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A First-year Soldering and Analog Music to Light Modulator Electronics Lab Project

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Abstract

This paper describes an introductory electronics lab project which has been iteratively improved over three years in an introduction to engineering course. This one credit course consists of a single 100 minute lecture and lab each week during a 14 week semester and thus requires each activity to be as time efficient as possible. The project was implemented in a course that consists of both electrical and mechanical engineering students at an urban, private institution in the Midwest.

For this hands-on project students learn about analog electronic components and soldering while building a circuit which can be used to make lights turn off and on with a music signal. The circuit can be connected to many music sources using an auxiliary cable and incorporates resistors, a potentiometer, an infra-red LED, an opto-TRIAC, and a TRIAC, as well as various connectors. Students spend two lab periods soldering their circuit together, making the mechanical connections to mount it in a clear plastic box and testing its performance. The students are allowed to keep their project when complete. During operation, when the music signal hits a threshold voltage Christmas lights will turn on. A successfully built circuit excites three physiologic senses (sight, hearing and touch) in that the base signal in music typically corresponds to the highest voltage which can trigger the lights. A user can hear and feel the base signal and see the lights turn on correspondingly. By analyzing a music signal during lecture, and how the various components affect this signal, students gain a practical understanding of the electronics and how they are integrated to create the circuit's functionality.

Surveys of 147 students used at the start of the semester have shown that only 37% of the students have prior experience with soldering or circuits. Of this 37%, only half still rate themselves as confident in their soldering ability at the start of class. An end of class survey and exam questions specific to this project are used to assess the quality of the project, its delivery and student learning. Results show that after completing this project 92% of students are confident in their ability to solder without supervision and 93% of students use the circuit they build for this project outside of class. The overall rating for the project is a 4.8/5 using a Likert scale making it the highest rated project ever implemented in this class. This paper describes the circuit, lab exercise, in-class curriculum and assessment of this project and provides a detailed bill of materials. Alterations to the current circuit which would provide a deeper experience with circuits and electronic components, such as amplifiers and RC filters, are also discussed and demonstrate the potential for this project to be applied in a variety of courses.

Introduction

First-year engineering curriculum can potentially cover an incredible array of topics. Inevitably an instructor must prioritize the topics and depth of coverage as they best see fit. This prioritization becomes of increasing importance in classes which involve students from multiple engineering disciplines as well as classes which are shorter than the more common four credit introduction to engineering class. At the University of St. Thomas introduction to engineering is a 1 credit course which has both electrical (~20%) and mechanical engineering students (~80%) and is comprised of a 100 minute lecture and a 100 minute lab that meet each week during a 14 week semester. The curriculum is heavily geared towards project-based and hands-on learning with a goal of exposing students to many facets of engineering.

There are many works out there which show that students, and specifically first-year engineering students, learn by doing and retention can be improved by incorporating hands-on projects and exercises.[1-9] Many students starting college anticipate that they will be working with engineering tools and components from the beginning and can react adversely in the face of initial prerequisite classes such as Calculus.[10-11] One study[12] has shown that the top motivator for studying engineering in men and second highest for women is the practical and hands-on aspects. Students also commonly use words such as "fun, exciting, interesting" when describing their reasoning for choosing a major.[13] If they are not provided with activities that live up to those words these students can be turned off from engineering. This research provides clear motivation for engineering instructors, particularly those who teach first-year courses, to provide interesting hands-on projects. In an introductory course which includes both ME and EE students it is important to include projects that incorporate electrical engineering concepts to not only cater to the EE students' interests, but because even ME students will take some EE classes before graduation.

The question then becomes, what type of projects will be best suited to one's class. In the current study most incoming students do not have the technical, and in many cases practical, skills in order to complete an open-ended design project in electrical engineering. Due to the limited amount of time in the course it would be unrealistic to adequately develop these skills while still covering the breadth of topics. Assignment projects,[14] similar to cookbook labs,[15] are projects where the problem, tools, process and outcomes are defined and controlled by the instructor. This type of project is not as student centered as an open-ended "project-based learning" or "problem-based learning" activity would be, but have been shown to motivate student learning and can be met with student satisfaction.[16] For these reasons, the project developed in the current study would be classified as an assignment project, however it was complemented with subject-based learning activities.

