

## TA preparation Circuit lab

1. Let them read the introductory page and have them work through the method of equivalent resistance part of the lab (Fig. 1).
2. Now teach for 15-20 minutes and explain the Voltage branch method by working circuit 1 on the black-board. Try to go slow enough so students can take notes. Also emphasize at the beginning that in the latter part of the lab students need to do a similar circuit analysis themselves on two other circuits.

A circuit consists of branches that connect at certain legs, or nodes. A branch contains one or more components that are connected in series with each other. Each branch has a certain current. Since all devices in one branch are in series with each other they all have the same current. The legs or nodes are the connection points of the branches. All parts of one leg are at the same electric potential. As we learned in chapter 24, the electric potential is the electrostatic potential energy of a test charge of 1 Coulomb. For potential energy we always have to define a zero level. In mechanics, for some problems you assumed that the zero level of potential energy was the ground, for other problems you put the zero potential energy level at the ceiling. This is similar in circuits. We have to choose one of the legs (or nodes) to be the zero level. We often choose the negative pole of the battery to be the zero level of the electric potential of the circuit, but there is not right or wrong in this choice. So for the circuit of Figure 1 we have two legs (or two nodes) and three branches. Please let the students verify this.

The objective of the voltage branch method is to calculate the values of all those branch currents. In this lab you will learn a systematic approach on how to determine all branch currents of an arbitrary circuit. Although the method of equivalent resistors might provide in a faster method to determine the branch currents for some circuits, the method of equivalent resistors cannot be used for all circuits. The branch current approach will allow you to determine the branch currents for any circuits, so we would like you to be able to use this technique. For the circuit of Fig. 1, there are three unknowns that need to be determined, i.e. the current through the battery, the current through R1 and R2, and the current through R3. So we need three independent relations.

These independent relation can be found from Kirchhoff's laws. You will use two different rules, called the Kirchhoff current law and the Kirchhoff voltage law:

1. Kirchhoff's current law (KCL) tells us that the sum of currents that flow toward a leg (or a node) is equal to the sum of currents that flow away from that leg. Note that a current is a charge per second. So KCL tells us that for each second the amount of charges arriving at the leg (or node) is similar to the amount of charges that is leaving the leg (or node). This law originates from the conservation of charge law and the fact that charges cannot accumulate at the legs (or nodes). Analogy: consider the cars traveling north on the segment of I-35 between San Marcos and Austin. Assuming that we do not have any parking spaces on I-35, the number of cars coming from New Braunfels over I-35 per hour, plus the number of cars per hour getting on I-35 via the ramps in San Marcos, Kyle, and Buda, minus the number of

cars per hour getting off I-35 via the exits in San Marcos, Kyle, and Buda, should be equal to the number of cars per hour arriving in Austin. In math we write:

$$\sum_k^n i_k = 0$$

Where the summations is over all branch currents connected to a certain leg (or node). Currents flowing towards the node are considered positive and currents flowing away from the node are considered negative. KCL is sometimes referred to as the continuity equation.

2. Kirchhoff's voltage law (KVL) tells us that when you walk around through a complete loop in the circuit, and you add up all electric potential differences across the devices, that the total must be zero. So in an equation form:

$$\sum_{l=1}^m \Delta V_l = 0$$

Where the summation is done over all components in the loop. Voltage rises are counted positive and voltage drops are counted negative.

Note that the electric potential is nothing else than the potential energy of a test charge of 1 Coulomb. So KVL says basically tells us that the change of potential energy of a test charge of 1 Coulomb when moved one time around in a loop of a circuit is equal to zero. So adding up all potential energy changes while moving the charge through one complete loop will result in zero. This rule originates from the fact that the electric field is a conservative field which means that its potential energy is independent of the time and only depends on the position (read the node (or leg))<sup>1</sup>. We saw this in chapter 22: see the example on page 634, the electric potential difference is independent of the path and only depends on starting position and final position. So if start and final position are equal, the electric potential difference is zero. Note that there is also the analogy with going hiking in the hill country. Your gravitational potential energy is the same upon return to your car at the parking space after a 2 hour hike as your gravitational potential energy at the beginning of your hike.

Now work the circuit with the following recipe (make sure students take notes):

1. Choose one leg (node) to be the ground, and indicate this node by labeling it as 0Volt.
2. Define the currents through the branches with an arrow and a names. Use  $i_1, i_2$ , etc. There is no right or wrong when defining the direction of the arrow.
3. Identify the loops with a capital letter and a clockwise arrow.
4. Now write down KCL for all legs (nodes) except the 0 volt one.
5. Now write down KVL for all loops. We will go around clock wise in each loop. Use the following rules:
  - A. If you go through a resistor in the direction of the current there will be a drop of the voltage (note if you go through a river in the direction of the water flow you will get a drop in height).
  - B. If you go through a resistor opposite to the current arrow, there will be a rise of the voltage.

- C. If you go through a battery from the negative to the positive pole, there will be a rise of the voltage.
- D. If you go through a battery from the positive to the negative pole, there will be a drop of the voltage.

Emphasize that voltage rises are counted positive and voltage drops are counted negative. Once you have set up all equations show them how they can be solved by substitution.

- 3. Now let them use the same technique to analyze the circuit of Fig. 2. Once they are done with that ask them to continue the lab at the top of page 39.

Add two questions to the end of the lab:

- 1. Explain in your own words the physics behind Kirchhoff's current law, i.e. the sum of all the currents flowing to a node (leg) zero.
- 2. Explain in your own words the physics behind Kirchhoff's voltage law, i.e. the sum of all the voltage drops experienced when moving around one time in a loop of a circuit is equal to zero.

Notes:

[1] Students will learn after spring break that this is no longer valid if you place your circuit in a time varying magnetic field. Also when the circuit contains high frequency voltage sources KVL might no longer be valid and one needs to treat the circuit as a wave –guide.