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Introduction

Specialist trade provides many multimeters with which you can perform comprehensive measurements at electronic components and circuits on your own. However, this requires basic knowledge don operation of this kind of universal meter and the components to be measured.

This learning package helps you lift the secrets of proper measuring step by step. In exercises based on each other, you will learn how to identify different components and measure them correctly, and how they behave in circuits. This

knowledge permits you to independently determine whether individual components are defective or how to install them in circuits correctly.
This learning package conveys all the basics needed for successful work with the multimeter.

Components - Basics

The Battery

The battery must be connected in the right polarity to every circuit. The required battery blot has one red connection wire to mark the plus pole and a black one to mark the minus pole each. Both wires must be connected to the experimentation board according to the polarity required.

Figure 1: Circuit symbol of a battery

Resistors

Resistors are among the simplest electronic components. They are labelled in a colour code of three rings that is read from the edge to the centre. A fourth ring a little offset from the others indicates the component tolerance. The colour code is read from the ring closer to the edge of the resistor. The first two rings represent two digits, the third the multiplier of the impedance value in Ohm. A fourth ring indicates the tolerance. The impedance value is indicated in Ohm [Ω].

Figure 2: Resistor colour code

Figure 3: A resistor with the colour rings yellow, violet, brown and gold has the value 470 Ohm at a tolerance of 5%.

Figure 4: The resistor

The learning package includes resistors of the following values:

330 Ohm Orange, orange, brown
1 kOhm Brown, black, red
2.2 MOhm Red, red, green

Figure 5: Circuit symbol of a resistor

The Ceramics Capacitator

The capacitator is another elementary electronics component. It is available in two versions. The simpler version is the small, round and flat ceramics capacitator. It is protected against polarity reversal. Capacities are indicated in Farad. The ceramics capacitator is labelled with a number code. "104" means "10 times 10 to the power of 4“, i.e. 100,000 pF (Picofarad).

Figure 6: Circuit symbol of a ceramics capacitator

Figure 7: The Ceramics Capacitator

The Electrolyte Capacitator

The larger electrolyte capacitator has a cylindrical body and must be installed in the correct polarity. The minus pole is marked by a white strip at the side and has a shorter connection wire. If the electrolyte capacitator is installed with reversed polarity, it is destroyed. It is labelled in plain text.

Figure 8: Circuit symbol of an electrolyte capacitator

Figure 9: The electrolyte capacitator must be installed in the correct polarity.

The LED

When installing a light emitter diode, generally observe polarity. The LED has two differently long connection wires. The longer one is the plus pole, called anode (A). The minus pole, also cathode (K), has the shorter wire.

The polarities are also visible inside the LED. The minus pole has the approximate shape of a large triangle. The plus pole is very delicate in contrast.

Figure 10: A light emitter diode must be installed in the correct polarity.
Figure 11: Circuit symbol of a LED

The Transistor

The transistor amplifies small currents. Its connections are emitter (E), base (B) and collector (C). The cylindrical housing is flattened on one side. This is where the type designation is printed on. If you are looking at the transistor so that the connections point down and you can read the label, the emitter is on the left. The base is in the middle.

Figure 12: The transistor with view of the flattened side. The connections, left to right: Emitter (E), base (B) and collector (C).

Figure 13: Circuit symbol of an NPN transistor

The Diode

A diode only permits current to flow in one direction. It can be imagined like a check valve of water installation technology.

Conventional diodes have a cylindrical shape, similar to impedances. The minus pole (cathode) is marked with a dash.

Figure 14: Circuit symbol of a diode

Figure 15: The Diode

The Possibilities of a Multimeter

Multimeters differ mainly regarding what they can measure. Of course, this does not mean that a simple instrument is self-explanatory. Look at the large adjustment wheel that sets the different measuring areas and values precisely. What is offered? What do you need at all? These questions should be answered before making your purchase.

Also deal with the strings. They have different colours (red: plus pole; black: minus pole). Learn about your device using the operating instructions before using it for your first measurements.

Figure 16: First get to know the instrument. A detailed look into the operating instructions helps with this.

CAT certification devices on the area of application. Multimeters must meet various protection criteria that warrant their safe use. Finally, measurement of current and voltages is not a game, but associated with risks!

Multimeters must be designed for a combination of constant voltages and so-called transient overvoltages. These protective measures are classified in 4 CAT classes. The higher the CAT class, the more diversely can the instrument be used.

CAT Classes
CAT I

Multimeters with CAT-I certification have only little protective measures. They must only be used for measurements in protected electronics areas and to perform measurements at devices. They must have a sufficient protection against transient overvoltages.

