

Circuit-X: Circuit Analysis meets the X Files

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Circuits education is one of the cornerstones in educating an electrical engineer. As Davis points out¹ there is a need to relate analysis skills to the real world. Other authors have done this by incorporating design into the circuits lab^{2,3,4} or by integrating computer tools into the lab^{5,6}. An additional strategy is to challenge the students with a circuit identification task, one where they have to design test procedures and from the results synthesize the unknown circuit. Most lab experiences consist of opportunities to build circuits from homework problems and verify already well established electrical principles. From a pedagogical point of view this represents the path of least resistance. Little effort is required to create, deliver and administer lab programs that follow such a paradigm. There is small risk that even marginally qualified teaching assistants will be unable to successfully supervise students thus engaged. Ohm's law is known, KVL and KCL are known, the measurements are predetermined and the outcome foreordained. With all the answers known in advance, it's difficult to imagine how anyone would expect any learning to take place. Circuit X is designed to challenge students' understanding of circuits, their reasoning skills, their mastery of test equipment operation, and their ability to convincingly present an argument.

The Circuit X lab experience occurs in the first few weeks of the first 3rd year lab. During the first week of the project each student team is given one of fourteen unknown circuits to analyze. The circuit is contained in a small black box (Figure 1.) that is riveted closed. The boxes and circuits were fabricated by the ECE department machine shop and electronic technicians. Each box contains a unique first or second order passive circuit that must be analyzed by the students to determine the circuit topology and component values. The graduate teaching assistants have access to the master record of which box contain which circuit. The boxes are numbered for easy identification. Electrical access to the interior circuit is limited to four banana style jacks arranged in a square on one surface of the box. Connector spacing makes it convenient to use banana-BNC adaptors along the sides of the square but not along the diagonals. The terminals are numbered for common reference.

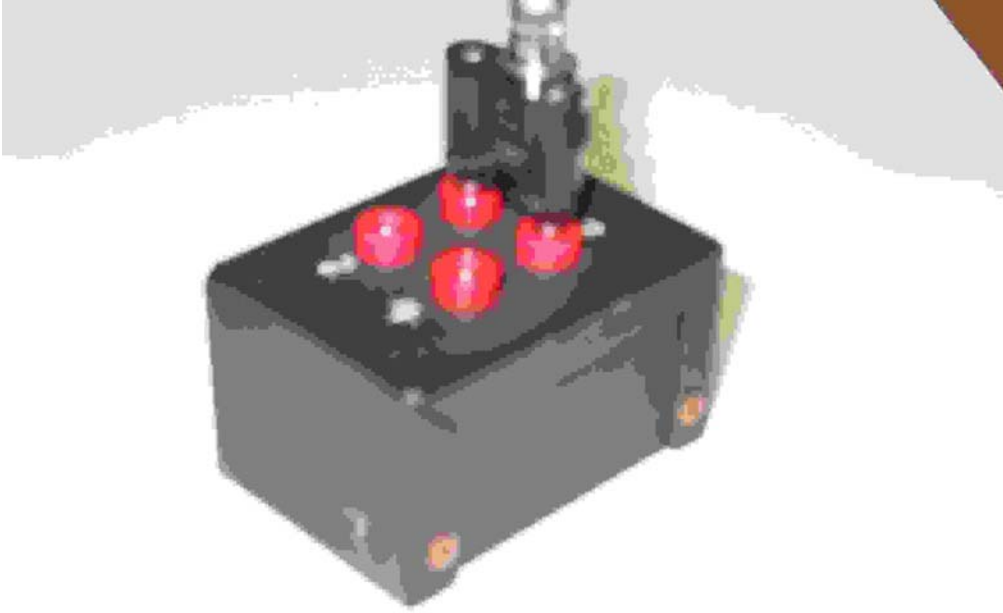


Figure 1. Photograph of a Circuit X student box.

The story line that creates a hook for the student's interest is that the black boxes contain "alien technology" and may hold the key to a source of cheap energy. The complete text of the student instructions follows.

Circuit X

Michigan Tech has received an urgent request from the global scientific community. The United Federation of Scientists (UFOS) has acquired several samples of suspected alien technology. Each device is enclosed in a sealed metal container with four electrical connectors. The scientific community is very curious about the device characteristics because they are reputed to hold the keys to a global source of cheap energy. Information received with the devices leads the UFOS community that they are electrical circuits composed of elements similar to what terrestrial scientists call "passive components."

