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Facilitating Student Learning with Hands-On Projects in an Electronics Course in a General Engineering Curriculum

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In a general engineering program at East Carolina University, an electrical concentration Electronics course does not have dedicated laboratory components. In the past years, PSpice simulation projects were utilized to reinforce electronic circuit analysis (mostly transistor-based) and design. These software-based hands-off projects were not received well by students due to the technical difficulties associated with the software and the lack of physically tangible excitement.

Two hands-on projects were recently introduced to the course, one consisting of a light-controlled LED and the other involving two alternatively fading LEDs,. On the first day of the class, both projects were demonstrated to the students to stimulate their interests. Early in the semester, the students were asked to build the circuit in the first project and show its function. Later in the semester, as bipolar junction transistors (BJTs) were introduced, the alternatively fading LED project was assigned. The students were asked to build and troubleshoot the circuit and write a comprehensive report describing various parts of the circuit, which included a triangle waveform generator, the DC biasing and AC changing of two complementary driving circuits that further consist of current sources and NPN and PNP BJT drivers. Based upon the hands-on experience, the students were challenged to design circuits to meet different load needs and alternating frequencies.

Many evidences from the semester have clearly shown that these hands-on projects successfully served as a vehicle to motivate student interests, facilitate classroom interaction, and improve learning outcomes. This paper presents the learning theory that supports hands-on experience, the basic structure of the course, the implantation and logistics of the projects, and assessment applied to evaluate outcomes as a result of this hands-on addition.

Introduction

“The function of the engineering profession is to manipulate materials, energy, and information, thereby creating benefit for humankind. To do this successfully, engineers must have a knowledge of nature that goes beyond mere theory.” [1] Various forms of laboratory learning experience are utilized in engineering curricula to assist students to gain this knowledge. Among these laboratory approaches, simulation based on computer software [2, 3] and hands-on experiments with physical tools [4, 5] are often adopted in different scenarios. Generally speaking, it is believed that both simulations and hands-on experiments can achieve two anticipated goals: (1) to provide “*experimental data to guide them* [the students] *in designing and developing a product*” and (2) “*to determine if a design performs as intended*.” [1] When evaluated under the three learning domains (cognitive domain, affective domain, and psychomotor domain), both approaches can achieve similar learning objectives under the cognitive domain. However, it is also recognized that simulation-based learning experiences may not provide as strong learning as their hands-on counterparts in the affective and psychomotor domains [6].

At East Carolina University, an undergraduate *Electronics* course in a general engineering program has just completed a round of course improvement that replaced simulation projects previously offered with physical hands-on projects: in the earlier years, the course incorporated an electronic design project based on PSpice simulation [7]. Students were asked to design a 5V DC charger with transformers and transistors (either bipolar-junction transistors or MOSFETs). In order to ensure all the students use the same version of PSpice for support convenience, the PSpice software was installed on central college blade servers. The students used the software through a remote access program called VMware View [8]. The course with this simulation project has been office twice. While the students were able to put together their circuits per the requirements and observe waveforms at various nodes of the circuits, this double-virtualized (some refer to simulation as virtual labs, yet here the software is installed on virtual computers, making it more virtual) laboratory did not provide the students much “tangible” experience. Moreover, the students’ learning was greatly limited by their ability to utilize the PSpice software (which requires a very steep learning curve) and was occasionally impaired by the frustration caused by Internet connection and data storage issues.

Fall 2015, a series of two hands-on projects that required the students to build transistor circuits on breadboards outside scheduled class time was developed to replace the PSpice projects. The first project was an introductory practice for the students with the purposes of demonstrating course relevance, refreshing breadboard wiring skills, and stimulating interests; the second integrated hands-on fun with deepened comprehension of subject matters.

This paper presents this course improvement exercise, including a brief description of the course, the development and implementation of the projects, and the assessment work at the end. Several noteworthy points are made based upon the assessment data collected.

Methodology

EENG3530—Electronics Course Overview

Established in 2004, East Carolina University's general engineering program was established to train employees that are prepared with general engineering skills for local business and industry employers in eastern North Carolina [9]. The curriculum was therefore structured with the combination of an engineering core and concentration-specific courses. As one of the six concentration courses for the Electrical Engineering (EE) concentration, *EENG3530—Electronics* exposes the students with the operation and applications of semiconductor elements such as diodes, BJTs (Bipolar Junction Transistors), MOSFETs (Mental Oxidized Semiconductor Field Effect Transistors), and their typical configurations. Prior to this course, students had a four-hour circuit theory class that introduced basic DC and AC circuit analysis with some circuit construction skills.

