Design of Experiment in a Junior-level RF Systems Lab

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Inspired by discussions at the 2016 American Society of Engineering Educators (ASEE) Conference and Exposition in New Orleans, we look to transform some of our “cookbook” lab procedures to design of experiment projects. In addition to providing a better learning experience, these projects will also be able to support the new ABET student outcome 6: An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions [1]. In this work, we will present our methods and results, along with a completed rubric to assess the new ABET student outcome.

Background – the Radio Lab

The RF Systems Laboratory is a required 1 credit hour junior-level course for the Electrical Engineering program at Auburn University (AU) [2]. Students simulate, breadboard, and measure the performance of a variety of AM radio building blocks (various amplifiers, detectors, etc.) on their way towards building a functional radio. The course has a common Monday lecture followed by a 2-hour lab section meeting later in the week. It is not tied to a specific class; it draws from and integrates concepts from several electrical engineering courses.

Table 1: RF Systems Lab Timeline

Week	Topic
1	Course introduction, basic AM radio operations, test and measurement
2	Common emitter amplifier
3-4	Audio amplifiers
5	AM detectors
6-7	RF amplifiers and overall radio
8	Antennas
9-11	Design of experiment
10-13	Radio enhancement project
14	Project presentations

In addition to providing hands-on electrical engineering experiences, the overall sequence of laboratories at AU is also tasked with developing our students` abilities to communicate (both oral and written) and to work in teams [3]. Written communication ability in the RF Systems lab is now developed by student use of eportfolios [4] and oral ability through end of semester presentations. The eporfolios were implemented as a part of AU’s quality enhancement procedure to increase student understanding of course material. The ability to design, conduct experiments, and analyze data is included in a required course, and again in the culminating senior design project. Based on our assessment and evaluation of student ability, we decided to add a design of experiment component earlier in the AU lab sequence with the RF Systems lab.

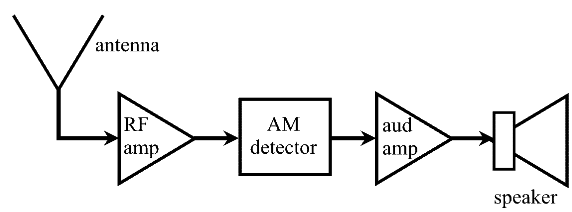
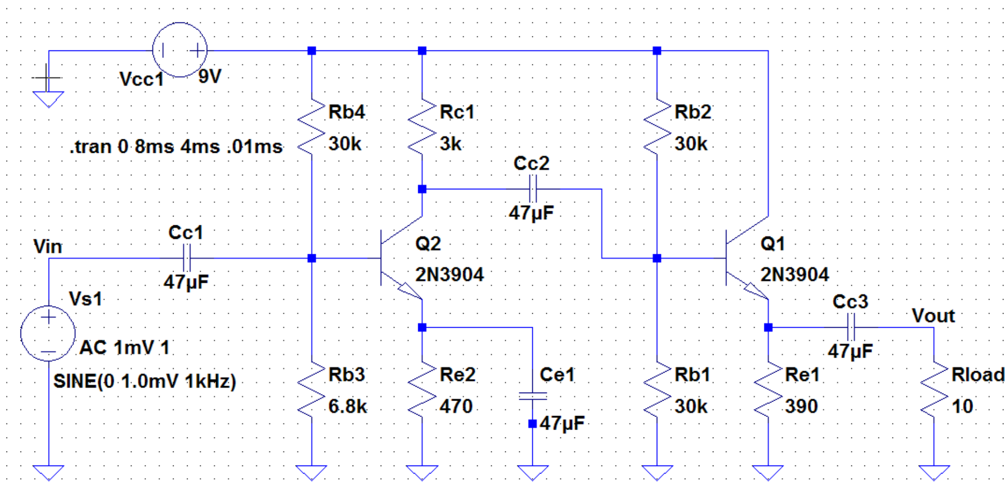