Subject-based learning,[15] also called topic-based learning,[17] is the pedagogical method wherein material is covered in a coherent order, as in a textbook or delivered lecture, but often lacks relevance in the eyes of the student. In the current study students were also presented electrical engineering fundamentals from a textbook reading and lecture material. By combining reading and lecture material the assignment project was turned into a more active learning experience, not simply an interesting soldering exercise. Furthermore, it has been shown that knowledge becomes more robust and useable when it is attained in a situation where it is actually used.[18] By providing a hands-on build project involving a circuit whose operation is based on electrical engineering concepts, the electrical engineering information (components, signal processing, etc.) covered in the reading and lecture was provided context, thus making it less abstract.

The goals of this combined lecture and lab experience were to:

- develop a time efficient exercise in which students learn to solder and apply that knowledge in constructing a project
- develop a project which would cost less than $25
- develop a project which would be of interest to both EE and non-EE students
- develop a project that would be safe for students to use unsupervised
- develop a project whose operation could be comprehended with only moderate instruction in electrical concepts
- use the project as a tool for understanding multiple aspects of electrical engineering

This paper describes the results from multiple iterations of a music-to-light circuit project as well as some of the lessons learned, assessments of the project and suggestions for improvements/additions that could be added in courses with more time.

Lecture Activity

To build excitement for the project, the circuit was demonstrated for 10 minutes before class early in the semester. As students came into the darkened classroom they could hear music playing and see the Christmas lights turning off and on with fluctuations in the music. The students were informed that they would learn exactly how this works, build it from scratch and keep it as part of the lab experience in the course. The circuit described in this paper is a modification on an available music-to-light modulator kit (CK1200, electronickits.com, $12.95). The modifications were made in order to make the completed project safe to use and easy to interface with systems students commonly use for playing music. A schematic of the complete set-up for using the circuit is shown in Fig. 1. In Fig. 1 the music source represents the device from which the music is being played which could be a stereo, Ipod, computer, cell phone, etc. The circuit also works for Ipod sound docks.

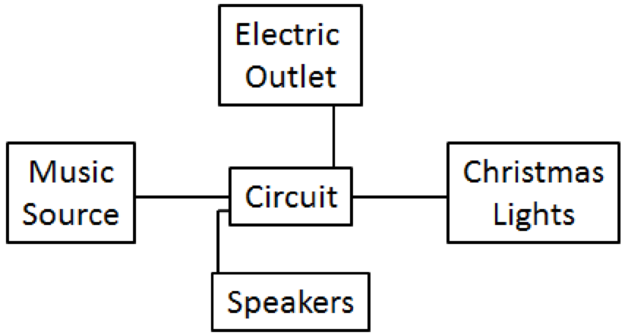


Figure 1. Schematic of complete system incorporating music-to-light circuit

Previous iterations of the project showed that students like having information on how the circuit works before they begin working on its construction. To this end, students were engaged in subject-based learning by reading about electricity fundamentals outside of class and then were presented with lecture activities related to the circuit. In their reading students were introduced to electrical concepts of voltage, current, resistance, power, Ohm's law, Kirchoff's voltage law, Kirchoff's current law, AC/DC and many common electrical components. The lecture activities included discussion, demonstrations and videos on the material presented in the reading as well as magnetic fields, Faraday's law of induction (qualitative), transformers, how electric generators and motors work, and why power lines are at such high voltages. These topics were covered in ~ 65 minutes of lecture and the following ~ 25 minutes of lecture discussed the details of the music-to-light modulator circuit which is shown in Fig. 2.

