



Crystal Clear Electronics

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04 - Laboratory Power Supply and Breadboard

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In this chapter you will learn about two useful tools, that will help you in assembling and operating circuits: the breadboard and the laboratory power supply.

THE BREADBOARD

If you want to build a circuit, you can do it clearly and simply with the help of a breadboard, designed for this specific purpose. The name derives from the fact, that you can easily push the components into this „board”, as if you were pushing them into a slice of bread.

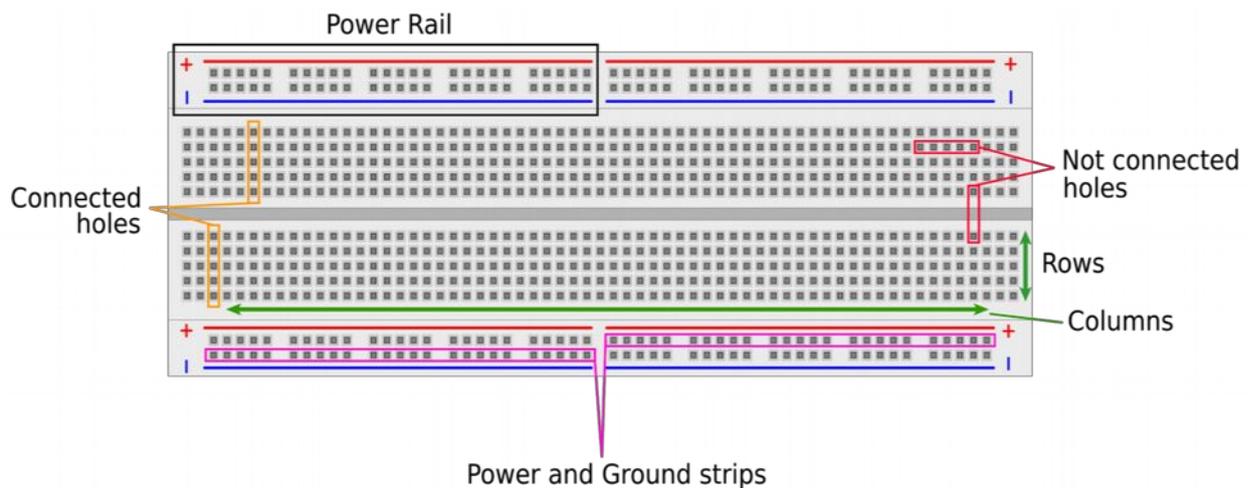


Figure 1 - Location of Conducting Tracks

The figure above shows that small holes can be found on the breadboard, to where you can push the ends (pins) of the components. These holes, as shown in the figure, are connected to the small metal rails embedded in the plastic. The line of holes adjacent to the two longer edges of the breadboard are called power rails, and their polarity is usually indicated by the manufacturers. For the sake of simplicity, the pair of adjacent positive and negative power strips are often referred to as a power rail only.

The power rails are not in electrical contact with each other. This is also indicated by the interruption of the polarity marking. You can connect the power supply terminals to the power rails, up to four different terminal voltages for the breadboard as shown in the figure above.



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There are breadboards that have only one longer power rail per side, therefore not four but only two different voltage sources can be connected. Before you use it, you should know what type you have in your hand, so it won't trick you!

We can define rows and columns in the middle partition, between the two sidewise power rails. The holes, which are perpendicular to the longer sides, are connected together and called columns, usually marked with numbers.

At the same distance, parallel with the longer sides the electrically non-interconnected holes are called rows. Generally, rows are marked with capital letters by the manufacturers. The breadboard is divided by the longitudinal groove in the centre (separation part) into two separate areas. These areas are not electrically interconnected. You can also see these names in the figure above.

When you start using the breadboard, the structure becomes clear right away, you don't have to be afraid of that. As an example, let's look at an image showing the connection of different components.

