Revisiting Electrical Circuit Labs

Jeffrey Ward
School of Engineering
Grand Valley State University
Grand Rapids, Michigan,
Jeffrey.Ward@gvsu.edu

Abstract

Laboratory based classes are often avoided in distant learning environments due to the test equipment needed to provide an equivalent learning environment. This is especially ironic for Electrical Circuits courses, since most of the concepts that the test equipment relies upon are covered in lectures. This paper will introduce a series of labs that will step student thru the construction of all of the common electrical test equipment, minus an oscilloscope. In addition, the prevalence of online teaching resources also allow instructors to replace textbooks with device similar to the myDAQ, in order to provide simple oscilloscope operations. Thus allowing students to construct their own electronic test bench for future lab based courses.

Introduction

As more courses are being taken online and in distant learning environments, many laboratory focused classes are left behind due to the inability to provide an adequate lab experience. This can be especially true for one of the most fundamental electrical engineering courses, Electrical Circuits. The irony is that most modern laboratory equipment actually rely upon the concepts taught in this class. This paper will outline a sequence of labs that will step students through the design and construction of their own lab equipment. Starting with the introduction of voltage and current dividers that enable students to scale common battery packs to the desired voltage levels. Students are then stepped through the use of an inexpensive panel meter, to design a simple multimeter. It is recommend that this is done early enough in the semester, so that motivated students can layout, populate, and test a custom printed circuit board. The battery packs and the student designed multimeter are adequate to study all DC circuits, including Operational Amplifiers. After the introduction of Op Amps, buffering can be added to the multimeter to improving its functionality and decreasing any loading effect. The minimal shunt capacitance in the multimeter circuit also allows it to be applied to RC and RL transient circuit analysis, so long as time constants are kept on the order of seconds. After transient circuits, student are shown how to use positive feedback Op Amps to create a multivibrators, in lieu of the classical 555 chip set. Additional Op Amps can be used to provide signal shaping into square, triangle, and sawtooth waveforms. A low Q tank circuit can also provide sinusoidal signals by filtering out harmonics from the triangle waveform. Low frequency DC biased AC small signal analysis can be performed using the student designed multimeter, or a National Instruments myDAQ or similar device which could be required in lieu of a textbook, as more open source resources become available. By the completion of this course sequence, students will have covered all of the fundamental measurement techniques and learned how to incorporate these simple circuits into more advanced systems. The only drawback to this method is that student will not gain familiarity with specific brands of high end test equipment. But that familiarly should be obtainable by reading the technical manual or by completing one or two quick tutorials on the specific device, since all of the fundamentals will have been introduced.

Week	Topic	Lab
1	Introduction	Intro of DC Based Lab Equipment
	Resisters, Sources, and Kirchhoff's Laws	
2	Basic Circuits (Voltage/Current Dividers)	LT Spice
	Self-Inductance	
3	Capacitors	CAD/Solder Lab
	Phasors and Impedance	
4	EXAM 1	Multimeter / Loading Part 1
	Impedance and Circuits	
5	Node Analysis	Multimeter / Loading Part 2
	Node Analysis w/ Supernodes and Dependent Sources	
6	Mesh Analysis	Transient Test Equipment (with myDAQ)
	Supermesh and comparison to Node Analysis	
7	Source Transformation	Node & Mesh Analysis
	Thevenin Theory	
8	EXAM 2	Diode Tutorial
	Complex Power	
9	Max Power Transfer	Thevenin Models and Max Power
	Mutual Inductance and Transformers	
10	Superposition and Linearity (AC & DC circuits)	Transistor Tutorial
	Operational Amplifiers (Intro Real/Ideal)	
11	Common Op Amp Topography	Op-Amp Circuits
	More Op Amp Circuits (Node Analysis)	
12	EXAM 3	Easy Bake Oven
	RL Natural Response (Intro)	
13	RL & RC Natural Response	Transient Lab
	RL & RC Step Response/General Solution	
14	1st Order System Solutions	Oscillator Circuit
	Review and Summary	

Table 1: Proposed topic and lab sequence used to help students construct their own electronic test bench.