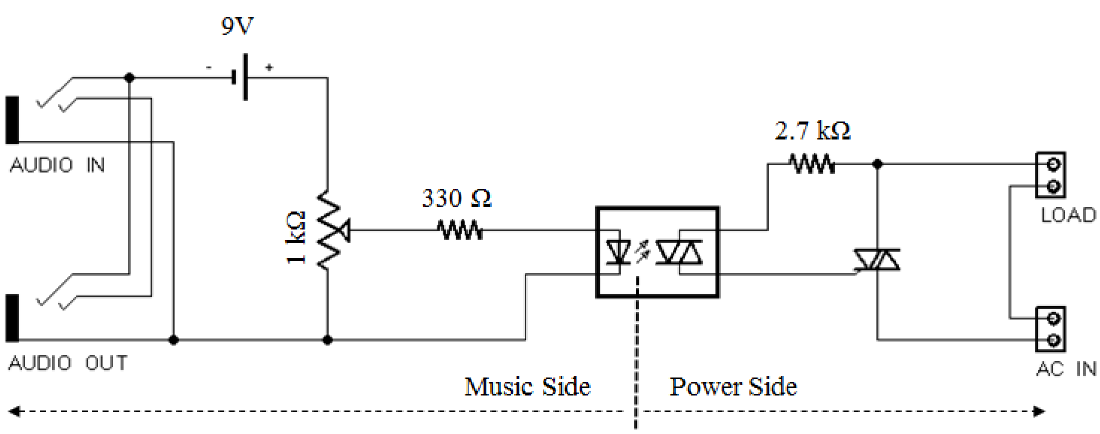


Figure 2. Music-to-light circuit diagram

In general terms, the circuit works by having a voltage signal fluctuate above and below a certain threshold. When the voltage is above the threshold the current flowing through an infrared LED produces a threshold amount of light. This light is then used to trigger an opto-TRIAC (MOC3021) which opens the terminal of an additional TRIAC (BT136, rated for higher power), thus allowing the AC wall electricity to flow into the "LOAD." In reality the load is anything one plugs into the electric plug connected to the circuit (obtained by cutting an extension cord in half), but for this project Christmas lights were used as the load. The circuit can be considered as two circuits which are optically isolated. In Fig. 2 there is a black rectangle surrounding the infrared LED and opto-triac which signifies where the music side of the circuit communicates with the power side of the circuit via light. Due to the fact that the circuit communicates with light there is not a physical connection between the two sides. If there were a physical connection one could risk a malfunction creating a short-circuit which would result in 120 VAC from the wall outlet being connected directly to the music source's audio output (like plugging an Ipod's headphones into a wall outlet). This would likely damage the music player. It is noted that the infrared LED and opto-TRIAC are housed in a single chip which ensures proper alignment.

The circuit incorporates two 3.5 mm audio jacks which are connected in a way to split the music signal. This allows a user to send the music signal to the circuit and use that signal to trigger the Christmas lights after being altered and yet still be sent unaltered to be played over speakers. Due to the importance of the music signal in meeting the threshold voltage, students are introduced to music as a time-varying voltage signal and how the signal can be manipulated. Through use of a LabVIEW USB data acquisition device, students were shown how the music signal depends on various system aspects during lecture. The source of the music and the volume of the music play a big role in determining the amplitude of the music signal. Figures 3 and 4 show the music signal before it enters the circuit. The effect that varying volume has can be seen in Fig. 3 which shows the voltage (y axis) of a song vs. time (x axis) at two different volume levels (100% and 50%). Looking at the value of the y axes reveals that the peak voltage amplitude at 100% volume is almost three times larger than the peak voltage at 50% (1V vs. 0.35V). There is also significant variation in the music signal based on the type of music which is being played. The song being shown in Fig. 3 is a rap song with a very distinct base signal. In this song the base signal coincides with the largest voltage peaks. Figure 4 is shown for comparison as the song displayed is largely instrumental and composed of soft, acoustic guitar music. In comparison with Fig. 3a one can note that the voltage peaks of the softer music are significantly lower in amplitude (0.5V vs. 1V).