Although it is widely believed that laboratory learning is a quite effective way to learn topics in such a course, scheduling formal weekly lab time within three credit hours as is done in many other EE programs, is very difficult. A viable solution to address this issue is to reinforce the electronic circuit building blocks (diode, op-amp, BJT, and MOSFET) with real-world examples using an independent "learning-by-doing" approach. Two hands-on projects, both requiring the students to build circuits on breadboards outside the class time, were developed. The first project was a warm-up exercise at the beginning of the semester, with the purposes of demonstrating course relevance, refreshing breadboard wiring skills, and stimulating interests; the second blended enjoyments from hands-on work with deepening comprehension of materials covered in the lectures. At the course level, these two projects are expected to support many course learning objectives, including:

1. Perform basic circuit analysis on op amp circuits
2. Describe the operation of an ideal diode and understand its I-V characteristics
3. Design basic circuits involving LEDs
4. Describe the physics and theory of operation of a bipolar junction transistor (BJT)
5. Describe the physics and theory of operation of a MOS field-effect transistor (MOSFET)
6. Utilize external components to design transistor bias circuitry
7. Utilize common transistor models to perform small- and large-signal analysis
8. Utilize common single-transistor configurations to design basic amplifier circuits
9. Build and troubleshoot practical transistor circuits and describe how transistors work

The Two Hands-on Projects

Two consecutive BJT-based LED lighting projects (see Figures 1 and 2), the first building a light-controlled LED circuit and the second building an alternatively fading LED circuit, were developed (original circuit ideas from [10, 11]). At the beginning of the first class, both circuits were pre-built by the instructor and demonstrated to the entire class. The operation of the two circuits, although the students did not have prior knowledge about transistors and did not fully understand, was also briefly introduced in order to give the students the first exposure.

For both projects, the students were provided with a 16.5' × 5.5' breadboard with wiring jumpers, a 9V alkaline battery, and all the necessary electronic parts (LEDs, resistors, op-amp chips, capacitors, and transistors, etc.) in a plastic zip bag. Schematics of the circuits (again see Figures 1 and 2) were also given in the instruction handouts. They students were asked to build the circuits, troubleshoot and make them work.

The first circuit was an LED illumination circuit, in which the light intensity of the LED is controlled by the amount of light detected by the photocell. In this circuit, the 470Ω resistor limits the current through out of the 9V battery and protects the LED from being overheated. The 500kΩ potentiometer allows the students to conveniently adjust the operating point of the transistor Q_1 so that the LED can be turned on with sufficient (but not too much) current, without the need of performing calculations and without using a multimeter to measure the base voltage of the transistor.

Again, this project was completed during the first week of the semester, with the primary purpose of engaging the students. The students did not have any knowledge about transistor circuits at this time. As a result, they were not required to write a formal project report, except a paragraph describing the purpose of the current limiting resistor R_1 in Figure 1.

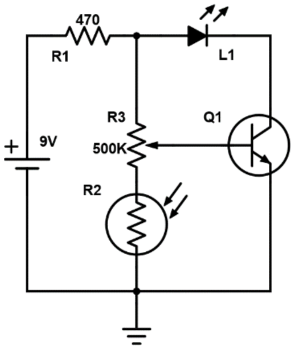


Figure 1. A light-controlled LED circuit

The circuit in the second project involves two differently colored LEDs. It alternates the brightness of the two LEDs by precisely controlling the current going through them. In Figure 2, the two op-amps, one works a comparator and the other as an integrator, form a triangular waveform generator, whose output is voltage v_o. As determined by the resistor values (R_1 and R_2), the generated triangle waveform v_o has an average of approximately 4.5V. As the output voltage v_o increases (as the result of the integrator) and approaches ~6.5V, the non-inverting voltage of the first op-amp v_+ is greater than the inverting voltage v_-, which turns the comparator's output v_1 from 0V to 9V. This causes the integrator output v_o to change towards its lower end. When reaching ~2.5V, the relationship between the two input voltages of the comparator changes, forcing v_o to increase. A triangular waveform is therefore generated. Resistance R_3 and capacitance C_1 determine the period of the triangular waveform.

