Why should a Laboratory be required for Linear Circuits I?

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Abstract **--- When in the fall semester of 2017 at the University of Pittsburgh at Bradford, a Laboratory was added to Linear Circuits I , it provided an absolute amazing insight into the absence of practical knowledge of students. They could not identify resistors, or capacitors. They had in most cases no idea what a DMM was and how to use it. Setting up fairly simple circuits on a proto-board and making voltage and current measurements had to be shown to each Lab group. A Lab experiment with an Op-Amp meant, that several of the Op-Amps were sacrificed to the smoke god. Students were amazed by what an Oscilloscope could do and how one could see the charge and discharge of a capacitor. At the end of each experiment, MatLab was used to verify the practical results obtained. What was gratifying at the end of the semester that each student group had high praise for the inclusion of a Laboratory into the curriculum. All the frustration and the extra work involved was worth it if one looked at the final result and that a practical component had been added to the students background, which would serve them well in a summer internship or in the Co-op program.**

Key Words – Practical Knowledge, Simple Circuits, Proto Board, DMM, Matlab

I. Introduction

Until the addition of the laboratory component into Linear Circuits I, the lack of some practical knowledge about their chosen field of study, was not evident about most of the students. Apparently, the hands on experimentation has been replaced by the excursions into the Internet and the discussion about model building, has been replaced by the "Smartphone". It was necessary to instruct each laboratory section about the components to be used, how to make simple measurements and how to connect function generators and oscilloscopes. Each Lab group consisted of 2 or 3students and each student had to write up the results of each experiment and had to hand it in. The experiments followed along with the information provided in the lecture portion of the course and since MatLab was used extensively in lecture, laboratory results required, that they were backed up in most cases by simple Matlab programs. Connections of circuit components were mostly made via a Proto-Board, which also had an on board power supply.

Starting out with series and parallel circuits, followed by series-parallel circuits, resistors had to be selected for a certain range from a box that contained numerous values. This would force each group to use the ohmmeter of the Digital Multi Meter (DMM) and it would also make each groups circuit different, preventing copying. Students at this point did not know the color code. Correct placement of the DMM leads to measure current, was the major challenge in the parallel portion of a circuit. A virtual Lab. by Argilent Technologies was helpful in proving Ohms Law, and KVL and KCL. It also showed very nicely how to make correct connections for voltage and current measurements.

A second order mesh equation problem, was verified, by using a MatLab program.

For the operational amplifier circuits, the old standby 741 op-amp was used, and both, a noninverting and an inverting amplifier were to be evaluated. Even though the connection diagram and the theoretical course material should have made it simple to lay out the circuit, it was not to be. To help in evaluating the operational amplifier Lab it was preceded by an exercise of knowing how to use an oscilloscope and a function generator. Here the output of the function generator was monitored so a similar evaluation could be done for the output of the op-amp. Since the 741 op-amp has two power supply connections and the commons of the power supplies, the function generator and the oscilloscope have to be connected properly on the Proto-Board it was for most lab groups some agonizing time. A few 741's went up in smoke and it was good that they are not very expensive and could easily be replaced. It showed again that when it comes to more sophisticated connections, the students lacked the ability that comes from tinkering with circuits in their spare time.

Transient Analysis using an R-C circuit gave the students a real insight into the charging and discharging rates of the circuit. By making the time constant long enough, the charging or discharging of the capacitor could easily be seen on the oscilloscope screen.

II. Applications and Programming Verification

The various applications discussed in the introduction portion will be highlighted to give reality to the various laboratory

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exercises. In some of the initial labs, calculations can be made quicker than to access one of the Laboratory computers, which have MatLab installed.

Since the first two Lab exercises (Series Circuit and Parallel Circuit) resulted in the third Lab as a series-parallel circuit, that again varied in component values from one Lab group to the next, a typical circuit and its results will be shown.

A) Application #1

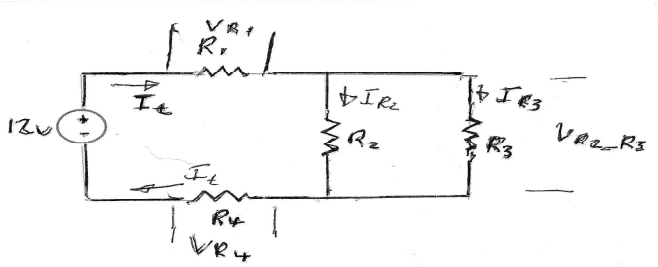

Fig 1: Series-Parallel Circuit

When the written MatLab program is put into calculator mode then the measured results should be close to the MatLab calculations. What is nice about this, that a copy from the command window can be inserted into the Lab Report Sheet for a neat appearance.