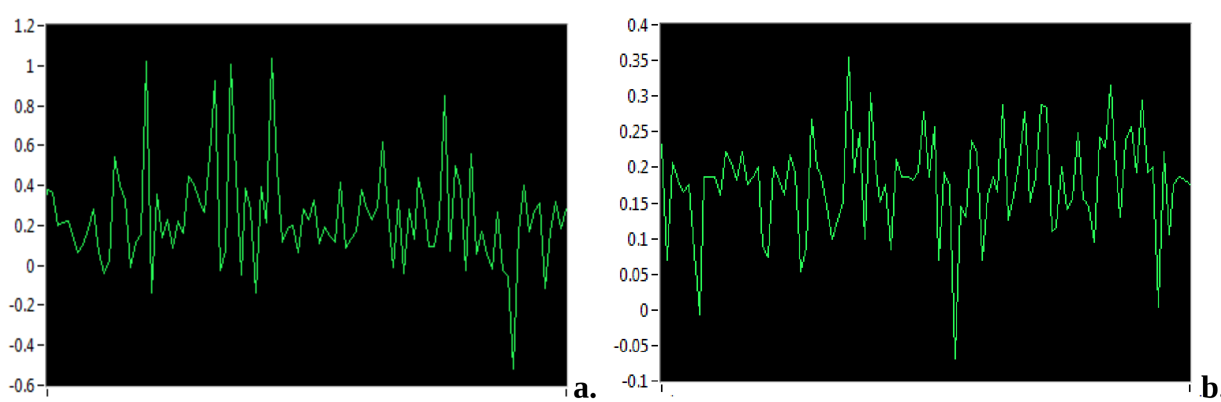


Figure 3. Jay-Z - Izzo at ~0:20-0:30 with computer volume at a) 100%; b) 50%

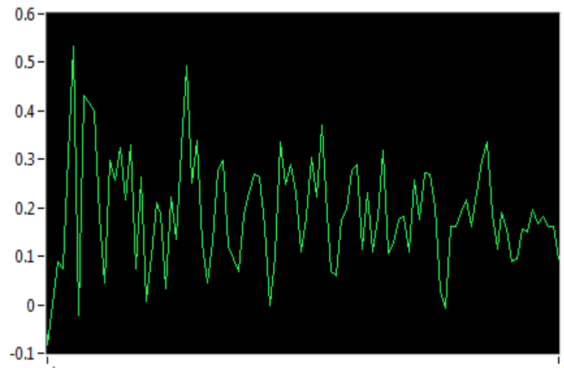


Figure 4. Bon Iver - Halocene at ~0:20-0:30 with computer volume at 100%

If one were to simply build the circuit based on the parts provided in the manufacturer parts kit experience has shown that the circuit might not reach its threshold voltage when using a computer as the source of the music, even when at full volume. It is speculated that the manufacturer circuit was designed for stereos that put out a stronger voltage signal. Due to the fact that most students use a computer as their primary source of music the circuit was modified with the inclusion of a 9V battery to provide a DC offset to the music signal. Figure 5 shows the music signal after passing through the 9V battery. Comparison with Fig. 3a shows that the battery acts as a crude amplifier which raises the peak voltage from 1V to 1.4V. It is worth noting that the manufacturer lists a trigger voltage of 2.3 Volts, but does not specify where that voltage should be measured. Despite the voltages shown in Fig. 5, with proper potentiometer adjustment this song at this volume provides adequate voltage to trigger the Christmas lights to flash with the music.

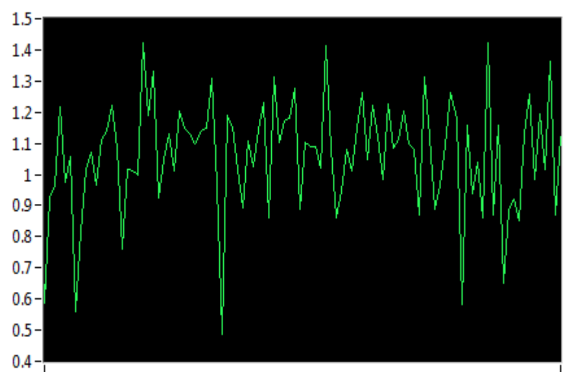


Figure 5. Jay-Z - Izzo at ~0:20-0:30 with computer volume at 100% after 9V battery

The 1kΩ potentiometer provides one more adjustment capability in addition to the song, the source of the music, the volume of the music and the DC offset provided by the 9V battery. Adjusting the potentiometer can adjust the music signal's offset and lower the amplitude of the voltage peaks without altering the sound of the music that one hears through the speakers. Figure 6 shows a music signal with the potentiometer setting at three different settings as represented by the white lines. It is noted that at the extreme adjustment the music signal has no offset and shows no voltages peaks. If the source of the music has a built-in DC offset, as some cellphones and Ipods do, adjusting the potentiometer too far one way results in the voltage always being above the threshold and adjusting it too far the other way results in the voltage always being below the threshold voltage. This would correspond to conditions where the Christmas lights would always be on or off respectively. Between these two settings is a narrow potentiometer position wherein the Christmas lights fluctuate with the music.

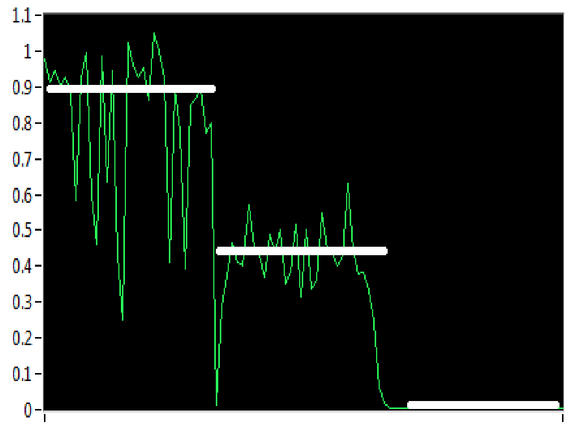


Figure 6. Jay-Z - Izzo at ~0.20-0:30 with volume at 100% after 330Ω resistor with potentiometer adjusted to three different settings (white lines)

Laboratory Activity

Students were provided two lab sections to practice soldering and work on their project. Each lab section was 100 minutes, had ~15 students and was staffed by the course instructor and 1-2 undergraduate student mentors. These paid student mentors were typically sophomore or junior engineering majors who had previously built the circuit. At the start of the first lab session all 15 students were given a 10-15 minute lesson which included the following topics:

