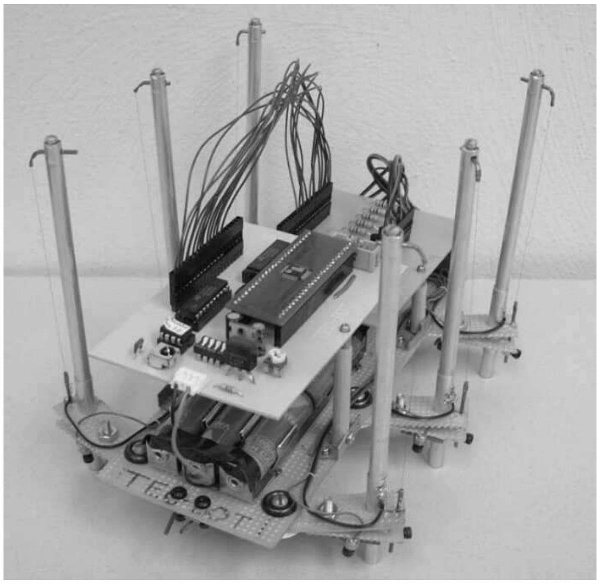
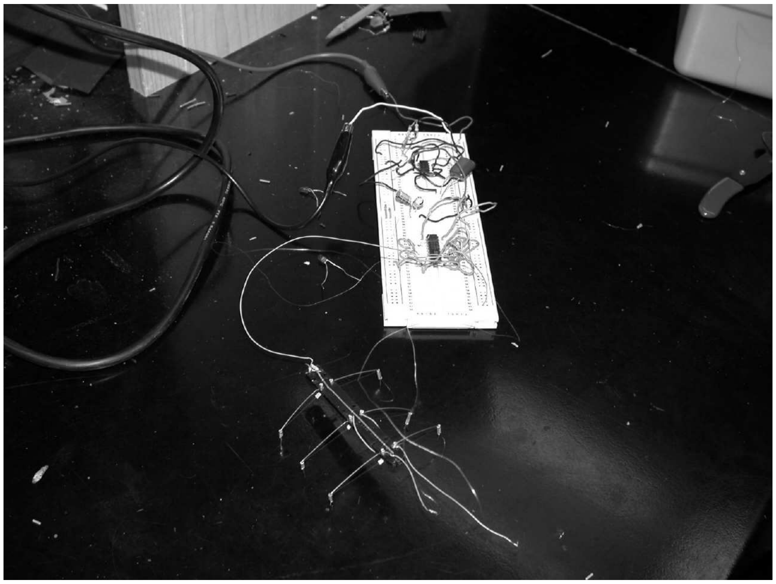
Introduction to Electrical and Computer Engineering:

Mobile Robotics

ECE 123





Dr. Frank Severance

Dr. Damon A. Miller

http://homepages.wmich.edu/~miller/RoboticsLaboratory.html
http://homepages.wmich.edu/~miller/ECE123.html

This material is based upon work supported by the National Science Foundation under Grant No. 0088158 and the Michigan Department of Education. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation or the Michigan Department of Education.

(version 1.3, April 2004)

Cover photographs: (left) TECBOT by C. Bush, T. Kracker, and E. Mulimba; (right) Stiquito^{TM}robot.

Originally created using WordPerfect^{TM}and Visio^{TM}. Revised using LaTeX and xfig (www.xfig.org) on a Linux system (www.linux.org, Linus Torvalds is the original developer of Linux).

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1 Acknowledgments

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Many experiments in this text are based on material from "Stiquito^{TM}for Beginners" by J. M. Conrad and J. W. Mills (www.stiquito.org).

The authors wish to thank the the following contributors to this text:

Dr. Betsy Aller, WMU	Strategies for a Successful Oral Presentation
Dr. John Gesink, WMU	Material on laboratory safety
Oklahoma State University, L.A.S.E.R. C.U.L.T. Light Applications in Science and Engineering Research	Compilation of material on cooperative learning

2 Syllabus

ECE 123 MOBILE ROBOTICS

Instructors:
varies by term

Course Evaluator:

Dr. Maria Suchowski, msuchowski@hotmail.com

Office Hours:
varies by term

Lab Hours:

The laboratory will be available a substantial amount of time beyond the regular class meeting times. The open lab hours will be posted on the lab door. You must follow all applicable safety standards; no one can work in the lab alone.

Description: ECE 123 Mobile Robotics (3-0), 3 hrs.

This course provides an introduction to the practice of electrical and computer engineering. Students learn skills that will be required throughout their academic and professional skills, including the art and science of engineering design, teamwork, basic electronics construction skills, and basic computer programming.

Prerequisites: Departmental approval. Also, basic high school mathematics through trigonometry is a must.

Text (required):

Stiquito^{TM} *for Beginners: An Introduction to Robotics*, James M. Conrad and Jonathan W. Mills, IEEE Computer Society, ISBN 0-8186-7514-4, 1999. **NOTE: THERE IS A STIQUITO**^{TM} **KIT INCLUDED WITH THIS TEXT: DO NOT BUY A USED BOOK IF THE KIT HAS BEEN OPENED!**

Topics: This course is centered on building a computer-controlled and an autonomous walking robot. Thus we will learn about:

1. electrical laboratory safety and practice;
2. teamwork;
3. basic electricity;
4. basic electronics;
5. nitinol wire;
6. levers;
7. electronics and mechanical construction skills;
8. using instrumentation (e. g. oscilloscopes);
9. basic computer programming and interfacing;

10. circuit simulation;
11. engineering design;
12. robotics;
13. engineering careers; and
14. technical communication.

See the course schedule for details.

Grading Basis:

mid-term exam	15%
final exam	25%
assignments, including pre-labs	20%
laboratory work	40%

Scale: 0-60 E | 60-65 D | 65-70 DC | 70-75 C | 75-80 CB | 80-85 B | 85-90 BA | 90-100 A |

The laboratory work grade will be based in part on your lab notebook, the functionality of your final robot, and **class attendance**.

COURSE POLICIES

ATTENDANCE is mandatory. In case of an emergency, contact your instructor as soon as you can. You are responsible for obtaining any material that you missed.

EXAMINATIONS AND QUIZZES will be closed-note closed-book unless otherwise noted. Examinations will be written in 8 1/2" x 11" exam booklets (blue book) unless other instructions are given. Failure to use such a booklet may result in a penalty on the exam.

Only under extremely unusual circumstances will make-up examinations be considered. If an emergency prevents you from attending a scheduled examination, contact your instructor PRIOR to the test or as soon as you can reach a telephone, e-mail terminal, etc. If the instructor cannot be reached directly, leave a message with the department (276-3150). Failure to adhere to this policy will result in zero credit for the exercise. Credit for an excused absence will be considered on on a case by case basis. Calculators (when allowed) must be from the approved list on Dr. Miller's website.

ASSIGNMENTS

Assignments are due at the beginning of class and will not be accepted late.

Use standard quadrille engineering paper and include your name, date, and assignment information. **Neatness is essential and sloppy work will not be accepted.**. The problem statement must be written, as well as the solution. Each page must be numbered and labeled. For computer assignments, provide program listings, output, and appropriate graphs.

LABORATORY NOTEBOOKS

The lab notebook is an integral part of this course. When preparing your lab notebook, assume that another student at the same level at another university will use **ONLY** your notebook to duplicate your results. Thus the description of each lab must be self sufficient. **Place a copy of you pre-lab in your lab notebook and turn the original in for evaluation**.

1. The notebook must be permanently bound (not loose-leaf) with a minimum of 60 sheets. Each sheet should have a square grid (4 or 5 divisions/inch is convenient) and be of 8.5 x 11 inch size. A spiral bound notebook is preferred since it will easily lie open on the lab tables. If the pages are not numbered, number them. Be sure to reserve several pages at the beginning for "global" information and a table of contents which may be entered as you fill the notebook.
2. The table of contents must consist of three columns: (1) date(s) that the work was performed, (2) title of the laboratory, and (3) space for the instructor to initial your notebook data for that lab.
3. Use a PEN for ALL entries in the notebook.
4. Put your name, the name of your lab partner, course number, and section number both on the cover and on the first page. If your lab partner changes, appropriately and clearly note the name of the new lab partner and the date of change.
5. Each page of the notebook must be numbered and contain material pertaining to only one experiment. Entry dates must be indicated.
6. If additional materials such as graphs and computer outputs are entered into the notebook, fasten them (e.g. tape or paste) securely and trim edges to prevent their protrusion from the notebook.
7. Enter data and calculations into the notebook **AS YOU WORK**. **DO NOT** take data on loose sheets or scraps of paper and later copy it into the notebook. Erasure of notebook entries is bad practice and is discouraged. Simply cross out mistakes, do not obliterate them. Often what appears at first to be a mistake will later be found to contain useful information.
8. Laboratory instruction sheets may be attached to pages of the notebook, however the sheets should be trimmed so that they do not protrude from the notebook.
9. Neatness and legibility are **VERY** important.
10. Following is a list of items that would appear in a well planned and executed laboratory notebook for **EACH** laboratory exercise. Use this list as a guide for your entries:
    a. Title, date, and name of lab partner
    b. Pre-lab calculations
    c. Measurement preparations and circuit diagrams
    d. Lab lecture notes
    e. Original data
    f. Calculation of theoretical values and data analysis
    g. Data presentation clearly showing discrepancies between experimental and theoretical values
    h. Answers to questions and conclusions, i.e. discuss discrepancies between experimental and theoretical values and on this basis clearly assess whether the objectives of the experiment were attained.

ACADEMIC HONESTY is expected and a course requirement.

You are responsible for making yourself aware of and understanding the policies and procedures in the Undergraduate (pp. 271-272) Catalog that pertain to Academic Integrity. These

> policies include cheating, fabrication, falsification and forgery, multiple submission, plagiarism, complicity and computer misuse. If there is reason to believe you have been involved in academic dishonesty, you will be referred to the Office of Student Judicial Affairs. You will be given the opportunity to review the charge(s). If you believe you are not responsible, you will have the opportunity for a hearing. You should consult with me if you are uncertain about an issue of academic honesty prior to the submission of an assignment or test.—provided by the Professional Concerns Committee of the Faculty Senate

See the “Plagiarism Test” at the end of this section.

OTHER NOTES

1. This course is based upon work supported by the National Science Foundation under Grant No. 0088158. Any opinions, findings, and conclusions or recommendations expressed in this course are those of the instructor(s) and do not necessarily reflect the views of the National Science Foundation. **Thanks to the NSF and Tektronix, Inc. for supporting this course.**
2. This is an experimental course. We are interested in studying and improving the effectiveness of this class. Dr. Suchowski will meet with you in “focus groups” to evaluate the course. Your input to these groups will remain anonymous and will be between you and Dr. Suchowski. The same goes for the attitude questionnaire and any other surveys. Instructors will only see results without names. None of this information will affect your grade. If there are any questions, please consult Dr. Miller (damon.miller@wmich.edu) or Dr. Suchowski.
3. We will most likely take some pictures during the lecture and laboratory. Some of these pictures might be posted on the course website or in other publications. If you do not want your picture to appear in such material, please let Dr. Miller know.
4. Some syllabus material adapted from work by Dr. John Gesink.

Fall 2003 ECE 123 Tentative Schedule

#	date	lecture	lab	item(s) due
1	9/3	course introduction laboratory safety teamwork attitude questionnaire basic electricity walking robots video		
2	9/8	skills pretest	(1) Instrumentation and Resistance	prelab (1)
			(2) Resistors and Resistive Networks	prelab (2)
3	9/10	diodes, LEDs, capacitors, and RC circuits	(1) Instrumentation and Resistance	
			(2) Resistors and Resistive Networks	
4	9/15		(3) Capacitors and RC circuits	prelab (3)
5	9/17	transistors, transistor circuits, and the Darlington arrays	(3) Capacitors and RC Circuits	
	9/19	**FRIDAY**		LABS 1-2 SIGNED OFF
6	9/22		(4) Transistors and Transistor Circuits	prelab (4)
			(5) Transistor Amplifiers and the Darlington Array	prelab (5)
7	9/24	Nitinol and levers	(4) Transistors and Transistor Circuits	
			(5) Transistor Amplifiers and the Darlington Array	
	9/26	**FRIDAY**		LAB 3 SIGNED OFF
8	9/29		(4) Transistors and Transistor Circuits	
			(5) Transistor Amplifiers and the Darlington Array	
9	10/1		(6) Nitinol: Lifting a Dead Weight	prelab (6)
			(7) Nitinol: Using a Lever	prelab (7)
			(8) The Stiquito^{TM} Emulator	prelab(8)
	10/3	**FRIDAY**		LABS 4-5 SIGNED OFF
10	10/6	Stiquito^{TM}] construction	(6) Nitinol: Lifting a Dead Weight	
			(7) Nitinol: Using a Lever	
			(8) The Stiquito^{TM} Emulator	prelab(8)
11	10/8		(9) Stiquito^{TM} Construction	prelab (9)
	10/10	**FRIDAY**		LABS 6-8 SIGNED OFF lab report due: RC circuits
12	10/13		(9) Stiquito^{TM} Construction	
13	10/15	SPICE	(9) Stiquito^{TM} Construction	
	10/17	**FRIDAY**		LAB 9 SIGNED OFF

ECE 123 Tentative Schedule (cont'd)

#	date	lecture	lab	item(s) due
14	10/20	AC signals, oscilloscopes, and signal generators	(10) SPICE DC Analysis using OrCAD^{TM}	prelab (10)
15	10/22	**EXAM 1**	(11) Using the Signal Generator and Oscilloscope (12) Waveforms and SPICE	prelab (11) prelab (12)
	10/24	**FRIDAY**		LAB 10 SIGNED OFF
16	10/27	RC circuits	(11) Using the Signal Generator and Oscilloscope (12) Waveforms and SPICE	
17	10/29		(13) RC Circuits: SIM (14) RC Circuits: EXP	prelab (13) prelab (14)
18	11/3	oscillators/555 timer	(13) RC Circuits: SIM (14) RC Circuits: EXP	
19	11/5		(15) Oscillator via a 555 Timer: SIM (16) Oscillator via a 555 Timer: EXP	prelab (15) prelab (16)
	11/7	**FRIDAY**		LABS 11-14 SIGNED OFF
20	11/10	QBASIC, parallel port	(15) Oscillator via a 555 Timer: SIM (16) Oscillator via a 555 Timer: EXP	
21	11/12		(17) Computer Interfacing	prelab (17)
	11/14	**FRIDAY**		LABS 15-16 SIGNED OFF
22			(17) Computer Interfacing	
23	11/19		(18) The Autonomous Stiquito^{TM}	prelab (18)
	11/21	**FRIDAY**		LAB 17 SIGNED OFF
24	11/24		(18) The Autonomous Stiquito^{TM}	
25	12/1	focus groups poster prep	(18) The Autonomous Stiquito^{TM}	
26	12/3	attitude questionnaire engineering careers video **OPEN HOUSE**		
	12/5	**FRIDAY**		LAB 18 SIGNED OFF
27	?	**FINAL EXAM** skills post-test		

Version 2.0, 9/3/03. Based on syllabi by Drs. Gesink and Severance, WMU.

3 Example Notebook Entry

example notebook entry

example notebook entry

example notebook entry

example notebook entry

4 What is ECE?

Definition of Electrical and Computer Engineering

5 Cooperative Learning- An Introduction

Credits

SOURCE:
Oklahoma State University, L.A.S.E.R. C.U.L.T.
Light Applications in Science and Engineering Research
Collaborative Undergraduate Laboratory for Teaching

http : //ee.okstate.edu/photonicslab/Resources/tutorial/teams.htm

This material has been adapted from numerous sources and is not original to OSU or Dr. Cheville. One source is NC State's SCALE-UP project and other papers by Dr. Beichner at NCSU. Other sources are notes taken by Dr. Cheville at the Case Study Workshop at SUNY Buffalo.

The Oklahoma State University Photonics Laboratory is supported through a National Science Foundation Course Curriculum and Laboratory Improvement Award. The information in this section may be distributed freely.

Cooperative Learning

As you might guess from the name, cooperative learning (CL) involves students working in groups and cooperating on tasks. Despite many experiences you may have had like this, it is important to realize that CL is not students sitting around a table studying together or assigning group projects where student ends up doing most of the work. Run correctly, by working in a group you will learn more than you can on your own and with less effort. The key here is doing group work correctly and effectively. In order for your group to learn in the environment of this class, there are several things you must do to ensure your group works together.

1. Interdependence. Team members have to rely upon one another.
2. Individual accountability. Each member is responsible for doing their own fair share of the work and for mastering all the material.
3. Face-to-face interaction. Some or all of the group effort must be spent with members working together.
4. Get along with each other. It is up to you to work with your team members. You are at a point in your life where not liking someone has become a luxury. You have to work with others, and personal attitudes just get in the way.
5. Regular self-assessment. Groups need to evaluate how well their team is functioning, where they could improve, and what they should do differently in the future. Take the time to do this!

Why are we using this approach? It is well documented that this teaching method improves student-faculty and student-student interaction, information retention (how well you remember what you learn), academic achievement (grades), higher-level thinking skills, attitude and motivation, teamwork, and communication skills. All of these are very similar to the concerns a prospective employer will have when he/she looks for qualified graduates. You must work with other people in today's workplace. There are also numerous employee surveys illustrating that team skills are a top hiring criterion. You will get a better job if you are trained to work in teams and can show your employer you have this experience!

Why does this method work? We are human, and as humans we are more interested in learning done in an active manner, rather than passive as in lectures. Also groups keep going when individuals might give up. Being part of a team means there is less fear in class to ask ”stupid questions”. Also you will discover that people learn best when they teach each other.