How many Resistors[R1,R2,---,Rn]=[95,125]
Choice of Rs or Rp?[Rs]:Rs Rs = 220

How many Resistors[R1,R2,---,Rn]=[159,220]
Choice of Rs or Rp?[Rs]:Rp

Rpfinal = 92.2955 Rtotal=Rs+Rpfinal

Rtotal = 312.2955 It=12/Rtotal It = 0.0384

VR1=It*95 VR1 = 3.6504

VR2_3=It*Rpfinal VR2_3 = 3.5465

VR4=It*125 VR4 = 4.8031

proof of KVL Vt=VR1+VR2_3+VR4 Vt = 12.0000

IR2=VR2_3/159 IR2 = 0.0223

IR3=VR2_3/220 IR3 = 0.0161

proof of KCL Itotal=IR2+IR3 Itotal = 0.0384

B) Application#2

To complement the above exercise, the virtual lab obtained from Hewlett-Packard through Agilent Technologies strenghtens the ability of the student to understand the three laws of Electrical Engineering that are the basis of this Engineering discipline. It takes the student from Ohms Law through KVL and KC, and uses the mouse to make all of the connections and then asks questions to see if an understanding of the outlined procedures was achieved. To finish the Virtual Lab properly, takes about an hour of time. It is a somewhat tedious procedure, but can be very beneficial to a good understanding of the basics of Electrical Engineering and be helpful to connect instruments properly.

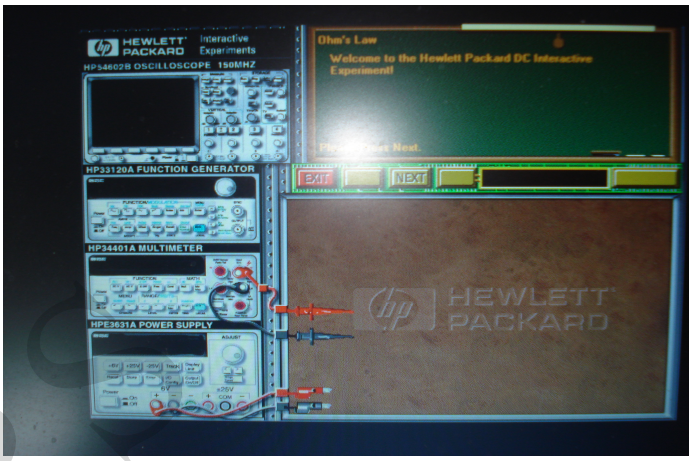

Fig 2: Outline of the Virtual Lab for Ohms Law, KVL and KCL

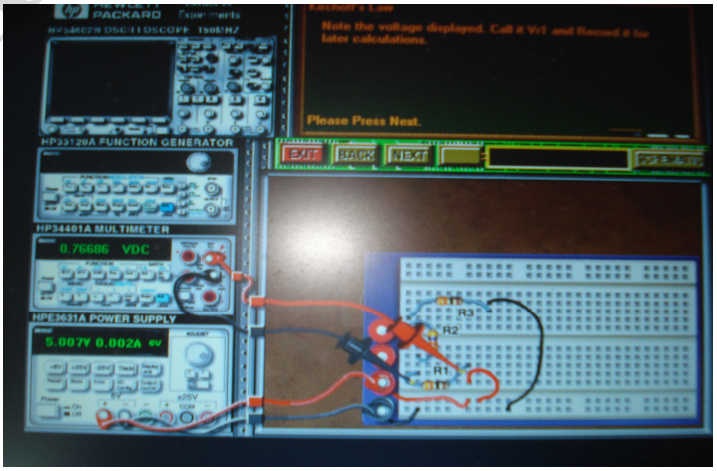

Fig 3: The actual connection for KVL Analysis

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Once the student is thoroughly familiar with the Laws, some of the equipment (DMM) and the procedures that are used in a laboratory environment, one can move on to topics that are more powerful when it comes to solutions of circuits like mesh and nodal analysis. Here again Matlab plays an important role where with just a few keystrokes, it can provide the answers for any order mesh circuit. Using again values typical of a specific Lab group, solutions for the loop currents and the difference of the loop currents can be obtained.

