University of California, Santa Cruz
Baskin Engineering School
Electrical Engineering Department

Laboratory 1
Fundamental Circuit Theory Laws

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EE101L
Intro. to Electronic Circuits Laboratory

1. DESCRIPTION AND OBJECTIVE

Kirchoff's two fundamental Laws, voltage and current, KVL and KCL, form the basis of all circuit theory. Knowing voltages and currents, their ratio gives us the useful property of resistance in Ohms [R or Ω], while their product gives us power flow in watts [W]. This lab experimentally investigates and verifies these fundamental laws and derived quantities. In this lab we will experimentally apply KVL and KCL to several simple lumped linear DC circuits to gain theoretical confidence and experimental skill using only the lab power supply and dvm. The second circuit introduces the concept of differential and common-mode voltages and the third circuit introduces non-linear resistances.

2. GENERAL DISCUSSION

You should ask yourself *why* KVL and KCL work? And why do they apply to *circuit theory*? KVL and KCL are conservation laws. Recall that voltage was defined to quantitatively describe work as charge is moved through a circuit by the force of an electric field. Thus, the total work done on or by moving charge is conserved. Current is conserved since we can have no more charge entering a node than leaving it. The beauty of circuit theory is that we can avoid the complexity of working directly with the underlying electric and magnetic vector fields by assuming that all node voltages and currents between them *change simultaneously*. This is the unique perspective of *lumped circuits*. Essentially lumped circuits completely omit time-delay. We must resort to field theory to deal with any circuit where propagation or time-delay is an important parameter; these are aptly called *distributed circuits*, like transmission lines and antennas.

3. OBSERVATION AND INVESTIGATION OF EXPERMENTAL CIRCUITS

Part 1

3.1 Verification of basic laws and derived quantities.

The following circuit is a network of lumped resistors called a “T-Network”. It is a building block circuit commonly used in audio and RF work.

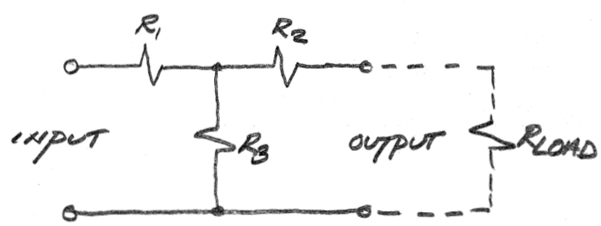

Fig. 1. Experimental T-Network circuit.

Construct it on your lab plugboard using three nominally equal resistances of your own choosing and letting the load resistance $R_{Load} = 0$, then design an experiment to obtain the following *only from measured voltage and current data*, unless otherwise indicated:

- Verification of KCL and KVL.
- The experimental resistances of R_1 , R_2 and R_3 . In your report compare these to the values measured for each one using the DVM. If they are different, consider what might account for this.
- Verify that total power is conserved by finding the power dissipated in each resistor and the power delivered from the power supply.
- The equivalent resistance between the two input nodes. Compare this to the resistance measured using the DVM. If they are different, consider what might account for this.
- Verify the current and voltage divider theorems at the three-branch node.

Guidelines and suggestions:

1. Transcribe this circuit into your lab notebook. Then, design your experiment and annotate the schematic by first identifying all nodes and branches, assigning voltage polarities and current directions using the sink-source convention, and choose a node to be the common node. Once you have a complete schematic, setup the lab power supply to generate a suitable DC voltage between +2 and + 15V and proceed to use the DVM to take DC voltage and current measurements aimed first at verifying KVL and KCL. However, before doing so choose resistors (see guideline 2 below) and take the time to draw equivalent circuits (in your engineering notebook!) of what the test equipment input looks like to assess whether it will significantly affect your circuit or the test equipment in different modes. Although this can readily be deduced by referring to the 34401 test equipment manual (on our website), for convenience we have done this for you:

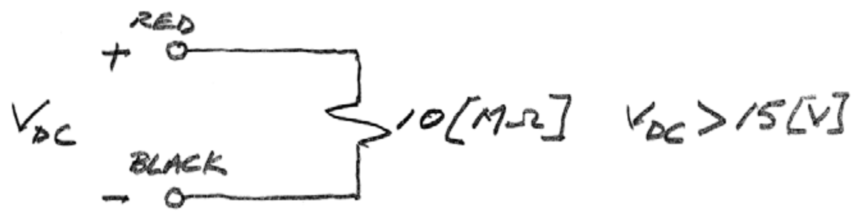

Fig. 2. DVM equivalent circuit when measuring DC voltage.

