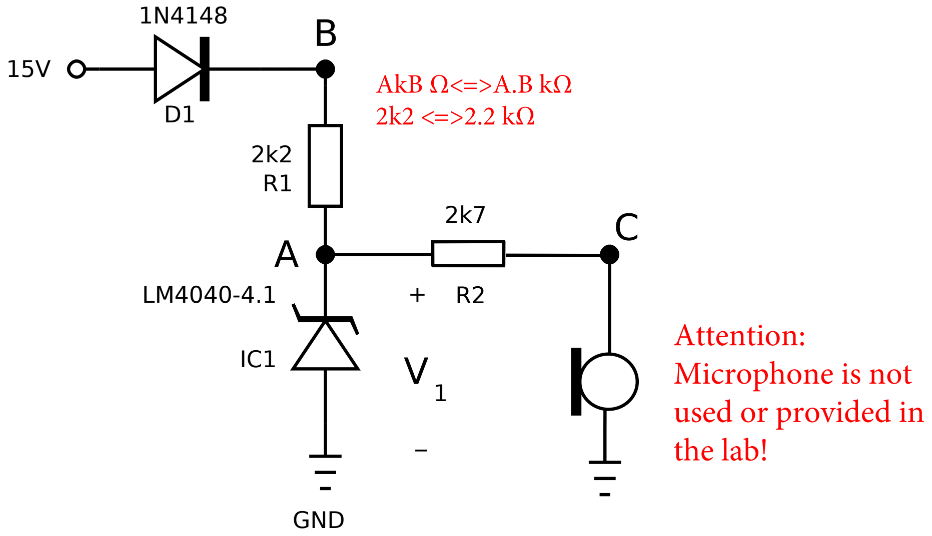



**Figure 3.9:** Blocks 1 and 2: power and signal input.

### 3.4.3 Block 3: Amplifier

Block 3 is the (non-inverting) amplifier circuit that amplifies the AC component of an input signal by $\frac{R3+R4}{R3} = 6$ (for more information, see Appendix E). Capacitor C1 is used to prevent amplification of the DC component of the input signal. For the audio frequencies it can be regarded as a short circuit and will have no influence on the amplification factor. The amplifier circuit is build around the TL072 op amp. This op amp package actually contains two op amps, see the pinout on the right of Figure 3.10. Note that only some of these pins are used for your circuit. Op amp IC2A has connections 1OUT, 1IN-, and 1IN+. Both op amps share the same power connections ($V_{CC-}$ and $V_{CC+}$) The op amp will be treated in Linear Circuits A (EE1C1).

Between the nodes F and H in Figure 3.1, capacitor C2 and resistor R5 form a high-pass filter that is used to filter out a DC component in the output signals of the amplifier.

### 3.4.4 Block 4: Inverter

Block 4 is an inverter that is implemented with the second op amp in the TL072 package. This op amp (IC2B) has connections 2OUT, 2IN-, and 2IN+. This op amp circuit inverts the output of the first op amp by amplifying the signal with $-\frac{R6}{R5} = -1$. This inverted signal is available at pin header OUT INV.

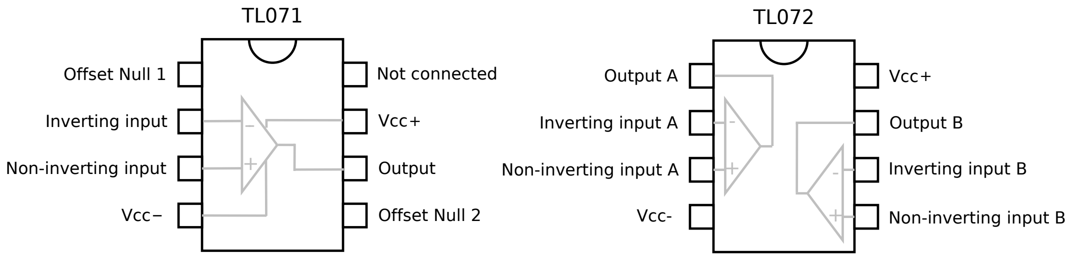



**Figure 3.10:** Pinout of the TL071 and TL072 op amp in DIL8 package.

## 3.5 Soldering the Circuit

The microphone amplifier consists of the following components:

- C1: 100 $\mu$F
- C2: 10 $\mu$F
- D1, D2: 1N4148
- IC1: LM4040-4.1
- IC2: TL072
- R1: 2.2 kΩ
- R2: 2.7 kΩ
- R3: 3.6 kΩ
- R4: 18 kΩ
- R5, R6: 15 kΩ

and furthermore:

- +15V, -15V, GND (2×), SIG GEN, OUT, INV OUT: 2-pin header
- INPUT SEL: 3-pin header
- jumper cap
- 3.5 mm jack socket
- DIL8 socket

These components have to be soldered onto a PCB. A PCB can be single sided, double sided, or even have multiple layers (currently 48 layers is possible) that are glued together. The PCB of the microphone amplifier is a double layer PCB, the most common type of PCB for simple circuits with through-hole components. The top view of the PCB is shown in Figure 3.11.

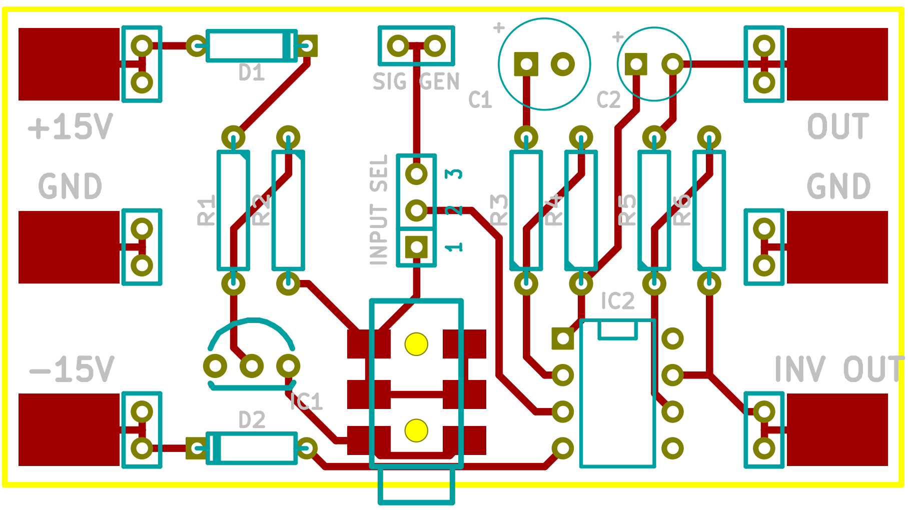



**Figure 3.11:** Top view of the microphone amplifier PCB

The text and component outlines are printed in the so-called silk screen and show the placement of the components. The component identifiers are identical to those in the circuit diagram of Figure 3.1.

When soldering a PCB it is advisable to start with the flattest components. This way the board is more level and stable while soldering. Most of the components of the microphone amplifier are through-hole components. These are leaded components with the leads going through the PCB. The leads are soldered on the backside of the PCB. When soldering such a component, you first bend the leads so the component fits in the PCB. You can then place the component in the PCB and slightly bend the leads outwards. This will make sure the component won't fall out of the PCB. After soldering the component, you can trim the leads. Place your hand over the leads when you cut them, otherwise they might end up in an eye!

The 3.5 mm jack socket is an SMD component. The two plastic pins on the bottom lock the component in place, so soldering it shouldn't be difficult.

The pin headers are used to connect measurement cables and should thus be soldered with the longest part of the pins on the top side!

Carefully observe polarity of the electrolytic capacitors, the diodes, and the op amp:

**Diode** The bar on the silkscreen shows the location of the cathode, the bar on the diode itself also indicates the cathode.

**Capacitors** The + terminal is annotated as such on the silkscreen. On the capacitor, the − terminal is indicated. Furthermore, the + terminal has a longer lead.

**Op amp** The op amp is not soldered directly into the PCB. Instead, a socket is soldered. The op amp has a dot next to pin 1, or a notch to indicate the top side. The socket has a notch to indicate the top side. The silk screen shows the position of the notch.

## 3.6 Verifying the Circuit

When you have soldered the circuit, you can test it to see if it works correctly. You can do a DC test with the multimeter to verify if the various DC voltages are correct. When the DC test is passed, you can use the signal generator to apply a known alternating input signal and verify the behavior of the circuit. But before electrically testing the circuit, you first perform a visual inspection.

