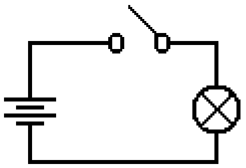
Chapter 9A – Review of Basic Electronics

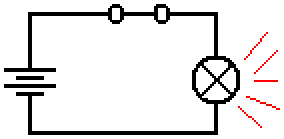
A traditional presentation of this material might have begun with a review of the basic concepts of direct current electricity. Your author has elected to postpone that discussion until this point in the course, at which time it is needed.

A Basic Circuit

We begin our discussion with a simple example circuit – a flashlight (or "electric torch" as the Brits call it). This has three basic components: a battery, a switch, and a light bulb. For our purpose, the flashlight has two possible states: on and off. Here are two diagrams.



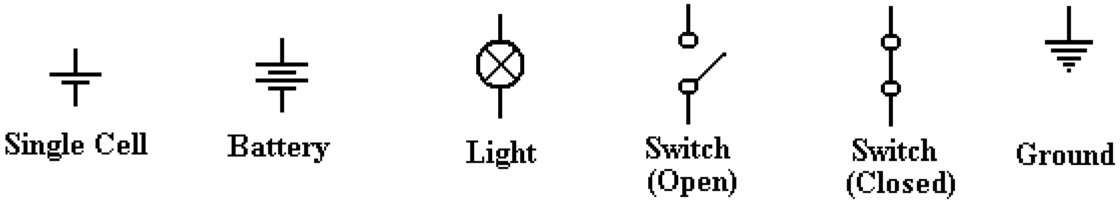
Light is Off



Light is On

In the both figures, we see a light bulb connected to a battery via two wires and a switch. When the switch is open, it does not allow electricity to pass and the light is not illuminated. When the switch is closed, the electronic circuit is completed and the light is illuminated.

The figure above uses a few of the following basic circuit elements.

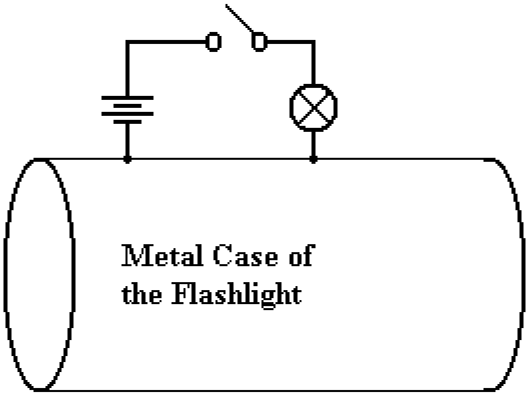


We now describe each of these elements and then return to our flashlight example. The first thing we should do is be purists and note the difference between a cell and a battery, although the distinction is quite irrelevant to this course. A cell is what one buys in the stores today and calls a battery; these come in various sizes, including AA, AAA, C, and D. Each of these cells is rated at 1.5 volts, due to a common technical basis for their manufacture. Strictly speaking, a battery is a collection of cells, so that a typical flashlight contains one battery that comprises two cells; usually AA, C, or D. An automobile battery is truly a battery, being built from a number of lead-acid cells.

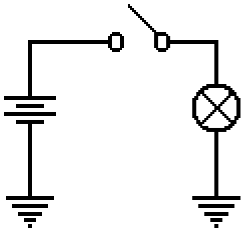
A light is a device that converts electronic current into visible light. This is not a surprise. A switch is a mechanical device that is either open (not allowing transmission of current) or closed (allowing the circuit to be completed). Note that it is the opposite of a door, which allows one to pass only when open.

The Idea of Ground

Consider the above circuit, which suggests a two-wire design: one wire from the battery to the switch and then to the light bulb, and another wire from the bulb directly to the battery. One should note that the circuit does not require two physical wires, only two distinct paths for conducting electricity. Consider the following possibility, in which the flashlight has a metallic case that also conducts electricity.



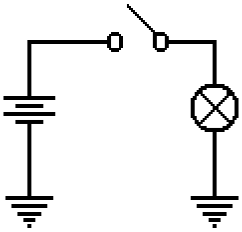
Physical Connection



Equivalent Circuit

Consider the circuit at left, which shows the physical connection postulated. When the switch is open, no current flows. When the switch is closed, current flows from the battery through the switch and light bulb, to the metallic case of the flashlight, which serves as a return conduit to the battery. Even if the metallic case is not a very good conductor, there is much more of it and it will complete the circuit with no problem.