Figure 1: Block diagram of a generic AM radio

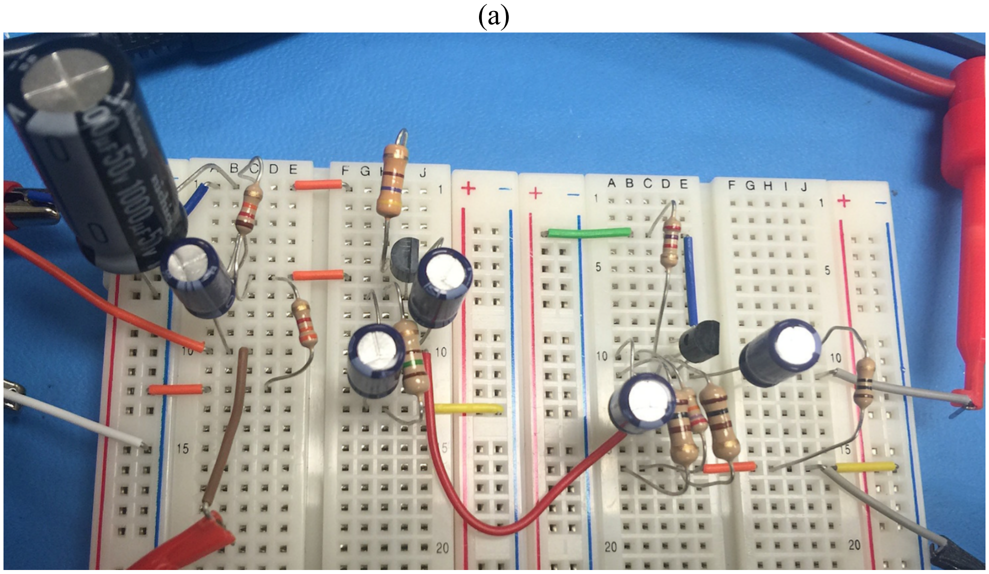
Table 1 shows the new course timeline for the RF Systems Lab. The first part of the course, through week 8, consists of studying and assembling the different components that make up a single-station

AM radio as shown in Figure 1. The free to use circuit simulation tool LTspice is used in the study of each functional block prior to bread-boarding, usually as part of a pre-lab assignment. For instance, Figure 2(a) shows the LTspice circuit schematic for a two-stage audio amplifier, while Figure 2(b) shows an audio amplifier circuit after a student constructs it on their breadboard.

Students begin working in teams of two or three students when designing and building the antenna. This is good practice for them as the team must then work together on the design of experiment lab and on the design project to enhance their radio. Finally, weeks 9-13 are more flexible labs where students work on design of experiment and on their self-selected design projects. Notable recent projects include design of a better audio amplifier to drive larger speakers, a bass/treble controller, and a remote controller for the radio.



(a)



(b)

Figure 2: (a) LTspice circuit schematic of a two stage audio amp, (b) breadboarded version of the audio amp (picture is from a student's eportfolio).

Implemented Laboratory Modifications
For the initial labs, the lab manual contains traditional guided lab activities on how to breadboard and test circuits (for instance, a common emitter amplifier). This so called "cookbook" approach is useful to teach students how to properly use signal generators and oscilloscopes. Also, a cookbook approach is a rapid way to expose the students to a variety of amplifier circuits (common emitter, common collector, push-pull, op-amp based) and detector circuits (simple diode detector circuit, with and without bias, a common-collector based detector, and the complementary feedback pair detector).

While much material can be covered rapidly with a cookbook approach [5,6], there is significant pedagogical advantage in transitioning to proposal-based guided design and design of experiments projects [7,8]. When implementing design of experiments, students are forced to use their ingenuity and creativity to solve open-ended problems thereby enhancing the learning of the students [9,10]. These self-directed learning opportunities stimulate life-long learning and foster increased retention of knowledge and follow trends in engineering education to make more education experiences feel more practical or "real-world" applicable [11,12]. We have therefore replaced some of the cookbook style labs with a design of experiment project.

Weeks 9-10 of the radio lab had been devoted to a heterodyne radio where the students followed a cookbook style approach to develop the stages of a heterodyne radio; normally a bandpass filter, a local oscillator, and a mixer. During the heterodyne labs, we noticed the students typically had low levels of excitement as several indicated they felt they were employing a more difficult method to create a breadboarded AM radio. This coupled with their excitement to work on something new, in this case their final project, led to lackluster effort on the heterodyne radio.

To increase the excitement at the end of the semester and to encourage the students to use more creativity in the final few weeks, the heterodyne radio was replaced with a design of experiment lab. The design of experiment lab extends over a three week period in the latter part of the semester. Using only the signal generator and oscilloscope available at their work station, students must devise a procedure for extracting actual values of the inductors and capacitors in their parts kit. After they determine the accuracy of their procedure, they are to measure their parts and draw appropriate conclusions.

The design of experiment project also serves as a vehicle for assessment of the new ABET student outcome 6: An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions [1]. Rubrics for assessing the various aspects of this outcome will be presented, and results analyzed for improving the approach.

