In videos #72 and #76 we started to make invisible electrons somehow visible. There, we dealt mainly with voltage. In this video, we continue with measuring current.

So, let’s start with a simple example: We use a 5-volt power bank and a 47 Ohm resistor connected together. According Ohm’s law we would expect a current of 5V/47 Ohm = 106mA. Even if we assume that our thin wires add a few ohms, we should get more than 100 mA. So, let’s measure.

The old-fashioned way to measure current is to use an analog meter. This works similar to an electromotor which is pulled back with a spring. The more current, the stronger the force of the motor, and the more amplitude until it is stopped by the spring. If we insert the instrument into the negative lead of our setup, it shows a little more than 100 mA, as expected.

Let’s use now more modern instruments. We take your multimeter and insert it into the same place and read the value. Very convenient.

I have three multimeters. The first is a bench meter. It measures 96 mA. Now we try the Uni-T multimeter. It shows more current. So, let’s take the Fluke. It shows even less current than the bench multimeter. So, what is the truth? And why do we get such big differences?

If I would use very cheap and imprecise multimeters, we would have an excuse. Unfortunately, this is not the case, my multimeters were not cheap and are quite precise. So, there must be another reason.

I take now the bench multimeter and change the lead from mA to A. Now, I also get 100 mA. With exactly the same multimeter. Strange.

One general remark for today’s video. I will not measure and calculate very precisely and I will not use precision setups because we will only discuss effects big enough to be relevant for all hobbyists. We do not want to find the hair in the soup, as the saying is here in Switzerland.

To get this problem sorted out, we have to know, that Multimeters do not measure current. They have a resistor between the two connectors and measure the voltage drop across it. And then, they use Ohm’s law to calculate the current.

Let’s simulate this setup: Instead of the multimeter, I connect a 1-ohm resistor and I measure the voltage across it. It is 102 mV. According ohms law, the current is I=U/R = 102 mA which is more or less what we measured before.

If we would try to measure only 1 mA, the voltage would 1 mV and not so easy to be measured. If we would measure 1 A, the voltage would be 1V and very simple to be measured. In this case, we could even use a smaller resistor and would still be able to measure the voltage exactly. This is the reason behind the behavior of the bench multimeter: Between the mA connector and COM is bigger than the resistor between the Ampere connector and COM.

Let’s check if we are right. But how can we measure the inner resistance of our multimeters? We apply a constant current and measure the voltage across the two leads. If we use our bench meter and use the mA input, we measure 0.56 volt at about 105 mA. So, the resistor is approximately:

R=U/I=0.56/0.105=5 ohm

If we use the Ampere input, we only measure 0.008 volt or 8 mV. This resistor is therefore only 0.1 ohms, much smaller. So, if we use the mA range, we actually have 47+6 =53 ohms and the current should be roughly 94 mA. In the case of the Ampere range, the inner resistance of the multimeter is negligible, because the tolerance of the 47-ohm resistor is bigger.

So, we discovered the first rule: We always introduce an error if we measure current because of the inner resistance of our instrument. This has nothing to do with the precision of the instrument itself. So, we best use the highest possible range of your multimeter.

Sometimes, this resistor is also called “shunt” resistor o just “shunt”. The name comes from our ancient ampere meter used at the beginning of this video. If we want to extend the range of this meter, we would have to “shunt” a part of the current with a small resistor. If I connect a 0.5-ohm resistor in parallel to the Ampere meter, it only shows 50 mA. So, its range is doubled. For higher current, also smaller resistors values exist. We will use them when we deal with higher currents.

But let’s come back to our topic. We inserted our multimeter or our resistor into the negative supply lead. We can also insert it into the positive lead and do not see any difference, because the current is exactly the same, and also the effect of our internal resistor is the same.

We were no able to measure constant currents. In many applications, we do not have constant current. One example was video #58, where we measured the current used by an ESP8266. There, we discovered big current spikes. How can we measure variable currents? Again, the multimeter is not capable to do this. But, we still have our oscilloscope which helped us out last time. And together with what we learned before, we easily can replace the multimeter by the oscilloscope in the setup with a shunt resistor. We just measure the voltage across the resistor with the oscilloscope.

Because we have two channels, we can use channel 1 to measure the voltage and channel 2 to measure current. Very convenient. So, we connect one probe to the 47 ohm load and the other one across the shunt resistor. So, channel one shows as expected a little more than 5V. But the other channel shows only about 20 mV. So, is seems, that nearly no current is flowing through the resistor even if it is connected exactly as before? This cannot be. So, we have to search somewhere else. Let’s look at the probes of the oscilloscope. Each probe has an alligator clip for ground and a probe to clip on a lead. If we measure the resistance between the two alligator clips, we see (or hear), that they are connected.

Let’s go back to our diagram and introduce this connection. We easily see, that we short-circuited the shunt. So, it is clear, that we cannot measure any voltage across it. What we saw was just a measuring error. This problem is called “ground loop” and can be dangerous. If you assume, that you use this setup with the resistor in the positive lead, you would short-circuit the load and a big current would flow through our resistor and the oscilloscope probes. And this can easily destroy your one of these parts, if you have a powerful supply. Why didn’t this happen with the multimeters? Because the multimeters run of batteries, they have no ground reference and are completely independent. A big advantage.

So, we discovered the second rule: Pay extremely attention to avoid ground loops. They destroy always your measuring results, and sometimes even more. Ground loops can exist also between different instruments like the oscilloscope and the spectrum analyzer or the signal generator, because the earth wires are connected behind the scenes. It is always good to check your bench instruments and power supplies if ground is connected to earth…

Summarized, we learned, that current is usually measured by introducing a “shunt” resistor in the circuit. The voltage measured across this resistor can easily be converted into a current reading. The smaller the shunt, the smaller the disturbing effect on our circuit. A small shunt also reduces the voltage and increases the requirements for the measuring of the volt. As we will see when we measure small currents, it also increases the vulnerability to noise.

Basically, we can measure current on the ground, or “low side”. We also can measure current in the connection to VCC, or “high side”.

This was the first possibility to measure current. It depended completely on Ohm’s law. We can also measure current using a completely different physical law by using hall sensors. A hall sensor is able to detect magnetic fields around a connector. A typical representative of this class is the clamp ampere meter. You just “clamp” it around one lead and it shows you the current flowing through this wire. If we look at its range, we see, that it has no mA range, but ranges of 40 and 600A. This explain also it inaccuracy in our measurements before. Its turf are high currents.

If we include both wires in the clamp, the meter reads zero, because the two currents are the same, but in different directions.

These meters have three big advantages:

1. Because it does not introduce anything into the circuit, we have no errors because of shunt resistors
2. Because there is no connection to our circuit, we have no problems with ground loops
3. They work for DC and AC

Apart from its inability to measure small currents, it has another big disadvantage: It measures all kind of magnetic fields. If I put a magnet close to its clamp, it shows big currents. This is, why these instruments have a button to zero the effects of any existing magnet fields before measuring.

Another well-known module uses this effect: the ACS712. Here, we have a small chip which contains a “cable loop” and a hall sensor in one case. As with the clamp meter, they are isolated from each other.

We get them in 5A, 20A, and 30A. Because they have to be inserted in the circuit, they are somehow similar to the shunt resistor, but they avoid the problem with the ground loops and can also be used for DC and AC. They are also used for bigger currents.

Today, we dealt with some topics around measuring current in general. In the next video I will concentrate on measuring small currents like sleep mode currents. And in another video I will concentrate on measuring higher currents, e.g. currents of solar panels.

I hope, this video was useful or at least interesting for you. Bye