There is only one problem with this approach– much of the work you have done to this point has been as an individual. This is not because individual work is better, but it makes it easier for your teachers to assign grades. Although you are probably not used to effectively working in teams, teamwork is something that can and must be learned. What follows is a quick resource to help you learn how to effectively function in a team.

Simple Ideas for Effective Teamwork

1. Respect each person's unique skills. Everyone has something to offer your team. Don't let your own insecurities masquerade as arrogance- you all have something to learn from each other.
2. The strength of the team is the ability to brainstorm. Do this on a regular basis. Here are some ideas for brainstorming:
    (a) Collect as many ideas as possible from all participants with no criticisms or judgments made while ideas are being generated.
    (b) All ideas are welcome no matter how silly or far out they seem. Be creative. The more ideas the better because at this point you don't know what might work.
    (c) Absolutely no discussion takes place during the brainstorming activity. Talking about the ideas will take place after brainstorming is complete.
    (d) Do not criticize or judge. Don't even groan, frown, or laugh. All ideas are equally valid at this point.
    (e) Do build on others' ideas.
    (f) Do write all ideas on a flipchart or board so the whole group can easily see them.
    (g) Set a time limit (i.e., 30 minutes) for the brainstorming.
3. Assign roles to each team member. The problem with team work is that it is very easy to assume the responsibility lies with another person. To avoid this you must have clearly defined roles. Here are some common roles assigned to team members- pick and choose which ones make sense for your team.
    (a) Facilitator or Leader: moderates discussions, keeps the group organized, assures work is done by all, and makes sure all have opportunity to participate and learn. If there is a person who is a natural leader or has more experience this is a good role.
    (b) Gate Keeper: monitors the status of the project and moves group along so that they complete the task in the available time. Keeps track of what tasks still need attention and assures quality of work.
    (c) Records the group's work, makes sure all needed information is transmitted between team members, and prepares and written documentation. Also responsible for budgets and scheduling.
    (d) Professor: makes sure that all group members understand the concepts and the group's conclusions. This person is responsible for assuring all team members keep up to speed on classwork independent of the project.

   (e) Ambassador: acts as a liaison between the team and other groups, TA, and professor. Helps resolve any disputes within the team.
   (f) Lab Monkey: takes on any tasks that are not done by other team members and helps out when needed.

   Be aware that different people have very different working habits. Some people are very methodical and make sure everything is correct before moving on to a new task. Others make big leaps from one concept to another and wait until the big picture is developed before working out the details. Another example is that some people like to wait until the last possible minute to complete a project then devote 18 hours at a time while others work at a steady pace. Make sure you know the characteristics of your team members and assign tasks based on their personalities and skills!

4. Be organized when solving problems. Don't rush off and start computer or lab work without knowing exactly what it is you wish to do. Often the GOAL approach is very easy to use:

   GOAL Problem Solving Steps

   Gather information: The first thing to do when approaching a problem is to understand the situation. Carefully define the problem, looking for key information. What information is given? Exactly what is required? Don't forget to gather information from your own experiences and common sense. What should a reasonable answer look like? Do you know what units to expect- do your equations work out to the correct units? Are there any limiting cases you can consider?

   Organize your approach: Once you have a really good idea of what the problem is about, you need to think about what to do next. Have you seen this type of problem before? Being able to classify a problem can make it much easier to lay out a plan to solve it. You should almost always make a quick drawing of the situation. Label important events with circled letters. Indicate any known values, perhaps in a table or directly on your sketch. Some kinds of problems require specific drawings. Once you've done this and have a plan of attack, its time for the next step.

   Analyze the problem: Because you have already categorized the problem, it should not be too difficult to select relevant equations that apply to this type of situation. Substitute in the appropriate numbers, calculate the result approximately- do your numbers make sense'

   Learn from your effort: This is actually the most important part. Examine your numerical answer. Does it meet your expectations from the first step' What about the algebraic form of the result before you plugged in numbers' Does it make sense' (Try looking at the variables in it to see if the answer would change in a physically meaningful way if they were drastically increased or decreased or even became zero.) Think about how this problem compares to others you have done. How was it similar' In what critical ways did it differ' Why was this problem even assigned' You should have learned something by doing it. Can you figure out what'

   For complex problems, you may need to apply these four steps of the GOAL process recursively to subproblems. For very simple problems, you probably don't need this protocol. But when you are looking at a problem and you don't know what to do next, remember what the letters in GOAL stand for and use that as a guide.

5. Set up a contract of team rules and have each member sign the contract to make sure they are understood and followed. Here are several ideas for team rules, feel free to come up with your own:
   (a) Be at all meetings at least five minutes early.

   - (b) Let all group member know by e-mail 24 hours in advance when you will not be able to make a scheduled event.
   - (c) Bring snacks or drinks.
   - (d) Anyone who misses a meeting has to take on an extra share of the work.
   - (e) All group members must show up for class.
   - (f) Let group members know when they are not putting in their fair share of the work.
   - (g) Don't complain or make excuses- take responsibility for failure.
   - (h) No bad-mouthing group members to other groups.

6. Think of a group name and identify yourself using this name.

6 Strategies for a Successful Oral Presentation

Provided courtesy of:
Dr. Betsy M. Aller
Engineering Communication Program, Western Michigan University
(Dr. Miller reformatted for LaTeX, any errors are his!)

Preparing for Your Oral Presentation

First, consider your audience! What do they know about your topic, what questions will you need to answer, what level of technical information can they handle? Will you go into great detail or just give an overview? And how will you get them to *want* to hear what you have to say?

Research your topic *thoroughly.* The more you know about your topic, the more confident you'll be in your presentation. Arrange your information in logical order, again keeping your audience in mind. Your information should go from more general to more specific, building on itself.

Use numbered note cards, an outline, or some other form of guide. Don't try to ad lib, even if your topic is second nature to you. And don't write out your speech or parts of it in total; it will sound "read." Put brief bits of information on each card or line as a basis for your discussion.

Prepare your visual aids: computer graphics, overhead transparencies, flip charts, models, samples (see **Visual Aids** section below). *Practice* using them until it's second nature.

Practice your speech. Practice your speech. *Practice your speech.* Say it to a friend, audio record it, talk to the mirror–whatever works. But stop short of memorizing it. This can be deadly, for if you forget even a brief phrase or word, you may lose it all.

Time your speech. Revise as necessary, and time it again. Speaking for twenty minutes in a ten minute slot is inexcusable in business; it says the speaker is inconsiderate and unorganized. Using only six of those ten minutes may win friends, but it suggests the speaker may not know much about the topic. Keep to two minutes one side or the other of your allotted time in speeches under 15 minutes. Practice and revise until you get there.

Visual Aids

Consider your audience! Visual aids should help your audience understand your speech, not add to their confusion.

Visual aids should support your speech, not guide it. This is an important distinction.

Make your aids legible. "Normal," 12-point type does not reproduce on a transparency large enough to be read easily. Use **bolded** type, at least 20 points large. Handwritten graphics are acceptable only in informal presentations, and they must be absolutely legible. Sloppiness lowers the credibility of your information.

Make your aids brief. Nobody likes to read heavy blocks of type; on a visual, it's virtually impossible. Break it up, use white space liberally, and keep your information on each visual to only a *few* lines.

Use font size, indents, and spacing between lines to clearly demonstrate the hierarchies of your information: what comes under what? Titles or 1st-level information might be 36 point bold; 2nd-level information might be 30 point bold; 3rd-level info 24 point bold, etc. Additional space between main sections makes sense, as does indenting 2nd- or 3rd-level information as appropriate.

Make use of overhead software, like PowerPoint^{TM}, if it enhances your visuals. But be sure that the resulting visual isn't too busy and is spaced as *you*—not the software—want. It's usually best to start with a blank page, rather than using the PowerPoint templates. Many of these templates were designed for use in marketing and sales fields with a somewhat different agenda than engineering. Avoid flashy and cute graphics that obscure or make less usable your information.

When using computer graphics, check ahead of time to be sure that all the technology will work together. Practice the slide show so it's seamless, and watch out for graphics that add little.

Make your aids consistent. If you use information gathered from various sources, try to summarize the information on new visuals so that the type faces and sizes are consistent. Items copied from the Internet may be small, faint, busy, or illegible. Too much variety in your overheads looks hodgepodge and unprofessional.

Group visuals should always be absolutely consistent in design, font, spacing, layout, capital letters, etc. Have one person in a group make all the visuals, preferably while group members look on.

The dimensions of a standard transparency are usually 10" by 10". Lengthwise graphics—process flow diagrams, drawings, etc.—may run off the sides. Try to view your visual aids well in advance of your speech in case you have to revise them.

Use blackboards and flip charts sparingly; their use means you can't make eye contact or, worse, will have your back to the audience. If you use them, practice beforehand.

Use handouts as information for your audience to take home, rather than as support during your speech. Otherwise, your audience will flip through the pages and focus on them, not you.

Giving Your Oral Presentation — Content

Consider your audience! You must create interest, establish rapport, *and* let them know why it's important for them to know what you're talking about almost immediately. Use "you" in the first 15 seconds (and liberally throughout). Be friendly and pleasant. And remember that the purpose of your presentation is to help your audience in some way—not to show off your superior knowledge of the topic.

Almost immediately provide a *thorough* "road map" of your presentation: where is this speech going and what route will you take to get there? *This is absolutely vital.* Without a preview of your topics, your audience has little chance to mentally organize the information as you go along. It's best to provide both a visual *and* an oral outline of the direction of your presentation. Spend enough time on your "road map" to prepare your audience for the body of your speech.

Keep referring back to your road map so your audience knows where they are: "As I mentioned, I'd like to tell you about the current uses of [this product]...." You may wish to put your visual outline back up occasionally; this helps keep them (and you) oriented and can bridge any long gaps between visuals.

Tie in technical or unfamiliar information to the known and familiar. We can only absorb and remember information if we have some way to connect it to something we already know. Use examples and comparison liberally: "[This product] has many everyday applications..." (and tell what some are), "The strength of this bond could be compared to that between...," and so on. Connect your information to something that matters to your audience.

Use transitional phrases to carry your speech and your audience along the road map you set out earlier. "The second function of...," "After the testing process is complete, we move on to...," "I've talked about.... Now, I'd like to move on to...," "The fourth and final use of...," and so on. Move smoothly between sections toward a conclusion.

Finally, have a conclusion. Let your audience know it's the conclusion so they can mentally begin to wrap up and store what you've told them. Use a transitional phrase, even if it seems overly obvious: "Today I've covered...," "As you can see...," "To summarize...," or even "In conclusion...." Take a minute or two to give a brief overview and/or the significance of your main points, make any recommendations, wrap it up, and invite questions.

Anticipate and practice responding to questions. In team presentations, have all team members stand together and share responsibility for responding to audience questions.

Giving Your Oral Presentation — Delivery

Consider your audience! Make eye contact with each person (assuming a small- to medium-sized audience). Try not to focus on your note cards or overhead transparencies. Also try not to focus just on one person or one side of the room, scan over the audience's heads, or stare blankly into space. And beware the urge to stare at the overhead screen!

Use comfortable and natural body language and mannerisms. Try not to stand stiffly, arms at sides or hands clenched, white-knuckled, in front of you. On the other hand, try to avoid waving your arms about wildly or attempting theatrical gestures. Generally, if you don't concentrate on body language, your natural instincts will seem fine to your audience.

Voices can do funny things when we're nervous. Some folks speed up, and a ten-minute speech in practice becomes a rapid-fire six minutes in actual delivery. Others may pause and drag as they try to think of what comes next. And some folks, especially those with deep voices, may flatten out and get monotonous. Try to be conscious of your voice rate, and remember to vary your inflection a little if your voice flattens out during presentations. People with already low or deep voices should be especially careful not to deepen into inaudibility.

Saying "um," "uh," "okay," and so on are ways we fill in the empty spaces that make us nervous. We are often unaware of how often we use these fillers until it comes time to make a speech, when we become superaware of them. If you use them to excess, consciously work on it as you practice, and remember that knowing what you're talking about is the best way to avoid these little fillers. But don't become overly disturbed by a few "ums"—chances are your audience won't notice them much, if at all.

Increasingly, the words "basically," "like," "you know," and other meaningless fillers are creeping into formal presentations. Avoid this overcasual approach, which many in industry find annoying.

Use appropriate language. Avoid slang, ungrammatical, and overly informal words and phrases, but also avoid using "quarter" words when "nickel" ones will do. Always be positive you know how to correctly pronounce technical or unfamiliar words. Be sensitive to gender-specific language that might exclude or confuse your audience, such as using "he" to describe all chemical engineers, auto workers, or university presidents.

Overcoming Nervousness

Consider your audience! Yes, it works here too. If you can genuinely focus *outward* ("What do my listeners need to learn from me?") rather than *inward* ("I'm so nervous that I'm gonna hurl!"), you will minimize your nervousness. Consciously direct your focus out, rather than in.

Find a calming strategy that works for you. Speak louder (this convinces your audience—and you—that you're full of confidence); unobtrusively wiggle your toes, cross your fingers, flex your muscles, whatever. The "10 deep breaths" strategy helps: take 10 deep, slow breaths that make your stomach, not your chest, go out.

Try to avoid these unconscious mannerisms: rocking, fidgeting with note cards or pen, staring at the overhead or your notes, standing utterly stiffly, playing with the pointer.

Try not to verbalize your nervousness or setbacks; they can be self-fulfilling prophecies. If you do lose your place or your composure, it's okay to stop and gather your thoughts. A graceful "I'm sorry, I meant to tell you about_____. This is important because...." is fine; just make sure your audience understands where you are in your road map.

Don't be afraid to stop and find your place, catch your breath, reorder your thoughts. Some speakers even build one or more such pauses into their speech; it keeps them on track.

In the rare event that nervousness makes you actually feel faint, find a chair and sit. Nobody will fault you for having the common sense to avoid passing out and possible injury.

Finally, remember at all times that you are doing far better than you think you are. We are our own toughest critics. Everyone in your audience has had public speaking scares, and they are far more likely to be sympathetic than critical.

After the Presentation

Take a deep breath, smile, and congratulate yourself on a job well done (and it was much better than you think).

Then, analyze your presentation. Take a few minutes immediately after to think about what worked well and what didn't. What did you do or say to cause your audience to nod their heads, to smile, to comprehend? At what points did their eyes glaze over, did they begin to fidget, did they look confused?

Consciously develop *specific* strategies that work for you and integrate them into your future presentations. And keep doing this throughout your academic and professional careers—in presentations, as in all things, improvement and success happen because we keep working at it.

Aller - Oral Presentation Hints - 2003

7 Robot Taxonomy

In order to have an intelligent discussion about robots, we must first define a classification system, or, a *taxonomy*. Without such a system, we would have difficulty agreeing on just what a robot is. For instance, of all things that we think of as robots, some are intelligent and others are less so; some stay fixed and others move about. This section presents one such classification scheme.

Mobility

- stationary
- movement in place
- locomotion

Control

- centralized
- distributed
- autonomous

Senors

- none
- local
- global

Actuation

- none
- affects self
- affects environment

Laws of Robotics
(Isaac Asimov)
A robot must...

1. not injure a human being or, through inaction, allow a human to be harmed;
2. obey orders given by a human except when the first law is compromised; and
3. protect its own existence except when the first or second laws are compromised.

8 Laboratory Safety

(Adapted from http://www.wmich.edu/ece/safety.htm and material by Dr. John Gesink)

There are a number of hazards present in any electrical engineering laboratory. Our laboratory is no exception. Safety in an electrical laboratory, as everywhere else, is a matter of the knowledge of potential hazards, following safety precautions, and common sense. For your and your partner's personal safety as well as the durability of the equipment you must always observe a number of basic safety precautions.

Death is usually certain when 0.1 ampere or more flows through the head or upper thorax. Currents of one-quarter to one-half this value have been fatal to persons with coronary conditions. The current depends on body resistance, the resistance between body and ground, and the voltage source. If the skin is wet, the heart is weak, the body contact with ground is large and direct, then 40 volts is often fatal (*Popular Electronics*, p. 31, January 1972) Therefore, never take a chance on "low" voltage.

When working in a laboratory, injuries such as burns, broken bones, sprains, or damage to eyes are possible and precautions must be taken to avoid these as well as the much less common fatal electrical shock.

Always observe the following safety precautions when working in the laboratory:

1. **Electrical circuits**
   (a) Do not work alone on energized electrical equipment.
   (b) Power must be switched off whenever an experiment or project is being assembled, disassembled, or modified. Discharge any high voltage points to grounds with a well insulated jumper. Remember that capacitors can store dangerous quantities of energy.
   (c) Make measurements on live circuits with well insulated probes keeping one hand behind your back. Do not allow any part of your body to contact any part of the circuit or equipment connected to the circuit.
   (d) Never touch electrical equipment while standing on a damp or metal floor.
   (e) Never handle wet, damp, or ungrounded electrical equipment.
   (f) Wearing a ring or watch can be hazardous in an electrical lab since such items make good electrodes for the human body.
   (g) Never lunge for a falling part of a live circuit such as leads or measuring equipment.
   (h) Never touch two pieces of equipment simultaneously.
   (i) Never touch even one wire of a circuit; it may be electrically hot.
   (j) Avoid heat dissipating surfaces of high wattage resistors and loads because they can cause severe burns.
   (k) Ask the instructor to check your constructed circuit before applying power.
   (l) Always wear safety glasses.
   (m) Never use water on an electrical fire. If possible switch power off, then use CO_2 or a dry type fire extinguisher. The CO_2 or dry type extinguishers are painted crimson red. Locate extinguishers and read operating instructions before an emergency occurs.
   (n) In case of electric shock, quickly remove the victim from the circuit without endangering yourself. If the victim is not breathing, apply CPR immediately continuing until he/she is revived, and have someone dial 911 for assistance.