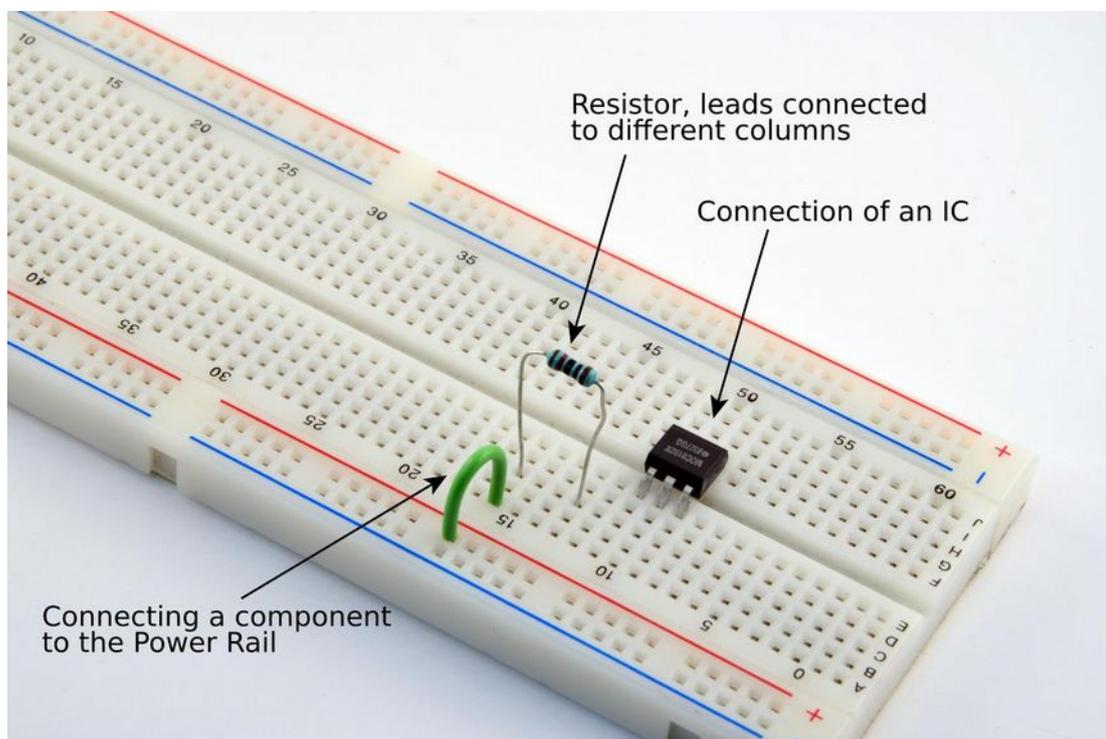


Figure 2 - Circuit Assembled on a Breadboard

The function and operation of the above circuit is irrelevant in our case. You should observe that the black, flat IC with six pins (which will be discussed later in detail) are plugged into the breadboard so that their pins are not connected through the panel. The three to three pins on the two longitudinal sides fall on the different sides of the separating groove. Note that such „multi-pinned” components must always be planted into the breadboard in this way! The pins of the IC are placed in separate columns and are not electrically interconnected. If several pins were in the same column, you would short-circuit their terminals, so you probably wouldn't be able to connect it to the power supply to properly work, or the IC would even suffer permanent damage.



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You should also pay attention to the placement of the two-pinned parts! Since connecting these terminals is pointless, they should be pressed into two separate columns. When you aim to establish an electrical contact, the wires or legs to be connected must be placed in the same column. The components we've seen so far have been easily placed on the breadboard, because they all had pins, but not only these types exist. Let's look at this issue in more detail below.

THE CONCEPT OF THROUGH HOLE AND SURFACE MOUNTED COMPONENTS

Previously we got to know how to make connections (on the breadboard), but there are also other ways to build a circuit. Most often, components are placed on a so-called Printed Circuit Board (PCB for short). PCBs consist of a carrier and conducting strips, which connect the individual components as desired. The carrier call substrate is most often made of fiberglass material, while the conducting strips are generally made of copper.

The PCB (Printed Circuit Board) structure can be very diverse. The easiest construction is to put conducting strips on one side of the substrate. In this case, the side of the board where the conducting strips are located is called the solder side, the other side is called the component side. It is often the case that conductive strips are placed on both sides of the carrier plate, they are the so-called double-sided or 2-layer PCBs. In their case it is not possible to conceptually isolate the component side from the solder side. It is not rare that conductive tracks are placed in the inner layers of the substrate, these are the multi-layer PCBs. In the case of two-sided or multilayer PCBs, the electrical contact between the conductive surfaces is ensured by drilled holes coated with conductive layer (with foreign word: galvanized). This kind of hole is called "via".

The components are manufactured with different outlet terminals and can be attached to PCBs in different ways. When a component has long legs, metal holes are made into the substrate to ensure the electrical connection and to make capable of soldering the component. These are called through-hole (TH) components. The other possibility, if the component does not have long terminals. They are soldered directly to the contact surfaces (they are the so-called pads) created on the conducting layer. These are called surface mounted devices (SMD). The great advantage of using surface mounted components is space saving, so these are more common building elements for the physical implementation of circuits.

Additional information

Less common name is the printed wiring board, in short PWB. This means a carrier plate with conducting strips but without implanted components. In practice, the two concepts may merge into one another in some cases, i.e. without a component or a ready-made circuit board. PCB naming is also used on a carrier plate equipped with components or with conducting strips even before the real implantation, but in most cases, this is not confusing.