C) Application#3

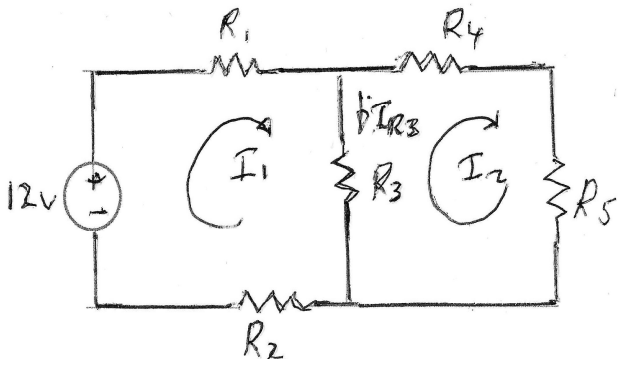

Fig 4: A simple second order Mesh circuit

Using the MatlLab Platform again in calculator mode for a specific written program, answers for given values of R1, R2, R3, R4, R5

```
>> R1=178; R2=122; R3=120; R4=180; R5=295;
>> % (R1+R2+R3)I1-(R3)I2=12
>> % -(R3)I1 + (R3+R4+R5)I2=0
>> Avector=[(R1+R2+R3),-(R3);-(R3),(R3+R4+R5)];
>> Bvector=[12;0];
>> LoopI1_I2=Avector\Bvector

LoopI1_I2 =

   0.0303
   0.0061

>> IR3=.0303-.0061        IR3 =  0.0242
```

The operational amplifier also just known as Op-Amp finds literally hundreds of uses in industry and in everyday life. Because of its importance it is introduced early in the Electrical Engineering curriculum. Since it is an integrated circuit it looks initially as if students in their first circuit course could never have the ability to solve problems associated with the Op-Amp. However by basically not even considering the internal structure, but using just external components, amplifiers and dozens of other circuits can be obtained. For the Lab experience the 741 Op-Amp was chosen. It is simple, it is cheap and it happened to be the first solid state Op-Amp to be on the commercial market. It was introduced in the mid 1960's by the Fairchild company and as can be seen is still viable.

D) Application#4

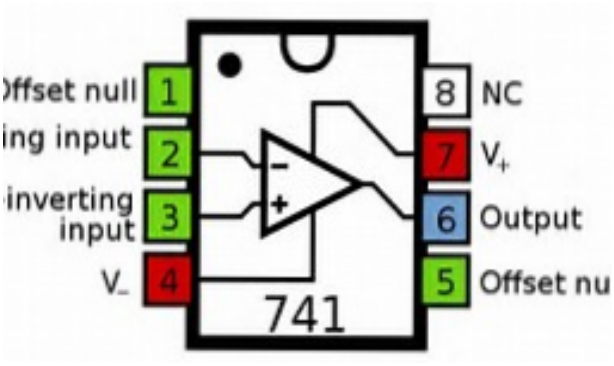

Fig 5: Pinout of the 741 Op-Amp

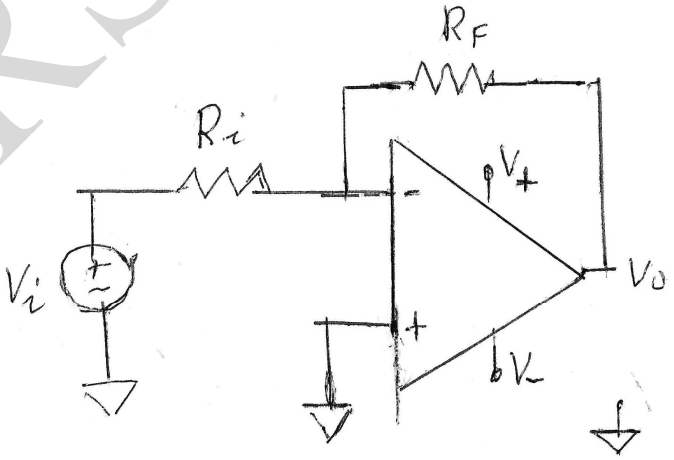

Fig 6: The Inverting Amplifier

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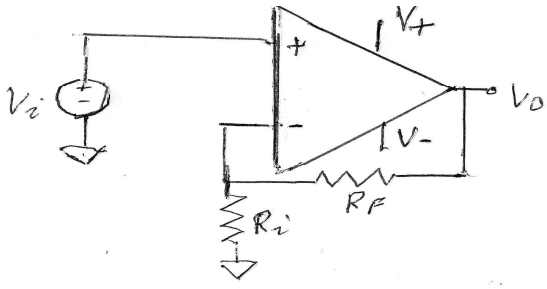

Fig 7: The Noninverting Amplifier

The derivation of the equations for both amplifiers were accomplished in the theory portion of the course. By considering only the external components, the following equations were arrived at.