Your task is twofold:

- Prepare and submit a test proposal that fully describes a set of tests that will reveal the exact nature of the circuit within the alien device.*
- After your test proposal is approved, conduct your examination and report your findings in the form of a schematic drawing of the alien circuit.*

First, you will work in teams to design a set of tests that will enable you to precisely describe the circuits contained in the alien devices. This Test Proposal must be submitted to your TA and approved BEFORE you conduct your tests. Please include a

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detailed, step-by-step description of all proposed tests including equipment required, connections to be made to the device under test, signal inputs, and the expected results of the test. Also, include decision trees, drawings and schematics as necessary to fully illustrate your test proposal. Each team will submit a test proposal to their TA not later than one-week after the device is received. You will not be allowed to proceed to the next step in the process until you have received an approved Test Proposal from your TA. This may take several attempts. Your TA will provide you with feedback to guide your efforts. **Safety Note:** The first attempt to open a container for examination resulted in a highly energetic response that caused the complete destruction of the lab, the scientists and a local village. DO NOT attempt to open the case on your test device. All examinations of these devices must be performed without exposing the contents. Restrictions: **Do not apply more than 5 V DC to any terminal of the device.** Do not remove the suspected alien technology from EERC room 619.

After you receive your approved Test Proposal from your TA, conduct the tests according to the procedures developed in the Test Proposal. Report your conclusions about the exact nature of the circuit, including circuit topology and component characteristics in standard lab report format prescribed by department policy. Include drawings, schematics and an assessment of your confidence in the precision of your findings. Your report will be deliverable one week after receipt of your approved Test Proposal. Be prepared to present your findings (3-5 minutes) to a panel of distinguished researchers one week after your report is delivered. All reports will be completed by Friday of Week 4. See the attached process diagram (Fig. 1) for more information.

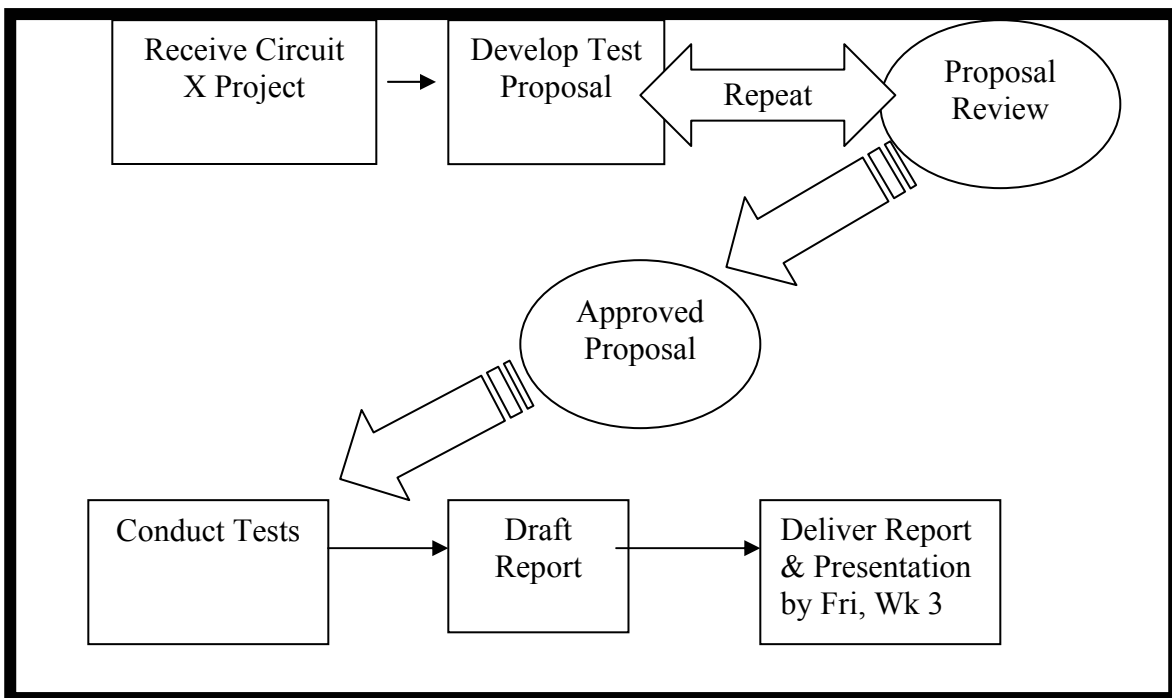


Figure 2. Circuit X Instructions

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Three two hour lab sessions are allocated for the Circuit X project. During the first lab session the student teams receive their test sample and instructions and begin to draft their test plan. No measurements are allowed during this introductory session. Each team has the usual bench test equipment available to them, including multimeters, power supplies, function generators and an oscilloscope. Each item of test equipment is connected via IEEE 488 bus to a desktop computer running Labview software. The only item of test equipment they are restricted from using is the LRC meter.