CAT II

CAT-II-capable instruments permit use for single-phase loads connected to a mains socket. This includes household appliances and portable tools. Mains sockets and lines must only be measured with limitations. Multimeter for electronics enthusiasts should have at least CAT II.

CAT III

Multimeters with CAT-III approval are already suitable for use in three-phase distributor grids and single-phase commercial lighting. They can already measure rotary current motors or power sockets for high loads.

CAT IV

CAT IV additionally permits use from the rotary current connection of the power plant and at overhead lines. These therefore are devices for measurements that a private person must not perform.

Correctly Connecting the Measuring Strings

Only few multimeters have the measuring lines connected right to the multimeter. Usually, the devices have 3 to 4 sockets to which the measuring strings can be connected. This generally must only take place when they have not been connected yet!

The black string corresponds to the minus line in the wider sense (return line). It is connected to COM. In which socket the right measuring line needs to be connected

– it corresponds to the plus or supply line - depends on the measurements to be performed and the socket labels. Our example instrument has three further sockets installed. The right one is labelled "HzVO". Connect the red line to it, e.g. to measure voltages (V) and impedances (Ω). "Hz" indicates frequency measurements that are needed by specialists only. Usually, this socket is selected for measurement of small currents as well, as they are usually found in electronic circuits. Our instrument has its own socket intended for this. It is labelled "µAmA". If usual currents in the area of electronics hobby construction are to be measured, the red string is connected here. For multimeters with 3 connections, the low-current, voltage and resistor function are accessible through a joint socket.

The fourth socket at the multimeter is labelled "20A MAX". It serves to measure particularly high currents and is rather not needed by electrical engineers who measure in circuits.

Details on the socket assignments and background for performance of measurements can be taken from the multimeter manuals.

Figure 17: Most multimeters are equipped with 3–4 sockets to which the two measuring strings are connected depending on measurement to be performed.

Figure 18: The black string is connected to COM. It corresponds to the return line (the minus pole).

Figure 19: If voltage and
resistance measurements are to be performed,
this model requires the red
measuring line to be connected to the right socket
HzVO. To measure
small currents, it would have to be connected to the socket µAm A.

Correctly Setting the Meter

Multimeters do not simply measure voltages, currents and impedances. They must be adjusted correctly. There are direct and alternating voltages and currents. The multimeters also have several measuring areas and measuring ranges; for example, the Voltcraft VC-11 alone has 5 direct voltage measuring ranges:
for very small voltages up to 200 Millivolt (mV), 2 V, 20 V, 200 V and 250 V.

Since it is often not possible to estimate precisely what voltage is expected in a measurement, you should always set the highest measuring range. For direct voltage measurements, this is 250 V in the Voltcraft VC-11. If the display only shows a very low measured value like 14 V, you may switch down to the 20-V measuring range. The device then measures highly accurately.

Processed in the same manner for all other measured values, i.e. alternating voltages, direct and alternating currents, impedance measurements, etc.

Start with the highest measuring range to protect the sensitive measuring electronics from overload and irreparable damage. Therefore, always start measurement with the highest measuring range.

Figure 20: Observe selection of the right measuring unit (e.g. "direct current" to ,measure direct currents).

Figure 21: Switch the device into the maximum measuring range before each measurement. In this device, it is 250 V in the direct voltage range.

1 How to Measure a Resistor?

Preparation work:

Bend the connection wires of one resistor of size 330Ω , 330 kΩ and 1 k and 2.2 MΩ. each by 90° so that you can plug them into the experimenting board (see figure 22).

To have both hands free for measurements, fashion test prods from two about 7 cm long completely insulated wire pieces by coiling them firmly around the blank parts of the test prods. About 1 cm should remain straight. Use this aid to plug the test prods directly onto the experimenting board.

To measure a resistor, you do not need any external power source like a 9 V battery. A power source for impedance measurements is installed in the multimeter already.

Now plug the two test prods in parallel to a resistor on the experimenting board and set the instrument to the impedance range of 2,000 kΩ. Measure all three resistors in this manner. Two measurements will show you "001" and the third one "1–".
These measured values are not very helpful,l even though you did everything right. What is that? It's about choosing the right measuring range. See exercise 2 for more on this.

Figure 22: After bending the connection wires of 3 resistors by 90° each at the sides, plug them onto the experimenting board.

Figure 23: About 7 cm long blank wire pieces are coiled around the test prods.

Figure 24: The measuring lines can be connected right to the experimenting plate in this manner.

Figure 25: In the highest measuring range that can be set, the measuring results are still rather imprecise.

Avoiding Measuring Errors
According to the last exercise, two resistors were of the same size. You are noticing a measuring error because the measuring range is set incorrectly.

Therefore, measure every resistor again at the circuit and reduce the measuring range step by step.