- when/where soldering is used
- what is a printed circuit board (PCB)
- how to populate a PCB with components
- what is solder
- what is flux
- how solder is different from conductive glue (i.e. metals are bonded)
- proper soldering technique
- common problems that can occur if too much or too little heat is used
- proper lead trimming technique
- proper safety procedures
- soldering demonstration

After this introduction the students were split amongst the 6-7 work stations. Each work station had 2-3 soldering irons (some sharing was needed for large lab sections), wire strippers, needle nose pliers, and solder. Students developed some proficiency by stripping short wire sections and then soldering these wires and some additional resistors to a practice PCB. A minimum of 8 practice solders were completed by each student and then inspected by the instructor or student mentor. If any of the soldered joints showed signs of forming an inadequate junction (too little solder, too little heat, too much heat, etc.) students were asked to either retouch that joint or complete extra joints.   When 8 satisfactory joints were completed and the student felt confident in their soldering ability they started working on their circuit project. Students who were not confident were given further guidance and allowed to practice soldering until they felt competent.

To complete the project students followed a detailed set of instructions while asking questions of the student mentors and instructor. Due to the fact that the project includes alterations to an available kit and the inclusion of a box in which the final product is housed the series of steps is quite long. The parts used to build the project are shown in Fig. 7. The complete set of instructions is available by contacting the lead author; an abbreviated set of steps includes:

- solder provided components to PCB (Fig. 8a)
- solder appropriate wires to two audio jacks to create a splitter (Fig. 8b)
- solder 9V battery leads into circuit (Fig. 9)
- drill holes in provided box for potentiometer, audio jacks, power and load cable bushings
- have soldering approved by instructor
- mount circuit within box
- mount power and load cables to box and connect to circuit (Fig. 10)

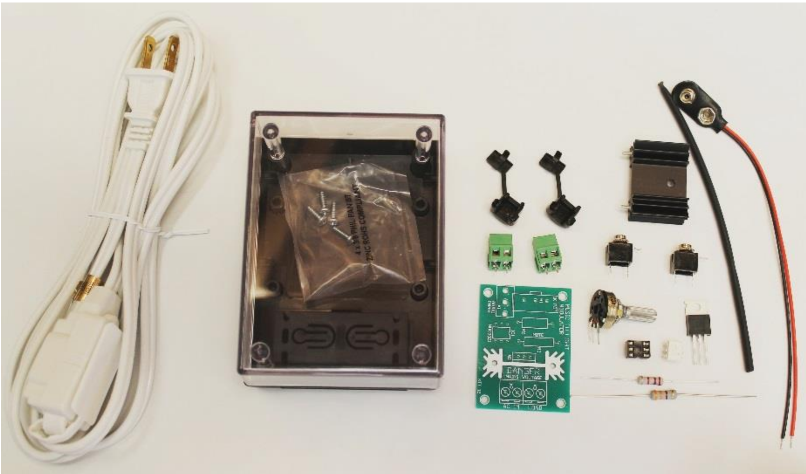
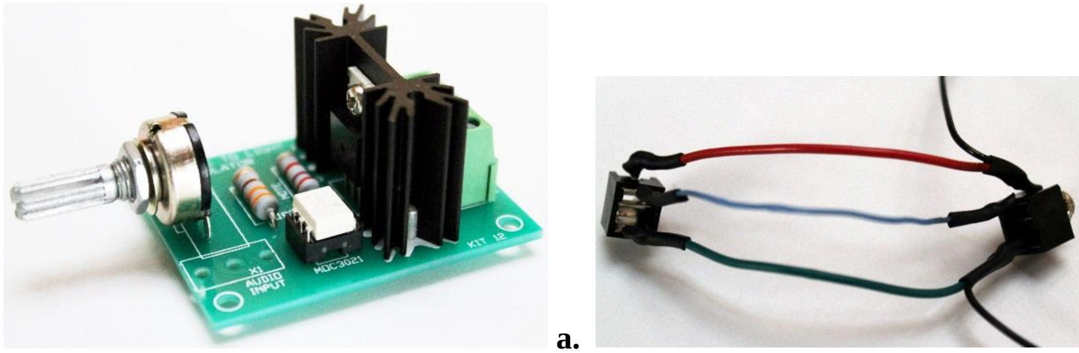


Figure 7. Parts needed to build and house circuit



a. b.