Course Structure

The standard Electrical Circuits course introduces students to the fundamental physical concept of electricity and leads them through Direct Current (DC) circuits and on into transient and sinusoidal time varying systems. A sample curriculum sequence taught at Grand Valley State University, based upon two lectures per week, is shown if Table 1. Lectures follow the standard sequence [1, 2, 3], with the exception that sinusoidal steady state is interwoven throughout the course in order to speed topic coverage.

The lecture sequence is divided into four primary groups; Introduction, Circuit Analysis, Special Analysis Techniques and Circuits, and First Order Transient Response, each with their own exam to verify students comprehension. Basic electrical concepts and divider circuits are introduced and immediately followed up by an exam to make sure the students learn the fundamentals before proceeding onto their applications. Then after the standard circuit analysis techniques are covered, as applied to standard factious and nonsensical circuits, students are shown how to apply circuit analysis to specific special cases like Operational Amplifiers. First Order Transient Responses are also covered in depth to aid students understanding of the multi-vibrator circuit used to create the oscillator.

While not as easily identifiable, the labs are also divided into four groups; Introduction, DC Multimeter Development and Application, Specific Lecture Topic Reinforcement or Replacement, and Electrical System Construction. During the Introductory labs, student's complete tutorial based labs in order to learn circuit analysis and printed circuit board layout software. Before completing specific Lecture Topic Reinforcement labs like the Node/Mesh, Thevenin, and Operations Amplifier (Op Amp) Labs. With the actual student developed test equipment occurring during the Multimeter labs and the Electrical System Construction labs.

Fundamental Labs

While many of the lecture topics and labs can be replaced or rescheduled in order to match specific instructor preferences, the CAD/Solder, Multimeter, Transient, and Oscillator labs are where the students to develop their test equipment. In the CAD/Solder lab, students are stepped through the capturing and laying out of a canned schematic. Then rather than wait for their canned schematic to be produced, the lab instructor will provide previously prepared PCB's that the students must then construct and test. This enables students to build the confidence needed to later prepare their test equipment for fabrication.

Once the students have been instructed on voltage and current dividers, they are ready to proceed to the Multimeter Labs. In these labs, they are shown how to use current dividers and shunt resistors to protect a 1mA panel meter from currents up to 100 mAs, see R1 in Figure 1. After the students can properly measure currents, a larger series resistor is added to limit the inrush for an unknown voltage, see R2 in Figure 1. The combination of R2 and the shunt combo produce a real world voltage divider that students can analyze. Later a known voltage source (9V battery) can be in series with the voltmeter to allow unknown attached resistors to modify the current read by the meter. An additional benefit of this circuit is that poor resistor selections can also lead to discussions over loading effects and how to compensate for it in measurement procedures. A fact that is lost when using modern Digital Multi Meters (DMM's).

The second piece of lab equipment the student will construct is a function generator as part of the system labs. Students lead through the process of constructing large more complicated systems in building blocks or subsystems that are troubleshot independently of the overall system. Starting with a non-inverting Op Amp with negative feedback, the feedback is changed to cause a runaway condition, see Figure 2. A first order resistor capacitor (RC) circuit is used to set a trigger threshold that controls when to "run in the other direction". Students trouble shoot the multivibrator and then watch as loading effect cause it to miss behave. To fix the issue, a unity gain buffer is added to isolate the multivibrator from its loading circuits. Figure 2's R5 can also be replaced by a capacitor to integrate the square wave and convert it to a triangle wave. The additional attenuation of the harmonic signals of the triangle wave also allow a simple second order inductor capacitor tank circuit to resonate at the primary frequency to produce a sinusoidal signal. The Q of the tank is usually poor enough to allow reasonable tuning of the oscillator via R3, in Figure 2, without significantly attenuating the output. If additional output voltage is needed, students can add a variable gain inverting Op Amp to boost the signal after the tank circuit.