1. $$Vo = -(Rf / Ri) * Vi$$

For the Inverting amplifier

2. $$Vo = (1 + Rf / Ri) * Vi$$

For the Noninverting Amplifier

So if the ratio of Rf and Ri is 10 then Vo is 10 times Vi in one case and 11 times Vi in the second case. Inverting simply means that the output is 180 degrees out of phase with the input.

This is the lab exercise that caused most of the problems. Even though the pinout seemed straight forward, mixing power supply pins and signal input pins caused a few 741's to expire and since the signal was provided by a function generator and output and input were monitored by a dual channel scope the common connection also known as ground, created many problems. It took a lot of time by the author to troubleshoot each setup but eventually each Lab group had at least one working amplifier.

To explore the behavior of the charge and discharge of a capacitor in the transient analysis of the course, students had to select a resistor and a capacitor so the time constant was long enough so charge or discharge could be observed on the oscilloscope.

E) Application#5

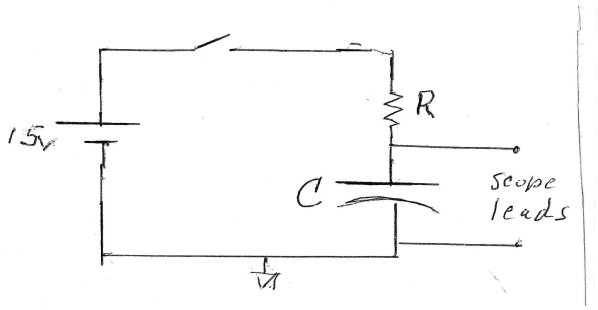

Fig 8: The R-C Time Constant Circuit

Each group of students picked their own resistor and capacitor of the ones that were in storage. The time constant should have been at least 2 seconds so the oscilloscope when set to a long time per division would show either the charge or discharge over the screen.

III. Conclusions

The laboratory examples shown are extracted from the information that is presented in the theory portion of the course. Since this was the first go around, some changes might be made in certain areas but in general the format seemed to appeal to the students. Each Lab time is only one hour and fifteen minutes so that meant that some of the more difficult lab sessions would extend over two lab periods. Having an informal evaluation at the end of the semester of the value of the laboratory experiences, most students felt that it helped them to understand many of the topics presented in theory, much better. The real value of the inclusion of the laboratory into the course is that students now have some practical knowledge about test instruments, components, like resistors and capacitors and that they have the ability to actually talk intelligently about their chosen field of study.

How expensive is it to equip the laboratory with some of the test equipment and the components needed for each lab? Since the function generator or the oscilloscope can be low frequency equipment and the oscilloscope does not have to be a digital storage scope, their cost should be very low. A good DMM should be available for under a $100 which means that a fairly decent number of Lab stations could be equipped for under $3000 for all of the equipment shown. Components are not really worth mentioning as far as cost is concerned.

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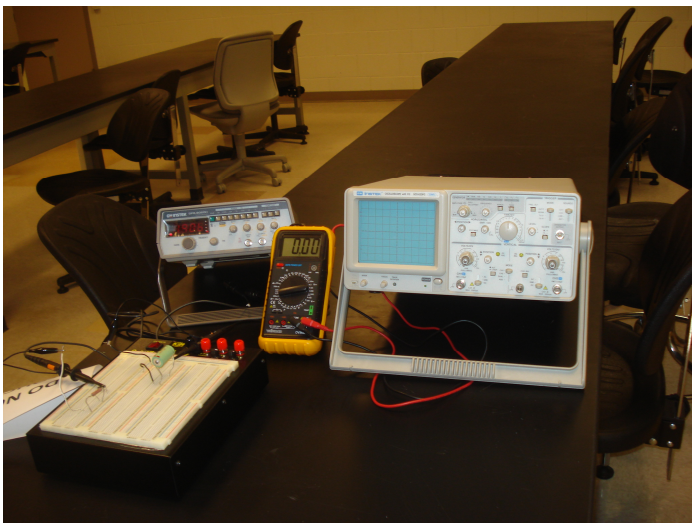

Fig 9: The equipment used during the experiments

It should also be mentioned that the laboratory was equipped with five computers that were available to the students for MatLab calculations .

ACKNOWLEDGEMENTS

The students that worked diligently in each laboratory session should be commended for sometimes difficult times where things did not go right but they continued in their quest to find the correct answer. Very little absentiism existed which meant dedication to the cause.

The Faculty Development Committee of the University of Pittsburgh should be thanked for appropriating a fair amount of money in case the paper gets approved for presentation at icsmet.

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