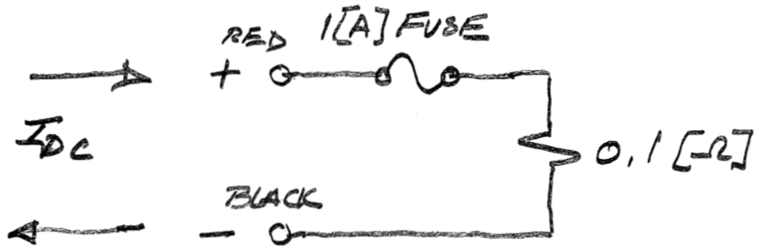

Fig. 3. DVM equivalent circuit when measuring DC current.

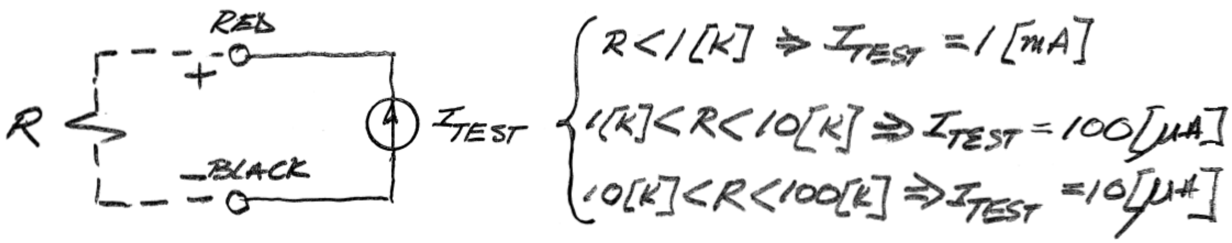

Fig. 4. DVM equivalent circuit when measuring Ohms.

Study these DVM circuits carefully. Figure 3, especially, reveals that if you connect the probes to a DC voltage source while trying to measure current, the *protective fuse will blow*, since current is a measurement obtained by putting a 100 $[m\Omega]$ test resistor in *series* with a circuit branch. By contrast, since voltage is potential difference it is measured by a *parallel* measurement across or between any two circuit nodes. Figure 4 reveals that an internal source of current is generated that dynamically depends on the range of resistance being measured (note that no current is generated unless an actual non-zero resistor is connected). Remember too that the DVM will take *floating measurements* of current and voltage so you don't have to worry about where the common node is located. Don't just mindlessly connect things. Be theoretically very clear about what's involved in taking different kinds of measurements.

2. When choosing resistor values be sure to carefully consider any relevant effects test equipment may have as well as the power capability of the actual 1/8 Watt resistors used in the lab. Use the universal three color resistor color code to verify the nominal value of resistors used.

3.2 Single-ended and Differential Circuits

Single-ended voltages are always referenced to a common “zero-volt” node, usually called “ground” because it’s assigned or associated with the lowest potential possible. Differential voltages are basically the *difference* between any two single-ended voltages. The study of op-amps, in particular, requires a clear understanding of this distinction. So the circuit we will now investigate looks ahead to op-amps where the concept of differential voltages will be figure greatly.

Consider the network shown in fig. 5 designed to convert a single-ended voltage V_1 to a differential voltage V_{23}. It too is a common circuit block called the *Wheatstone Bridge*.