"1" for 1 kΩ in the 2,000 kΩ range turns 0.98, i.e. 980 Ω, in the 20 kΩ measuring range.
Now switch to the 2,000-Ω-range, determine a measured value of 983 Ω. You have now determined the best and most accurate measuring range. If you switch down to the 200 Ω area, you will only see "1–" in the display. This means that the measuring range set is too small.

Perform this measurement with the second resistor, where you originally measured "1" for 1 kΩ as well. You will find that it actually has about 326 Ω. Therefore, this is the 330-Ω resistor.

For the third, the 2.2 MΩ resistor, you will see "1—" for any measuring range set. This shows that the multimeter is not suitable for measuring very high resistors. When selecting the right multimeter, consider what you want to do with it.

A measurement is only precise when the measuring range is utilised as well as possible. Therefore, you should always switch to the smallest possible area. The larger the selected measured range, the larger the measuring error and the less precise the measurement. This also applies regarding current and voltage measurements.

Figure 26: In the 2,000 Ω measuring range, a impedance value of 983 Ω is measured. Therefore, the best measuring range for this resistor has been found.

Figure 27: If measured correctly, the second resistor originally measured as 1 kΩ turns out to be a 330 Ω resistor

How do Resistors Switched in Series Behave?

Resistors are installed in circuits not only individually but also in combination. One possibility is switching resistors in series.
For this, plug two 1 kΩ resistors into the experimenting field in series.

Now connect a measuring string to the left end of the left resistor and the second one to the right end of the right resistor and determine the impedance. In our test setup, you will find about 1,970 Ω, i.e. approximately 2 kΩ. When switching several resistors in series, the overall impedance that you have now also measured equals the sum of the individual resistors. Therefore:

R_{ges} = R1 + R2 + … Rn
2 kΩ = 1 kΩ + 1 kΩ.

Also try switching in series with several and different resistors. This way, you can build any resistor that you have no single component at hand for currently.

Figure 28: Two resistors in series;
to determine the overall impedance, connect one measuring line to the left connection of the left resistor, the other to the right connection of the right resistor.

Figure 29: Two resistors switched in series.

Figure 30: The overall impedance for resistors switched in series always corresponds to the total of the individual impedance values.

How do Resistors Switched in Parallel Behave?

Resistors can also be switched in parallel. A simple parallel circuit comprises at least two resistors. Of course, several resistors can be switched in parallel as well.

Plug two 1 kΩ resistors below each other on the experimenting board. They are switched in parallel now. Now apply the two measuring strings to the ends of the two resistors. Now determine the overall impedance. In our circuit, it is 493 Ω and therefore only half of a single resistor.

Now switch a 1 kΩ resistor and a 330 Ω resistor in parallel.
The total impedance now is about 245 Ω. Try other resistor combinations as well.

When switching resistors in parallel, the overall impedance is always lower than the smallest single impedance.

The overall impedance of resistors switched in parallel can be calculated according to the following formula:

$1 / R_{ges} = 1 / R1 + 1 / R2 + … 1 / Rn$
248 Ω = 1 / 1,000 Ω + 1 / 330 Ω.

To get to the overall impedance, push the button 1/x on the calculator.

Figure 31: When switching two resistors in parallel, the overall impedance is always lower than the smallest single impedance.

Figure 32: Two resistors switched in parallel on the experimenting board

Figure 33: Two 1 kΩ resistors switched in parallel lead to an overall impedance of 493 Ω.
The result is not precisely 500 Ω because of production tolerances in resistor manufacture.

5 Measuring the Capacitator

To be able to measure the capacitator capacity, you need a multimeter that also permits capacity measurements (e.g. the Voltcraft VC840).
Unfortunately, only relatively few and high-quality multimeters have capacity measuring ranges. Standard multimeters usually only have volt, ampere and ohm measuring ranges.

Attention!
Before connecting a capacitator to the meter, you must discharge it! For this, short-circuit the two connections. Use pliers or a screwdriver that you put across the tow contacts. Only hold the tool by the isolated grip. Short-circuiting of capacitators may cause high-energy discharge. Therefore, never touch the connections of capacitators with more than 35 V direct voltage/25 V alternating voltage – in particular if you do not know if it is charged or not. Caution, danger to life!

Now pug the capacitator to be tested onto the experiment field so that the two self-made wire test prods can be placed on the experimenting board without the two measuring device strands touching.

Capacitators to be measured must never be installed in circuits or circuit parts.

The measuring setup in capacitator measurement corresponds to the impedance measurement. You only need to hold the red and black strings to the two capacitator connections. To keep both hands free for the multimeter, use the self-made test prods as well that you can use to connect the two measuring lines firmly to the experimenting board.