### 3.6.1 Visual Inspection

Before applying any power to the board, do a visual inspection first. Check the following:

- The values of all components
- The orientation of all polarized components (diodes, electrolytic capacitors, op amp socket)
- The soldered connections: no missing connections, no bad connection, no short circuits

Check both your own PCB and that of your lab partner.

### 3.6.2 DC testing

It is a good habit to build and test a circuit in small pieces at a time, especially for large, complex circuits. The different parts of complex circuits interact, which makes it difficult to track down a problem. The first electrical test is a DC test. With this test you can verify all the DC levels in the circuit.

- Carefully remove the op amp from the socket using a flat screwdriver.
- Make sure the part of the table you work on is free of any metal parts (trimmed component leads, screwdrivers, ...). These can short pins on the backside of the PCB!
- Use three measurement cables banana plug→mini clip (in the appropriate colors) to connect the PCB to the symmetrical power supply. Watch the polarity!

If everything is connected properly, set the power supply to ±15 V and switch it on. Select the correct scale on the multimeter. Now we can start the measurements, starting with block 1: power.

- Use the multimeter to measure the voltage on the anode of diode D1, relative to ground. What voltage would you expect and what do you measure? If this is not the value you expected, you've probably reversed the connections of the power supply.
- Measure the voltage at the cathode of diode D1. This value should be 0.7 V lower than the value at the anode: there is a 0.7 V voltage drop over a diode in forward bias. If you measure 0 V, you've probably reversed the connections of the power supply or you've reversed the diode.
- As you can see in the circuit diagram of Figure 3.1, the power lines are also connected to the op amp. Use the datasheet to find out which pins are connected to the positive and negative power supply.
- Measure the voltages at those pins. If these values are incorrect, verify if the orientation of the socket is correct. Also check the soldering of the socket. Ask an assistant if the problem persists.
- Calculate the current through resistor R1 (Hint: what is the voltage drop over R1?).

Attention: For the oscilloscope, use probes (and not mini-grabbers) and for the function generator, use mini-grabbers (and not probes).

If all these measurements have the expected result, the power block functions correctly. Now switch off the power supply and insert the op amp back into the socket. Place the jumper cap over pins 1-2 of the INPUT SEL jumpers and switch on the power supply. Since there is nothing important to measure in block 2, we will do measurements in block 3 and block 4.

- With the jumper cap in place over pins 1-2, the microphone input is connected to the non-inverting input (annotated with the +) of op amp IC2A. Use the datasheet to find out which pin is connected to this input. What voltage would you expect here? What do you measure?
- Use the datasheet again to find out the pins connected to the inverting input (annotated with the −) and the output of op amp IC2A. At these pins you should measure the same voltage as at the non-inverting input. What voltage do you measure at these pins? If this is not correct, check the soldering of the resistors R3 and R4 and capacitor C1. Ask an assistant if the problem persists.
- What voltage do you measure at header OUT?
- Given the voltage at header OUT, what voltage would you expect at header INV OUT and why? Verify your answer by measuring that voltage. Use both channels 1 and 2 of oscilloscope to compare voltage OUT and INV OUT using two probes.

### 3.6.3 AC testing

Now that the DC levels at the circuits are correct, you can test the behaviour when it is exposed to an alternating input signal. First, switch off the power supply. Place the jumper cap of the INPUT SEL jumper on pins 2-3 to select the signal generator as input device. Connect the signal generator to the circuit using the headers SIG GEN and GND. Set up the signal generator:

- The input impedance of the microphone amplifier is very high, set up the Load Impedance setting accordingly. See the short manual of the generator in Appendix D;
- Select a sine wave with a frequency of 100 Hz and an amplitude of 1 $V_{pp}$;

Connect the oscilloscope with a probe to header OUT. First switch on the power supply, then switch on the output signal of the signal generator.

- By now, you know the op amp is used to amplify the input signal. Verify the op amp circuit in Block 3 indeed amplifies the input signal by $\frac{R3+R4}{R3} = 6$ (as you will see in Chapter 5 of

[1]). Which proper way do you propose to verify this? Do the measurements and report the results in your Logbook.

- The microphone amplifier is used to amplify audio signals ranging from 20 Hz–22 kHz. Does the circuit work properly for the audio frequency range?
- Select a frequency of 500 kHz. What is the amplification factor? Is this a problem?
- Does the inverted output at INV OUT work correctly? How would you verify this?