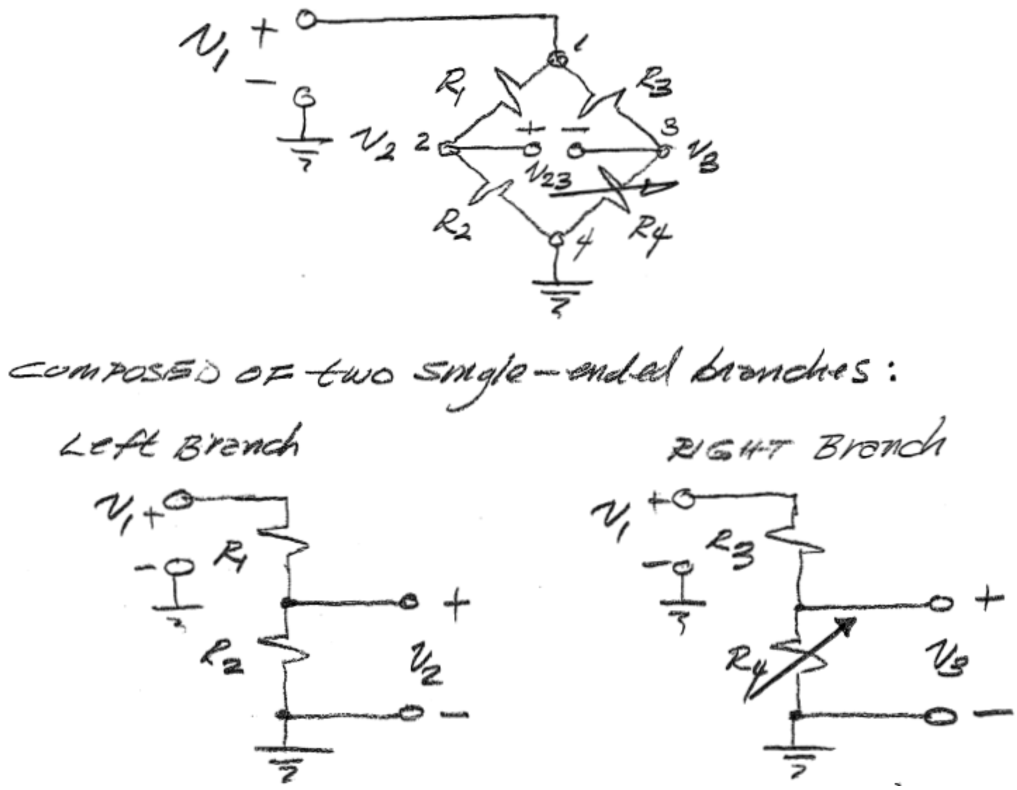

Fig. 5. Fundamental Wheatstone Bridge with resistive elements.

It has many uses. It can be designed to measure unknown resistances, especially very large ones; it can be used in sinusoidal oscillators if some of the resistors are replaced with capacitors and combined with active amplifier devices. It is also frequently used with sensors of all types (discussed in CMPE167). Here we will use it to illustrate how a single-ended voltage can be converted to either a positive, zero, or negative differential voltage, $V_d = V_2 - V_3$ having a non-zero common-mode voltage, $V_{cm} = \dfrac{V_2 + V_3}{2}$.

Single-ended voltages have only one property, namely their voltage with respect to the common node. Differential voltages, however, have two properties: their differential voltage and the average of the single-ended voltages they have in “common”; hence this is call the *common-mode* voltage and is equal to $V_{cm} = \dfrac{V_2 + V_3}{2}$. If V_2 happens to equal V_3, then V_{CM} is the same as either of them, and the differential voltage,

$V_d = 0$. The point of this exercise is to experimentally observe the three basic properties associated with single-ended and differential circuits. Many electronic devices, like the op-amp, require a differential input voltage, but will fail to work properly when the associated common-mode voltage exceeds prescribed limits.

Construct the bridge circuit on your lab plugboard and excite it using a nominal +10V DC source. Choose resistor values for $R_{1,2,3}$ so they are all the same nominal values, about half of the potentiometer in your lab kit, and use the potentiometer to make R_4 variable. For those unfamiliar with "pots", we will discuss them in the lab.

Take sufficient measurements of relevant DC quantities to obtain the following:

- Single-ended voltages and how they relate to differential and common-mode voltages.
- The actual experimental resistance of R_1 , R_2 and R_3 .measured with the DVM.
- The conclusion that the differential voltage depends primarily on ratios of the bridge resistors, while the common-mode voltages depends primarily on their magnitudes (sizes).

Part 2

3.2 Non-linear resistances.

The concept of linearity is important to circuit design, performance and analysis. Non-linear circuit elements can cause unwanted distortions of various kinds, but they can also be used to introduce stabilities into some electronic circuits, notably oscillators where they appear as feedback elements. A linear circuit is one that fundamentally obeys superposition and whose input-output response is homogeneous (passes through the origin). For example, if we apply a voltage (input) to a resistor, the current (output or response) will obey Ohm's Law, and if the resistor is linear the derivative of this volt-amp ratio will be constant. This property simply means that its absolute resistance is independent of the applied voltage. Moreover, the response must pass through zero when the applied voltage is zero. Otherwise the resistor would be required to have an internal source of power.The purpose of this section is to introduce these concepts by experimentally investigating the non-linear volt-amp ratio of a simple incandescent lamp.

Several lamps are included in your lab kit. You can work with only one or both of them. Devise an experiment to show that an incandescent lamp has a non-linear volt-amp ratio and that its response is homoneneous. In particular, a lamp's resistance varies with temperature. The "cold" resistance of an incandescent lamp is quite low, but as it heats up due to current flow and internal power generation, it increases. Use the the lab power supply to vary voltage and resulting current. Collect enough pairs of data to make an accurate two-dimensional plot of a single lamp's behavior.

To help make this concept clear repeat this experiment with a fixed linear resistance and observe that the slope is now constant. From your experiment and data show that:

- The resistance is non-linear by creating a 2-dimensional graph of your data clearly showing that the conductance slope $\left.\frac{\partial i}{\partial v}\right|_{V_{DC}}$ varies with each applied DC voltage while the fixed resistance's slope doesn't.
- Show analytically (mathematically) that the response of the lamp doesn't obey superposition, while the fixed resistor's response does. Discuss what the concept of superposition means and how your data demonstrates this property.

4. REPORT AND SUBMISSION.

Submit a report (see the handout on reporting guidelines; this is posted on our website) discussing the work done in this laboratory. Treat each of the three tasks in separate sections.