When connecting the measuring lines, observe correct polarity in particular for electrolyte capacitators. Connect the red line to the plus pole and the black one to the minus pole of the capacitator.

After switching on the multimeter, set the impedance measuring range with the large dial switch. It is multifunctional. Then push the function switch until the display at the right edge reads "nF". This means "Nanofarad". Farad is the unit for electrical capacity. Most capacitators have capacities between some picofarad (pF) and some microfarad (mF).

Measuring a capacitator takes some time. Several seconds pass before the final measured value can be read at the display.

Figure 34: Capacitators must only be measured outside of circuits or circuit parts. The capacitator to be measured must be plugged onto the experimenting board. Both measuring lines must be connected to it in the correct polarity.

Figure 35: Set the capacity measuring range at the multimeter. It will take some seconds before the measured value can be read.

Capacitators switched in series
In the exercise "How do Resistors Switched in Series Behave?", you found that the overall impedance is the total of the resistors switched in series.

Switch two capacitators in series on the experimenting board (e.g. with a capacity of 10 µF each. Check that the two capacitators are installed in the correct polarity. For electrolyte capacitators, the minus connection wire of the first must be connected to the plus connection wire of the second. Since capacitators are measured alone (without consumer and power source), you may already connect the red string of the multimeter to the plus connection of the first capacitator and the black string to the minus connection of the second one.

Now switch the multimeter to capacity measurement and wait for a few seconds until the measured value no longer changes. You will now measure about 5.7 µF, i.e. half of the two 10 µF capacitators.

If follows:

The overall capacity drops the more capacitators are switched in series.

The overall capacity of capacitator switched in series can be calculated according to the following formula:

$1 / C_{ges} = 1 / C1 + 1 / C2 + \ldots 1 / Cn$

To get to the overall capacity, push the button 1/x on the calculator.

Figure 36: Two capacitators switched in series

Figure 37: Make sure that the polarity of the two capacitators is correct when installing the two electrolytic capacitators. The measuring lines must be connected with the correct polarity as well.

Figure 38: When two 10-µF capacitators are switched in series, you will measure half of the individual capacity of a capacitator.

Capacitators switched in parallel

In the exercise "How do Resistors Switched in Parallel Behave?", you found that the overall impedance of the resistors switched in parallel is less than the smallest individual resistor.

Switch two capacitators in parallel on the experimenting board (e.g. with a capacity of 10 µF each). Check that the two capacitators are installed in the correct polarity. For electrolyte capacitators, connect the plus connection wires and the minus connection wires.
Since capacitators are measured alone (without consumer and power source), you may already connect the red string of the multimeter to the plus and the black string to the minus connections of the capacitators.

Now switch the multimeter to capacity measurement and wait for a few seconds until the measured value no longer changes. You will now measure about 23.2 µF, i.e. twice that of the two 10 µF capacitators.

If follows: When capacitators are switched in parallel, the overall capacity corresponds to the total of the individual capacities.

The overall capacity of capacitator switched in parallel can be calculated according to the following formula:

$C_{ges} = C1 + C2 + … Cn$

Figure 39: Circuit setup to measure two capacitators switched in parallel.

Figure 40: Make sure that the polarity of the two electrolytic capacitators switched in parallel is correct. The measuring lines must be connected with the correct polarity as well.

Figure 41: When two 10-µF capacitators are switched in capacitator, you will measure twice of the individual capacity of each capacitator.

How to Measure Direct Voltages?
First build a simple LED circuit on the experimenting board. For this, switch a 1 kΩ resistor in series with an LED. Install a wire bridge to return from the LED to the minus pole of the battery.

To measure direct current,s the multimeter must be switched into the direct voltage area. Voltages can be measured either right at the battery by connecting the red string to the plus and the black one to the minus pole. Since the multimeter for voltage measurements has a very high internal impedance, nearly no current will flow, so that the battery is not discharged.

Our LED circuit actually comprises of two consumers: The resistor and the LED. A voltage drop occurs at either. Its total corresponds to the total voltage.

Mow determine the voltage drop at the resistor by connecting both strings to its two connections. Observe correct polarity. The red string corresponds to the plus pole, the black one to the minus pole. If you connect the strings to the circuit in the wrong direction, you will read a negative prefix before the measured value. Also set the correct measuring range for the most precise measurements possible. Also measured the voltage drop at the LED and the overall voltage drop at resistor and light emitter diode.

When consumers are switched in series, the voltages are at the following ratio:

$U_{ges} = U1 + U2 + … Un$

Figure 42: Setup of the simple LED circuit. A voltage drop occurs at both consumers, i.e. the resistor and the LED (U1 and U2).

