Resistor Exercise

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The most important goal in building the line following robot is to understand how each circuit operates. In order to understand the line detection circuit of the robot, we need to understand the behavior of resistors in series circuits. The line detection circuit has four photoresistors (R4, R5, R6, R7), one variable resistor (R3) and one fixed resistor (R2). The photoresistors are connected as two series pairs (R4 and R5 are in series and R6 and R7 are in another series). The two pairs of photoresistors are wired in parallel to each other. The two series are connected together by the variable resistor R3. Resistors R3 through R7, as a group, are in series with R2.

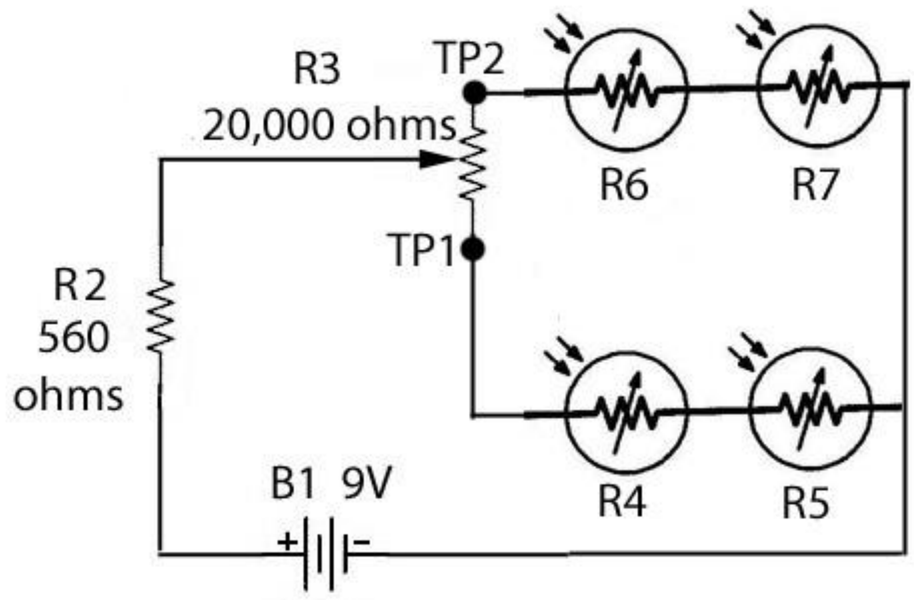

Figure 1 Line detection circuit

The above circuit is fairly complex. In order to understand the function of the circuit, it would be helpful to look at a simplified version (go to next page).

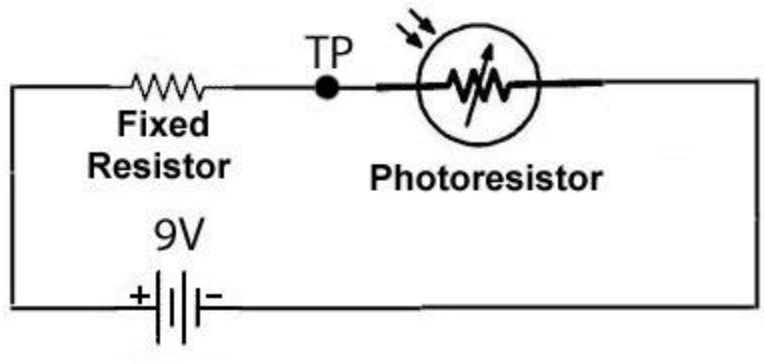

Figure 2 simplified circuit

In Figure 2 we have a simplified circuit that is easier to understand. Here we can see that there are two resistors, one which is fixed, and one which is a photoresistor. These two resistors are in series and are connected to a nine volt battery. In between the resistors there is a test point (TP) we can use to measure voltage with our meter.

The fixed resistor has a resistance that does not change. The photoresistor is a type of variable resistor. When the amount of light shining on the photoresistor increases, the resistance of the photoresistor decreases. If we place the photoresistor in a dark room, it will have a high resistance value. If we shine a bright light on the photoresistor, it will have a low resistance value. At intermediate levels of light the photoresistor will have intermediate values of resistance.

Now suppose we use our meter to measure the voltage drop across the photoresistor. We touch the red probe of our meter to the test point (TP) and the black probe to the negative side of the battery. Also suppose that a bright light is shining on the photoresistor. Then let's say our meter indicates a voltage drop of 2 volts.

Now we cover the photoresistor with a strip of dark paper, which blocks a significant amount of light from shining on the photoresistor. And when we measure the voltage drop across the photoresistor, we find that it is 6 volts. Why did the voltage increase when the strip of paper was placed over the photoresistor? The voltage increased because the resistance of the photoresistor increased. If we understand how resistors behave in a series circuit, then we understand why the voltage increased.

Rules for resistors in series

1. The total resistance of a series of resistors is the sum of the resistances of the individual resistors. Suppose our fixed resistor in Figure 2 is 10 ohms and the photoresistor with bright light shining on it is also 10 ohms. Then the total resistance of the circuit will be 20 ohms (10 + 10 = 20).