In electrical terms, the case of the battery is considered as a common **ground**, so that the equivalent circuit is shown at right. Note the new symbol in this circuit – this is the ground element. One can consider all ground elements to be connected by a wire, thus completing the circuit. In early days of radio, the ground was the metallic case of the radio – an excellent conductor of electricity. Modern automobiles use the metallic body of the car itself as the ground. Although iron and steel are not excellent conductors of electricity, the sheer size of the car body allows for the electricity to flow easily.



To conclude, the circuit at left will be our representation of a flashlight. The battery provides the electricity, which flows through the switch when the switch is closed, then through the light bulb, and finally to the ground through which it returns to the battery.

As a convention, all switches in diagrams will be shown in the open position unless there is a good reason not to.

The student should regard the above diagram as showing a switch which is not necessarily open, but which might be closed in order to allow the flow of electricity. The convention of drawing a switch in the open position is due to the fact that it is easier to spot in a diagram.

Voltage, Current, and Resistance

It is now time to become a bit more precise in our discussion of electricity. We need to introduce a number of basic terms, many of which are named by analogy to flowing water. The first term to define is **current**, usually denoted in equations by the symbol **I**. We all have an intuitive idea of what a current is. Imagine standing on the bank of a river and watching the water flow. The faster the flow of water, the greater the current; flows of water are often called currents.

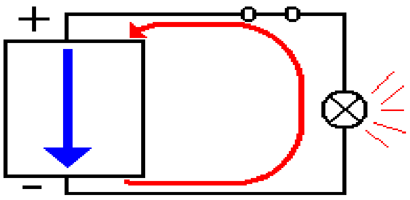
In the electrical terms, current is the flow of electrons, which are one of the basic building blocks of atoms. While electrons are not the only basic particles that have charge, and are not the only particle that can bear a current; they are the most common within the context of electronic digital computers. Were one interested in electro-chemistry he or she might be more interested in the flow of positively charged ions.

All particles have one of three basic electronic charges: positive, negative, or neutral. Within an atom, the proton has the positive charge, the electron has the negative charge, and the neutron has no charge. In normal life, we do not see the interior of atoms, so our experience with charges relates to electrons and ions. A neutral atom is one that has the same number of protons as it has electrons. However, electrons can be quite mobile, so that an atom may gain or lose electrons and, as a result, have too many electrons (becoming a negative ion) or too few electrons (becoming a positive ion). For the purposes of this course, we watch only the electrons and ignore the ions.

An electric **charge**, usually denoted by the symbol **Q**, is usually associated with a large number of electrons that are in excess of the number of positive ions available to balance them. The only way that an excess of electrons can be created is to move the electrons from one region to another – robbing one region of electrons in order to give them to another. This is exactly what a battery does – it is an electron "pump" that moves electrons from the positive terminal to the negative terminal. Absent any "pumping", the electrons in the negative terminal would return to the positive region, which is deficient in electrons, and cause everything to become neutral. But the pumping action of the battery prevents that. Should one provide a conductive pathway between the positive and negative terminals of a battery, the electrons will flow along that pathway, forming an electronic current.

To clarify the above description, we present the following diagram, which shows a battery, a light bulb, and a closed switch. We see that the flow of electrons within the battery is only a part of a larger, complete circuit.

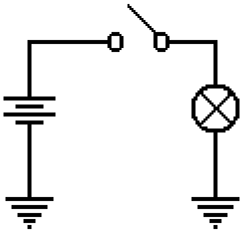
Inside the battery, the electrons are pumped from the positive region to the negative region.



In the circuit outside the battery, the electrons flow from negative to positive.

Materials are often classified by their abilities to conduct electricity. Here are two common types of materials.

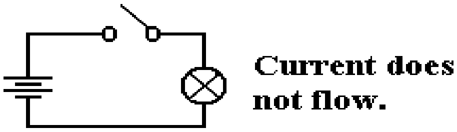
Conductor	A conductor is a substance, such as copper or silver, through which electrons can flow fairly easily.
Insulator	An insulator is a substance, such as glass or wood, that offers significant resistance to the flow of electrons. In many of our circuit diagrams we assume that insulators do not transmit electricity at all, although they all do with some resistance.