Design of Experiment Lab
The first design of experiment lab was implemented during the Fall 2016 semester with 2 sections, 20 students, completing the new design of experiment, and 3 sections, 21 students, completing the original heterodyne experiments over a three-week period. The students completing the original heterodyne labs comprised the control group. The design of experiments was implemented in all

subsequent semesters and sections, but following feedback received from the TAs and students, it was completed in two weeks instead of three weeks. Table 2 shows the difference between the control and test group labs.

The students worked in groups of two for the experiment. The first lab meeting of the design of experiment was devoted to the students writing a proposal on both the design of experiments project and the final project. The class was divided into 2 one hour sections where at the end of the first hour the draft of the design of experiment proposal draft was due, and at the end of the second hour the final project proposal draft was due. The drafts were submitted as paper copies, and the TAs provided written feedback. The students were heavily encouraged to research their methods for the design of experiment before the lab. The students were required to have already decided and received approval on their final design topic before the proposal lab.

The drafts of the design of experiment proposals were graded and commented by the teaching assistants overnight and were available to the students the next morning so they could complete the final draft of the proposal and have it submitted before the Monday lab lecture the next week on Canvas, AU's learning management system. The final draft of the proposal was graded and feedback was provided promptly by the TAs so the students could implement the feedback into their design of experiments project. The drafts were graded on a completion basis and the final drafts were graded more thoroughly.

The TAs purposefully did not give feedback that would lead the students to a more correct way to conduct their experiment as the goal was for the students to learn, not for the experiment to be necessarily successful. Instead, feedback focused on aiding the students with the organization of the test and guiding them to have a clearly defined test procedure.

One of the lab lectures is devoted to design of experiment. This lecture describes the task at hand and what is expected. It emphasizes the importance of a precise, repeatable measurement strategy as well as the importance of multiple measurements to achieve statistical significance. Also, this lecture encourages students to look for more than one way to extract the sought data in order to reduce systemic error. Both the control and the test groups listened to both the lecture on the heterodyne radio and the lecture on the design of experiments. In lab, the students were recommended to create and calibrate their test procedures utilizing known components from their test kits and at the end the students were given components with unknown values to test to verify their procedure. Questions were put on the final exam covering both the design of experiment and the heterodyne radio. These results will be discussed in a later section of the paper.

After the completion of the lab, the students were required to write a final report on their project. These were graded on a rubric created by one of the authors and can be seen in the Appendix. The Fall 2016 group wrote their reports in their lab eportfolios that we were using to replace standard written technical memos [4]. For the Spring 2017 semester, we switched to standard written reports as they are easier to save and file, but following feedback from students and TAs, future semesters transitioned back to eportfolio final reports.

Final Exam Data

Table 2 shows the material coverage of the test group and the control groups. Questions were prepared for the final exam to compare the test group's abilities with those of the control group regarding design of experiment. The results are shown in Figure 3.

Table 2: lab topic coverage for the control and test groups

<table>
<tr><th>CONTROL GROUP</th><th>TEST GROUP</th></tr>
<tr><td colspan="2">Lab introduction/Test and Measurement</td></tr>
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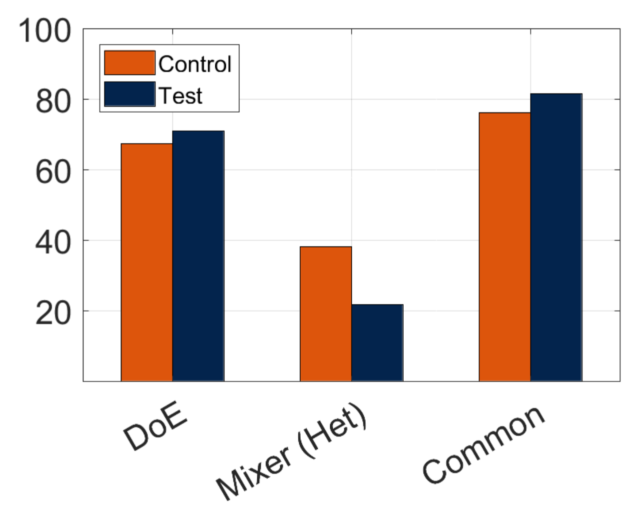

Figure 3: Observations from the Final Exam (Fall 16)

For the final exam, two questions on the design of experiment were presented to the students. There was one question on the mixer from the heterodyne labs, and several questions on material independent from our test on labs 1-6 are lumped into the common section. The test group slightly outperformed on the design of experiment questions. As expected, the test group did not perform as well on the mixer lab as they did not complete that experiment. An interesting data point is that the students in the test group performed 5% better than the control group on the common questions.