2. The current flowing through a series of resistors is determined by the voltage applied and the total resistance. Let's take our example from rule one. We have a total resistance of 20 ohms. We will use a 9 volt battery for the circuit. Then by using Ohm's Law, we can calculate the current:

Current = Voltage/Resistance

Current = 9 volts/20 ohms = 0.45 amps

3. The voltage drop across the combined resistors will equal the voltage supplied by the battery (assuming there are no additional loads between the resistors and the battery). We call this the total voltage drop. In other words, if we place a meter probe at each end of the series of resistors, we will be measuring the total voltage drop across all resistors combined.

4. The voltage drop of each resistor in the series can be calculated using Ohm's Law if you know the amount of current flowing in the series circuit and the resistance of the resistor. This rule is the most important one for us in understanding why the voltage drop changes for a resistor in a series circuit when the resistance changes (as it can with the photoresistor).

If we have two resistors in series and both have the same amount of resistance, we can quickly determine the voltage drop across each resistor. It is just half the voltage supplied by the battery. In other words, if we have two resistors of the same amount of resistance connected in series and supplied 9 volts from a battery, each resistor will have a voltage drop of 4.5 volts (which is half of 9 volts).

In the case of our simple series circuit with a fixed resistor and photoresistor, it is very unlikely that both resistors will have the same amount of resistance. How do we calculate the voltage drops then? We use rule number 4.

Let's take some examples (I have used much lower resistances in these examples than the actual resistors used for the robot just to make the calculations easier to follow).

Example 1.
Calculate the voltage drop across the photoresistor when light is NOT shining on it and it has a resistance of 15 ohms. The fixed resistor has a resistance of 5 ohms. The voltage supplied is 9 volts.

Step 1. Calculate the total resistance of the circuit using rule number 1:

Total resistance = resistance of fixed resistor + resistance of photoresistor

Total resistance = 5 ohms + 15 ohms = 20 ohms

Step 2. Calculate the current in the circuit using rules number 2 and 3:

Current = Total Voltage Drop/ Total Resistance

Current = 9 volts/20 ohms = 0.45 amps

Step 3. Calculate the voltage drop across the photoresistor using rule number 4:

Voltage drop of photoresistor = Current X Resistance of photoresistor

Voltage drop of photoresistor = 0.45 amps X 15 ohms = 6.75 volts

Example #2.

Calculate the voltage drop across the photoresistor when light IS shining on it and it has a resistance of 3 ohms. The fixed resistor has a resistance of 5 ohms. The voltage supplied is 9 volts.

Step 1. Calculate the total resistance of the circuit using rule number 1:

Total resistance = resistance of fixed resistor + resistance of photoresistor

Total resistance = 5 ohms + 3 ohms = 8 ohms

Step 2. Calculate the current in the circuit using rules number 2 and 3:

Current = Total Voltage Drop/ Total Resistance

Current = 9 volts/8 ohms = 1.12 amps

Step 3. Calculate the voltage drop across the photoresistor using rule number 4:

Voltage drop of photoresistor = Current X Resistance of photoresistor

Voltage drop of photoresistor = 1.12 amps X 3 ohms = 3.36 volts

Let us now review the results of the two calculations above. When light was shining on the photoresistor it had a resistance of 3 ohms and we calculated the voltage drop to be 3.36 volts. When light was not shining on the photoresistor, it had a resistance of 15 ohms and we calculated the voltage drop to be 6.75 volts. This is the key to the function of the line detector circuit. When light is shining on the photoresistor the voltage drop will be lower than when light is not shining on the photoresistor. The different voltages at test points one and two of the complete circuit act as signals sent to the voltage comparator circuit where they are used to turn on or off the robot motors. When the voltage drop across one pair of photoresistors is greater than the voltage drop across the other pair, the robot knows a dark line is under the pair of photoresistors that have the larger voltage drop.

Let us take a look again at our complete line detection circuit on the next page.