The voltage is amount of pressure in the voltage pump. It is quite similar to water pressure in that it is the pressure on the electrons that causes them to move through a conductor. Consider again our flashlight example. The battery provides a pressure on the electrons to cause them to flow through the circuit. When the switch is open, the flow is blocked and the electrons do not move. When the switch is closed, the electrons move in response to this pressure (voltage) and flow through the light bulb. The light bulb offers a specific resistance to these electrons; it heats up and glows.

As mentioned above, different materials offer various abilities to transmit electric currents. We have a term that measures the degree to which a material opposes the flow of electrons; this is called **resistance**, denoted by **R** in most work. Conductors have low resistance (often approaching 0), while insulators have high resistance. In resistors, the opposition to the flow of electrons generates heat – this is the energy lost by the electrons as they flow through the resistor. In a light bulb, this heat causes the filament to become red hot and emit light.

An open switch can be considered as a circuit element of extremely high resistance.



Summary

We have discussed four terms so far. We now should mention them again.

Charge	This refers to an unbalanced collection of electrons. The term used for denoting charge is **Q**. The unit of charge is a **coulomb**.
Current	This refers to the rate at which a charge flows through a conductor. The term used for denoting current is **I**. The unit of current is an **ampere**.
Voltage	This refers to a force on the electrons that causes them to move. This force can be due to a number of causes – electro-chemical reactions in batteries and changing magnetic fields in generators. The term used for denoting voltage is **V** or **E** (for **Electromotive** Force). The unit of current is a **volt**.
Resistance	This is a measure of the degree to which a substance opposes the flow of electrons. The term for resistance is R. The unit of resistance is an ohm.

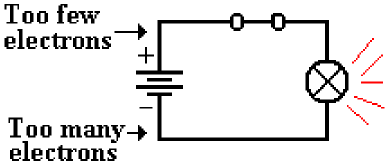
Ohm’s Law and the Power Law

One way of stating Ohm’s law (named for Georg Simon Ohm, a German teacher who discovered the law in 1827) is verbally as follows.

> The current that flows through a circuit element is directly proportional to the voltage across the circuit element and inversely proportional to the resistance of that circuit element.

What that says is that doubling the voltage across a circuit element doubles the current flow through the element, while doubling the resistance of the element halves the current.

Let’s look again at our flashlight example, this time with the switch shown as closed.



The chemistry of the battery is pushing electrons away from the positive terminal, denoted as “+” through the battery towards the negative terminal, denoted as “–“.

This causes a voltage across the only resistive element in the circuit – the light bulb. This voltage placed across the light bulb causes current to flow through it.

In algebraic terms, Ohm’s law is easily stated: **E = I•R**, where
E is the voltage across the circuit element,
I is the current through the circuit element, and
R is the resistance of the circuit element.

Suppose that the light bulb has a resistance of 240 ohms and has a voltage of 120 volts across it. Then we say E = I•R or 120 = I•240 to get I = 0.5 amperes.

As noted above, an element resisting the flow of electrons absorbs energy from the flow it obstructs and must emit that energy in some other form. Power is the measure of the flow of energy. The power due to a resisting circuit element can easily be calculated.

The power law is states as **P = E•I**, where
P is the power emitted by the circuit element, measured in **watts,**
E is the voltage across the circuit element, and
I is the current through the circuit element.

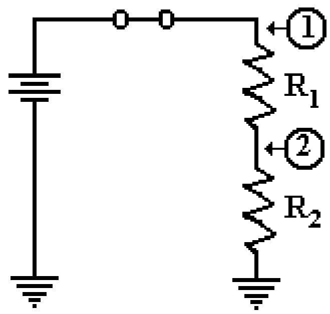
Thus a light bulb with a resistance of 240 ohms and a voltage of 120 volts across it has a current of 0.5 amperes and a power of 0.5 • 120 = 60 watts.

There are a number of variants of the power law, based on substitutions from Ohm’s law. Here are the three variants commonly seen.

$P = E \bullet I \qquad P = E^2 / R \qquad P = I^2 \bullet R$

In our above example, we note that a voltage of 120 volts across a resistance of 60 ohms would produce a power of $P = (120)^2 / 240 = 14400 / 240 = 60$ watts, as expected.

The alert student will notice that the above power examples were based on AC circuit elements, for which the idea of resistance and the associated power laws become more complex (literally). Except for a few cautionary notes, this course will completely ignore the complexities of alternating current circuits.



Resistors in Series

There are very many interesting combinations of resistors found in circuits, but here we focus on only one – resistors in series; that is one resistor placed after another. In this figure, we introduce the symbol for a resistor.