The output of the triangle waveform generator v_o, after being lowered with two voltage dividers (R_7 and R_8 as a pair and R_{13} and R_{14} as the other), drives the base of two complemental transistor branches, each drives a LED of different color. When v_o is at its average (4.5V), both LEDs have about the same brightness. As this voltage increases, it brings a larger i_{b1} to the NPN transistor Q_3, which in turn increases the brightness of LED L_1 and weakens the current i_{b2} to the PNP transistor Q_4, resulting a dimmer LED L_2.

After building and testing the second circuit, the students were required to write a report that elaborate the following technical details (See Appendix 2):

a. How does the waveform generator work?
b. How is the cycling time of the alternation achieved?
c. How does the brightness of the two LEDs alternate?
d. What are the changes need to be made in order to drive a heavier load?

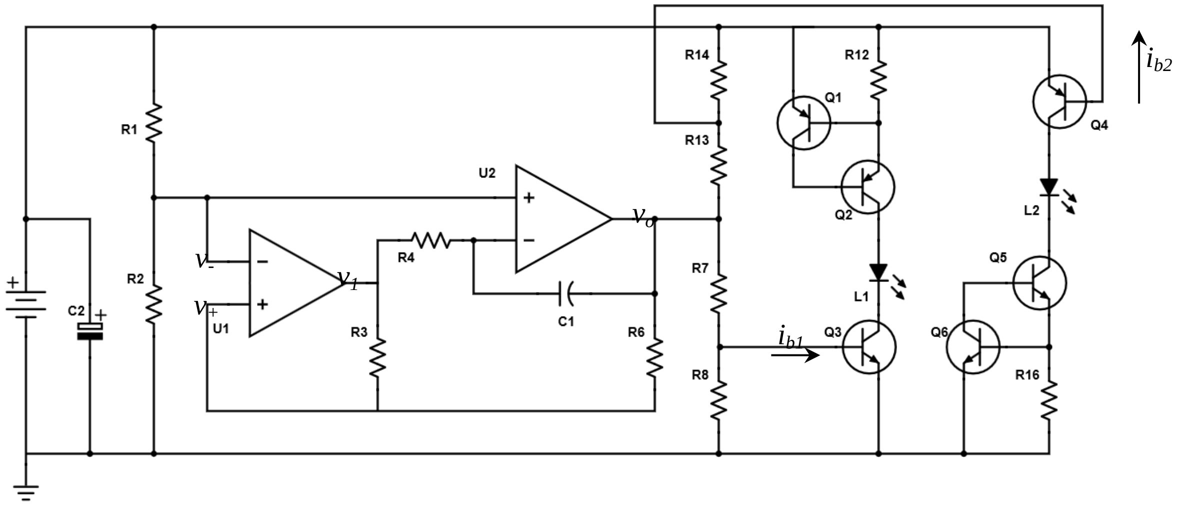


Figure 2. An alternatingly fading LED circuit

Project Assessment

Referring to a validated *Pittsburg Engineering Freshman Attitude Survey* [12], the two hands-on projects, as an instructional intervention, were assessed primarily in three areas: (a) how the projects helped students learn the subject matters; (b) how the projects affected the students' perception about the subject and the electrical engineering discipline; and (c) how the students thought about completing independent hands-on electronics laboratories without close supervision/assistance from the instructor. Twenty questions addressing these three areas were asked with their order randomized. Five level Likert-type scale was utilized for the answers to these questions, with 1 to be the least positive and 5 the most positive.

Out of the 27 students in the class, 22 responses were collected after the completion of the two projects. The results from the survey were re-grouped corresponding to the three categories and the results (average scores and the standard deviations) are presented as illustrated by the three figures (Figures 3-5) below:

(a) Five questions were asked about how the projects helped the students gain various related skills or knowledge. Specifically, these concepts/skills include: circuit analysis skills, operation and applications of transistors, applications of op-amps, wiring and troubleshooting skills, and datasheet reading skills.