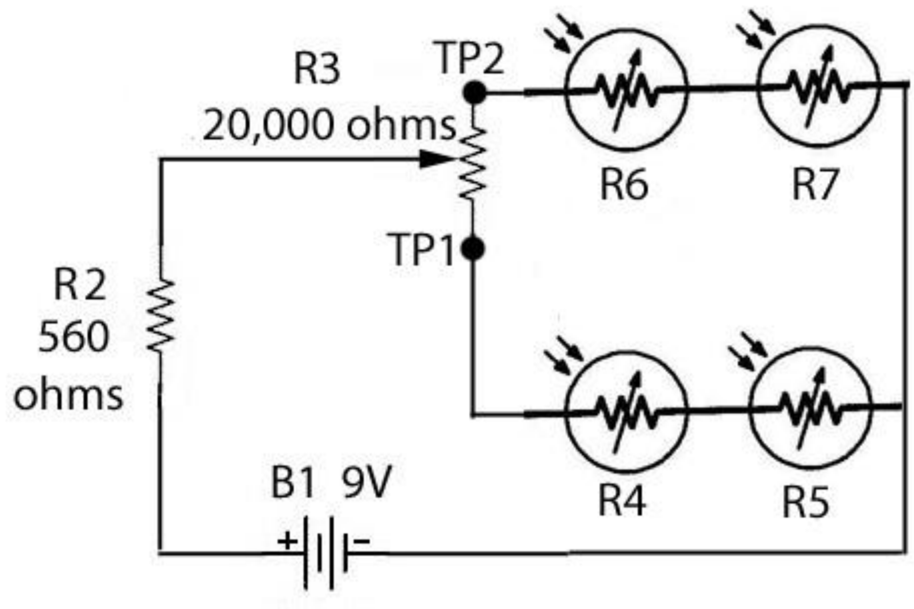

Figure 3 Line detection circuit

The line detection circuit is essentially a set of two of the simplified circuits of Figure 2. If more light is shining on R6 and R7 than on R4 and R5, then the voltage drop at test point 1 (TP1) will be greater than the voltage drop at test point 2 (TP2). Therefore, the robot will know that a dark line is under R4 and R5. It will then turn on the proper motor to steer the robot in such a way that it will center the line underneath the robot.

I have now explained, using Ohm's Law, why the voltage drop changes as the resistance of the photoresistor changes. My explanation is by way of mathematics. I realize that you might still be wondering why resistors behave the way they do in series circuits. So let's continue with another approach to explaining this interesting and important behavior of resistors in series.

Let's take a look at a very simple circuit with one resistor (Figure 4). Suppose the resistor has a value of 9 ohms. Then by Ohm's Law we know that the current for this circuit will be 1 amp (9 volts/9 ohms). Let us imagine we can see the current flowing in the circuit. As the current enters the resistor, it collides with many of the atoms in the resistor. For each collision of an electron with an atom, some of the electron's energy is converted into heat energy. We can say that the current has lost some of its electrical energy. Assuming a uniform interior to the resistor, by the time the current has moved half way through the resistor, it has lost half of its electrical energy. As the current exits the resistor, it has the same potential energy as the positive terminal of the battery (9 volts different than when it left the battery). The key is that the electrical energy is converted to heat energy as electrons pass through the resistor. At the midpoint of the resistor, half the electrical energy has been lost by conversion to heat.

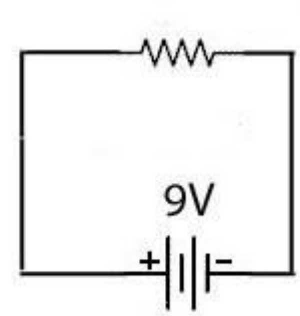

Figure 4 one resistor

If we cut the resistor in half, then each half of the resistor would contain half as much resistance as the whole resistor. Suppose we make a series circuit with the two halves of the resistor, each with a resistance of 4.5 ohms. Since the two resistors in series have the same amount of resistance, we know that the voltage drop across each resistor will be 4.5 volts. Perhaps this seems logical to you. When the resistor was whole, it consumed all of the nine volts. When cut in half it consumes only half the voltage (provided it is in series with the other half).

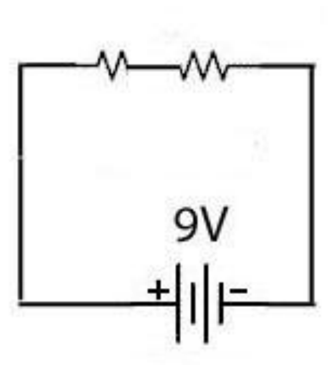

Figure 5 half-resistors in series

If we cut the resistor in two parts, so that one part contains two thirds of the resistor, then our resistor parts will be 3 ohms and 6 ohms. Suppose we make a series circuit with these two resistors. Then there will be a 3 volt drop across the 3 ohm part and a 6 volt drop across the 6 ohm part. The 6 ohm part is twice the length of the 3 ohm part so it makes sense that the voltage drop across the 6 ohm part would be twice the voltage across the 3 ohm part.

Perhaps you will notice in my two examples above, I have created a situation similar to the simple series circuit of Figure 2. If I measure the voltage drop at a point between the two resistor parts and the negative side of the battery, I will have more voltage drop when 6 ohms are between the meter test probes than when there is 4.5 ohms between the test probes.

Resistors in series exercises

Now you can work out a few calculations on your own. When you have finished I will give you the answers so that you can check your work.

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1. The circuit contains two resistors in series connected to a 9 volt battery. R1 is 6 ohms and R2 is 9 ohms. What will be the voltage drop of R1?

2. The circuit contains three resistors in series connected to a 12 volt battery. R1 is 5 ohms, R2 is 10 ohms and R3 is 15 ohms. What will be the voltage drop of R2?

3. The circuit contains two resistors: R1 is 100 ohms and R2 is 150 ohms. The circuit is connected to a 15 volt battery. What will be the voltage drop of R2?