Similar data were collected from the next two offerings of the lab, Spring and Fall 2017. In these sections, all groups completed the design of experiment. The results of the Fall 2016 test and control groups and the Spring and Fall 2017 results are shown in Figure 4.

The final reports for the design of experiment were graded and applied to our rubric designed for ABET student outcome 6. Fall 2016 the students submitted the final reports with an eportfolio, and Spring of 2017 the students submitted typed written reports. The average grade for each semester can be seen in Table 3. The written reports were composed by the group of students, and the eportfolio was written by each student. The grades in the written reports had less variability than the eportfolio reports. We believe this was due to the students working together where inevitably one student in the group may have greater expectations and led to an improved report. Since the eportfolio reports were independent, there could be a large quality difference between students in the same group. For future semesters, all reports will be completed with eportfolios to ensure each student writes about his or her own work. Additionally, in surveys and through verbal comments, the students seemed to prefer the eportfolio option to the technical written report.

Table 3: Rubric Assessments

Semester	**Average Score (out of 24)**
Spring `17 (written)	12.9
Fall `16 (eportfolio	10.2

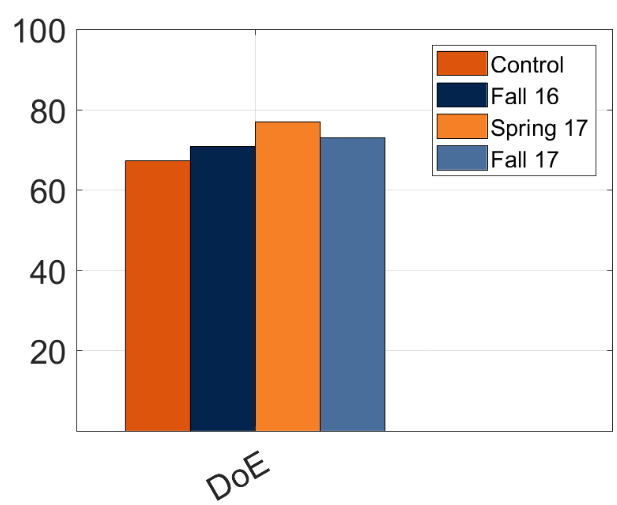

Figure 4: Observations from the 3 semesters

Student Survey Responses

In Fall 2016, the students completing the design of experiment module were asked to complete a survey on the course. The survey was devised to ask questions on their opinions on the lab as a whole and on certain aspects such as the reports and design of experiment. A question and selected responses on the design of experiment can be seen below.

Q) What are your thoughts about the design of experiment component of the lab? How could it be improved?

- I very much enjoyed the design of experiment part of the lab. Honestly, there could be more added to it with the time allowed. Examples of expectations for the report would be extremely helpful.
- The design of experiment seemed thrown into the overall lab schedule; it did not seem to fit the rest of the lab. It was still interesting to complete, but should be more related to the rest of the lab structure.
- A little more elaborating/example of a real life or previous design of experiment would help.
- Could have benefitted from an extra week
- Design of experiment was very easy; perhaps do multiple components (C and L)
- The topic did seem a little tough. If the emphasis is on designing an experiment, then a topic that everyone knows about would be smoother.
- Not enough guidance was given, and then had to write a paper on how it didn't work.
- It made us determine how to perform a task rather than a cookbook approach

The first implementation of the design of experiment took place over a three-week period, and following the feedback from the students and TAs it was reduced to two weeks. For the design of experiment, we were purposely vague with the students regarding how to complete it, and vague with our grading procedures and outcomes. For the next semester, we implemented the students` feedback and had better defined project goals and a more structured final report template.

In Spring 2017, the students were asked to complete an anonymous online survey about their experiences and opinions with design of experiment lab. Selected responses are displayed below.

- This was also helpful in teaching us the amount of detail that goes into designing an experiment, and how specific you have to be. The biggest improvement I would make is more lab time to let us work out the kinks before actually running the experiment. After the first lab period, we decided to change our approach completely, and needed at least one more meeting to make sure our new process worked.
- I like it. This challenged us to really understand the material and apply it. I think a potential way to improve it would be to maybe give general topics of approaches to choose from. This would make lab sections more standard, regardless of the TA.
- This was probably the most interesting part of this lab.
- Went well, added more of a creative thinking spin on the lab.
- The design of experiment challenged me. It was good figuring it out with a partner. I would include an outline that design of experiments that does not provide the answer but helps with organization.
- I think there could have been more clarification on how to test the capacitors.
- While interesting, the design of experiment sidetracks us from making modifications to our radio project. It (design of experiment) is awkwardly placed in the semester.
- Design of experiment was okay but was at a bad time in the semester when we had another project proposal due.
- It was a little too loosely guided.