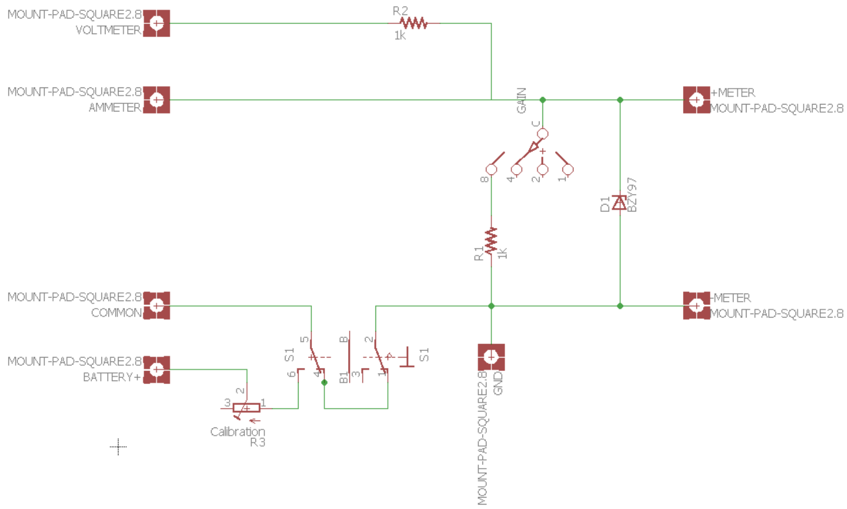

Figure 1: Sample Multimeter schematic with variable sensitivity gain and Ohm meter zero out setting.

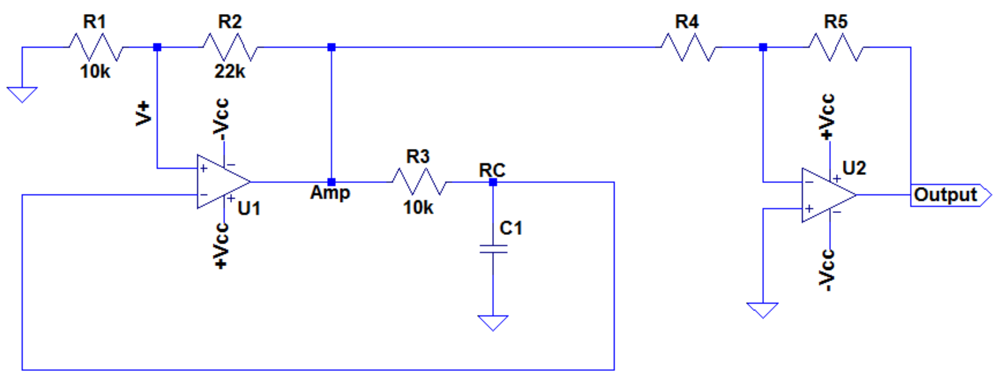

Figure 2: Sample Oscillator schematic.

Results

Electrical Engineering students enrolled in GVSU's EGR 214 Electric Circuits class typically enjoy learning the fundamental operations of the test equipment that they rely upon. In fact some have even developed converted their multimeter circuit into a Print Circuit Board (PCB), as see in Figure 3. Accuracy of the multimeter can match that of bench top units if students spend time performing their current dividers and customize the panel meters face plate. The oscillator sinusoidal output can also be improved by increasing the order of the tank circuit, which can be linked to topics covered in follow on circuit analysis class.

The only drawback to this current lab sequence, is that it still relay upon benchtop oscilloscopes or commercial myDAQ units that utilize Analog to Digital Converters and computers to post process the results. However it could be possible to continue the students test bench development in an embedded processor course with a multi-line display used to display variations on the voltages as a function of time. Advance courses could even add algorithms to perform Fast Fourier Transforms, as the sky becomes the limit to what our student can accomplish.

Figure 3: A Student built multimeter.

Bibliography

1. James W. Nilsson, Susan A. Riedel, "Electic Circuits" Pearson, 2019.
2. Roland E Thomas, Albert J Rosa, "The Analysis and Design of Linear Circuits" John Wiley and Sons, 2004.
3. Charles K. Alexander, Matthew N.O. Sadiku, "Fundamentals of Electric Circuits" McGraw Hill, 2017.