U_{ges} indicts to total voltage drop at all consumers.

Figure 43: Setup of the simple LED circuit

Figure 44: The overall voltage of 8.2 V was determined.

Figure 45: A voltage of 5.59 V drops at the 1 kΩ resistor. For precise voltage measurement, always set the best measuring range.

How to Measure Alternating Voltages?

Alternating voltages are generally measured like direct voltages. Observe that the multimeter is set for an alternating voltage range. Otherwise, you your not measured any voltage even though it is there.

Switch the multimeter to the alternating voltage range of 200 V and take the LED circuit set up before in operation again. Now measure the individual voltages at the resistor and the LED, as well as the overall voltage.
Although the LED is still lit, the display will always show twice the voltage value.

If you want to determine the alternating low voltage of a mains adapter while the multimeter is set to direct voltage, you would instead measure 0.0 V – although there is,in fact, voltage applied!

Do not perform any measurements with 230 V voltage at a mains adapter. For one thing, this would mean working with high voltages where you may contact blank, current-conducting parts directly at the measuring prods. This may cause fatal accidents! Multimeters also often are designed for a maximum voltage of 250 V only. In direct proximity of a substation, this may be exceeded and overload the meter.

Figure 46: If you try to measure voltage drops at the circuit with an alternating voltage range set, you will determine twice the voltage as when the instrument is set correctly to direct voltage. In fact, the circuit did not change as compared to before.

10 How to Measure Currents?

You have already learned that a voltage drop occurs at every component if several consumers (like the simple LED circuit) are switched in sequence. The total of these individual voltages is the overall voltage. Let us have a closer look at this circuit again. You will see that all consumers are in a single line strand. The same current flows through all of them. The overall current therefore is the same as the current strength flowing through every single consumer.

To measured currents, the multimeter must be switched in series with the consumer or consumers. Therefore, remove the wire bridge between the LED and the minus pole of the battery. Connect the multimeter instead. The red string must be connected to the LED, the black one to the battery's minus pole.

Before connecting the battery, switch the multimeter to the largest current measuring range of 200 milliampere (mA). Then reduce the measuring range until you can read the precise measurement.
In this measurement, this is the 20 mA range with which you will determine about 5.5 mA flowing through the circuit.

Do not switch to too small a current measuring range. The meter would be overloaded.

Usually, current measuring meters are protected by fuses. They must only be replaced when the multimeter is not performing any measurements.

The same current as for the other consumers of this circuit flows through the meter. Since the multimeter has a very low internal resistor in the area of current measurement, it does not falsify the circuit and therefore the measured result.

Attention! Never measure the current right at a consumer. If you touch both strings to the connections of a battery, this would be about the same as short-circuiting it. Extremely high currents would flow, which are very dangerous and would also destroy the meter!
Figure 47: To measure currents, the multimeter must be installed in the circuit.

Figure 48: The multimeter is installed in the circuit to replace the wire bridge. It is switched in series to the other consumers.

Figure 49: The same current as for the other consumers of this circuit flows through the multimeter.

How to Measure a Line Passage?

Measurement of line passages can be interesting for several reasons. For example, if you want to find a specific core in a multi-core wire or if you check a cable for function or cable break.

Many multimeters have their own measuring range for this, which no only displays the measuring results but also have a beeper installed that will emit an acoustic signal at line passage.

Line passages can also be determined easily with the ohm meter function (impedance function). A few basics on this: Switch the multimeter to the Ω range and put the two measuring prods of the measuring lines together. The display shows 0.0 Ω, meaning "no impedance" (line passage). Moving the two test prods apart increases the impedance to infinite and the multimeter shows "1—". This means "no passage" or a cable break. Try determining the line passage for different cables.

To determine the line passage, a cable must be powered down.
It must not be connected to any power source!

Figure 50: Holding the two strings together will cause the multimeter to show 0.0 Ω or 0.01 Ω when impedance measurement is set. This means that line passage is present, which equals nearly no impedance.

Figure 51: Moving the strings apart turns the impedance infinite, which is displayed as "1—". This would mean cable break or wires not found in a multi-core cable.

Figure 52: Determination of the line passage at a cable.

Measuring in a Circuit: Determining Individual Voltages at Components

Set up a combined circuit where you switch the two 1 kΩ resistors in parallel and in series to the two 330 Ω resistors before installing the LED. This ,leads to a circuit with four consumers where you can measure the individual voltages. Touch the two measuring strings to the two connection wires of each resistor and the LED each.

You will find that the two 330 Ω resistors show the same voltage drop (1.59 V). The two resistors switched in parallel are to be considered one, so that you will only measure a "quasi mutual" voltage drop. No matter if you determine the voltage drop at the 1 kΩ resistors individually or as a parallel circuit - it is always the same. In our example, it is about 2.41 V. The LED shows a voltage drop of about 3.2 V.