Consider the circuit at right, with two resistors having resistances of R_1 and R_2, respectively. One of the basic laws of electronics states that the resistance of the two in series is simply the sum: thus $R = R_1 + R_2$. Let E be the voltage provided by the battery. Then the voltage across the pair of resistors is given by E, and the current through the circuit elements is given by Ohm's law as $I = E / (R_1 + R_2)$. Note that we invoke another fundamental law that the current through the two circuit elements in series must be the same.

Again applying Ohm's law we can obtain the voltage drops across each of the two resistors. Let E_1 be the voltage drop across R_1 and E_2 be that across R_2. Then

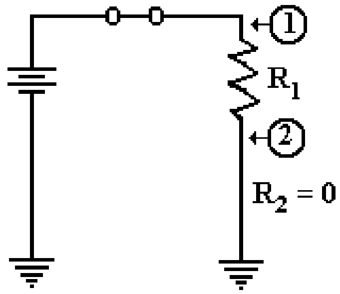
$E_1 = I \bullet R_1 = R_1 \bullet E / (R_1 + R_2)$, and
$E_2 = I \bullet R_2 = R_2 \bullet E / (R_1 + R_2)$.

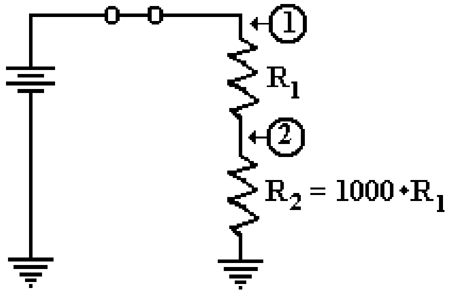
It should come as no surprise that $E_1 + E_2 = R_1 \bullet E / (R_1 + R_2) + R_2 \bullet E / (R_1 + R_2)$
$= (R_1 + R_2) \bullet E / (R_1 + R_2) = E$.

If, as is commonly done, we assign the ground state as having zero voltage, then the voltages at the two points in the circuit above are simple.

1) At point 1, the voltage is E, the full voltage of the battery.
2) At point 2, the voltage is $E_2 = I \bullet R_2 = R_2 \bullet E / (R_1 + R_2)$.

Before we present the significance of the above circuit, consider two special cases.



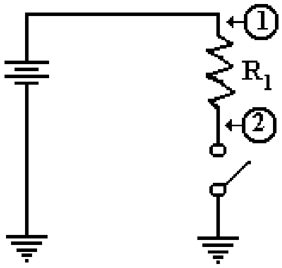


In the circuit at left, the second resistor is replaced by a conductor having zero resistance. The voltage at point 2 is then $E_2 = 0 \bullet E / (R_1 + 0) = 0$. As point 2 is directly connected to ground, we would expect it to be at zero voltage.

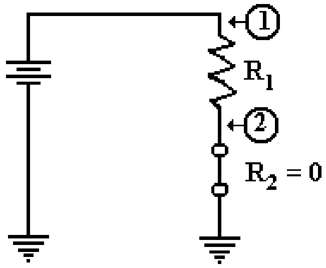
Suppose that R_2 is much bigger than R_1. Let $R_1 = R$ and $R_2 = 1000 \bullet R$. We calculate the voltage at point 2 as $E_2 = R_2 \bullet E / (R_1 + R_2) = 1000 \bullet R \bullet E / (R + 1000 \bullet R) = 1000 \bullet E/1001$, or approximately $E_2 = (1 - 1/1000) \bullet E = 0.999 \bullet E$. Point 2 is essentially at full voltage.

Putting a Resistor and Switch in Series

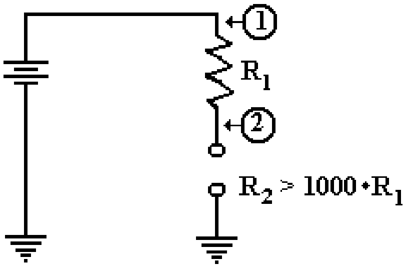
We now consider an important circuit that is related to the above circuit. In this circuit the second resistor, R_2, is replaced by a switch that can be either open or closed.



The Circuit



Switch Closed

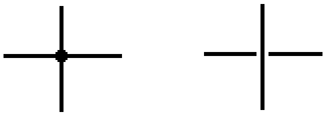


Switch Open

The circuit of interest is shown in the figure at left. What we want to know is the voltage at point 2 in the case that the switch is closed and in the case that the switch is open. In both cases the voltage at point 1 is the full voltage of the battery.