The teaching assistant is available to answer questions and offer suggestions for the remainder of the lab period. The object of the test plan is to encourage the student teams to determine what information they will need in order to characterize the circuit and exactly how they will use the test equipment available to them in order to extract it. The teaching assistants are coached to reject test plans that do not provide sufficient detail. Sufficient detail is defined here to mean: enough detail for *someone else* to execute the plan and arrive at an inevitable conclusion. Each step must define what they will do, how they will do it, what data will be acquired, and how that data leads to information about the circuit. Most teams will have a rudimentary test plan prepared by the end of the period. Most test plans go through multiple iterations before they receive approval from the "Test Director," their TA. This iterative process typically takes place via e-mail over the following week, outside the lab. The intent is to require the student teams to be disciplined and thorough in their investigation and avoid time wasting random experimentation. All teams are given two weeks to finalize their test plans and have them approved in time for the next scheduled Circuit X lab meeting.

During the execution phase of Circuit X each team has the opportunity to explore just how effective their test plan was as they carry out the process they created. This does not always go smoothly. Students regularly observe data that do not fit their preconceptions. Flexible teams regroup and reassess the underlying assumptions that led them to a particular step or conclusion and move forward. Less robust teams are forced by circumstances to reevaluate not only their test plan but, in many cases, their basic understanding of circuits and test equipment operation.

The lack of certainty posed by the unknown circuit causes a number of secondary effects. First, the teams are forced to examine and in most cases strengthen their understanding of basic circuit theory in order to be able to determine what data will be relevant. Second, they must develop a deeper understanding of the operation, abilities and limitations of their test equipment in order to be able to tell the difference between data that doesn't fit their model and bad measurement technique. The TA's are cued to watch for and guide the frustration that inevitably results from the conflict between expectation and reality. It is in this sometimes painful process of question and answer that deeper understandings can develop. For example, many students will immediately turn to their handy multimeter for initial measurements. Puzzled expressions occur when ohmmeters are placed in parallel with capacitors and inductors. The questions that follow lead students to discover how common meters actually measure resistance. Ultimately they are brought to the ability to actually apply what they have learned in the classroom to solve a problem.

The final phase of the project is the written report and oral presentation of results. Each team produces a written report to document their work. In addition they deliver a 5 minute presentation to the class. Both these forms of communication are vital to the successful student and ultimately to the practicing engineer. The teaching assistant challenges each team with questions that revolve around a central theme, "What's the answer? Is that the only answer? How do you know?" In every case the student teams must demonstrate the ability to present their argument convincingly. Both the report and the presentation are graded using a common rubric

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in order to ensure consistency between sections supervised by different teach assistants. These rubrics are included as appendices. It is worthwhile to note that the “correct” answer contributes at most 10 points of the total points available for the project.

A prerequisite exam is administered to all students in the Circuits and Analysis lab during the first week of the semester. The exam is designed to assess mastery basic circuit analysis skills and knowledge. The exam includes questions requiring knowledge of Wheatstone bridge circuits, nodal analysis of circuits with dependent and independent sources, and a first order RL circuit. The mean score on 36 exams was 10.6 out of a possible 20 points, with a standard deviation of 4.5. One question dealt specifically with a first order RL circuit. Only two individuals received full credit for the question, the mean score for that question was 0.73 out of a possible 5 points. After completion of the Circuit X lab experience, the sections were invited to participate in a post test to assess any change of state. Three individuals volunteered and were given a single question related to first order circuits. All three volunteers were able to correctly answer questions regarding frequency response, transfer function, and time constant for a first order RC circuit. Clearly more participation in the post test would have been desirable but even this small sample points toward a successful transfer of information.

Its easy for both the students and the teaching assistants to get wrapped around the circuit. In fact the circuit is just a small part of the overall experience. The substance of this lab rests on three foundations: Discovery, Design, and Delivery. First the student teams must design an effective test plan that will lead them from the known, i.e. circuit theory, through the unknown, and back again. This design process challenges their reasoning skills as well as their understanding of circuits and equipment. What do I need to observe?. How can I measure it? Is this the right tool? What does my observation tell me about the item under test? And always, “What went wrong?” The discovery part happens when they put their plan into action. They discover that they don’t understand circuits as well as they thought they did. Six papers were drawn from a pool of approximately 60. All six reported that at least one step in their test plan was not performed because one or more assumptions conflicted with observations in the execution phase. They discover that they need a deeper understanding of how their measurement equipment works or how to interpret what it tells them. All six reported data that did not fit their expectations and described their efforts to understand what they observed. Mostly they persevere until they develop this deeper understanding that enables them to deliver on the project. Four of the six teams were able to correctly determine the topology and the element values despite the challenges they encountered. Every team strengthened their knowledge of circuits, and deepened their understanding of equipment operation by meeting this challenge, overcoming it, and then telling the world about their experience.