Figure 8. a) PCB populated with parts from kit; b) Two 3.5 mm audio jacks soldered together to create a splitter

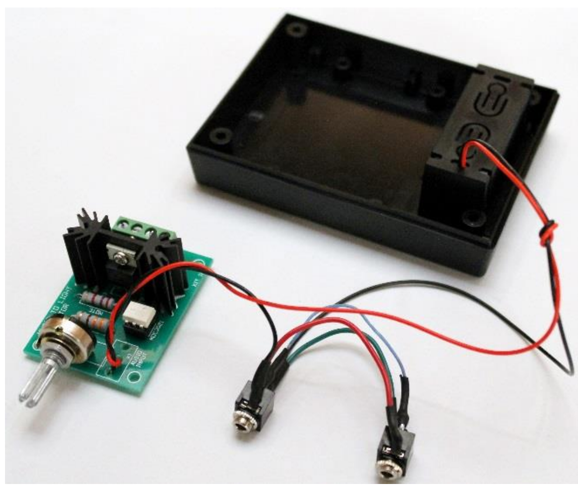
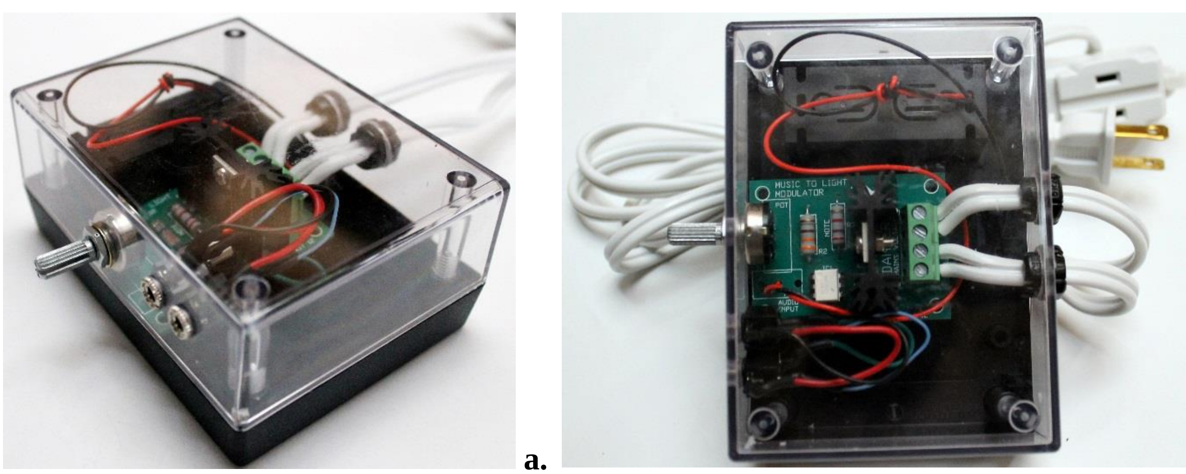


Figure 9. Project with soldering complete



a. b.

Figure 10. Completed project mounted in clear housing

When a student completed their project the instructor used a multi-meter to check for shorts on the power side of the circuit. If a short exists in this part of the circuit plugging it into an outlet will result in a spark and a circuit breaker being tripped. Once it was confirmed to be free of a short the instructor gave the project a visual inspection to ensure that all parts were in their appropriate places. A 9V battery was then inserted, the project was connected to Christmas lights and to a computer to be tested with a song of the student's choosing (played via Youtube). If the project did not work the instructor would trouble-shoot the circuit while explaining to the student exactly what they were doing. Once the problem was detected the student was asked to fix it and have their project re-tested. If the project was completed successfully the instructor showed the student how the circuit behavior depended on the volume of the music and on the potentiometer setting. Students were allowed to take their successful project with them.

Project Assessment

To assess how well the music-to-light circuit project did at meeting its objectives a pre-project and post-project survey were used as well as specific questions on the course midterm and final exam.

Soldering ability: The pre-project survey was used to gauge incoming student ability with soldering and experience with circuits. It was found that only 37.5% of incoming students had built a circuit before, showing that this project would be a unique experience for many students. It was also found that 37.5% of the students came into the class having previously soldered. Of the students who had previously soldered 50% indicated that they were not currently confident in their ability to solder without instruction. Thus, 81% of the class required soldering instruction. This demonstrates the importance of the mini-lesson on soldering and practice soldering before starting the project. The post-project survey showed that 92% of the students would be confident soldering without supervision after completing the project and 91% believed that they had sufficient practice. From this the authors conclude that the requirement of 8 successful practice solders, in addition to the soldering needed to complete the project, is adequate training in the process of solder for the vast majority of students and provides a good balance between time required and student learning.