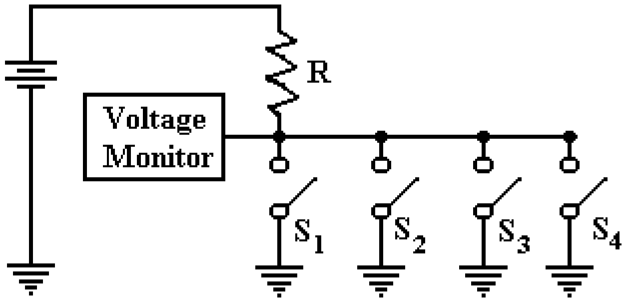
When the switch is closed, it becomes a resistor with no resistance; hence $R_2 = 0$. As we noted above, this causes the voltage at point 2 to be equal to zero.

When the switch is open, it becomes equivalent to a very large resistor. Some say that the resistance of an open switch is infinite, as there is no path for the current to flow. For our purposes, it suffices to use the more precise idea that the resistance is very big, at least 1000 times the resistance of the first resistor, R_1. The voltage at point 2 is the full battery voltage.



Before we present our circuit, we introduce a notation used in drawing two wires that appear to cross. If a big dot is used at the crossing, the two wires are connected. If there is a gap, as in the right figure, then the wires do not connect.

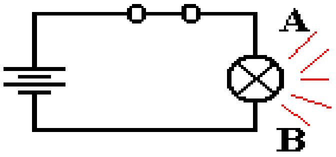
Here is a version of the circuit as we shall use it later.

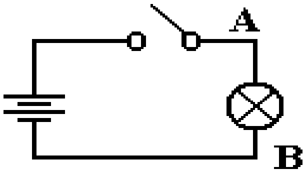


In this circuit, there are four switches attached to the wire. The voltage is monitored by another circuit that is not important at this time. If all four switches are open, then the voltage monitor registers full voltage. If one or more of the switches is closed, the monitor registers zero voltage. This is the best way to monitor a set of switches.

Back to Tri–State Buffers

We use the above verbiage to present a new view of tri–state buffers. Consider the following two circuits, which have been used previously in this chapter. Suppose that the battery is rated at five volts. In the circuit at left, point A is at 5 volts and point B is at 0 volts. In the circuit at right, point B is clearly at 0 volts, but the status of point A is less clear.



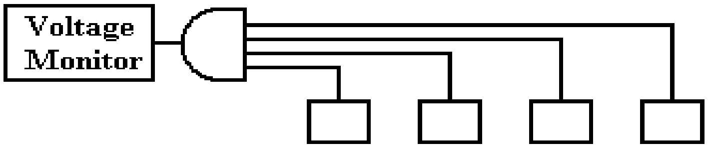


What is obvious about the circuit at right is that there is no current flowing through it and no power being emitted by the light bulb. For this reason, we often say that point A is at 0 volts, but it is better to say that there is no specified voltage at that point. This is equivalent to the third state of a tri–state buffer; the open switch is not asserting anything at point A.

Perhaps the major difference between the two circuits is that we can add another battery to the circuit at right and define a different voltage at point A. As long as the switch remains open, we have no conflict. Were the switch to be closed, we would have two circuits trying to force a voltage at point A. This could lead to a conflict.

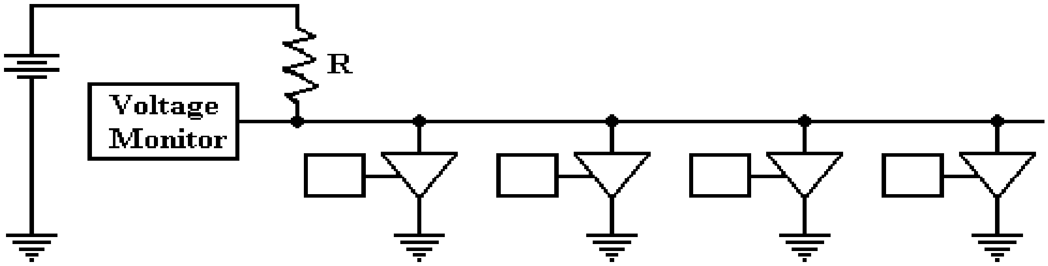
Device Polling

Here is a more common use of tri–state buffers. Suppose a number of devices, each of which can signal a central voltage monitor by asserting logic zero (0 volts) on a line. Recalling that a logic AND outputs 0 if any of its inputs are 0, we could implement the circuit as follows.