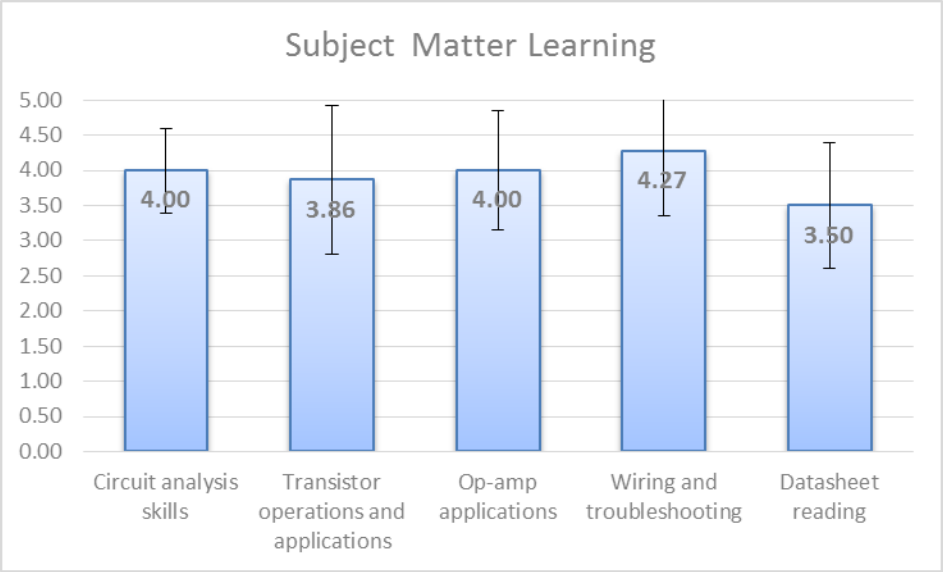


Figure 3. Survey results for how the projects helped subject matter learning

(b) Five questions were asked to gain an understanding of how the students liked the hands-on learning experience and how the projects helped them understand electrical engineering as an engineering discipline.

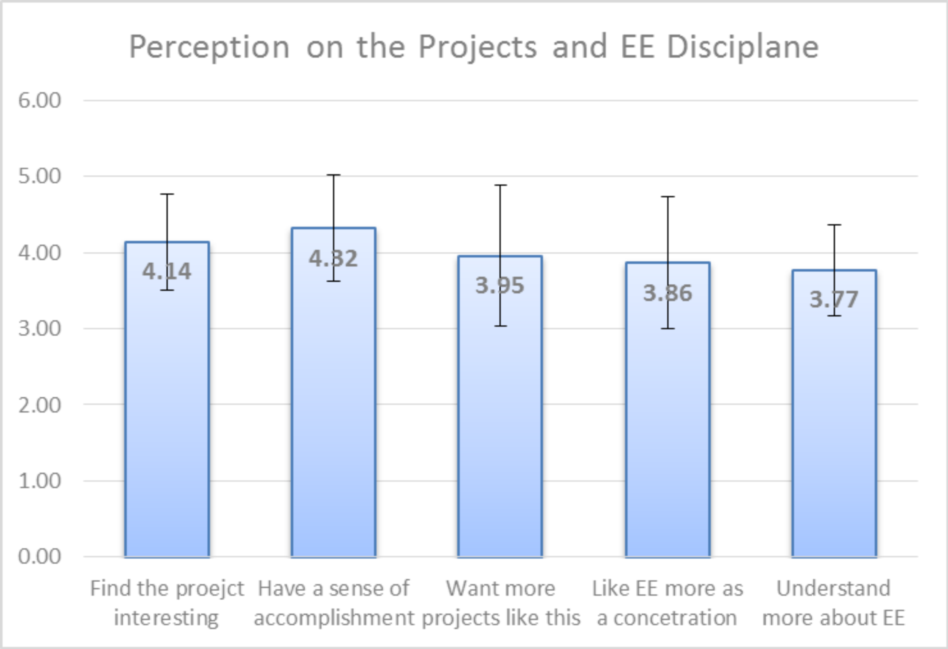


Figure 4. Survey results for how the projects affected students' perception

(c) Four questions were asked to collect the students' opinions on how comfortable they felt with completing similar projects independently and their inputs on how the hands-on learning experience can be improved.