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PRESENTATION GRADE SHEET

NAME OF STUDENT		TOPIC		DATE						
Unsatisfactory		L	Satisfactory	I	Outstanding	U	L	S	H	O
ORGANIZATION										
INTRODUCTION (ATTENTION STEP & OVERVIEW)	Emotional; failed to introduce self/subject; vague/laundry listed.	Appropriate; claimed audience's attention/highlighted main points.	Stimulating; original; clear/well expanded; prepared listeners fully.	0	1-3	4-6	7-9	10		
SUPPORT (VISUAL & VERBAL)	Inadequate development/errors/sloppy; awkwardly used, inadequate sources.	Adequate development; credible facts/supported or illustrated ideas, cited sources.	Comprehensive development/stimulating; well timed; skillfully used, incorporated sources throughout.							
ORGANIZATION (LOGIC & TRANSITIONS)	Vague; lacked balance/mechanical transitions throughout.	Main ideas related to purpose/each other/used some creative transitions.	Skillfully led audience/creatively related previous points to new points.							
CONCLUSION (SUMMARY & CLOSURE)	Incomplete; laundry listed/abrupt; no sense of finality.	Reviewed highlights of main points/ definite; appropriately tied to subject.	A synthesis; fostered retention of ideas/positive impact creative.							
DELIVERY										
VERBAL EXPRESSION	Articulation problems; incorrect grammar/pronunciation; vocalized pauses; poorly worded; monotone; too soft/loud; too slow/fast; artificial; lacked confidence.	Not distracting; natural force, pitch, rate, and emphasis; positive.	Exceptional articulation, pronunciation, grammar; precise word choice; dynamic; spontaneous; conversational; varied.							
MOVEMENT	Static movement, pacing, distracting, hindered communication, nervous.	Varied movement, usually purposeful.	Purposeful movement, comfortable, confident, enhanced presentation.							
GESTURES	Mechanical gestures, mechanical, exaggerated, poorly timed, distracting, nervous.	Appropriate gestures, aided communication.	Gestures enhanced presentation, spontaneous, natural, consistently reinforced meaning.							
EYE CONTACT	Missing or partial eye contact; focused on visual-aids or notes.	Included most listeners; acceptable reference to notes.	Direct eye contact; random; rarely used notes, sought feedback.							
<p>U = unsatisfactory, L = Low satisfactory, S = satisfactory, H = high satisfactory, O = outstanding</p>										

Instructor _____ Student _____

Class _____ Section _____

Circle the box that best describes the lab report. Assign points on the right and total at the bottom.

Attribute	0-2 Unacceptable	3-5 Below Expectations	6-8 Meets Expectations	9-10 Exceeds Expectations
Report Mechanics				
Organization	Inappropriate content in most sections of report	Some inappropriate content in some sections of report	Content appropriate in all sections of report	Unique organization enhances readability and/or understandability of report
Format	Tables and figures can not be read/understood, fonts difficult to read, so many format errors as to make the report useless	Some portions are sloppy and difficult to read, some format errors	Text, tables, figures are readable and understandable.	Text, tables, figures so clear and understandable as to enhance the report's impact, unique format enhances report's impact
Grammar, Punctuation, Spelling	Excessive spelling, grammar, and punctuation errors	Some spelling, grammar, and punctuation errors	Only a few spelling, grammar, and punctuation errors	Completely free of spelling, grammar, and punctuation errors
Length	Far too long or too short	Too long or too short	Appropriate report length	
Content				
Abstract	Problem not stated, conclusion not summarized, process statements only	Problem somewhat stated, significant results not included	Problem clearly stated, key results or conclusion stated clearly	So clear and complete as to enhance the impact of the report
Introduction	Problem not stated, constraints or assumptions not explained, contains results/conclusions	Problem stated poorly, limited discussion of constraints, assumptions	Problem clearly stated, impact of constraints and assumptions clearly discussed	So clear and complete as to enhance impact of report
Discussion—Quantitative Analysis--	No apparent understanding of lab tasks, no quantitative support provided	Poor understanding of lab tasks, poor quantitative support,	Lab tasks clearly understood and discussed, solid quantitative support,	Discussion clearly reveals insight and understanding beyond level expected
Conclusion—What did you learn	Omitted	Weak	Clear	Conclusion clearly reveals insight and understanding beyond level expected
Questions	Did not address questions posed in lab materials	Some questions correctly answered	All questions correctly answered	