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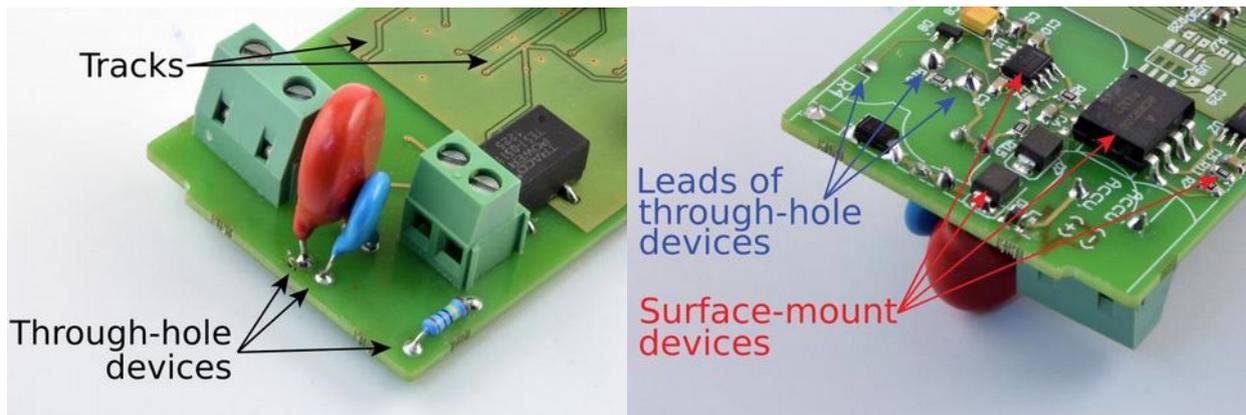


Figure 3 – Double-sided PCB, in which parts can be fixed in any ways

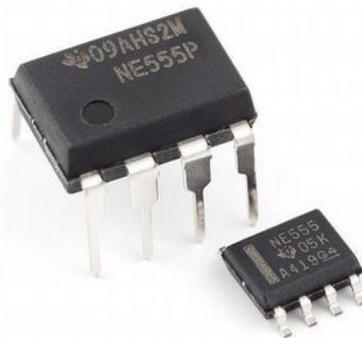


Figure 4 – Same component, but one is through-hole, the other is surface mounted component

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https://commons.wikimedia.org/wiki/File:NE555_DIP_%26_SOIC.jpg

Most of the components are available in both through-hole and surface mounted form. The breadboard can be used to fix the through-hole components, that's why we will mostly use such components to build our circuits.

THE NUMERATION OF COMPONENT LEGS

It is a legitimate question, that how do you know what should be attach to which lead of a „multi-lead” component? Always read the datasheet provided by the manufacturer, in most cases these are available on the Internet in English. You can also find descriptions of the components mentioned in this tutorial on the website. If you look up such a specification, you will see that the component leads are numbered, and next to the numbers are written their functions. Manufacturers usually mark the 1st lead or pin, and that can be done in several ways. The most widespread mode is a dot on the case. Another commonly used marking technique is using a semi-circular groove on one side of the component's package. If you put the IC in front of you, and the grooving is at the top, the top left lead is the Pin 1. Some manufacturers use a line instead of grooving, in which case Pin 1 is defined similarly to the previous version.

Perhaps the most enchanted way of marking is when one side of the IC is chamfered. It looks like, as one side of the IC has been filed. If you encounter such a thing, you should also put the „multi-lead stuff” on the table standing on its own leads with the filed side from your left. Then the top-left lead is the Pin 1. If



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we have found Pin 1, then the numbering is identified by a unified system. If you put the IC in front of you on the table, then the numbering moves from the 1st lead counterclockwise (right to left) in ascending order.

The above markings are summarized in the following figures:

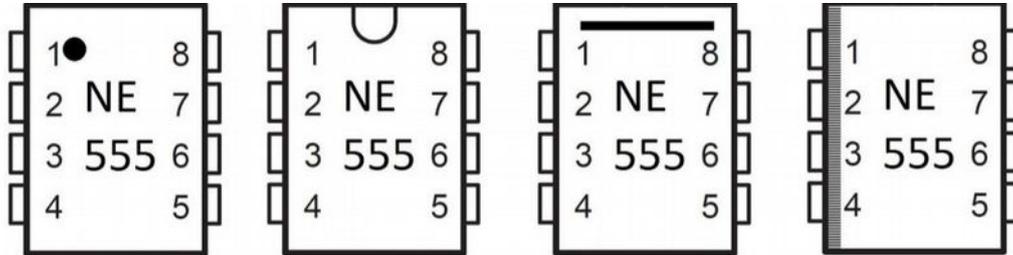


Figure 5 - Pin markings

POWER SUPPLY

Above we got to know the breadboard, on which we can build our circuits consisting of through-hole components. We need to provide electrical power for their operation, so we need a voltage source!

We have several ways for powering a circuit. You can choose well-known galvanic cells from everyday life or environmentally friendly rechargeable batteries:



Figure 6 - Different galvanic cells

Source: Lead holder [CC BY-SA 3.0 (<https://creativecommons.org/licenses/by-sa/3.0/>)]

https://commons.wikimedia.org/wiki/File:Batteries_comparison_4,5_D_C_AA_AAA_AAA_A23_9V_CR2032_LR44_matchstick-1.jpeg

Now we choose another way that is less known. For those who have not built circuits so far, the laboratory power supply is familiar maybe only from the physics classes in high school. The term „laboratory” refers to a structure used for experimentation, development, and DIY. The laboratory power supply converts the AC voltage from the mains to a DC voltage. It is also possible to control the electrical voltage between the terminals and the maximum limit of the current flowing through the circuit. We will see that it is not only useful, because it never gets depleted, but it has several other advantages over a simple battery.