- Design of experiment was my favorite day in lab over the whole semester. Perhaps because we took it more seriously than any of the other groups and ended up getting great results.
- Honestly, I felt it was a little confusing. I get the purpose, but it felt a little unrelated to the course.
- Design of experiment was a different experience but I enjoyed it. My only question is when will I need to know the EXACT value of something when the given value within 1% tolerance wouldn't be sufficient.

Here, the comments were similar to the previous iteration of comments, but with less emphasis given to the length of the lab and the reporting procedure. The common complaint seen were the students expressing they did not like the placement of the experiment in the lab as it was in the last third of the semester coinciding with increased workloads in other courses. Many groups of students enjoyed the challenge we presented them, but thought a more interesting experiment should have been used, which we plan to create for future semesters.

Conclusions

In the paper, we presented an implementation of design of experiments into a junior level lab. We have also included our data on the student's feedback and test results. The design of experiment task added to the quality of the lab by forcing the students to think about how they create and conduct experiments compared to the cookbook method that was employed in previous semesters of the course. This is expected to yield better results on the new ABET student outcome 6 related to design of experiments that is assessed in a later lab course.

Future Improvements and Modifications

In future iterations of the lab, we will implement guided designs into the lab prior to the design of experiment project. We feel that short guided designs could be placed into existing labs with minimal effort. These simple guided designs would give the students introductory experiences with being creative and creating small tests and modifications to the lab before the larger design of experiment effort later in the semester. Table 4 shows where we will insert guided designs into the lab.

Table 4: Proposed Guided Design Placement

<table>
<tr><th>CONTROL GROUP</th><th>TEST GROUP</th></tr>
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References:

[1] ABET Criterion 3: Student Outcomes http://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2016-2017/#outcomes

[2] S. Wentworth, "AM Radio Construction: A Junior Level Electrical Engineering Core Laboratory," *2009 Annual Conference & Exposition,* Austin, Texas.

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New ABET Outcome 3: An Ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgement to draw conclusions.

		Rubric			
		Unsatisfactory	Developing	Meets expectations	Exceeds expectations
Performance Indicators	1. Ability to develop and conduct appropriate experimentation				
	(a) Develop experimental procedures	Misunderstands theory and cannot determine what data is needed. Equipment and/or methods not appropriate for the task	Understands little of the theory and fails to select most of the appropriate data Some of the equipment or methods are inappropriate	Mostly understands the theory and selects most of the appropriate data. Some appropriate equipment and methods are chosen.	Understands theory to determine what data is needed Chooses appropriate equipment and methods to acquire needed data
	(b) Acquire data	Data collection procedure is haphazard. No demonstration of variability/repeatability	Some pertinent data collected Limited demonstration of variability/repeatability	Most pertinent data is collected Some examination of variability/repeatability	Follows methodical data collection procedure Demonstrates measurement variability/repeatability
	2. Ability to analyze and interpret data				
	(a) present data in a meaningful way.	No evidence of thought given to a clear presentation of data.	Data is somewhat clear and informative	Data presentation is mostly clear and informative.	Data presentation is exceptionally concise, yet clear and informative.
	(b) Summarize data and compare to expected results	Does not summarize findings or related them to expected results. Can't reach meaningful conclusions from analysis of experimental data.	Summarizes findings in an incomplete way. Can make some sense of the data, but results not compared to expected outcomes.	Some of the findings are summarized and compared	Summarizes findings in a complete way and compares them to expected results.
	(c) Correctly interpret data	Mistakes in data analysis and interpretation No insight gained	Little insight gained Few conclusions drawn	Some insight gained and conclusions drawn	Derives unique insight or conclusions from the experimental data
	3. Ability to use engineering judgment to draw conclusions				
	(a) extract valid conclusions from analysis	Makes wrong conclusions.	Extracts some valid conclusions for the experiment, but may miss some valid conclusions.	Extracts all relevant and valid conclusions from the experiment.	Uses conclusions to propose new questions and experiments. Determines shortcomings in collected data and makes suggestions on further experiment