2. **Power and machinery**
    (a) When using rotating machinery, place neckties or necklaces inside your shirt or, better yet, remove them. Long hair must be put up.
    (b) Keep clear of rotating machinery. Do not be fooled by the stroboscopic effect.
    (c) Never open field circuits of D-C motors because the resulting dangerously high speeds may cause a "mechanical explosion".
    (d) Keep your eyes away from arcing points. High intensity arcs may seriously impair your vision or a shower of molten copper may cause permanent eye injury.
3. **General considerations**
    (a) Chairs and stools should be kept under benches when not in use. Sit upright on chairs or stools keeping the feet on the floor. Be alert for wet floors near the stools.
    (b) Be careful when two lab groups are working back to back.
    (c) In an emergency all power in the laboratory can be switched off by depressing a large red button. Locate one nearest you. It is to be used for emergencies only.
    (d) Horseplay, running, or practical jokes must not occur in the laboratory.
    (e) The lab must remain locked at all times.
    (f) This lab contains expensive equipment - please be careful when working, particularly with solder. Activities which might cause excessive vibration (e.g. hammering) must not be done on the benches.
    (g) No food or drink in the lab.
    (h) Lab benches must be kept clear when you finish for the day. Your project might be damaged by facilities personnel if you do not follow this rule.
    (i) The rule that there must be at least two people in the lab remains in effect.
4. **Precautions when using laboratory instruments**
    (a) Fuse circuits to protect ammeters and wattmeters.
    (b) Do not drop or bang instruments on the lab tables.
    (c) Never short a power source.
    (d) When using instruments connected to the power line, connect all ground leads to the same point.
    (e) When using a voltmeter or ammeter, begin with the highest range and work your way down.
    (f) Never use an ohmmeter on a live circuit.
    (g) Keep instruments away from the edge of the work bench.

9 Basic Electricity and Electronics

Electricity is the flow of electrons in the form of an electric *current.* It is sometimes helpful to think of an electric current as *a flowing liquid*, e.g. water. Electric current is measured in units of amperes (amps).

So how can we get electrons moving? We need some sort of a *pump* to force the electrons to move. In an electric circuit this force is called *voltage.* Electric voltage is measured in units of volts and **is always measured between two points**.

Figure 1 shows a water system and an electric circuit which behave in similar ways. The water system uses a pump to move the water; a voltage source (e.g. a battery) forces the electrons to move in the circuit. Since the diameter of the pipes restricts the water flow, moving water more quickly through the pipe requires a more powerful pump. A *resistor* R has a similar effect as the pipe diameter by limiting the circuit current flow. Note that both systems require a closed path (a circuit) for the "liquid" flow of water and electrons. It should also be noted that electrons are actually moving in the opposite direction as shown in the circuit; this is the standard convention for describing current, i.e. a positive current is in an opposite direction from the actual electron flow.

Electronics is the art and science of building devices which use electricity to do useful tasks, e.g. radio, computers, etc. Electronics is usually thought of a subset of electrical engineering which deals with small components (e.g. transistors) as opposed to other larger electrical devices (e.g. generators). There are a surprisingly few number of basic building blocks used in electronics. This section describes the electronic components that you will use to build your mobot.

9.1 Resistors

As previously mentioned, resistors restrict the flow of current; for our water analogy, a larger resistor would be a narrower pipe. The higher the resistance, the less current that will flow for a given voltage. This may simply be stated as Ohm's law:

$$I = \frac{V}{R} \tag{1}$$

where I is the current that flows when V is across a resistor of value R. Refer to Figure 13. Resistors are typically color coded (Figure 3).

9.2 Capacitors

Capacitors are used to store voltage by storing electrons. We can think of a capacitor as a bucket raised above the ground into which we can pump water (Figure 13). Opening valve 1 and closing valve 2 fills the bucket; closing valve 1 and opening valve 2 will enable the stored water in the bucket to turn the water wheel. The analogous circuit operates in a similar manner; closing switch 1 and opening switch 2 allows the voltage source to *charge* the capacitor. Opening switch 1 and closing switch 2 will enable the capacitor to create a current through R. Note that the bucket (capacitor) will provide water (current) only for a certain amount of time before it has to be refilled (recharged).

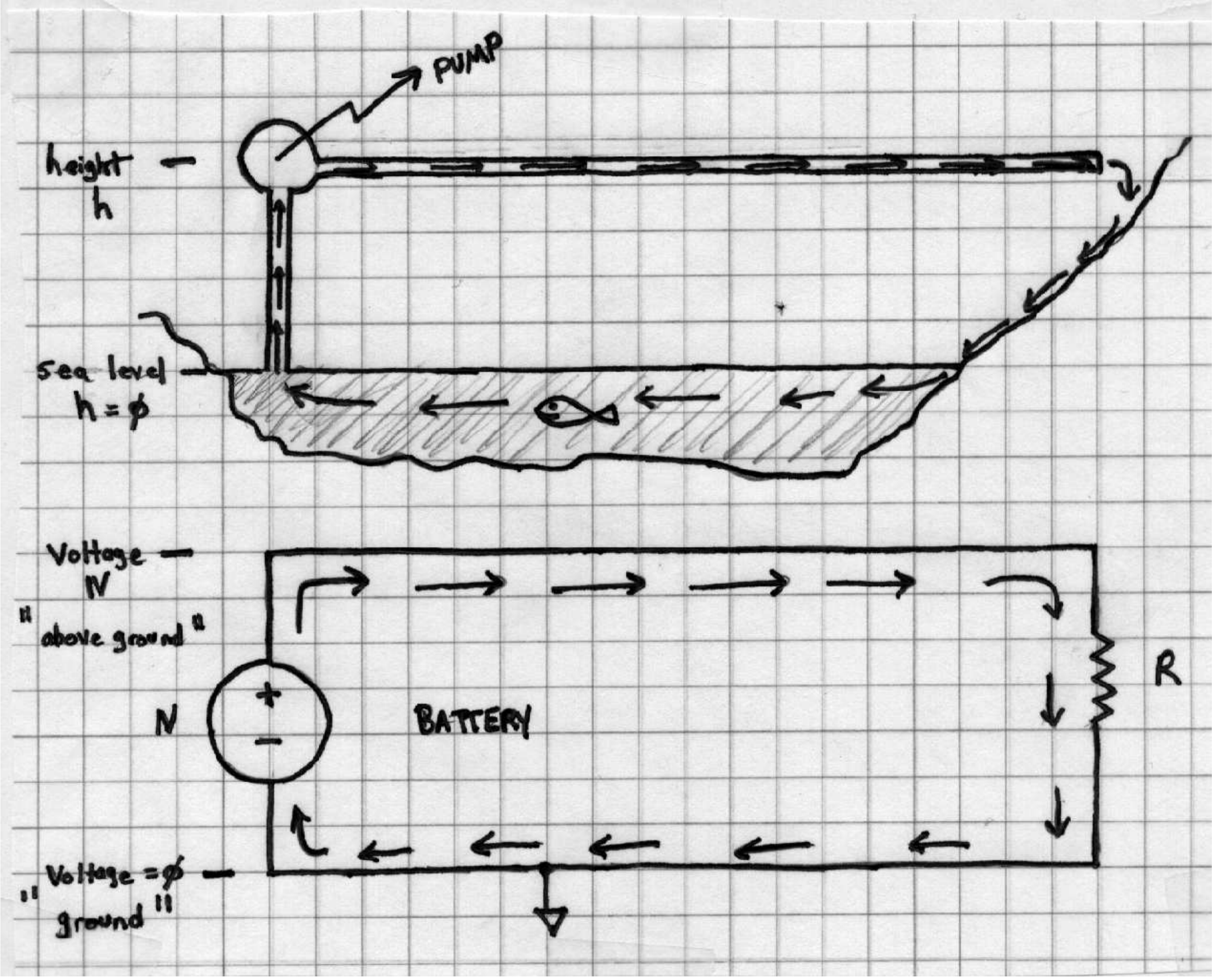


Figure 1: A water system and an electric circuit

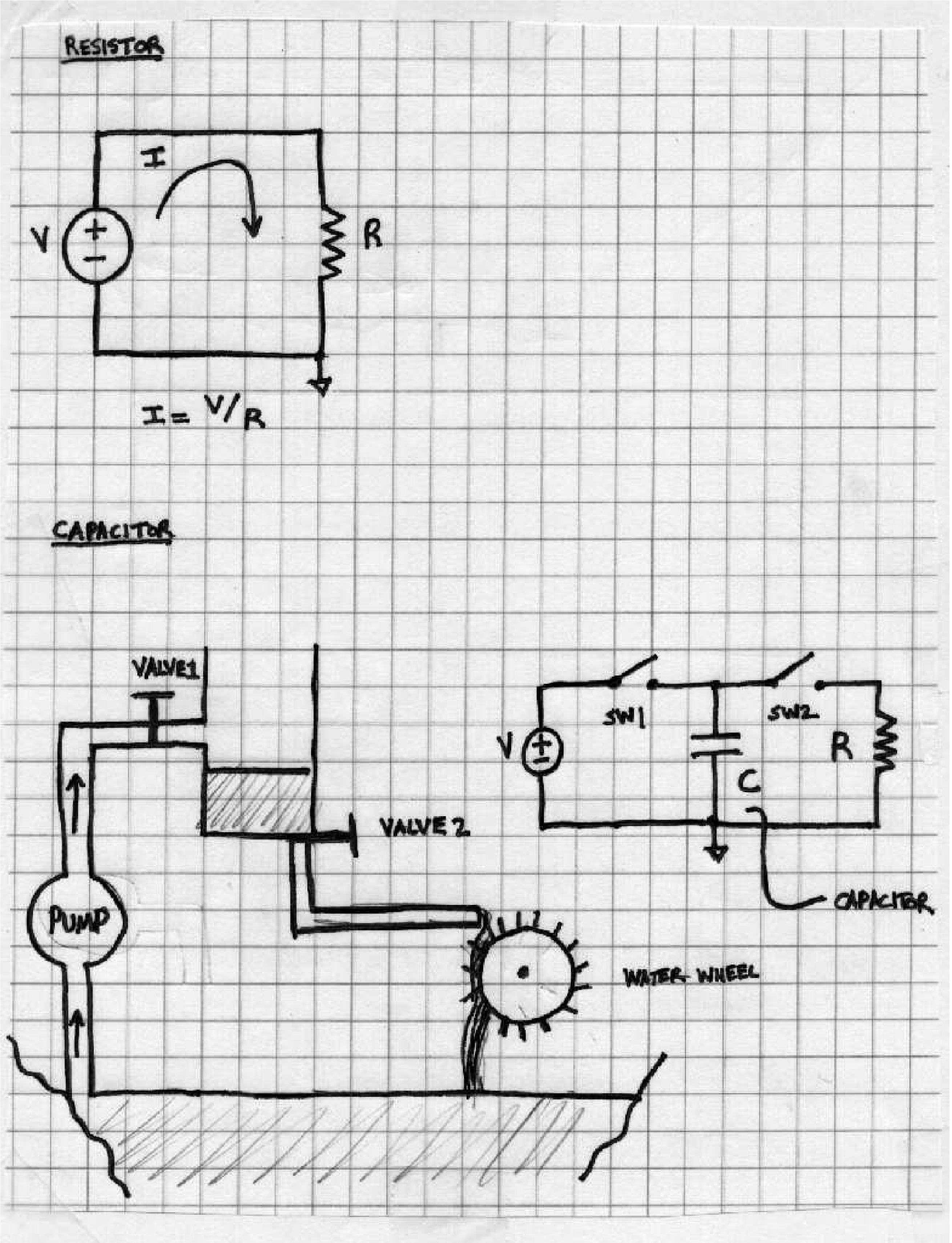
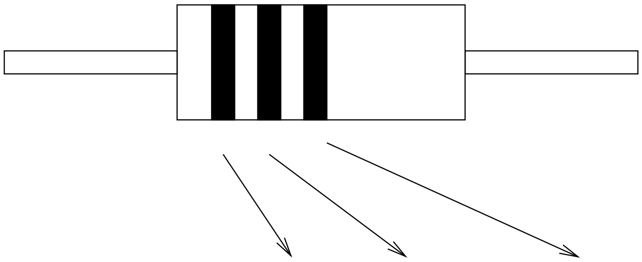


Figure 2: Resistor and capacitor notes



COLOR	1	2	MULTIPLIER
BLACK	0	0	1
BROWN	1	1	10
RED	2	2	100
ORANGE	3	3	1000
YELLOW	4	4	10,000
GREEN	5	5	100,000
BLUE	6	6	1,000,000
VIOLET	7	7	10,000,000
GRAY	8	8	100,000,000
WHITE	9	9	none

Fourth color band indicates tolerance (if present): GOLD: +/−5%

Note that k=1000, e.g. 10k = 10,000 ohms

EXAMPLE:

BROWN BLACK RED = 1 0 x 100 = 1000 ohms

Figure 3: Resistor color codes

9.3 Relays

Relays are electrically controlled switches (Figure 4). The simplest relay consists of a coil and a mechanical switch. When current is allowed to flow in the coil, the switch closes; otherwise it is open. Many different configurations are possible.

9.4 Buzzers

A buzzer makes a noise when an electric current is passed through it.

9.5 Amplifiers

In electronics there is often a need to amplify, or make larger, electric currents and voltages. The electrical signal reaching a radio is very small; the radio must amplify and process this signal to produce enough power to drive a loudspeaker. Amplifiers are used to amplify weak signals (Figure 4).

9.6 Photocells

Photocells are essentially resistors with a resistance that depends on how much light is striking the face of the photocell. We will use these devices to enable our mobot "to see."

9.7 Transistors

Transistors are current amplifiers; the current into the base controls how much current flows from the collector to the emitter; only a small base current is needed to control a large collector-emitter current (Figure 5). Transistors will be used to allow small electronic devices to control the larger currents required by our mobot motors.

9.8 Motors

Motors turn when an electric current is passed through their windings. We will use a small motor to steer the mobot and a larger one to move it forward.

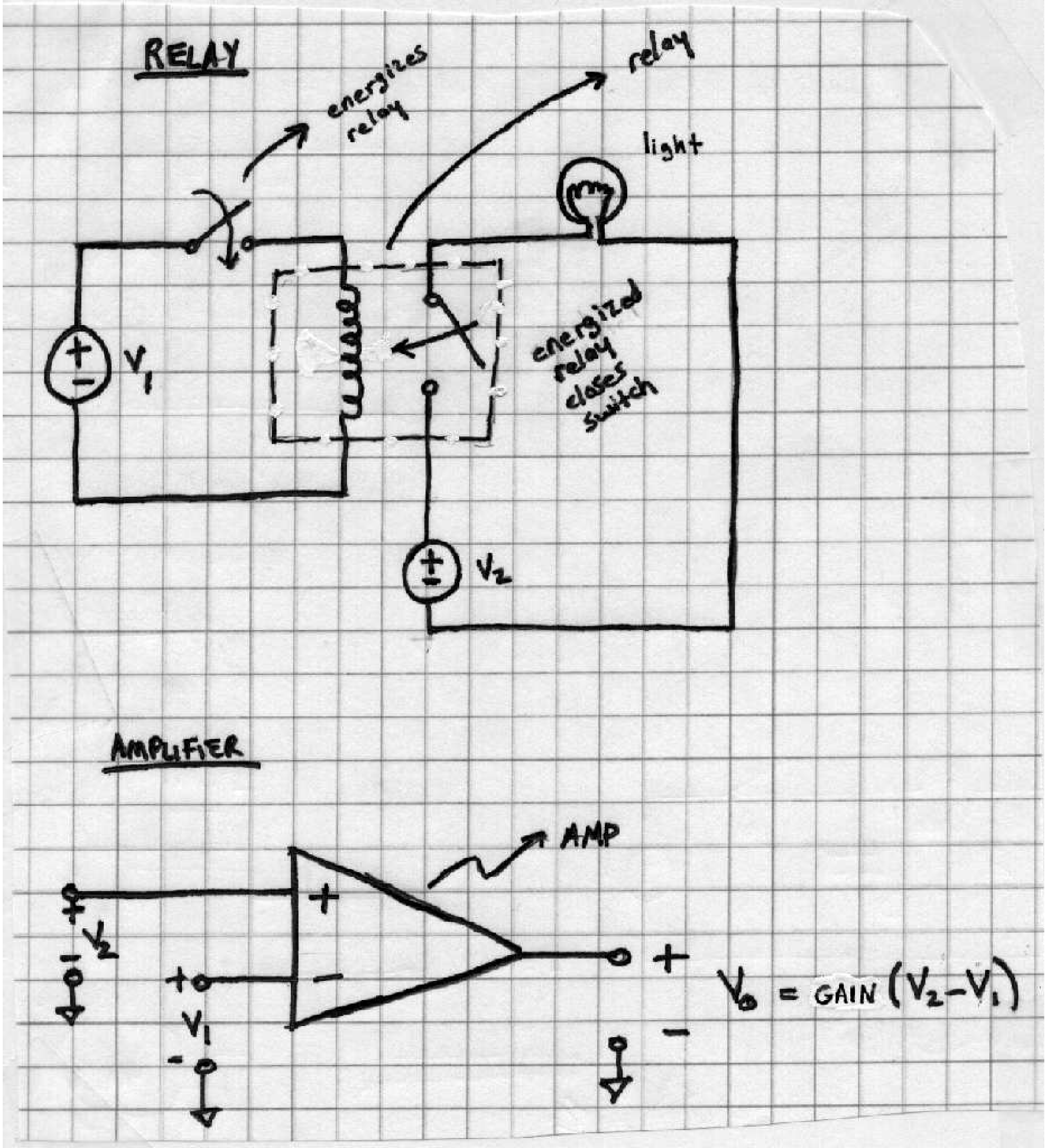
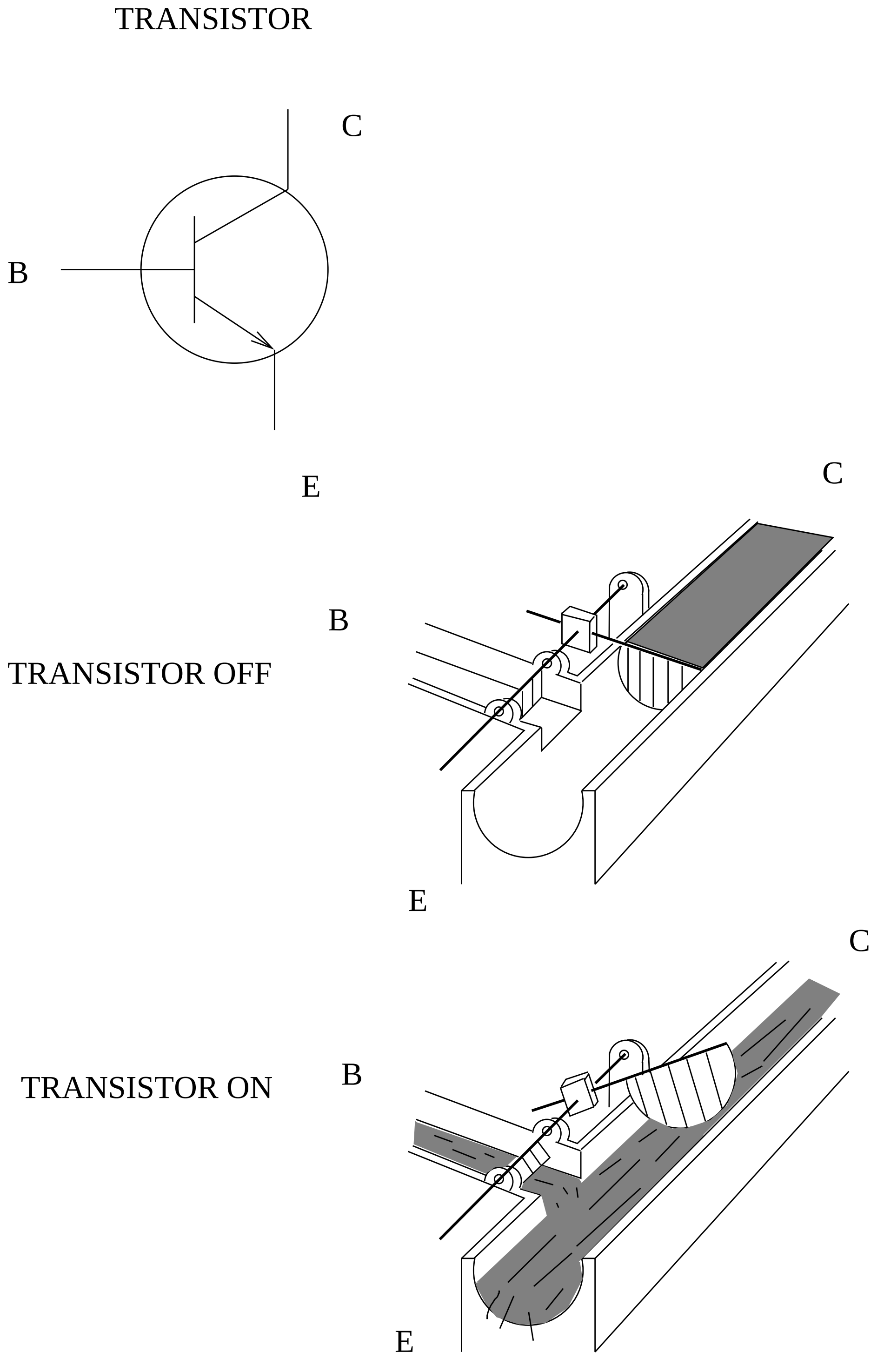