Figure 53: Mixed LED circuits of two parallel 1 kΩ and two serial 330 Ω resistors; the circuit also shows the possible measuring points.

Figure 54: Circuit of a mixed serial and parallel circuit controlling an LED.

Figure 55: No matter where the voltage drop is measured at each individual one of the two resistors switched in parallel or all of them together - it is always of the same size.

Figure 56: The same voltage drop will occur at two equally sized resistors in series.

Measuring Resistors in a Circuit

When measuring individual resistors in a circuit, always observe whether any other components may be switched in parallel with them that may be measured as well. For example, this occurs in case of resistors switched in parallel. You may only determine the overall impedance for them. If you want to measure the individual impedances, you need to remove at least one connection of the resistors switched in parallel from the circuit. Only this permits testing every single one of the individual resistors, which may also be more than two.

You may also measure total impedances, such as the total impedance of all resistors or the joint circuit. The total impedance of our circuit, for example, is 1,139 Ω. The 2,000 Ω measuring range is sufficient for this. These 1.1 kΩ correspond approximately to the dropping resistor of 1 kΩ that an LED needs to light up.

Including the LED, the overall impedance of the circuit is 31.3 kΩ. To be able to measure it, switch to the 200 kΩ range.

Impedance measurements in circuits are to be performed without voltage supply only, so that no battery must be connected to the circuit.

Figure 57: Only the overall impedance of, in this case, 493 Ω, can be measured at the two 1 kΩ resistors installed in parallel in the circuit.

Figure 58: To determine the individual resistors in a parallel circuit, disconnect the resistor on one side. Only this permits measurement of the impedance values of each individual resistor.

Figure 59: Measurement of individual resistors in a circuit works correctly only if no other components are switched din parallel with them.

Figure 60: Determination of the overall impedance of the circuit; if an infinite resistor was measured, this may suggest a defective circuit.

14
Measuring in a Circuit: Determining Individual Currents in the Circuit
In a pure serial circuit, the same current will flow through all consumers (e.g. resistors). Therefore, the current is the same everywhere. Where several consumers are switched in parallel, the overall current splits up into individual currents. They become larger the lower the impedance of the consumer and vice versa. The total of the individual currents of a parallel circuit is the same as the total current. This results to the following relationship for parallel circuits:

$I_{ges} = I1 + I2 + … In$

For series circuits with several consumers, the following applies:

$I_{ges} = I1 = I2 = … In$

For this measuring exercise, set up a circuit of three resistors in parallel, two of which with 330 Ω each and the third with 2.2 MΩ. To be able to switch the multimeter in the different paths, provide wire bridges that you can pull out easily of required. Provide another 1 kΩ resistor in series with the three parallel resistors. Last, install the LED supplied via the resistors. Provide a possibility for current measurement in this string as well.

The total current I_{ges} determined for this circuit is at 4.87 V. It is the total current that flows through the three parallel and then through the series resistor and the LED.

Hardly any current flows through the very high 2.2 MΩ resistor. A measurement current of approx. 1 mA, however, suggests a very high measuring error. To actually have a current of 1 mA flow through it, a voltage of 2,200 V would be needed. About 2.4 ma each flow through the two 330 Ω resistors. The total of the individual currents measured is a little less than the overall current determined. The reason is in the unavoidable measuring errors.

Figure 61: In this circuit of several parallel and series resistors, wire bridges are required. The wire bridges may be replaced by the multimeter for current measurement.

Figure 62: To receive suitable measuring points for current measurement at the paths of the parallel resistors, the three resistors must be bent to different lengths.

Figure 63: The total current determined for this circuit is at 4.87 mA. It is the total current that flows through the three parallel and then through the series resistor and the LED.

Figure 64: Hardly any current flows through the very high 2.2 MΩ resistor. The measured value of 1 mA is, however, only due to a high measuring error. In fact, it is much lower.

Figure 65: About 2.4 A each flow through the two 330 Ω resistors.

Check Measuring Results

You have already seen some formulas in the exercises above. This chapter deals with the most important formula: Ohm's law. It describes the interrelation between current, voltage and resistor and once again shows by calculation what you have already found in several measurements: For example, that very low currents flow through high resistors and that there are high voltage drops there.

Ohm's law for direct currents/direct voltages

$R = U / I$
$I = U / R$
$U = I * R$

U ... Voltage in volt (V)
I ... Current in ampere (I)
R ... Impedance in Ohm (Ω)

helps to support measurements by calculation as well. Calculations can also help recongnise possible measuring errors that may happen when, e.g, a mistake has been made when reading the display's decimal digit.