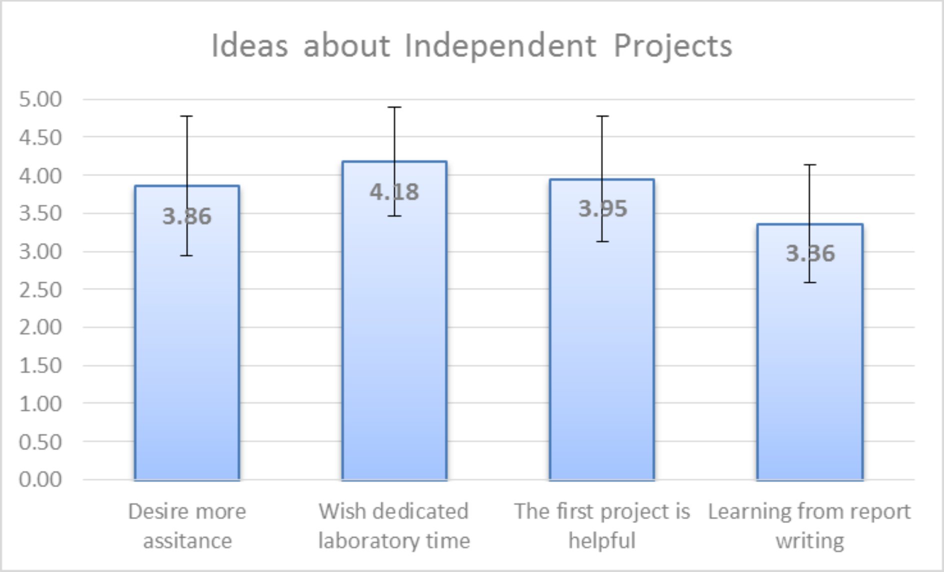


Figure 5. Survey results for how the students thought about completing projects independently and improvement areas

Discussion

The assessment results from the three categories of interest provide meaningful insights in what the hands-on projects brought to the students and possible ways to improve student learning:

(a) Overall, the learning of five areas of skills was all positive with the reported score ranging from 3.5 to 4.27. The students felt noticeably stronger in three of the areas (Circuit analysis, Op-amp, and Wiring and troubleshooting) than the other two areas (Transistors and Datasheet reading). This is possibly because, for the three areas scored higher, the projects were more of a review and reinforcing process since all the students had *ENGR2514—Circuit Analysis*, an engineering core course that introduces these skills. The other two areas that received lower scores, however, were new learning objectives in the *Electronics* course. It is worth noting that the skills related to building circuits on breadboard showed the greatest improvement which cannot be achieved through the original PSpice-based projects. This observation confirms the benefits of moving from computer simulation to the hands-on projects.

(b) The students found the projects very interesting (scored 4.14) and completing the projects gave them a high level sense of accomplishments (scored 4.32), as expected. At a broader level, the impact of the projects to the students' perception about EE as a discipline or an occupation, although also positive (scored ~3.8), was not as significant. It is interesting to observe the student's enthusiasm when one of mechanical concentration student responded “Mechanical always” as the answer to the question “After the project, I am glad that I chose (or I wish I had chosen) EE as my concentration.” This rewarding experience evidenced by the survey results is believed to have engaged the students well in the course and, more importantly, is anticipated to positively impact them in the future.

(c) Assessment results for the third category of interest clearly show that independently working on hands-on projects without immediate assistance is not easy for many students. Although they believed, in the two-project progressing sequence, the first project helped them warm up for the more challenging one (3.96), the students wished more assistance were available (3.86) and requested dedicated laboratory hours (4.18). These inputs are very helpful for curriculum improvement in the future. When asked how writing the report helped them learn, the students responded with a relatedly low score of 3.36. They also expressed their wishes in more detailed in their comments. More specific instructions in the report-writing guideline should also help the learning of subject matters discussed earlier.

In addition to the findings from the assessment results, several other improvement opportunities have been identified through this first-trial. For example, the current projects did not include significant design elements: the students were mostly asked to build the circuits with the complete schematics provided. More design components are planned in the future in order to challenge the students and provide more active learning experience. In the second project, the block diagram of the triangle waveform generator will be provided, but the detailed circuit design and part value need to be figured out by the students.

Conclusions

This paper presents the implementation of two hands-on circuit building projects in an Electronics course in a crowded general engineering curriculum. The students independently completed the two sequential projects outside of class time. While it was observed to be challenging for the students and the learning experience can be further improved, the assessment results show that the projects served as a great engagement tool and facilitated subject learning.