Of course, if you have already a similar device, feel free to use it, not just the one which is shown in the curriculum. Such a power supply is not really wallet friendly, but a significantly cheaper alternative is the power plug.



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If you get a feel to learn more about the interesting field of electronics, you will definitely need a lab bench power supply, as it is an exceptionally useful tool!

THE POWER PLUG

Let us examine more closely the alternatively recommended power plug. The power plug, as its name implies, is a power supply that can be directly plugged into a wall outlet. The device shown in the curriculum produces a constant DC voltage of 12V between its terminals and can supply the connected circuit with a maximum of 1.2A DC. With these parameters, it is capable to operate all circuits examined in this curriculum.



Figure 7 - The Power Plug

The power plug terminal is a circular two-pole connector which cannot be attached directly to the breadboard, you will need an adapter. The adapter consists of a socket capable of receiving the power supply connector and a two-pin contact, which can be pushed into the breadboard.

Take care of the polarity of the pins! The outer pole of the power plug is the negative pole, and the internal pole is the positive pole, if you connect it to the adapter, the polarity of the two pins is shown in the following figure:



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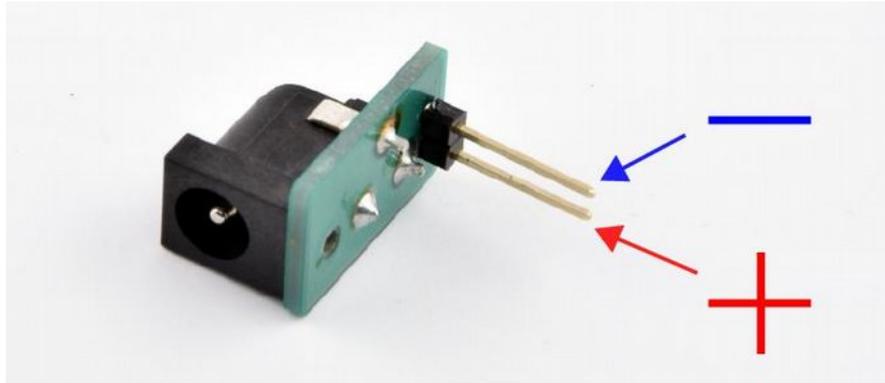


Figure 8 - Polarity of the pins

It is therefore advisable to connect it to the breadboard so that the polarity can be directly read from the power rail, for example by this way:

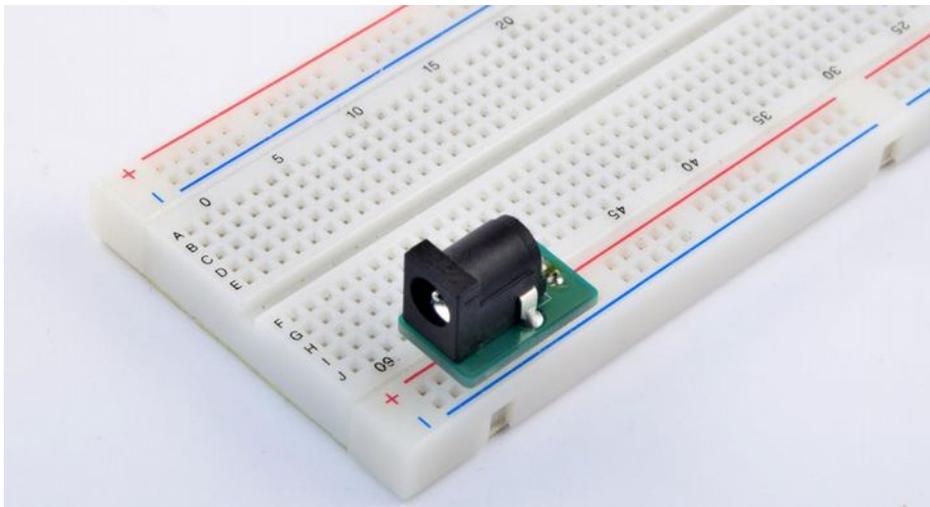


Figure 9 - A possible, polarity correct connection

If you have already successfully connected the power source to the breadboard, try it out! Get a high-power (max.) 5W, 47 Ω resistor.

Be careful when assembling the circuit, because it should not be kept turning on for a long time! During its operation significant heat develops, so you can burn yourself and damage the breadboard as well!

Bend the legs of the resistor, then push it into the breadboard and connect it to the power supply with two wires. A resistor is not sensitive to polarity, so you can connect it to the power plug as you wish. The following image will help you to assemble:



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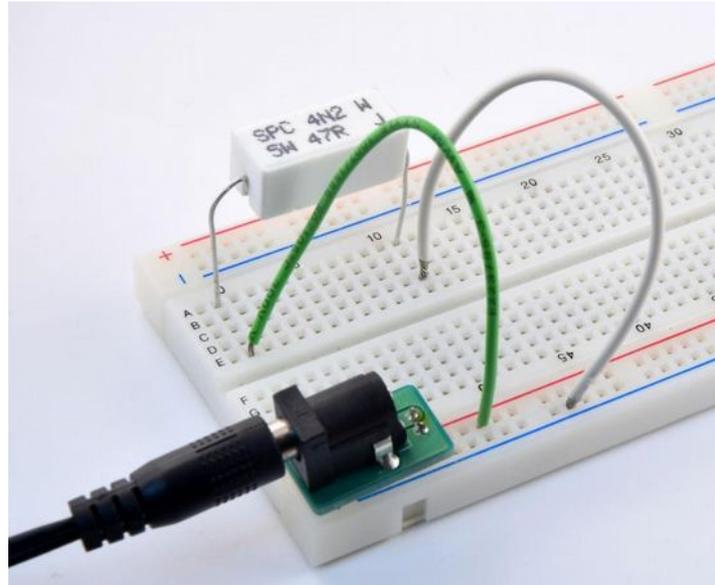


Figure 10 - A possible assembly

Of course, you can also push the terminals of the resistors directly into the power rail, but it helps transparency if you do not place components there during the construction phase.

If you plug the power plug into the power outlet, you may soon notice that the resistor is warming up to 100 °C. Do not keep the circuit switched on for a long time.

In the second chapter, you learned of the resistance that the moving electrons (current flow) collide with the stationary nuclei, therefore some of their motion energy is released into the environment in form of thermal energy, with technical word, it is dissipated. The fact, that this resistor is rated for 5 watts means it is capable of dissipating that much heat, generated by electrical power without any damage.

The small, cylindrical metal layer resistors are of lower power, they are having small heat capacity due to their size and are capable of heat dissipation on a smaller surface. In the figure below, you can see resistors designed for different power:



Figure 11 - Resistors designed for different power



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Based on the formula learned in the second chapter, we can calculate the electrical power in this case, as we know that it has a 12V DC voltage, and a value of 47Ω :

$$P = \frac{U^2}{R} = \frac{(12 [V])^2}{47 [\Omega]} = 3.06 [W]$$

And this can cause a considerable amount of warm, as you can feel too.

LABORATORY POWER SUPPLY

Let's examine our laboratory power supply in detail! The recommended laboratory power supply is described below, but the followings are generally true for most power supplies of the same category. If you are not using this type, it is also worth to study this section, because the features are likely to be similar.

To get familiar with it, first you have to set up the power supply. To do so, connect the appropriate end of the power cord to the socket on the back of the laboratory power supply and plug the other into end the wall socket. It is recommended to read the instruction manual of the power supply!

The power supply can produce a maximum of 30V voltage between its terminals, which you can read at a tenth of a Volt resolution from the display. The maximum current output can be 5A, which can be read accurately as hundredths of amps.

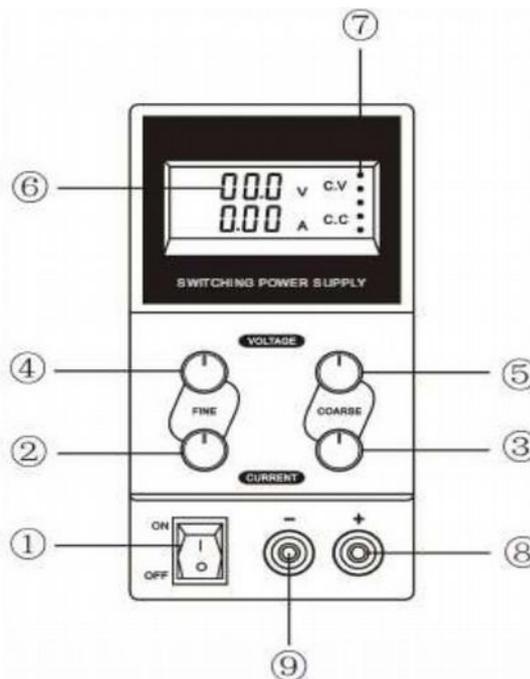


Figure 12 – Power supply display and controls

Hereinafter, the individual controls are identified based on the numbering shown in the figure above.

You can turn on the power supply with the switch (1). You can connect the power supply to the circuit board by plugging the banana plug into the connectors (8) and (9).



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There are four controls in the middle of the panel, which are variable-value resistors (so-called potentiometers, or pots for short). On the one hand, you can control the voltage between the terminals of the power supply, also called the terminal voltage, and on the other hand, you can set the current limit, i.e. the maximum current flow that we want to allow between the terminals. You can set the voltage between the outputs with potentiometer (4) and (5), and the current with (2) and (3). The term „coarse” indicates that the potentiometer (5) and (3) can control the terminal voltage and current limit in large steps. And with the „fine” (2) and (3) potentiometers you can adjust the same quantities with small steps. Practically, do the rough control first, and then the fine-tuning.

The display section (6) shows the voltage between the outputs in volts, and below the current flow supplied by the power supply can be read in ampere. The display section (7) tells you in what mode the power supply is currently working. These are C.V. and C.C, and we will become more familiar with the meaning of these acronyms in detail later. The set of consecutive points gives graphical feedback about the supplied current strength.

You can connect the terminals of the laboratory power supply to the circuits in many ways if you work on the breadboard. You can also use the cable provided for the laboratory power supply for this purpose. At the one end there is a banana plug, and at the other end there is a crocodile clip. You can also pinch the crocodile clips directly onto the leads of components.