Ohm's law also helps you save measurements. For example, if the voltage and resistance are already known, you can use the formula I = U / R to calculate the current that flows through the circuit. Of course, you may also determine partial currents or voltages in a circuit. Even resistors can be calculated.

Some example calculations:

How high if the current flowing through a 330 Ω resistor when the voltage at it drops by 9 V?

I = U / R 9 V / 330 Ω = 0.027 A = 27 mA

The total resistance of a circuit is 1,500 Ω, the total current flowing through the circuit
is I_{ges} = 40 mA. What voltage is the circuit connected to?

U = I * R 0,04 A * 1,500 Ω = 60 V

16 The Multimeter as a Battery Tester

Multimeters meet the function of a battery tester as well. Since multimeters measure voltages precisely, they permit a precise statement on how charged a battery or rechargeable battery still is. The OK/NOK indication of many battery testers only permit very vague statements.

To inspect battery voltage, the multimeter must be switched into the direct voltage area. Since you already know how high the expected maximum voltage is, you can set the correct measuring range at once: e.g. 2 V for 1.5 V batteries.

Now put the red string to the plus pole, the black one to the minus pole.
You can already read the precise voltage of the energy storage on the display.

Several multimeters, including the Voltcraft VC-11, have separate measuring ranges for battery tests. They are at about 1.5 V and 9 V. You may use these areas to measure batteries particularly precisely.

Even if the multimeter displayed voltages with an accuracy of two decimal digits - the significance is not very high. The idle voltage measured here is always higher than the voltage a battery supplies under load.

An indicative measuring result is only possible if the voltage drop is determined at the battery or rechargeable battery under load.

Figure 66: The idle voltage of this battery is 9.6 V.

Figure 67: Under load,. the voltage drops to 9.43 V. Only under the load at which the battery is usually operated can a reliable statement be made about whether its charge is still sufficient.

Measuring Diodes
A diode only permits current to flow in one direction. To determine flow direction, multimeters often have a dedicated diode test function integrated. It usually also works as a passage tester and has a beeper that emits an acoustic signal at current passage.

Diodes can also be measured with the multimeter's impedance function. When very low impedances are determined, measurement takes place in flow direction, for very high impedances, measurement takes place in reverse direction.

First build a simple LED circuit. It comprises an LED with 1 kΩ resistor. Add a diode installed in the line strand. Put a second LED strand on the experiment board in parallel. Now, however, install the diode in the reverse direction. You can recognise diode direction at a ring on one side of the cylinder. Once you have connected the battery, only one LED will be lit. the other one remains dark, because its diode is operated in reverse direction. Remember which LED is lit and which one is not. Then disconnect the battery from the circuit.

Now put the multimeter to impedance measuring and put the strings to both ends of a diode as if to measure impedance. To this with both diodes in turn. When the display shows "1---", you have measured the diode in reverse direction. If a measured value is displayed, you have measured in passage direction.

If you have measured the reverse direction in the lit LED, this shows that the measuring lines are attached to the diode swapped. Always observe correct polarity when testing diodes. The red measuring line must be connected to the ring side. Generally, however, you need to observe the current flow direction in a circuit.

This measuring method can be used to test diodes for function. Only when they only permit current to flow in one direction and block it in the other direction are they OK. Any other measuring result indicates a defective component.

Figure 68: The diode test circuit looks rather complicated. However, it should help to not only recognise what happens when the diode is installed correctly and incorrectly, but also how to touch the measuring strings to the diode correctly.

Figure 69: This circuit uses two simple LED circuits. One diode was installed in each strand - one in passage and one in reverse direction.

Figure 70: This diode is operated in reverse direction. The impedance determined is infinite.

Figure 71: If the red string is touched to the diode side marked with the ring,, it is measured in passage direction.

Figure 72: A second option is the diode test function of the Voltcraft VC-11. If a measured value is displayed, the diode is measured in passage direction.

18 Inspecting Transistors

Only few multimeters can be connected for precise measurement of transistors. Nevertheless, it is possible to inspect their general function with a simple multimeter. However,. you need to limit yourself to the statement of "works" or "doesn't work".

Imagine a transistor comprising of two diodes, which also corresponds to its equivalent circuit diagram. First set the multimeter for diode test. In the Voltcraft VC-11, it is marked with the red circuit diagram of a diode. To test an NPN transistor, apply the rated measuring string to the base connection, the black one alternatingly to the collector and emitter. In both cases, the instrument should not display about the same measured values. If the instrument indicates voltages in this measured range, you need to measure about 0.7 V to 0.8 V each. The VC-11 shows only relative values. They are, however, about equal on either side with about "1080". This provides information on whether a transistor is generally OK or not.