References:

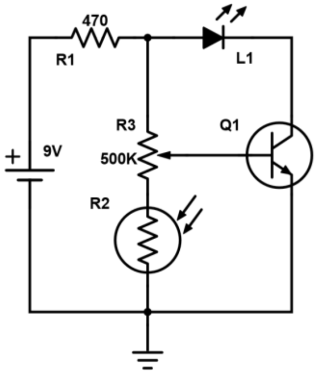
1. Feisel, L. D. and A. J. Rosa. "The Role of the Laboratory in Undergraduate Engineering Education," *Journal of Engineering Education*, pp. 121-130, January 2005.
2. Campbell, J. O., R. J. Bourne, P. J. Mosterman, and J. A. Brodersen. "The Effectiveness of Learning Simulators in Electronic Laboratories," *Journal of Engineering Education*, vol. 91, no. 1, pp. 81-87.
3. Hodge, H., H. S. Hinton, and M. Lightner. "Virtual Circuit Laboratory," *Journal of Engineering Education*, vol. 90, no. 4, pp. 507-511.
4. Leva, A., “A Hands-On Experimental Laboratory for Undergraduate Courses in Automatic Control,” *IEEE Transactions on Education*, Vol. 64, No. 2, 2003, pp. 263–272.

5. Flack, K., and R.J. Volino, “A Series-Parallel Heat Exchanger Experiment,” *Journal of Engineering Education*, Vol. 88, No. 1, 1999, pp. 27–30.
6. Warren, S., and J. Yao. “Portable Cyber-Laboratories for Electrical Engineering Education,” *Proceeding, 2010 Annual ASEE Conf.*, Louisville, KY, USA.
7. http://www.orcad.com/products/orcad-pspice-designer/overview
8. https://www.vmware.com/products/horizon-view
9. Kauffmann P., R. Rogers, and P. Lunsford. “A Case Study: Development of a Practice Oriented Engineering Program with Implications for Regional Economic Development,” *Proceeding, 2004 ASEE Annual Conference and Exposition*, Nashville, Tennessee.
10. LED with Light Sensor. http://www.kobakant.at/DIY/?p=1940
11. Fading LEDs. http://electronics-diy.com/electronic_schematic.php?id=622
12. Besterfield-Sacre, M., C.J. Atman, and L.J. Shuman. https://www.engineering.pitt.edu/uploadedFiles/_Content/Sub_Sites/Centers/EERC/_Documents/Reference_Materials/Pittsburgh%20Freshman%20Engineering%20Attitudes%20Survey.pdf

Appendix1:

EENG 3530— Electronics

Project #1: A Light-Controlled LED Circuit



Objectives:

1. Read circuit schematics.
2. Search for and read diode and transistor datasheets.
3. Wire circuits on a breadboard.
4. Troubleshoot electronic circuits.
5. Develop interests in electronic circuit theory and applications.

Parts:

Photocell 16-33KOHM; BC547 NPN Transistor; Breadboard;
LED; 470Ω resistor; 500KΩ Potentiometer; 9V Battery and battery holder; Jumper Wires.

Procedure:

1. Read the schematic and make sure you understand the connections.
2. Search the datasheets for the BC547 NPN transistor and the C5SMF-RJS-CT0W0BB2 LED and make sure you understand their pins. (Mis-connections may result in part damages).
3. Wire the circuits (except the battery) on the provided breadboard.
4. In order to prevent possible part damages, you may want to, instead of securely connect two battery leads to the proper nodes of the circuits, first momentarily touch them to the circuit and observe. You can connect them if you observe no signs of smoking or heating.
5. If you have burnt any parts, let me know to get replacements.
6. After the entire circuit is built correctly, adjust the potentiometer so that the LED starts emitting light of some level.
7. Test if the intensity of the LED increases when your finger moves over to the photocell.

Deliverables:

To get full credits (it is an equivalent of a homework assignment), do the following before the deadline:

1. Demonstrate the built circuit and its function.
2. Disassemble the circuit and place all the parts to the provided plastic bag.
3. Return all the parts.

Discussion: What is the purpose of the 470Ω resistor?

Appendix 2:

EENG 3530— Electronics

Project#1: Alternatively Fading LEDs Driven by Transistors

Objectives:

1. Read circuit schematics
2. Read for and read diode and transistor datasheets
3. Wire circuits on a breadboard
4. Build a triangular waveform generator with operational amplifiers
5. Design the time constant of the triangular waveform
6. Build circuits that alternatively fade two LEDs
7. Describe the amplification of the BJT transistor circuits
8. Troubleshoot electronic circuits

Parts:

R1,R2: 4K7 1/4W Resistors
R3: 22K 1/4W Resistor
R4: 1M 1/4W Resistor (See Notes)
R5: 2M2 1/4W Carbon Trimmer (See Notes)*
R6,R10,R11,R14,R15: 10K 1/4W Resistors
R7,R8: 47K 1/4W Carbon Trimmers (See Notes)*
R9,R13: 27K 1/4W Resistors
R12,R16: 56R 1/4W Resistors

C1: 1µF 63V Polyester Capacitor
C2: 100µF 25V Electrolytic Capacitor
D1-D4: LEDs (any type and color)
IC1: LM358 Low Power Dual Op-amp
Q1,Q2,Q4: BC327 45V 800mA PNP Transistors
Q3,Q5,Q6: BC337 45V 800mA NPN Transistors
B1: 9V PP3 Battery
Clip for PP3 Battery

*Notes: In our project, no switch; R4=3.3M, R9 & R13=47K; Trimmers are replaced by a short.

Overview:

This circuit shown in the figure operates two LED strips in a pulsing mode, i.e. one LED strip goes from off state, lights up gradually, then dims gradually, etc. while the other LED strip do the contrary.

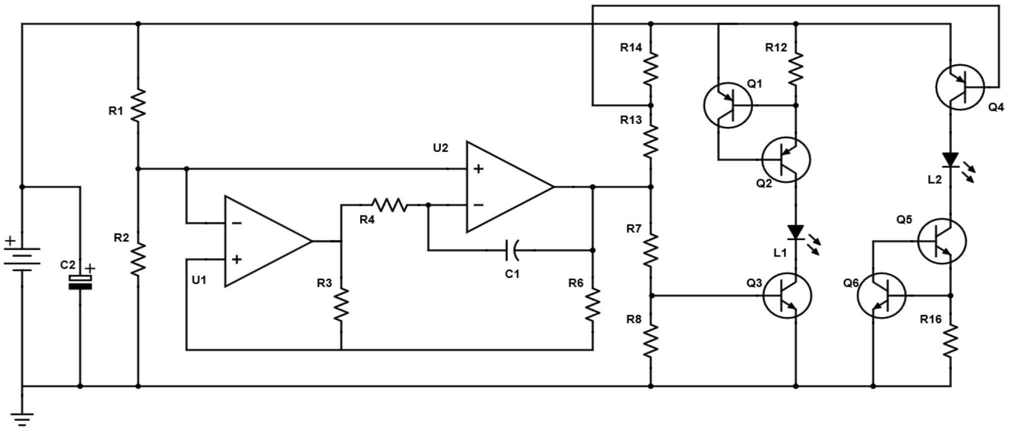


Figure 1. Alternatively fading LED circuitry.

In the circuit, the two op-amps form a triangular wave generator. The rising and falling voltage obtained at pin #7 of the chip controls two complementary circuits to drive two LEDs. Each of the two complementary circuits is formed by a 10mA constant current source (Q_1, Q_2 and Q_5, Q_6) and a driver transistor (Q_3 and Q_4).

Tasks:

1. Go through the provided parts and make sure you have everything you need.
2. Build and test the triangular waveform generator circuit. Demonstrate the working circuit to your instructor.

3. Build and test the entire circuit. Demonstrate the working circuit to your instructor.

4. Return all the parts to the instructor.

5. Write a project report.

Report Requirements:

Your report should include the following components: a cover page, an abstract, a circuit overview, descriptions and calculations of different parts of the circuit, and a discussion section.

Circuit parts that require detailed descriptions include the triangular waveform generator (alternating period, function of the two op amps, etc.), the complementary circuits, the current sources (how they work) and the driving transistors (DC biasing and changing/AC condition).

The discussion should include at least: what needs to be changed if the fading cycle needs to be three times faster? How many parallel LEDs can this circuit drive? How to modify the current source if we need to drive 3 parallel LEDs? If you are asked to modify the circuit two drive two tungsten bulbs, what needs to be changed?

Use waveforms and circuit schematics to assist your description when necessary. Waveform figures and circuit schematics should be placed right after the first time they are referred to. Simple calculations should be included in the main body of the report. If long calculations are involved, they can be attached in an appendix.

You are expected to prepare your report professionally. No handwritten material will be accepted. For schematics, you are suggested to use www.schematics.com.

Equipment Use:

You may need an oscilloscope and a multi-meter. Please see your instructor or lab supervisor for access of oscilloscopes and other equipment you need.

Grading:

Functioning Circuit: 20%

Written Report: 80%