Time required: Roughly 5% of students finished and tested their circuit within the allotted two lab periods and the other 95% needed to spend time outside of lab to finish. The student mentors held multiple open lab hours in the evenings during which students could complete their work. The post-project survey revealed that on average a student spent 3.1 hours on this project outside of the two allotted lab periods to complete their project. This is an adequate result as students are expected to spend roughly 2.5 hours of time outside of class each week and there were no other reading or HW assignments required before the project was due. However, there are some areas where gains could be made in reducing student time requirements. The post-project survey revealed that 35% of students did not have a circuit that worked on their first try. Of those that did not work 70% had a problem with their power cable or load cable connection, 15% had soldered their audio jacks incorrectly, 8% had installed their IC chip incorrectly and 7% soldered resistors in the wrong place on the PCB. If these problems were diminished by greater oversight and instruction more students would finish on their first attempt and thus spend less time. It was also found that the soldering was typically done quite quickly, yet students struggled in drilling and making the mechanical connections. It is possible that written instructions are cumbersome and that a video would be easier and faster to follow. When asked how the project could be improved, the clarity of the instructions was commonly brought up. One could also go to the extreme of having the holes drilled for the students by the lab instructor or student mentor beforehand. This would also lead to less boxes being wasted by students improperly drilling holes.

Cost and safety: The total cost in parts for the completed circuit shown in Figure 10 is $22.82 (see Appendix) which includes a 9V battery and a 3.5 mm auxiliary cable. The battery and cable add $2.48 to the total cost, but allow the student to use their circuit immediately without need for purchasing anything. The clear box with a built-in 9V battery slot costs more than some other boxes but serves two important functions. First, it allows students to see their circuit better than a black box, making it easier for them to describe the circuit to friends and family when showing it off. Second, it allows the battery to be replaced without risk of a person touching any part of the circuit. When the circuit is plugged into a wall outlet many components are at the same voltage as the wall outlet creating, a safety concern for anybody who would have to get near the circuit components to replace a battery. In the current configuration, after students test with the instructor to confirm that they have a working project, there would be no reason to open the box which makes it safe to use unsupervised.

Student interest in project: To assess if the project was of interest to students the post-project survey asked students to state if they had used their circuit outside of class and to rate their interest in the overall project. It was found that 93% of students used their circuit outside of class suggesting that there was great interest in the product produced. Using a Likert scale with 5 = I was very interested in this project, 4 = I was interested in this project, etc., the distribution of student interest ratings was obtained (Fig. 11). These results show significant interest in this project and the average student rating was 4.8/5. This rating is higher than the microcontroller (Arduino) and higher than the mechanical engineering project that students also complete as part of the lab. This result is remarkable due to the fact that the class is composed of 80% mechanical engineering students and shows the broad appeal of the project. Past research has shown the importance of non-EE majors being exposed to electrical engineering content which they find engaging and relevant to their interests without becoming overwhelmingly difficult[19-20] in order to promote the interdisciplinary nature of engineering.

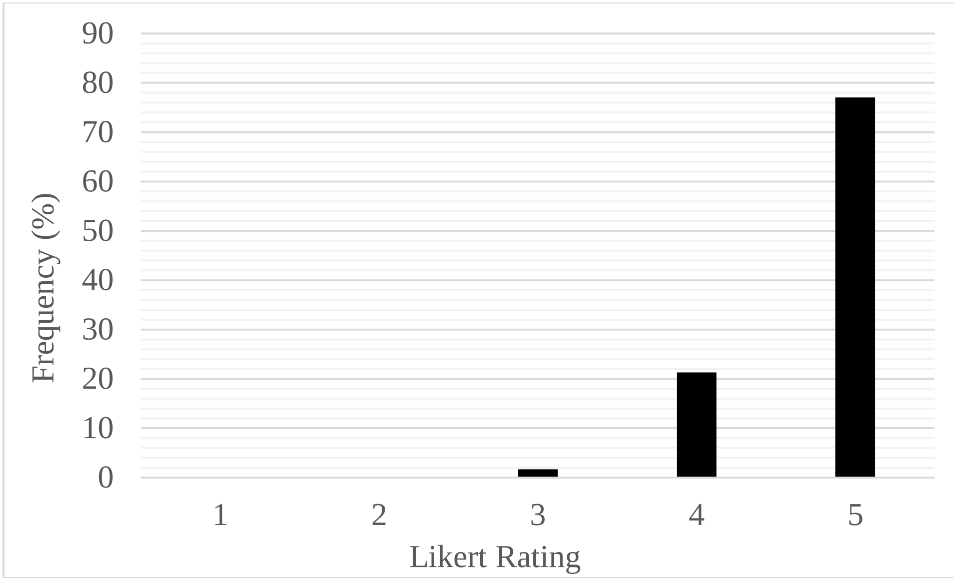


Figure 11. Student interest distribution in project using Likert Scale (1 = very disinterested in this project, 5 = very interested in this project)