Figure 4: A relay and an amplifier



Adapted from a figure by H. Hock in Science Fun Experiments in Electronics

Figure 5: A transistor and its water analogy

10 Tools and Equipment

10.1 Stripping Wire

Properly removing insulation from wire is a valuable skill. There are tools which do a good job automatically; however, with practice, you can use wire cutters to strip wires. Placing an index finger between the cutter handles. Apply a light pressure on the handles until the insulation is cut, then pull the insulation off with the cutters. Start over if the copper is nicked as the wire will easily break.

10.2 Using a Breadboard

Using a breadboard is a great way of building circuits. Refer to Figure 6. The breadboard is a grid of holes into which wires and parts can be inserted. The *rails* are long lines of electrically connected holes and are best used for power and ground as these voltages are often needed throughout the breadboard. The other smaller rows of holes are used for inserting parts. Use different colored wires for different types of signals to aid troubleshooting. Cut wires to length to avoid a rat's nest of wires which may be impossible to troubleshoot. **BE NEAT.**

10.3 Soldering

We will need to solder some connections during construction of the mobot. Soldering is an essential skill which is relatively easy to master. Here are the basic steps:

1. Be sure that the soldering iron tip is clean and shiny. If not, clean with a damp sponge and then add some solder to the tip (this is known as "tinning").
2. The connection to be soldered needs to be mechanically secure (unless you are soldering components to a printed circuit board). Solder should not be relied on to make a secure connection.
3. Heat the connection with the tip of the iron. "Apply the solder to the joint — not the iron. A small amount of solder on the tip will improve heat transfer. The iron and solder should be applied simultaneously to the joint ... Make sure that there is no movement or stress during cooling and solidification of the solder" (from *The ARRL 1986 Handbook for the Radio Amateur*, ARRL).
4. If the part being soldered is temperature sensitive, grip the leads with a pair of pliers to reduce the heat transfer to the part itself.
5. Wash hands after handling solder as the solder contains lead.

10.4 Using a Digital Multimeter

We will use digital multimeters (DMMs) to measure voltages and resistance. Use of the meter is straightforward and will be discussed as a group.

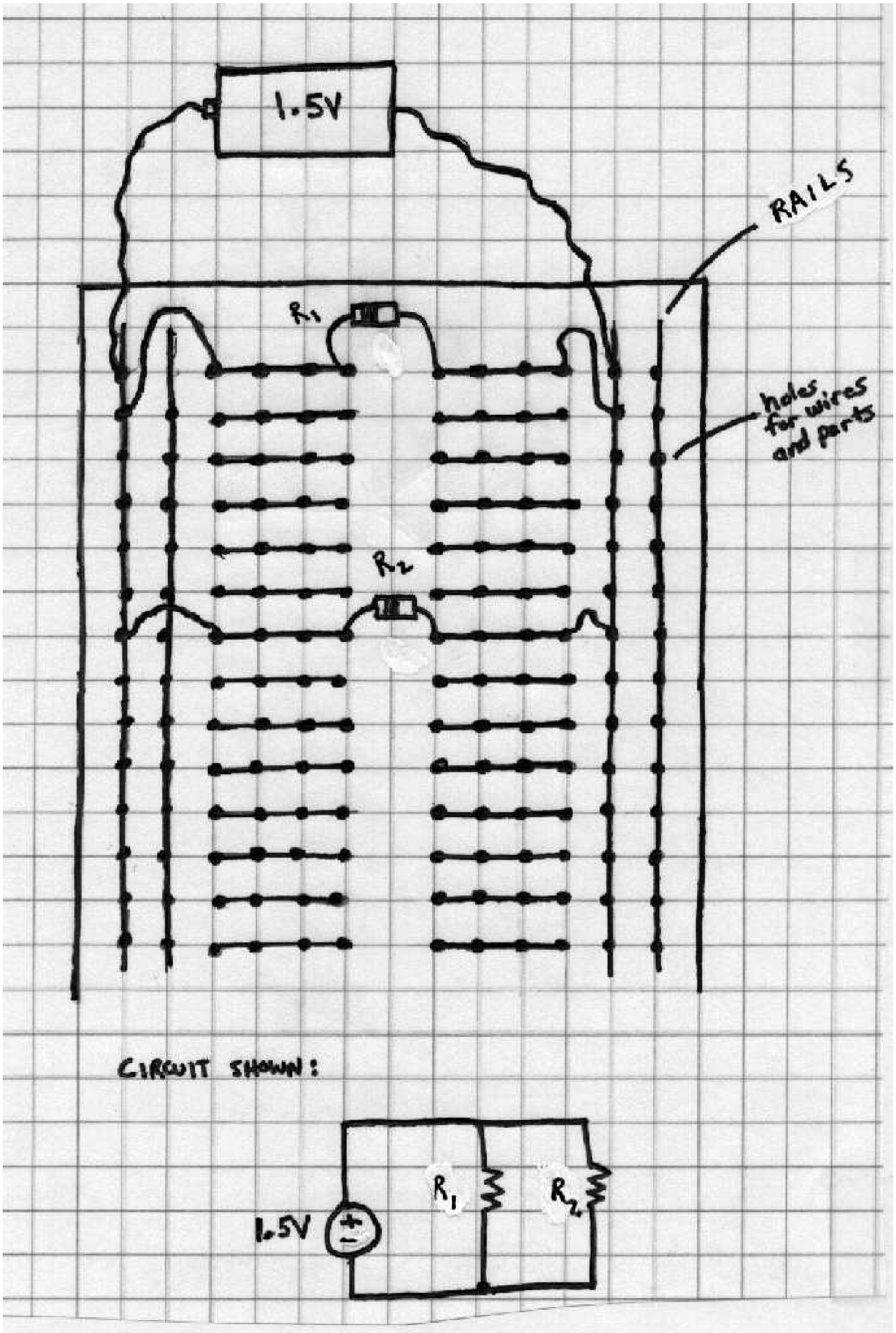


Figure 6: Using a breadboard

10.5 Using a Power Supply

We can use a power supply instead of batteries during most of our mobot design work. This will also be covered in class.

11 Available Components

This page lists parts that are commonly available in the laboratory.

1/4W 5% Carbon Film Resistors
10, 47, 100, 150, 220, 270, 330, 390, 470, 510, 680, 1k, 1.5k, 2k, 2.2k, 2.7k, 3.3k, 4.7k, 5.1k, 5.6k, 10k, 15k, 20k, 22k, 33k, 47k, 56k, 100k, 220k, 470k, 1M, 10M

1/4W Potentiometer
10k

50V 20% Ceramic Capacitors
10pf, 100pf, 220pf

100V 10% Mylar Capacitors
0.001uF, .0047uF, 0.022uF, 0.033uF, 0.01uF, 0.047uF, 0.1uF, .22uF, .47uF, 1uF

25-50V 10%-20% Electrolytic Capacitors
4.7uF, 10uF, 22uF, 47uF, 100uF

Integrated Circuits
LM741, 4007 MOS array

12 Mobile Robotics Laboratory Supplies Log Sheet

LAB STATION:____________

TEAM MEMBERS (print):

____

____

I understand that the "responsible person" will be held accountable for the checked-out items; items that are lost or damaged must be replaced at the cost of the "responsible person."

SIGNATURES:

____

____

item	date of checkout	date of return	responsible person (**initial**)

item	date of checkout	date of return	responsible person (**initial**)

13 Labs

13.1 Instrumentation and Resistance

Objectives:

To understand and practice the measurement of fundamental electrical quantities: voltage, current and resistance. This will involve using the power supply and digital multimeter instruments.

Instruments:

1. Digital multimeter
2. Power Supply

Parts:

1. Breadboard
2. Five random resistors

Prelab:

1. Consider the following set of five *standard value* resistors in which the resistances, maximum power ratings and tolerances are given. In each case,
   (a) determine the appropriate color code,
   (b) calculate the maximum voltage that the resistor can tolerate; and
   (c) calculate the maximum current the resistor can tolerate.

Resistance	Power	Tolerance
$82\,\Omega$	1/4 W	10%
$430\,\Omega$	1/2 W	5%
$1.5\ \mathrm{k}\Omega$	1/4 W	20%
$6.8\ \mathrm{M}\Omega$	3/4 W	10%
$36000\ \ \Omega$	1/2 W	5%

2. For each of the components in the table above, calculate the range of promised resistance values assuming the tolerances given.

A copy of these calculations must be placed in your lab notebook in preparation of your up-coming lab; turn in the original.

Bench work:

1. Take a set of five "random" resistors. Record their rated and measured values, and the resistor tolerances. Also compute the relative percent error relative to the rated resistance, and the maximum voltage and maximum current that the resistor can tolerate. Assume $\frac{1}{4}$ W resistors.

resistor #	rated	measured	tolerance interval	% error	maximum voltage	maximum current
1						
2						
3						
4						
5						

2. Select a resistor with a resistance of at least 500 Ω and create the following simple series resistive circuit (Fig. 9) using the power supply as the voltage source. Do not turn on the supply voltage until your circuit has been approved by the instructor.

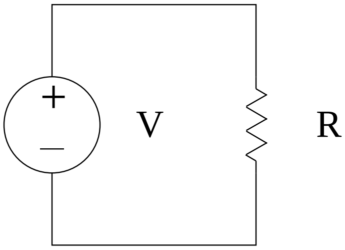


Figure 7: Simple series resistive circuit

   (a) Once given the go-ahead, make sure that the supply voltage and current are zeroed. Turn the supply on and observe that the "sufficient current" indicator light is red (meaning that there is insufficient current to drive the circuit.) Gradually increase the current dial until the "sufficient current" light turns green.

   Turn the supply off again and insert the ammeter (DMM) into the circuit as indicated in Fig. 8. Select the ammeter setting on the DMM and use the highest current scale. Again ask your instructor to verify correct setup.

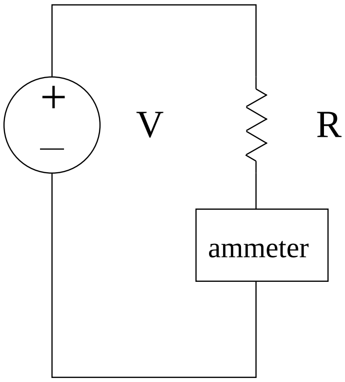


Figure 8: Using an ammeter

(b) Turn the power supply and DMM on and complete the following table. You should record voltages from 0.0 to 10.0 Volts in increments of 0.5 volts. At each stage, insure that the "sufficient current" dial is green. (If it is red, then increase the current dial until the light turns green.) Be sure to take note the units! What should the resistance of the ohmmeter be?

voltage V (V)	current I (mA)	power (mW)
0.0		
0.5		
…		
10.0		

Analysis of your results:

1. Analyze your results by first finding a computer with Excel^{TM}or some other suitable spreadsheet program. Enter the data and create an easy-to understand spreadsheet. From this create a graph of the first column (voltage) as the x-value and the second column (current) as the y-value. Put a copy of this graph in your lab notebook.
2. Find out how to do "regression analysis" in your spreadsheet. Use this to find the equation of the best fitting straight line that goes through the origin. Using the slope thus obtained, compute the estimated resistance of the resistor that you used. Compare this against the actual value measured in part 1.

Summarizing in your lab notebook:

In general, your lab notebook should have no loose papers. If you want to print graphs, tables, etc. which are computer generated, cut and paste (literally); use either glue stick or scotch tape. Written text must be permanent. Colors and markers to help explain things are really a plus. Do not simply turn in the lab instructions!

In writing the portfolio, remember that the person will not know what was to be done or even the lab instruction sheet along side. In other words, this should be a stand-alone, self-contained document that explains everything from the word "go"! As is always the case, consult with your instructor as to your ideas and suggestions. The notebook should be viewed as an on-going project in which you are keeping track of your academic record. It is your record of "you" as you would like to be seen.

13.2 Resistors and Resistive Networks

Objectives:

To study resistive networks and their standard configurations. How to use light emitting diodes (LEDs) as current indicators.

Instruments:

1. Digital Multimeter
2. Power Supply

Parts:

1. Breadboard
2. 100 Ω resistor
3. 220 Ω resistor
4. 470 Ω resistor
5. 825 Ω resistor
6. 1000 Ω resistor
7. 2000 Ω resistor
8. (2) integrated LEDs

Prelab:

Consider the circuits shown in Figures 9 and 10.

1. Number the circuit nodes. What is the minimum set of voltages such that any circuit voltage can be computed only using voltages from that minimum set of voltages?
2. How many different currents will there be in each circuit? Disregard opposing currents. Label each branch using color coded arrows.

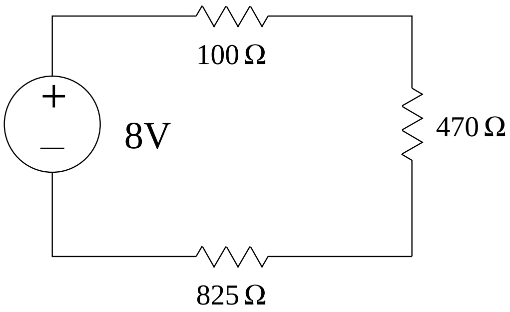


Figure 9: Series resistive circuit

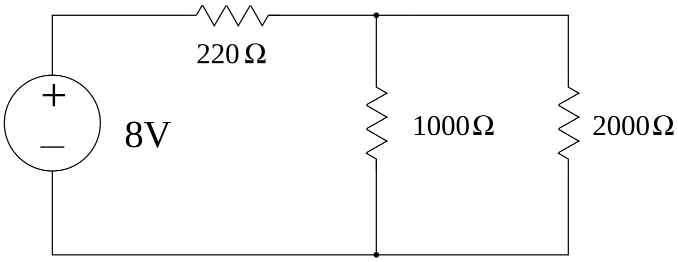


Figure 10: Series-parallel resistive circuit

3. Using the standard subscript notation conventions defined in lecture, compute each of the different voltages and currents.