For clearness, if you make two wires that are stripped at both end of the insulation, you can clamp the crocodile clips at one end, and then push the other end into the power rails of the breadboard with correct polarity. It is very important to make sure that the crocodile clips or wire ends do not touch each other accidentally, because then you will short-circuit the power supply! In this case, you should also pay attention to the amount of current, which is flowing through the thin wires!

The conductors inside both the wire and the breadboard can become very hot, even in case of a few amperes, so that the insulation of the wire or the plastic of the breadboard can melt. In case of the circuits included in the curriculum, you do not have to worry about these problems in case of normal operation.

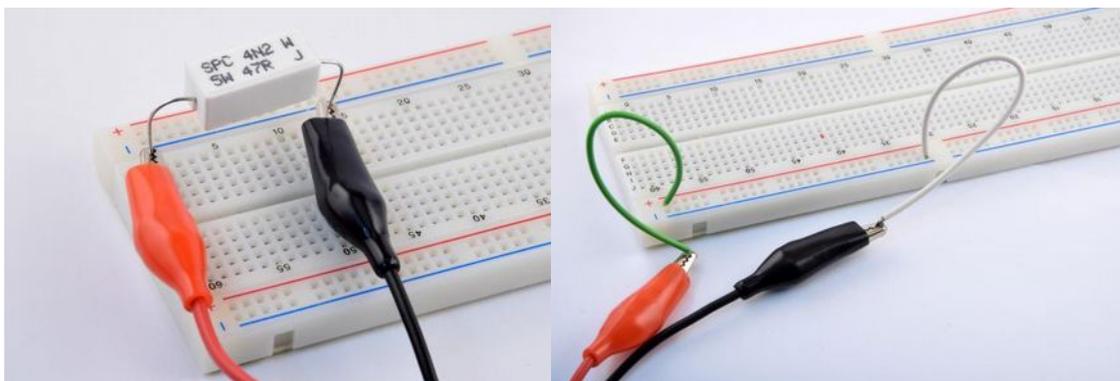


Figure 13 - Two possible ways of connections

ADJUSTING THE OUTPUT VOLTAGE

Now we are going to use the laboratory power supply for the first time! First, disconnect the wires and turn it on. Make sure that the current limit is not set to zero, so that the controls (2) and (3) are not completely turned to the left.



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There is some voltage on the display, but the current is zero, since you have not connected anything to the terminals. For practice, try to set different terminal voltages on the lab power.

Then take the terminal voltage to the minimum, which you can check as the display shows no voltage. Push a $68\ \Omega$ 10W power resistor into the breadboard, and connect its leads to your laboratory power supply outlet. Gently twist the voltage regulator potentiometers, set several different but less than 12V terminal voltages. (This assembly can also warm up considerably, so don't use it for a long time!) You can see that higher voltages results proportionally higher currents, we will discuss about their relationship in detail later.

If you remove the load from the terminals during the experiment, you will see that the terminal voltage does not change significantly. Based on this, it can be concluded that the lab power supply keeps the set terminal voltage independently to the load (up to the current limit), which is a huge advantage over a simple battery. (It is possible that the open-circuit voltage between the terminals of a pocket battery is close to the nominal value, but it may decrease due to the load, which is especially spectacular when the battery is close to total depletion.)

Before moving on to experiment, let's put a little bit of theoretical detour! The laboratory power supply is primarily more than an average pocket battery, because it can realize with a very good approximation two building blocks, which exist only at a theoretical level, these are the ideal voltage source and the ideal current source.