Student learning: The midterm and final exam for the course included problems to test student knowledge and comprehension of how the components in the circuit collectively produce the final product. To test student knowledge they were shown the circuit diagram in Fig. 2 with some components circled and asked to identify the component (resistor, potentiometer, LED, etc.) and/or identify their function (i.e. limit current to …, acts as an electric switch, etc.). To test for comprehension students were asked how the circuit would behave differently if a component was replaced by a piece of wire. Student comprehension was also tested by asking them to identify reasons why a correctly completed project might not make Christmas lights fluctuate with music which related to music signal manipulation. On the midterm and final students averaged 94% and 92% respectively on knowledge questions related to the circuit. On the midterm and final students average 85% and 80% respectively on comprehension questions related to the circuit. The overall average grade on the midterm and final exam were 84% and 80%. Based on this it is concluded that students developed and retained knowledge and comprehensions of the circuit components, their individual functions, how they work together, and how the circuit manipulates a music signal better than most course material. When one considers the limited amount of time dedicated to instruction on these concepts (1 lecture, plus ~ 15 minutes of review) these results demonstrate the utility of the project as a learning tool.

Conclusion

A music-to-light modulator circuit has been adapted from an electronics kit and implemented in a 1 credit introduction to engineering class consisting of electrical and mechanical engineering students. The lab based assignment project was used to motivate and provide context for subject-based learning on electricity. In the process of developing the final product students get hands-on experience with soldering and drilling. The final product is a robust product which costs less than $23, is safe to operate, can be used with multiple music players and can be built by students after brief training in soldering in roughly 5-6 total hours. Readings on electricity fundamentals and in-class lessons transform the project from a very constrained build project into a tool for learning practical skills as well as about electrical components, circuits, and signal manipulation. The project is extremely well received by both mechanical and electrical engineering students who end up with a product that they can take with them and will be used. Exam questions show that activities described lead to a good level of student knowledge and comprehension of the various aspects of the circuit. The results support previous conclusions[16] that assignment projects, when done well, can motivate student curiosity and learning of conceptual topics and practical skills.

This project appears especially well suited for introductory courses as the circuit incorporates a relatively small number of components. This makes it easier to build and easier to understand than a project that utilizes more components (capacitors, op-amps, etc.). However, there is room for improving the functionality of the circuit in a class where more time can be dedicated to the project. The incorporation of an op-amp would provide a more elegant method for increasing the amplitude of the voltage peaks in a weak music signal. Amplifying the entire signal rather than using a DC offset as done in the current version would also give greater ability for adjustment. The current circuit has a narrow potentiometer setting due to the fact that the entire signal is moved close to the threshold voltage while the peak to peak amplitudes remain small. An additional improvement would be to incorporate RC filters in order to isolate different frequency ranges. Finally, one could incorporate a microphone to pick up a music signal rather than using a cable to directly connect the circuit to a music player. It is believed that the strength of this project lies in the fact that students take the project from individual components to a complete product whose operation they fully understand and which performs a function that they find interesting. If enough time and instruction is provided to adequately incorporate any of these suggestions it is likely the project will be as successful, if not more so, than the current configuration. One interested in doing so could pick out parts to incorporate in the current project, or start from a different kit (for example: CANCK185, electronickits.com, $39.95).

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Appendix

Music-to-Light Modulator Project Bill of Materials

Part	**Supplier**	**Part #**	**Cost/unit**	**total Cost**
Light modulator kit	Carl's Electronics	CK1200	$12.95	$12.95
extension cord	Home Depot	SKU 145-017	$1.47	$1.47
Box	Digikey	SR232-CB-ND	$4.23	$4.23
9V battery snap lead	Digikey	BS12I-ND	$0.51	$0.51
Audio jacks	Marlin P. Jones & Associates	5515 PL	$0.38	$0.76
Strain relief bushings	Jameco	182351	$0.12	$0.24
3.5 mm audio cable	sfcable.com	10A3-06	$1.28	$1.28
9 V battery	McMaster-Carr	7697K34	$1.20	$1.20
		Total Cost:		**$22.82**

Other materials needed:

- Heat Shrink
- Wire (different colors recommended: Black, Red, Blue, Green)