Bench work:

1. Wire each of the circuit schematics shown in Figures 9 and 10. Measure each voltage and current in the list of different voltages and currents determined in the prelab. Watch your sign conventions closely! Make sure the "sufficient current" power supply light is green.
2. Now construct the circuits of Figures 11 and 12. Remember the "one way street" principle, and apply it to decide how to place your LED.

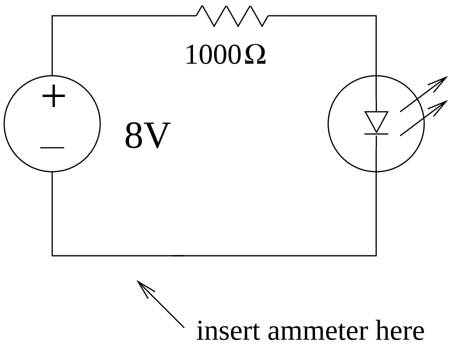


Figure 11: Series resistive circuit with LED

   (a) First measure the resistance of the resistor using the multimeter as an Ohmmeter.
   (b) Now construct the circuit. Find the voltage drop across the resistor and LED. Do these add up to 8 V?
   (c) Using the results of parts (a) and (b) along with Ohm's law, calculate the total current going through the circuit. Measure the current using the multimeter configured as an ammeter. How does this value compare to the computed current value?

3. Now repeat the procedure given in part 2, but use the following circuit with parallel branches instead.
   (a) First measure the resistance of the resistors using the multimeter as an ohmmeter.
   (b) Now construct the circuit. Find the voltage drop across each resistor and LED.

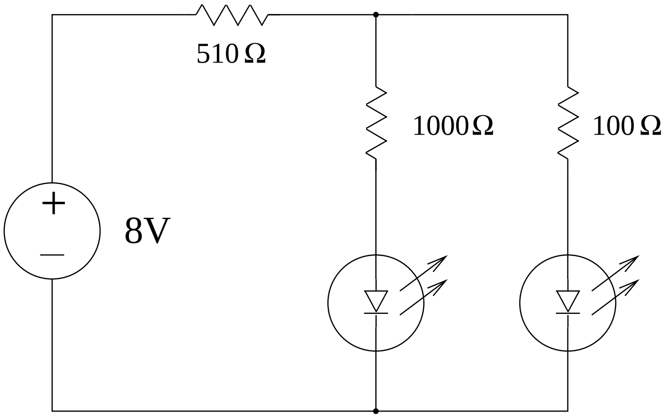


Figure 12: Series-parallel resistive circuit with LED

(c) Using the results of parts (a) and (b) along with Ohm's law, calculate the total current provided by the voltage source. How much of this current flows in each of the parallel branches? How does this compare to its measured value?

(d) By simply viewing the LEDs, can you tell which resistor has the most current flowing through it, 1000 Ω or 100 Ω ? Explain.

(e) Design a circuit that will turn a red LED on if the "battery" is correctly placed and a green LED if it is placed backward. Test and demonstrate.

Analysis of your results:

Calculate the theoretical voltages and currents for the prelab. How do these compare with the values measured in the experiment? If the results contradict your calculations, find the percent error and explain. In general, this analysis should be done using Excel^{TM}or some other suitable spreadsheet.

13.3 Capacitors and RC Circuits

Objectives:

To investigate the fundamental properties and applications of capacitors. This includes the fundamental charge/discharge cycle as described by the the basic dynamic RC step response equation

$$v_c(t) = V_\infty + (V_0 - V_\infty)\,\mathrm{e}^{-\left(\frac{t-t_0}{\tau}\right)}. \tag{2}$$

Instruments:

1. DC power supply
2. digital multimeter
3. soldering equipment: soldering iron, tip cleaner, solder, vise, solder

Parts:

1. Breadboard
2. 1.0 kΩ resistor
3. 10 kΩ resistor
4. 22 kΩ resistor
5. (2) 51 kΩ resistors
6. 47 μF capacitor
7. SPDT switch

Prelab:

Consider the RC circuit of Figure 13 in which the source voltage varies over time. The input is considered to be the source $v_s(t)$ and the output is the voltage across the capacitor, $v_C(t)$. The simplified network is shown on the right. As is the convention, simplified schematics always show voltages with respect to ground.

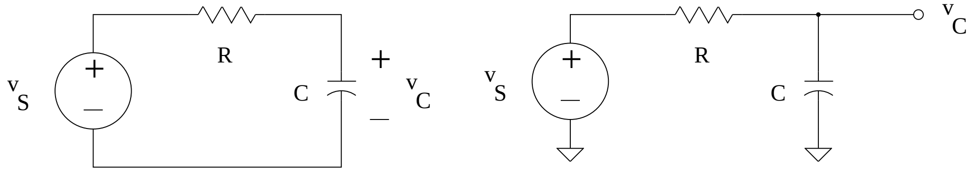


Figure 13: RC circuit

1. Let the resistance R = 51 kΩ and the capacitance C = 47 μF . What is the value of the time constant τ? Assuming an initially discharged capacitor and a voltage of $v_s(t) = 5$ Volts for $t \geq 0$, complete the following table, showing the voltage across the capacitor as a function of time for 10 seconds with an interval of 1 second.

Time, t (sec)	Voltage, $v_C(t)$ (V)
0	
1.0	
2.0	
. . .	
10.0	

2. Repeat the theoretical experiment of part (1), but this time change the resistance to R = 22 kΩ .

3. Using Excel^{TM}(or some other appropriate spreadsheet), graph the voltages of parts (1) and (2) as a function of time.

Bench work:

1. *Create a capacitor discharger.* This is done by soldering two approximately one-foot long wires to a 1.0 kΩ resistor. A capacitor can be discharged by touching each end of the wires to the capacitor leads. Be careful not to be a part of the circuit!

2. *Wire the connections to a Single Pole, Double Throw (SPDT) switch.* This is done by soldering short (two inch) wires to the three poles of a SPDT switch. Figure 14 shows a circuit that uses this kind of switch. The center pole is common to both switch positions, while the other two wires complete either of the two circuits. Test your switch before proceeding.

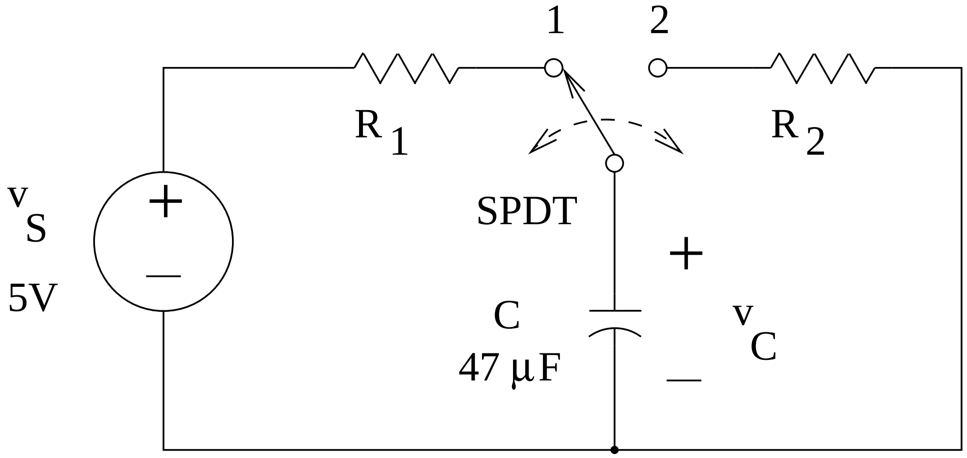


Figure 14: Switchable RC circuits

3. Construct the circuit of Figure 13 using a resistance of R = 51 kΩ and capacitance of C = 47 μF . Note that this capacitor is probably electrolytic. This means that there is a polarity and the (-) must be oriented toward ground. If you fail to do this, the capacitor could explode.

   Configure the digital multimeter to measure the voltage across the capacitor. Be sure the multimeter is turned off. Preset the power supply to provide a 5 Volt voltage source. Once this is done, switch this off too.

(a) Now watch the multimeter closely to observe the change in $v_C(t)$ as you turn the power supply on. Create a table as in the prelab. Compare this table to your prelab results. *Suggestion:* Use one of the switches on the SPDT switch in series with the power supply; use this to either connect or disconnect the supply from the circuit. This should improve your timing accuracy.

- Estimate the time it takes for the voltage achieve its final value. What is the final voltage?
- Once you have achieved this final value, turn the power supply off.
- Manually discharge the capacitor by shorting the capacitor with your capacitor discharger. Be sure you don't form part of the circuit!

(b) Repeat (3a), but this time use a resistance of $R_2 = 22\,\mathrm{k}\Omega$.

4. Construct the circuit given in Figure 14 in which a Single Pole Double Throw (SPDT) switch makes two different circuits: one in which there is a voltage source to charge the capacitor and one to connect a resistor in parallel with the capacitor so that it discharges.

   Connect the digital multimeter so as to show the voltage across the capacitor. By placing the switch left or right, notice the voltage changes in the charge mode (left) or discharge mode (right).

   (a) Estimate the comparative charge and discharge time constants using your watch.

   (b) Fix the left resistor at $R_1 = 51\,\mathrm{k}\Omega$. Further, let $R_2 = 51\,\mathrm{k}\Omega$ and find the charge and discharge time constants using your watch. How do the charge and discharge time constants compare? What about for $R_2 = 22\,\mathrm{k}\Omega$?

   (c) For the two cases of part (4b), find the equation that describes $v_c(t)$ for both the charge and discharge cycles. Graph the results by generating a set of points assuming the capacitor becomes fully-charged and discharged.

   (d) Now check some points on the four graphs of (4c) using your circuit.

13.4 Transistors and Transistor Circuits

Objectives:

Transistors are fundamental electronic devices. In this laboratory we will build basic npn transistor circuits that utilize various operating modes. From these we will measure critical parameters such as the common emitter current gain α and the common base current gain β.

Instruments:

1. DC power supply
2. Digital multimeter

Parts:

1. $100\,\Omega$ resistor
2. $1000\,\Omega$ resistor
3. 10 $\mathrm{k}\,\Omega$ resistor
4. 100 $\mathrm{k}\,\Omega$ resistor
5. $47\,\mu$F capacitor
6. $220\,\mu$F capacitor
7. $680\,\mu$F capacitor
8. (2) 2N2222 npn transistors
9. (2) non-integrated LEDs
10. SPST toggle switch
11. breadboard

Prelab:

1. Read Experiment 6, pages 44 and 45 of the Stiquito^{TM}text.
2. Browse the 2N2222 data sheet at the end of this lab.
3. Consider the circuit of Figure 15. Fill out the following table for each of the listed values of R. Assume $\beta = 50$, $\alpha = 1$, and $V_{BE} = 0.7$ as appropriate.

R (Ω)	V_1	V_B	V_C	I_C	I_B	I_E	V_{BE}	V_{BC}	α	β	Mode
1000											
10k											
100k											
∞											

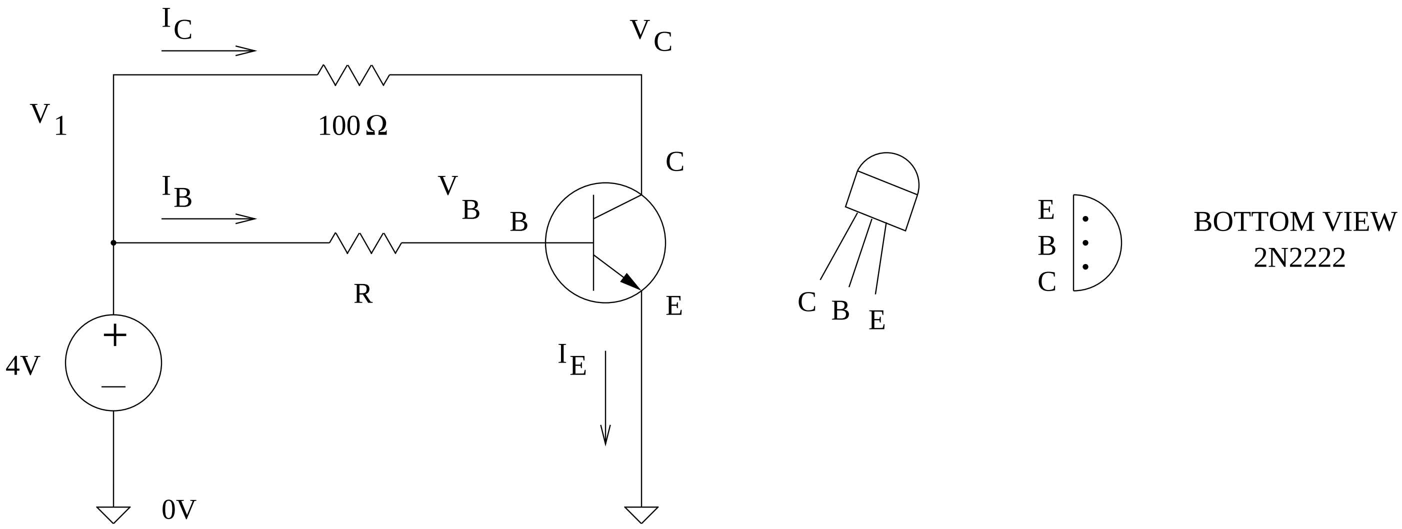


Figure 15: NPN transistor circuit

Bench work:

1. Construct the circuit in Figure 15 using the 2N2222 npn transistor. Resistance R is variable.

   Fill out a new table as in the prelab for each R. Be sure to record the nominal resistances and not the ideal ones listed.

2. Now build the circuit of Figure 16, which uses two LEDs so that we will be able to “see” the current a bit better! Be sure to observe the capacitor polarity.

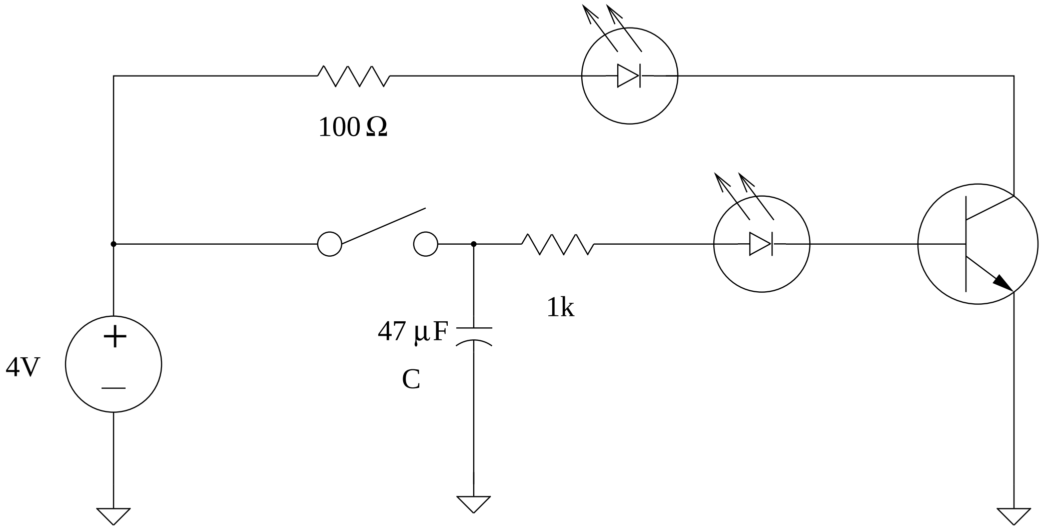


Figure 16: NPN transistor circuit with LED current indicators

   (a) Close the switch and turn on the power. After a short period of time, what happens when the switch is opened?

   (b) Now repeat the actions of part (a) using several different capacitors - you might try C=220 μF and 680 μF . Be sure to safely discharge large caps! Can you explain what is going on and why?

Analysis of your results:

1. Verify the experimental data for the table of bench work part 1.
2. What important fact do you notice regarding columns V_{BE}, α, and β? Explain.
3. Give a qualitative response to the transistor/LED circuit experiment: What effect does the capacitance have?
4. Calculate the time constants for each different resistance of the transistor/LED circuit.

2N2222 data sheet 1

2N2222 data sheet 2

2N2222 data sheet 3

2N2222 data sheet 4

2N2222 data sheet 5

2N2222 data sheet 6

13.5 Transistor Amplifiers and the Darlington Array

Objectives:

To understand how simple amplifiers work and how to implement them. Specifically, we will use a very important arrangement of transistors known as a Darlington array. These transistors are packaged into a DIP chip with 8 transistors having an especially large gain (in the so-called Darlington configuration) to provide extra power that is useful for certain applications. This includes applications such as the Stiquito, where things are heated up to move, requiring a large amount of current.

Instruments:

1. DC power supply
2. Digital multimeter

Parts:

1. $100\,\Omega$ resistor
2. 100 $\mathrm{k}\,\Omega$ resistor
3. (2) 2N2222 npn transistors
4. ULN2803 Darlington array
5. 8 switches in 16 pin DIP
6. (8) integrated LEDs

Prelab:

1. Browse the ULN2803 data sheet at the end of this lab.
2. Consider the transistor circuit given in Figure 17. Assuming the critical transistor parameters to have values of β=50, V_{BE}=0.7 V, and $V_{CEsat} = 0.2V$, "solve" the circuit. That is, find the voltage at each node (with respect to ground) and current through each branch (all in terms of V_{signal} and V_{power}) **FOR EACH OF THE THREE POSSIBLE TRANSISTOR OPERATING MODES**.

Bench work:

1. Consider the transistor circuit given in Figure 17. Notice that there are two voltage sources, one called the signal and one called the power. This is a classical transistor configuration in that the signal controls the power delivered to the load resistor. That is loosely to say, the higher the signal voltage, the more the power delivered to the $100\,\Omega$ resistor by V_{power}. Of course this depends on the transistor mode, since we know that transistors are nonlinear components.
   (a) Build the circuit of Figure 17. Use the two voltage sources on the power supplies for V_{signal} and V_{power}.