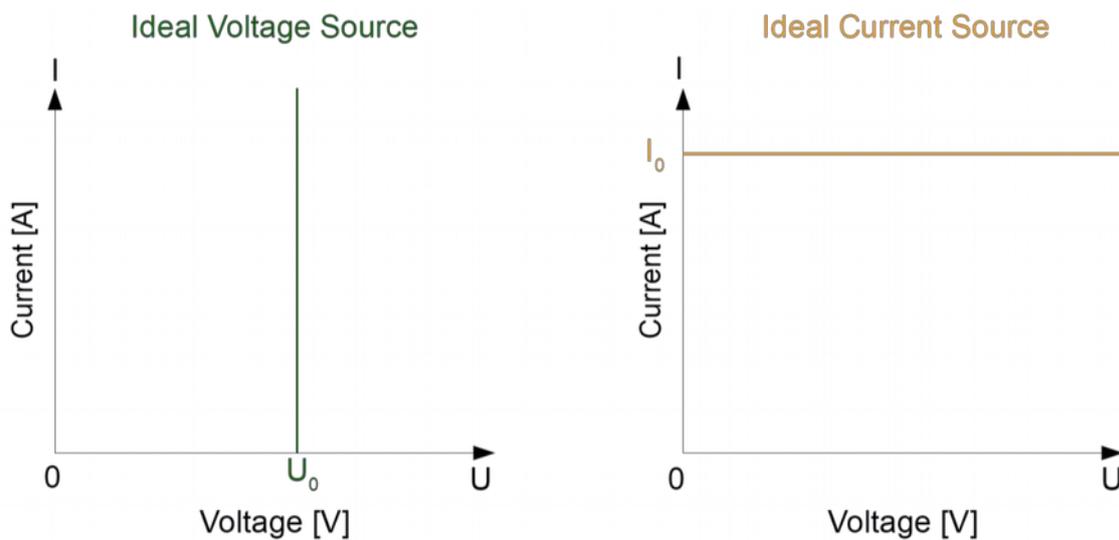


Figure 14 - U-I characteristics of the ideal voltage and current source

Additional information

It is worth to take a little more time to describe reality with physical models and laws! A variety of fictitious equivalents of circuit elements can be interpreted. The significance of these is when we want to determine the behaviour of a circuit in a theoretical way, the reality must be put into a mathematically descriptive, computable form. We can do this easily with the help of the ideal elements, but only with the right approach!



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Modelling the reality helps the work of engineers. So, we can draw conclusions about the operation of an untested circuit without construction or experimentation. For example, calculations help to select proper components, and understand problems.

The importance of the two ideal building block we have learned before is that we can model operation of the laboratory power supply with their help. So, if you know these two fictitious elements, you will also better understand the operation of the lab power supply!

Of course, as any model trying to approach physical reality, they also have limits. Which means that the predicted value of physical quantities based on theory is only a good approximation compared to the values measured in the assembled circuit. You'll see this soon, because only under certain conditions can the power supply be considered as an ideal voltage source or ideal current source.

During the previous experiment, you could observe that while you controlled the voltage applied to the power resistor, C.V. (Constant Voltage) lit up on the lab power display. This indicated that the laboratory power supply functioned as an ideal voltage source, i.e., the set voltage value was maintained between the terminals, regardless of the current consumption of the circuit. If you set a terminal voltage when unloaded, it did not change significantly even when the load was connected. The lab power supply works as an ideal voltage source until the current limit is reached by the connected circuit (max. 5A). This mode of laboratory power supply can also be called voltage generator mode.

ADJUSTING THE CURRENT LIMIT

The current limit of the power supply guarantees that no higher current than the set value can flow at a given output. When does the current limit come well? First and foremost, if we want to protect our circuit elements from overcurrent, for example due to a short circuit. It is also very useful if you are not sure that everything is connected according to your plans.

Before we proceed, let's clarify a few details about the power supply's internal structure! Very simplified, the device is built logically as shown in the following figure.

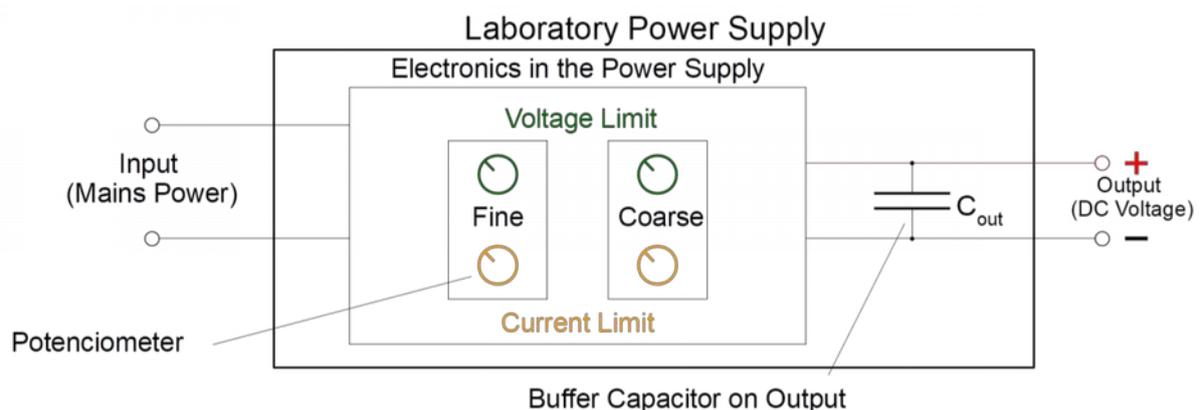


Figure 15 - The simplified internal structure of the lab power

You can see that there is a buffer capacitor in the outputs. Do you remember? The energy stored in the capacitor depends on the capacity and the voltage at the capacitor. The buffer capacitor is important for the proper operation of the power supply, but it is located after the control electronics, so the current



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between its terminals is not limited. So, if the capacitor is charged and the power supply outputs are short-circuited, the outputs will suddenly have a high current that can damage the capacitor.

Additional information

You may have a problem when you connect a sensitive circuit to the outputs that you want to use only with a current barrier in the mA range. If the circuit is malfunctioning (abnormally high current, for example due to a short circuit), you can „charge” the energy stored in the capacitor to the circuit, and it can be damaged. This fault case should be taken into account as the power supply terminal voltage is the same as the buffer capacitor voltage, as shown in the figure above. For this reason, if you use the power supply, there is certainly some charge on the capacitor, so in case of a short circuit the current between the outputs may be higher than the current limit for a short time.