Suppose we wanted to add another device. This would require pulling the 4–input AND gate and replacing it with a 5–input AND gate. Continual addition of devices would push the technology beyond the number of inputs a normal gate will support.

The tri–state solution avoids these problems. This circuit repeats the one shown above with the switches replaced by tri–state buffers, which should be viewed as switches.

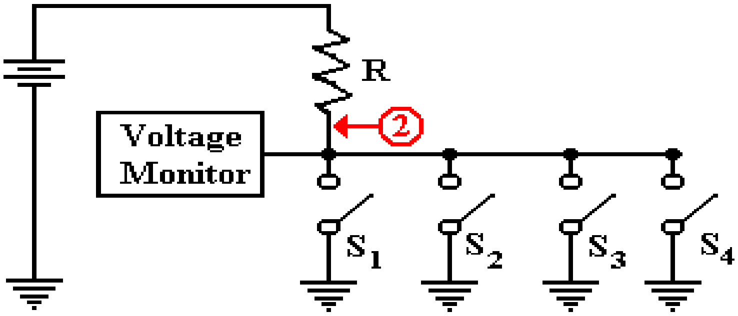


One should note that additional devices can be added to this circuit merely by attaching another tri–state switch. The only limit to extensibility of this circuit arises from timing considerations of signal propagation along the shared line.

Analysis of the Four–Tristate Circuit

In order to analyze the circuit at the bottom of the previous page, we refer back to the circuit on the page before that. We need to understand the voltage at the monitor, which is assumed to be the input to a digital gate in the control logic of the CPU. While a precise discussion of this circuit involves treating resistors in parallel, such is not needed to be accurate here.

First, assume that none of the tri–states are enabled. In that case, the circuit is equivalent to the one in the next figure.



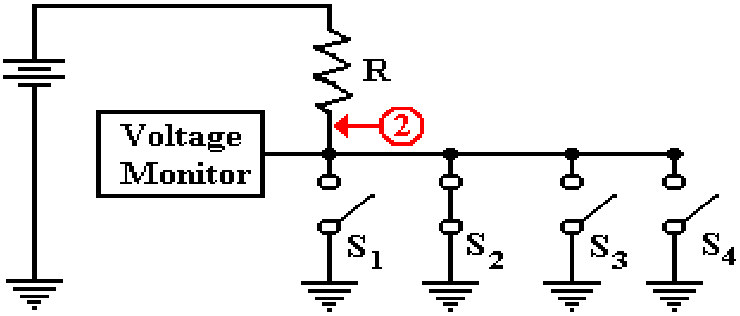
The voltage at point 2 is the full battery voltage, as the resistance between that point and ground is essentially infinite.

$E_2 = E / (1 + R_1/R_2)$

$E_2 \approx E \bullet (1 - R_1/R_2)$,

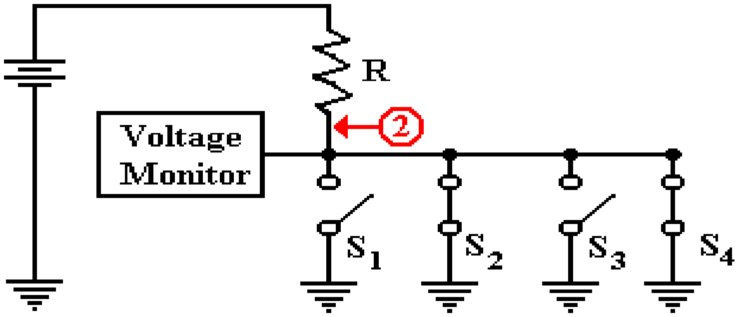
but $R_1/R_2 \approx 0$.

Now consider the situation in which one of the tri–state buffers is enabled. Tri–state 2 has been chosen arbitrarily.



Now there is a direct path of zero resistance between point 2 and ground. The voltage at that point drops to 0, with the entire voltage drop being across the resistor R.

Finally consider the situation in which more than one of the tri–state buffers is enabled. As before, the choice is arbitrary.



Again, there is a direct path of zero resistance between point 2 and ground. The fact that there are two such paths has no practical consequences. The only criterion is one or more path of zero resistance.