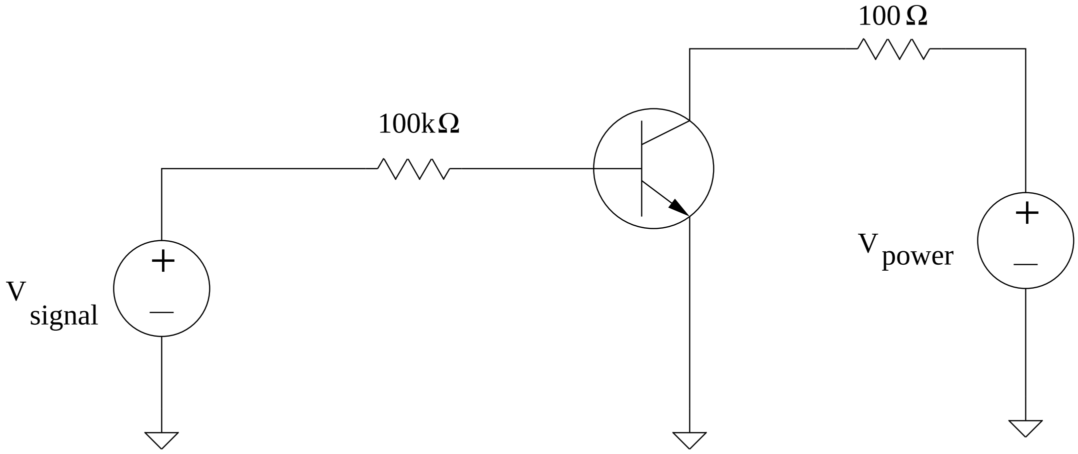


Figure 17: NPN transistor circuit with two sources

(b) Fix power voltage at V_{power}=6V. Record the voltages across the 100 Ω and 100 k Ω resistors as well as V_{BE}, V_{BC} and V_{CE} for the transistor for the different signals in the following table. Be sure to record your assumed polarity. Fill in the entire table.

V_{signal}	V_{100}	V_{100k}	V_{BE}	V_{BC}	V_{CE}	I_B	I_C	I_E	α	β
0										
0.5										
1.0										
...										
5.0										

(c) Graph the characteristic curve I_C (y-axis) versus I_B (x-axis). This will show the effect of the input signal on the power.

2. It is often necessary to step up the current gain of a transistor. That is, we need to further amplify the current in order to power some external device such as a heater or motor. One common solution is to force transistors to work in tandem in order to increase the overall gain of the system. Such an amplifier is called a *Darlington configuration*, which is in Figure 18. The following circuit schematic is a repeat of the previous circuit with a Darlington pair replacing the single bjt transistor.

(a) Build the circuit shown in Figure 18. Use the two voltage sources on the power supplies for V_{signal} and V_{power}. Even though you use two individual transistors here, it is best to think of the entire dotted package as a single transistor with the usual three terminals.

Fix the power voltage at V_{power}=6V. Record the voltages across the 100 Ω and 100 k Ω resistors as well as the other listed voltages for the different signals in the following table. Fill in the entire table.

V_signal	V_{100}	V_{100k}	V_{BE}	V_{BC}	V_{CE}	I_B	I_C	I_E	α	β
0										
0.5										
1.0										
. . .										
5.0										

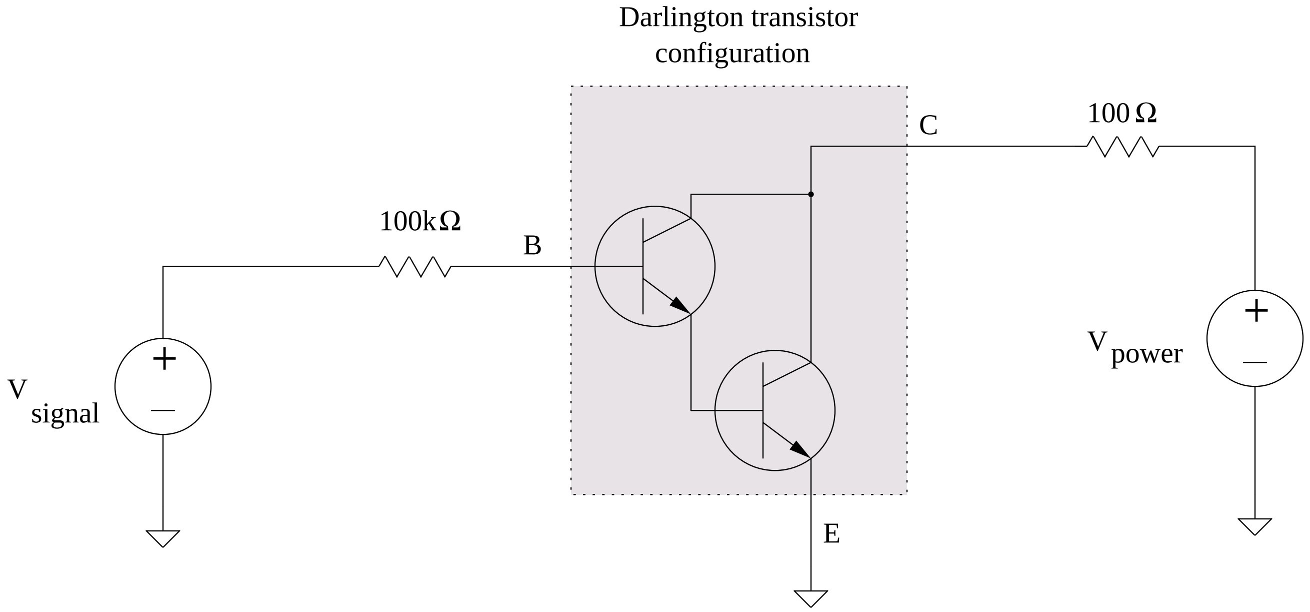


Figure 18: NPN Darlington transistor circuit

3. As a convenience, Darlington pairs are packaged as an array of eight pairs. This is called a Darlington array and is useful for computer applications since the eight transistors correspond to eight bits available in one byte.
    (a) Construct the circuit shown in Figure 19 using a ULN2803 integrated circuit (IC). Note that this IC comes in a standard DIP package as do the switches.

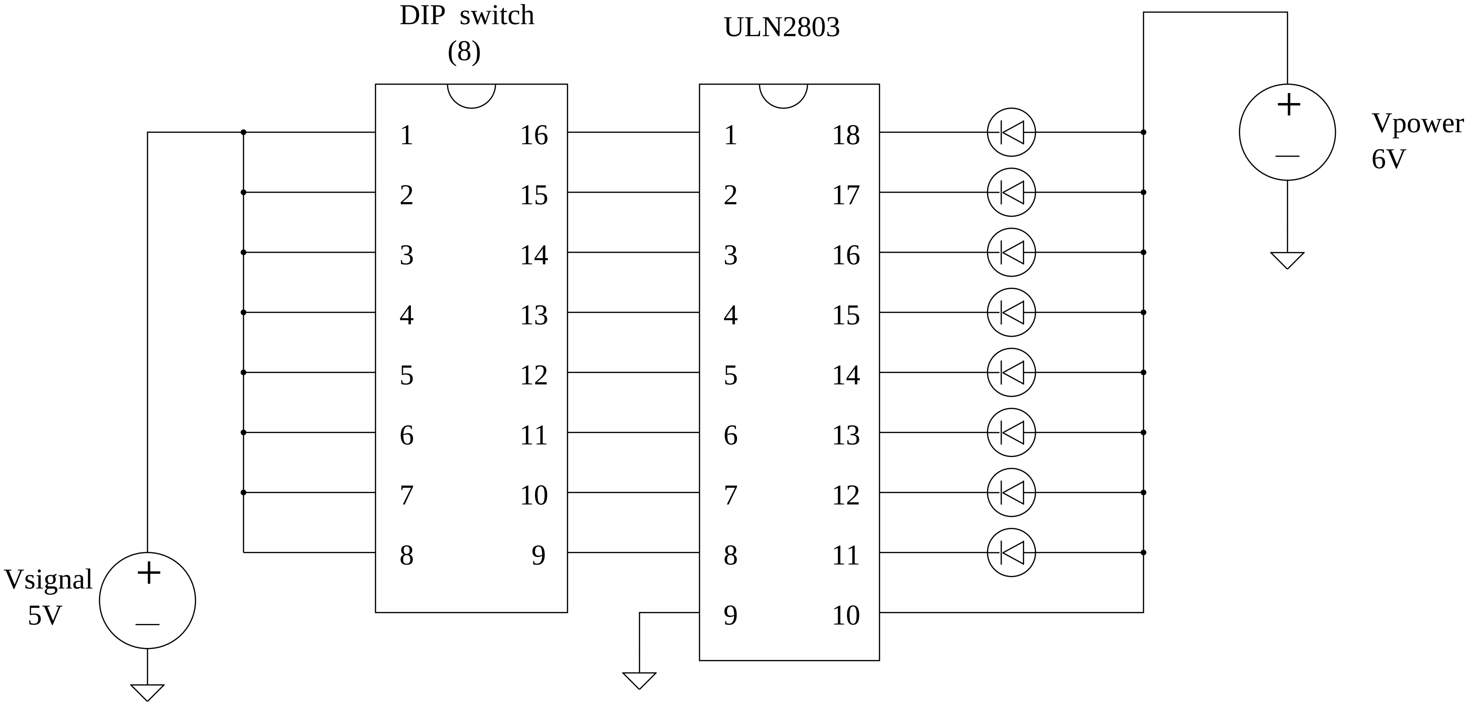


Figure 19: Using a Darlington array

(b) Verify the correct working of your circuit by exercising each of the DIP switches. Do they turn the correct lights on and off?

(c) Measure the α, β, and V_{BE} parameters. How do these measurements compare to those found in part two?

ULN2803 data sheet 1

ULN2803 data sheet 2

ULN2803 data sheet 3

ULN2803 data sheet 4

ULN2803 data sheet 5

ULN2803 data sheet 6

13.6 Materials Science: Nitinol Wire: Lifting a Dead Weight

Objectives:

To explore the unique material characteristics of nitinol wire. Nitinol wire will be used as the "muscle" in our Stiquito^{TM}robot.

Instruments:

1. DC power supply
2. custom made test stand fixture
3. metric ruler

Parts:

1. black banana plug to banana plug cable
2. red banana plug to banana plug cable

Prelab:

Read chapter four of the Stiquito^{TM}text.

Bench work:

Dead Weight Test

1. Examine the test stand (Figure 20). This lab uses the bottom section of the test stand. If not already done, attach the nitinol wire as shown in Figure 21. Fill the plastic bag with 18 pennies (about 50g) and hang as shown.
2. Sketch a wiring diagram of the bottom section of the test stand in your lab notebook.
3. We will use the leftmost supply in the power supply. Note that one knob adjusts the available current and one knob adjusts the voltage. Note also that a small black switch determines whether the supply voltage or current is displayed on the meter.
4. Adjust the current knob to about 10% of full scale. Turn on the supply. Set the meter to measure volts and set the voltage to 3V.
5. Set the meter to measure current. Short the voltage supply using a banana plug to banana plug cable; that is, insert one plug into the black terminal of the supply and the other into the red terminal of the supply **Note that in general you should never short a supply; these supplies are designed to handle a short.** Adjust the current knob so that the meter reads 0.18A (180 mA). Remove the short and turn off the supply.
6. Connect the test stand to the leftmost supply using the banana cables; red terminal to red terminal and black terminal to black terminal of the leftmost supply.
7. Measure and record the length of the nitinol wire (h) (do not include the length of the brass hangers).

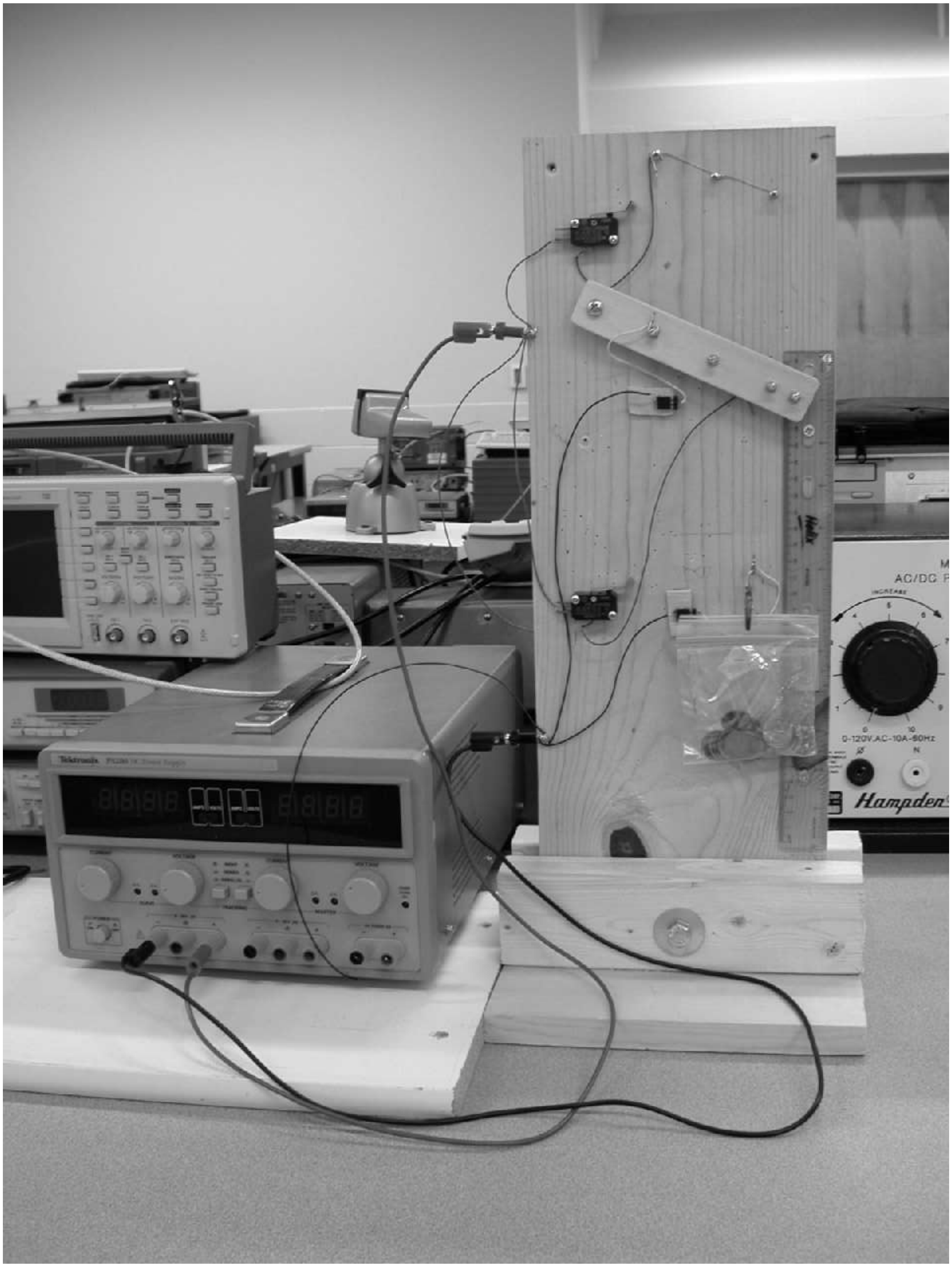


Figure 20: Nitinol test stand

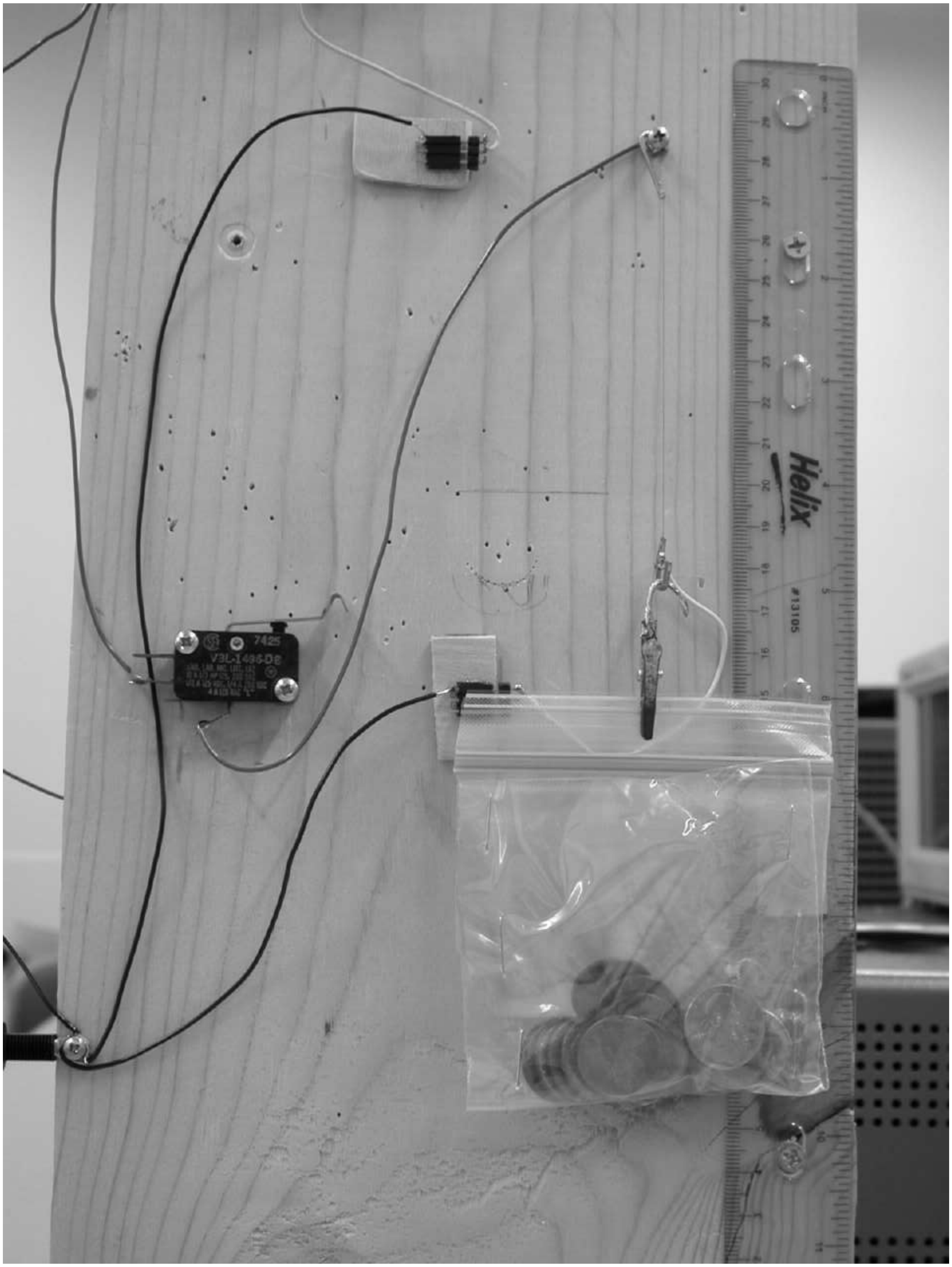


Figure 21: Nitinol dead weight lift setup

8. **You will be asked to depress the switch in the following procedures: It is imperative that you depress the switch NO LONGER THAN 1 second.**

9. We will now complete the following table to investigate how much the nitinol wire contracts as different voltages are applied. Follow this procedure for each row of the table:

   (a) Set the supply meter to measure volts. Set the voltage as indicated in the table.