In case of typical use of the power supply, you can use the following steps to set the current limit:

1. Remove everything from the power supply terminals. Set the terminal voltage as desired.
2. Turn the controls (2) and (3) to the leftmost position. This sets the current limit to zero. You can see that C.C. (Constant Current) lights up and the terminal voltage slowly decreases to zero. It is important to wait until this happens! The terminal voltage is the same as the buffer capacitor's voltage, practically you can see that the buffer capacitor is discharged slowly by the internal electronics.)
3. Then short-circuit the power supply terminals. (It is important to wait for the terminal voltage to be zero, otherwise you would short-circuit the charged capacitor, which could damage it.)
4. Now you can control the current limit (the current value can be read from the display), set the desired value!
5. When you have finished the settings, remove the short-circuit, you will see that the terminal voltage is set to the pre-set value, the actual current is zero, but the current limit is valid.

With this sequence of instructions, you have set up the power supply, from now on feel free to use it!

You may also encounter a power supply, where the terminal voltage does not start to decrease, even though you have set the current limit to zero. If you experience this, you should do the same as above, with the following differences. In step 1, set the terminal voltage to zero. In step 3, after short-circuiting the outputs, set some terminal voltage (the point is that it should not be zero). After removing the short-circuit in step 5, set the terminal voltage to the desired value.

To test the current limit, use the well-known 68Ω 10W rated power resistor. Set the power supply to 12V terminal voltage and a current limit of 0.06A as described above. (This layout can also get hot, use it carefully!) If you connect the load, you can see that the current flows through the resistor with the set current limit, and the terminal voltage is less than 12V and C.C. lights up.

Increase the current limit in small steps during the usage (use the fine control pot). You can see that the terminal voltage changes so that the current corresponding to the set current limit flows between the outputs while C.C. lights up. (If you set the current limit over about 0.17A, the power supply mode will change, this will be discussed in detail in the next section.) We can say that the power supply in this mode (when C.C. is lit) works like an ideal current source, with variable current. Thus, the terminal voltage is



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adjusted very quickly until the current corresponding to the set current limit will flow between the outputs. This mode of power supply is also referred to as current generator mode.

It is important to clarify that the power supply can be regarded as an ideal current source only in current generator mode. In this case (12V voltage limit, 68Ω) this is about 0-170 mA range.

By now, many questions may have arisen in you, let's discuss this topic a little in the next section!

RELATIONSHIP BETWEEN MODES OF THE POWER SUPPLY

Let's stay at the layout that was previously assembled. If you increase the current limit slowly (under load), you can see that at about 0.17A the power supply switches to voltage generator mode, that is C.V. will light up. The reason is that the voltage at the outputs must be greater than 12V in order to have a current more than 0.17A, and this cannot happen, because you set the maximum terminal voltage (i.e. the voltage limit) to 12V.

To sum it up, we can conclude that it is not really necessary to think of two separate modes. Just think about that you set a maximum voltage and current limit. The operation of the power supply is determined by their mutual relationship.

C.V. (Constant Voltage) feedback indicates that the voltage between the terminals is the same as the set voltage value, and the circuit consumes less than the actual current limit. C.C. (Constant Current) indicates that the current limit has come into effect, i.e. the circuit consumes equal to the current limit, and the voltage between the terminals is less than the set value. In this case the terminal voltage is adjusted in a way, that the current flow is the same as the current limit.

Additional information

It is worth to mention that the power supply control electronics can only adjust the terminal voltage. Therefore, when the current limit is validated, the terminal voltage is controlled so that the current between the terminals is equal to the set current, as it would be the case with an ideal current source.

The control always sets the voltage between the outputs to be less than or equal to the set terminal voltage, or the current flowing between the output is less than or equal to the current limit. Obviously, one of the limitations must be in force, otherwise there would be no control on the terminal voltage.

Due to the above, it is also dependent on the load whether the current limit or the voltage limit is in force, since other loads consumes different current at a given time.

Now we can also clarify why setting the current limit is the most practical in the manner described. If you short-circuit the lab power without load, then the current according to the current limit will flow between the terminals, which you can read from the display, so you can adjust it to the exact value. Of course, when setting the current value, it is necessary not to apply voltage limit, which (because of the very low resistance of the cables) would only apply with a good approximation in the case of zero set voltage limit.

If you disconnect the output short-circuit, there is no current between the terminals, so the voltage limit will apply, and the set terminal voltage will appear.



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IF YOU USE ANOTHER TYPE...

If you are using a different type of laboratory power supply, there may be some differences in the external design or display mode, but the most important difference can be that how to set the current limit.

It is advisable to read the instructions manual carefully. There are some more expensive power supplies, that continuously display the actual current limit when you control it, so you don't need to short-circuit the terminals for setup. Such a device can be easily recognized by changing the display value even if you turn the current limiting pots when it's in an unloaded condition.

SUMMARY

In this chapter, you learned about a way to assemble circuits on the breadboard. You had the chance to learn how to number the pins of the integrated circuits and how to use them on the breadboard. We also talked about ways to power our circuits. We got to know the power plug, and we also tested the laboratory power supply. You can see now how they differ from each other, and how they perform compared to for example a simple pocket battery.



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