If you want to test a PNP transistor in this manner, you only need to swap the measuring strings.

Figure 73: Simple multimeters can only be used for a general statement on whether a transistors is OK or not. To test an NPN transistor, apply the rated measuring string to the base connection, the black one alternatingly to the collector and emitter.

Figure 74: In both cases, the display should not display about the same measured values.

19 Inspecting Light Emitter Diodes

A very simple method to test light diodes can be performed with any multimeter. Build a simple LED circuit on the experimenting board. Then precede the LED with a 1 kΩ resistor and connect a 9 V battery so that the LED is lit.

Now measure the voltage drop at the LED. Connect the two measuring strings to the two LED connections for this. Now the multimeter is switched in parallel to the consumer, as generally required for voltage measurements. The voltage drop determined in this manner is about 2 V. In addition to this, you can check if the LED is lit or not.

Figure 75: With this simple LED circuit, the function of a LED can be tested with the voltmeter function.

Figure 76: The voltage drop at the LED is about 2 V.

20 Measuring Temperatures

Various multimeters can also measure temperatures. This requires a separate temperature sensor. In the Voltcraft VC840 multimeter, for example, a so-called NiCrNi sensor(Nickel-Chrome-Nickel type K) is used. The temperature measuring range of the instrument is from -40 °C to +1,000 °C. The wire temperature sensor included with the multimeter is meant for temperatures up to +400 °C.

First set the multimeter to the measuring range "°C". It symbolises temperature measurement. Switch on the device now. You will see that you can measure the ambience temperature even without the temperature sensor connected. This permits quick determination of the room temperature.

Now connect the two measuring lines of the temperature sensor to the multimeter. Connect the black string to the COM socket as usual. The red string is connected to the ΩmA°C socket. Since you will hardly need this socket for measurements at electrical components or circuits, this is unusual. This is also one of the most common error sources when a temperature measurement is not working.

Attention! Do not connect any voltages to the ΩAmA°C socket. This may destroy the multimeter.

Observe that only the sensor at the tip of the wire temperature sensor is designed for resisting high tempters. Never subject the multimeter or measuring lines to any high temperatures! While you can usually read electrical values directly, temperature measurement takes some time. Since the temperature sensors comprise different materials, they have to heat to he temperature to be measured first. Therefore, touch the temperature sensor to or hold it into the medium to be measured until the display has stabilised. This usually take about 30 seconds.

Figure 77: Once you have set the temperature measuring range at the multimeter, you may measure the ambience temperature.

Figure 78: For temperature measurement, a so-called NiCrNi(nickel-chrome-nickel type K) sensor is used. It is designed for temperatures of up to +400 °C.

Figure 79: The black string is connected to the instruments COM socket. The red one is connected to the Ωsocket.

Figure 80: The air temperature close to a halogen spotlight is determined here. Only the measuring prod of the wire temperature sensor must be subject to high temperatures.

Annex: Power and Work

Indirectly, the multimeter can also be used to calculate power intake and the work performed by the electrical energy in it. For this, determine power intake first. This requires a current and voltage measurement at the circuit. The total current I_{ges} and total voltage U_{ges} must be measured in each case.

Use the formula: P = U * I
P ... electrical power in watt (W)
U ... Voltage in volt (V)
I ... Current in ampere (A)

to calculate power intake of the circuit. If you also want to know how high the electricity consumption is, e.g. within one hour, you need to multiply the previously determined power by 3,600 seconds.

The formula: W = P * T
W ... electrical power in watt seconds (Ws)
P ... electrical power in watt (W)
T ... Time in seconds (s)

Our current meters work according to the same principle, by the way. While you are working with the small unit of watt seconds here, however, the current meter usually uses kilowatt hours (kWh).

Figure 81: To determine power intake and the electrical work performed, first determined only the overall voltage U_{ges} ...

Figure 82: … and the current I_{ges} flowing through the circuit. Then the desired values only need to be calculated.

Imprint

www.elo-web.de

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ISBN 978-3-645-10091-5

Produced at the order of Conrad Electronic SE, Klaus-Conrad-Str. 1, 92240 Hirschau

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Key of figures

Farbe	Colour
Ring 1	Ring 1
1. Ziffer	1. Digit
2. Ziffer	2. Digit
Multiplikator	Multiplier
Toleranz	Tolerance
Schwarz	Black
Braun	Brown
Rot	Red

Orange	Orange
Gelb	Yellow
Grün	Green
Blau	Blue
Violette	Violet
Grau	Grey
Weiß	White
Gold	Gold
Silber	Silver
LED	LED
Iges	I_{ges}