   (b) Depress the switch for about 1 second **AND NO LONGER**. Record the meter voltage during the time the switch is depressed. Note that this voltage might differ from the voltage set in part (a) if the supply is current-limited as indicated by the red supply light.

   (c) Set the supply meter to measure current. Depress the switch for about 1 second **AND NO LONGER**. Record the meter current during the time the switch is depressed.

   (d) Compute and record the actual power P = (Actual V) I.

   (e) Depress the switch for about 1 second **AND NO LONGER**. Measure the maximum change in the length of the nitinol wire during the time the switch is depressed (Δh).

   (f) Compute and record the percentage change $\Delta h/h$.

Voltage (V)	Actual Voltage V (VOLTS)	Current I (AMPS)	Power P (WATTS)	Change in height (Δh)	Relative change in height (%) ($100\ \Delta h/h$)
0					
0.5					
1					
1.5					
2					
2.5					
3.0					

Analysis

1. Using Excel^{TM}(or some suitable spreadsheet), graph the voltage as a function of current (put voltage on the y-axis and current on the x-axis). From this, determine the resistance of nitinol using Ohm's law V = I R. Compare your value to the datasheet value of 1.2Ω/cm.

2. Using Excel ^{TM}(or some suitable spreadsheet), graph

   (a) the relative change in height as a function of current;

   (b) the relative change in height as a function of voltage; and

   (c) the relative change in height as a function of power.

3. Why do the curves of question 2 "flatten out?"

13.7 Material Science: Nitinol Wire: Using a Lever

Instruments:

1. DC power supply
2. custom made test stand fixture

Parts:

1. black banana plug to banana plug cable
2. red banana plug to banana plug cable

Prelab:

Consider the diagram shown below.

1. Come to class prepared to discuss the results of the first materials lab.
2. Refer to Figure 22. Show that the relationship between the Nitinol distance Δh_n and the actuation distance Δh_a is $\Delta h_a = \frac{R}{r}\Delta h_n$. ($R$ is distance between the pivot point and actuation point and r is the distance between pivot point and nitinol point.)

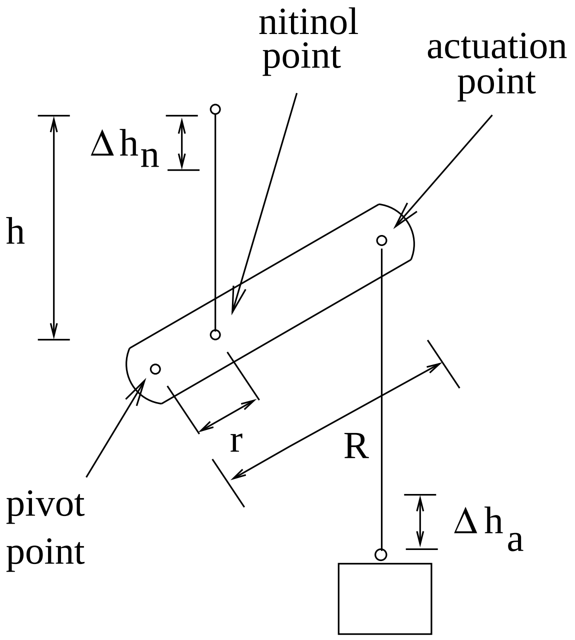


Figure 22: A lever

Bench work:

Using a Lever

1. Examine the test stand (Figure 23). This lab uses the top section of the test stand. If not already done, attach the nitinol wire as shown. Fill the plastic bag with 5 pennies (about 15g) and hang as shown.

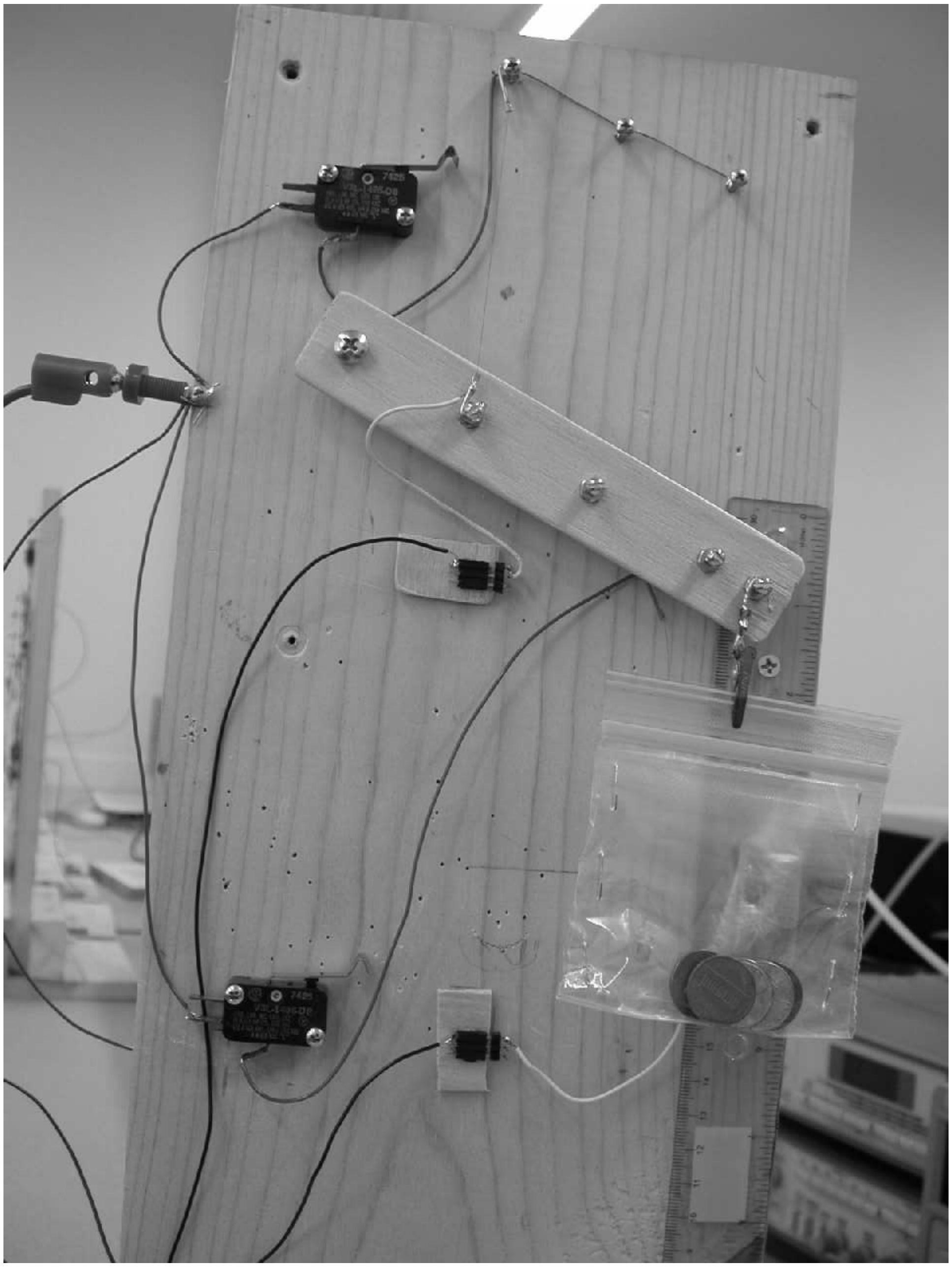


Figure 23: Nitinol-based lever setup

2. Sketch a wiring diagram of the top section of the test stand in your lab notebook.

3. We will use the leftmost supply in the power supply. Note that one knob adjusts the available current

and one knob adjusts the voltage. Note also that a small black switch determines whether the supply voltage or current is displayed on the meter.

4. Adjust the current knob to about 10% of full scale. Turn on the supply. Set the meter to measure volts and set the voltage to 3V.
5. Set the meter to measure current. Short the voltage supply using a banana plug to banana plug cable; that is, insert one plug into the black terminal and the other into the red terminal **Note that in general you should never short a supply; these supplies are designed to handle a short.** Adjust the current knob so that the meter reads 0.18A (180 mA). Remove the short and turn off the supply.
6. Connect the test stand to the leftmost supply using the banana cables; red terminal to red terminal and black terminal to black terminal of the leftmost supply.
7. Measure and record the length of the nitinol wire (h) (do not include the length of the brass hangers). Measure and record the length r between the pivot point and closest bolt (the nitinol wire is attached here). Measure and record the length R between the pivot point and the furthest bolt (the bag or *load* is attached here). Use this information to sketch the stand lever system in your notebook.
8. Compute and record the lever ratio R/r.
9. **You will be asked to depress the switch in the following procedures: It is imperative that you depress the switch NO LONGER THAN 1 second.**

10. We will now complete the following table to investigate how much the nitinol wire moves the load as different voltages are applied. Follow this procedure for each row of the table:
    (a) Set the supply meter to measure volts. Set the voltage as indicated in the table.
    (b) Depress the switch for about 1 second **AND NO LONGER**. Record the meter voltage during the time the switch is depressed. Note that this voltage might differ from the voltage set in part (a) if the supply is current-limited as indicated by the red supply light.
    (c) Set the supply meter to measure current. Depress the switch for about 1 second **AND NO LONGER**. Record the meter current during the time the switch is depressed.
    (d) Compute and record the power $P = VI$.
    (e) Depress the switch for about 1 second **AND NO LONGER**. Measure the maximum distance Δh_a that the load (bag) moves during the time the switch is depressed.
    (f) Compute and record the percentage change $100\Delta h_a/h$.

Voltage (V)	Actual Voltage V (VOLTS)	Current I (AMPS)	Power P (WATTS)	Change in height (Δh_a)	Relative change in height (%) ($100\ \Delta h_a/h$)
0					
0.5					
1					
1.5					
2					
2.5					
3.0					

Analysis

1. Compare the maximum relative change in the movement of the load for this (using a lever) and the previous experiment (no lever). Justify using prelab results.
2. Using Excel ^{TM}(or some suitable spreadsheet), graph
    (a) the relative change in height as a function of current;
    (b) the relative change in height as a function of voltage; and
    (c) the relative change in height as a function of power.
3. What is the primary advantage and disadvantage of using a lever?

13.8 The Stiquito^{TM}Emulator

Objective:
To learn the basic concepts of computer interfacing. In this lab we will use a computer parallel port to control a mock-up of the Stiquito^{TM}robot that you will build in the next lab. We will learn in a future lab how to write a program similar to the one used in this lab.

Instruments:

1. Power supply
2. Stiquito^{TM}emulator
3. PC
4. DOS^{TM}boot disk with WALK.BAS

Parts:

1. RED banana plug to banana plug cable
2. BLACK banana plug to banana plug cable
3. DB25 male to DB25 female straight-through 25 conductor cable (Belkin 472283)

Prelab:

1. Read pages 128-131 of the Stiquito^{TM}text.
2. Examine the Stiquito^{TM}emulator shown in Figure 24. The emulator has pieces of "springy" music wire that act as mock legs. The end of the music wire is connected to a piece of nitinol wire that acts as the leg muscle. The nitinol wire pulls on the music wire and forces it to bend slightly; thus the nitinol is under a constant tension. When a current is passed through the nitinol wire, the nitinol wire contracts, and the music wire is further bent. When this current is removed, the music wire re-stretches the nitinol wire. The result is a leg movement.

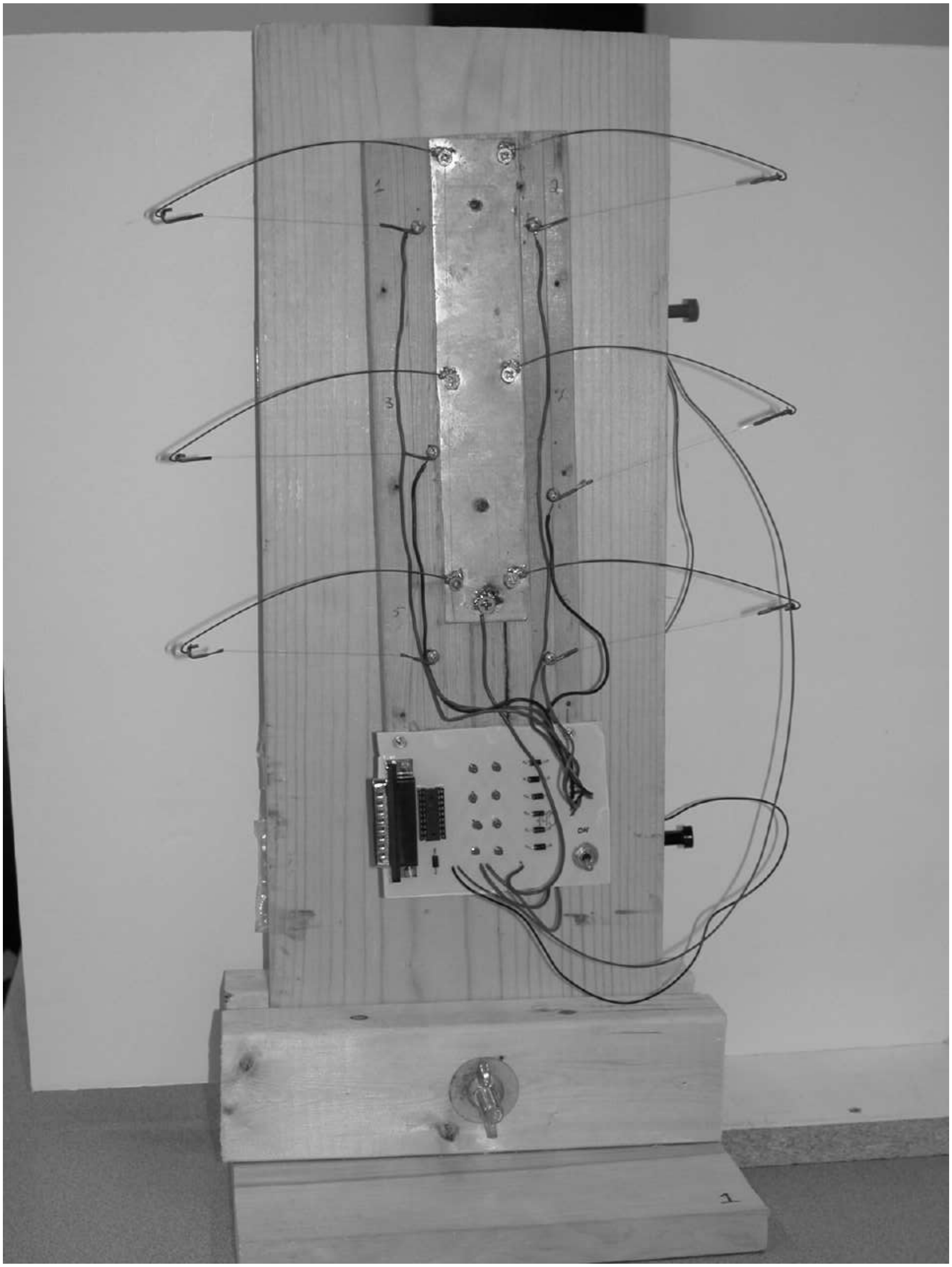


Figure 24: Stiquito^{TM}emulator

The six legs on the Stiquito^{TM}emulator are numbered as follows:

1 ○ 2 ○
3 ○ 4 ○
5 ○ 6 ○

Each leg is associated with a single bit (a bit is either 0 or 1). A "1" turns on power to that leg causing it's "muscle" to contract. A "0" means that leg is off. The computer uses its parallel port to send these bits to the Stiquito^{TM}emulator. The parallel port actually has 8 bits to use. To turn on the 1st, 4th, and 5th legs, use the following bit settings:

1 ● 2 ○
3 ○ 4 ●
5 ● 6 ○

	nibble 1				nibble 2			
leg	8 (no 8th leg)	7 (no 7th leg)	6	5	4	3	2	1
bit	0	0	0	1	1	0	0	1

The computer program uses a *hexadecimal* code to set these bits:

nibble (binary number) 8421	hexadecimal code	decimal
0000	0	0
0001	1	1
0010	2	2
0011	3	3
0100	4	4
0101	5	5
0110	6	6
0111	7	7
1000	8	8
1001	9	9
1010	A	10
1011	B	11
1100	C	12
1101	D	13
1110	E	14
1111	F	15

Thus the hexadecimal code to turn on the 1st, 4th, and 5th legs is &H19 (&H indicates that the code is in hex to the computer).

3. Provide the hexadecimal codes for these three leg patterns:

    1 ○ 2 ●
    (a) 3 ● 4 ○
    5 ○ 6 ●

(b)
1 ● 2 ○
3 ● 4 ○
5 ● 6 ○

(c)
1 ○ 2 ●
3 ○ 4 ●
5 ○ 6 ●

Bench work:

1. We will use the leftmost supply in the power supply. Note that one knob adjusts the available current and one knob adjusts the voltage. Note also that a small black switch determines whether the supply voltage or current is displayed on the meter.
2. Adjust the current knob to about 70% of full scale. Turn on the supply. Set the meter to measure volts and set the voltage to 6V.
3. Set the meter to measure current. Short the voltage supply using a banana plug to banana plug cable; that is, insert one plug into the black terminal and the other into the red terminal **Note that in general you should never short a supply; these supplies are designed to handle a short.** Adjust the current knob so that the meter reads 1.5A. Remove the short and turn off the supply.
4. Make sure the supply is OFF and that the switch on the emulator is in the OFF position. Connect the Stiquito^{TM}emulator to the leftmost supply using the banana cables; red terminal to red terminal and black terminal to black terminal of the leftmost supply.
5. Connect the Stiquito^{TM}emulator to the computer using the parallel port cable. The completed setup is in Figure 25.

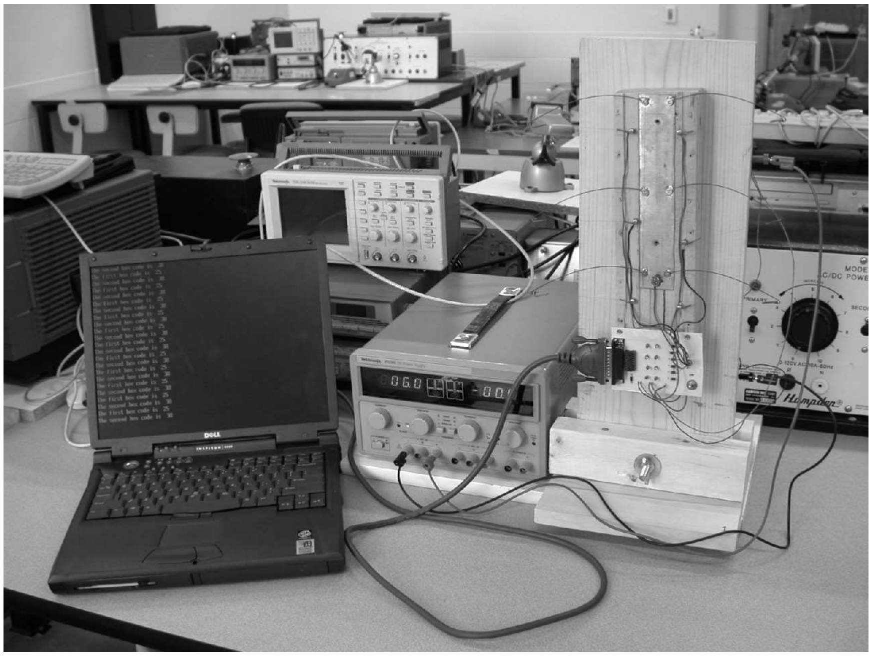


Figure 25: Stiqutio Emulator setup

6. Insert the ECE 123 boot disk into the computer and turn on the computer.
7. Turn on the power supply.
8. Type **qbasic walk.bas** on the PC and hit return. Press F5 to start the program. At the “first hex code” prompt type **&H19** and at the “second hex code” prompt type **&H26**. Hit return at the “third hex code” prompt. Verify that the emulator LEDS are alternately lighting in a 1-4-5::2-3-6 sequence. If this is not working, consult your instructor before proceeding.
9. **NEVER LEAVE THE EMULATOR SWITCH on FOR MORE THAN A MINUTE OR SO.** Turn on the emulator switch; verify that the leg movements match the LEDs. Turn off the emulator switch.
10. To stop the program, hit return twice.
11. Now use the setup to implement a 1-3-5::2-4-6 sequence using your prelab hex codes. Demonstrate to your instructor. Remember not to leave the emulator switch on for more than a minute.
12. Experiment with different walking gaits. Record your hex codes, the expected results, and the actual results.

Analysis:

1. What is the problem with a 1-3-5::2-4-6 walking gait?
2. What major result from the lever lab was not used in the design of the Stiquito^{TM}emulator?
3. Suggest one design improvement for the Stiquito^{TM}emulator system (hardware or software).

13.9 The Manual Stiquito^{TM}

Objective:
To build the basic Stiquito^{TM}robot (Figure 26. This will include assembling the body, legs, and electrical circuitry. A manual controller connected by a tether will provide actuation signals to the robot.

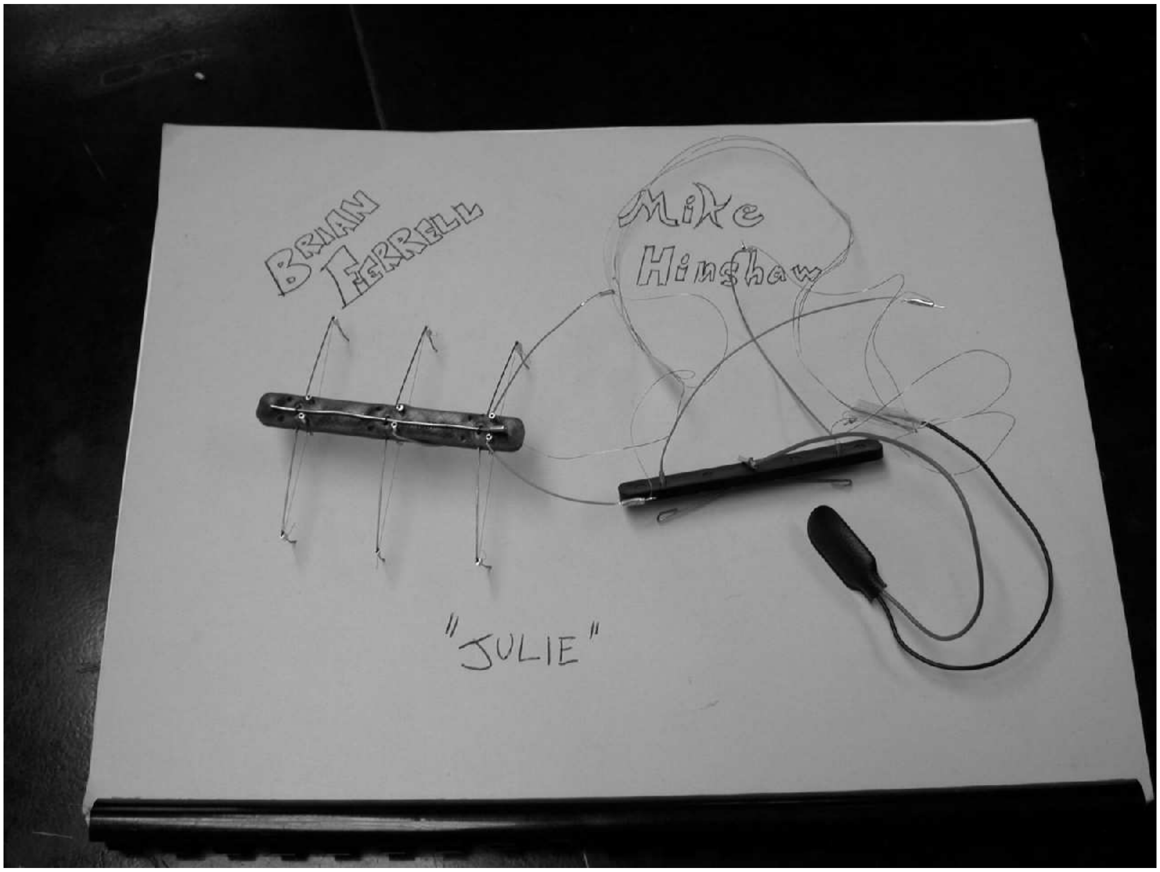


Figure 26: A student-built Stiquito^{TM}robot

Instruments:

1. Power supply
2. Digital multimeter

Parts:
Stiquito^{TM}kit included in your textbook.

Prelab:

1. Read chapters 5 and 6 of the Stiquito^{TM}text.
2. Draw the Stiquito^{TM}actuation circuitry schematic assuming that each nitinol wire is a resistor. Estimate the value of the leg resistance. Include the power supply, switch, etc.
3. Compute the maximum current that can flow given a 9V supply voltage.

Bench work:

1. Using your textbook as a guide, construct the Stiquito^{TM}robot. Be careful to do precise work since nitinol wire is very delicate and the legs must sit squarely on the surface simultaneously.
2. Construct the manual three-state switch. Connect to the Stiquito^{TM}body using magnetic wire. Be careful to remove the insulation as described in the text.
3. Demonstrate the finished Stiquito^{TM}. You should be able to move in a straight line for a distance of at least one foot.
4. Have the lab instructor fill out the Stiquito^{TM}grading sheet on the next page.

Analysis:

1. Measure the actual resistance of each piece of nitinol wire.
2. Create a more accurate schematic comparable to part (2) of your prelab.
3. Make a list of all problems so as to improve your next Stiquito(TM) .
4. Give the results of your walking distance - part (3) above.

Stiquito^{TM}Grading Sheet

LAB STATION:____________

TEAM MEMBERS (print):

____

____

Evaluator:

____

criterion	possible	earned
overall appearence (e.g. accuracy of dimensions, symmetry, etc.)	40	
basic functionality (how many legs work?)	40	
straight line test	20	
TOTAL	100	

Comments:

13.10 PSpice®DC Analysis Using Orcad®

Objectives:
Orcad®is a powerful general-purpose tool for designing and analyzing electrical circuits. In addition to schematic capture, simulation and optimization, it creates files needed for PC board routing and layout. Orcad®and other similar tools have become indispensable to the electrical and computer engineering world. If, after you have used it and you decide that you like it, you can get a free copy! Just check out the Orcad®web site for a free download or CDROM.

Part of Orcad®is the powerful defactog standard electrical circuit simulator, SPICE. The Orcad®version, called PSpice®, is efficient and powerful, but requires some "getting used to". The purpose of this lab is to practice using this basic engineering tool.

Instruments:

1. power supply
2. digital multimeter
3. breadboard

Parts:

1. (8) 1 kΩ resistors
2. 620 Ω resistor
3. 4.7 kΩ resistor

Software:
Orcad®Capture

Prelab:
Consider the resistive network shown in Figure 27.

1. Using the general values, R_1, R_2, and R_3 (not the nominal values shown), determine formulas for the voltages V_1 and V_2 along with currents I_1, I_2 and I_3. Your equations should be of the form f(13.8V, R_1, R_2, R_3).
2. Use the formulas of 1 to calculate the values of each voltage and current for the particular values of R_1, R_2, and R_3 shown.

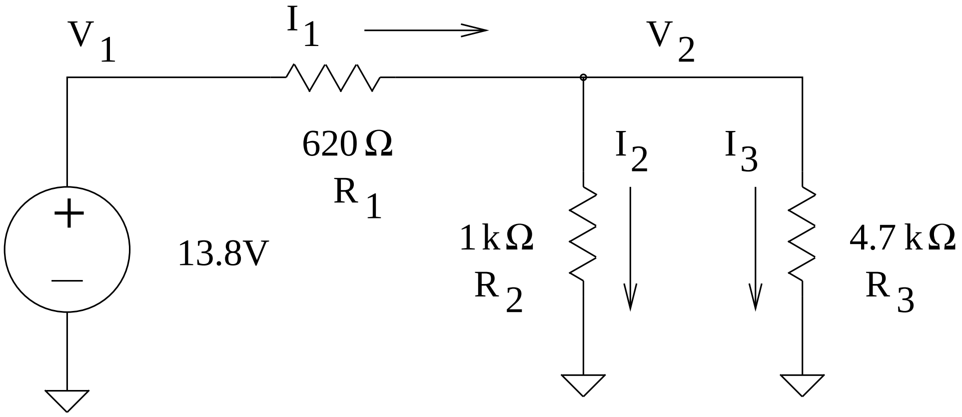


Figure 27: A resistive network

Bench work:

1. Use the Orcad®software package along with the PSpice®simulator to find each of the node voltages V_1 and V_2 along with currents I_1, I_2 and I_3 for the circuit of Figure 27. Document your steps in your lab notebook:
    (a) Open a new project. Select the Analog or Mixed-Signal Circuit option choose your working directory as your home directory add all library volumes to your project.
    (b) Draw the schematic using Capture. Use library "source" for voltage and current sources and library "analog" for all components. Use 0/source for the GND available on the right vertical tool bar.
    (c) Assign resistance values.
    (d) Assign voltage source values.
    (e) Label nodes.
    (f) Create and view the net list.
    (g) Place voltage markers.
    (h) Create a new Simulation Profile under PSpice®; use a time domain analysis.
    (i) Run PSpice®
    (j) Find voltages using Probe®graph.
    (k) Remove voltage markers.
    (l) Place current markers.
    (m) Run PSpice®.
    (n) Find currents using Probe®graph.
    (o) Print the schematic, net list and simulation results. Place these in your lab notebook. Do these results match those expected based on the prelab?
2. Now try a second circuit as seen in Figure 28.
    (a) Simulate the circuit using seven 1 kΩ resistors and a 6V source voltage. Find each node voltage and branch current.

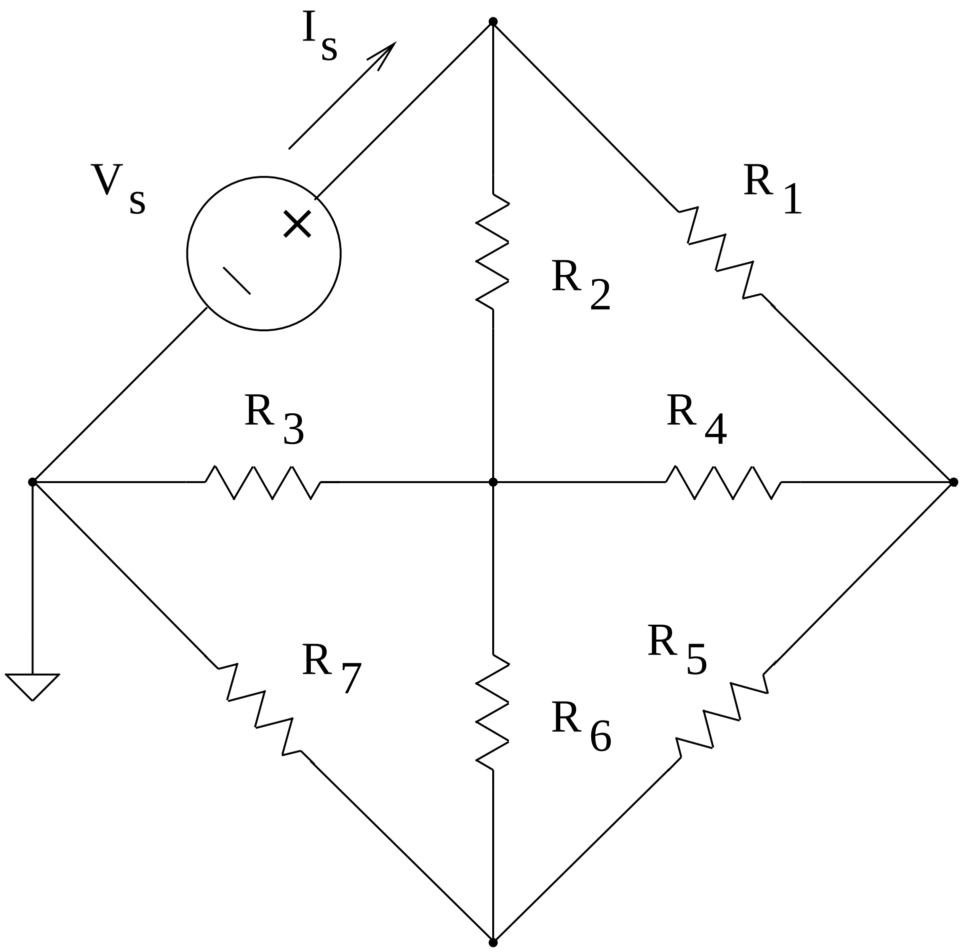


Figure 28: A second resistive network

(b) Using trial and error, determine the source voltage required so that the total current, I_s, is fixed at 10 mA.

(c) Find the voltage at each node relative to ground and the current through each resistor. Note that your work-to-date will not permit you to analyze this circuit using pencil and paper.

3. Now build these two circuits. Use resistors with values closest to the nominal values listed. Measure all voltages and currents.

Analysis

1. For the circuit of Figure 27, compare the calculated, simulated, and experimental voltages and currents. **Use a a table.**
2. For the circuit of Figure 28, compare the simulated and experimental voltages and currents. **Use a a table.**
3. This laboratory must be written up with printed copies of the schematics, net lists, and graphs pasted in your lab notebook.

13.11 Using the Signal Generator and Oscilloscope

Objective:
The ability to effectively use a signal generator and oscilloscope is a fundamental electrical engineering skill. While the signal generator creates a variety of signals (primarily square waves, triangle waves, and sinusoids), the oscilloscope allows us to view them.

Instruments:

1. waveform generator
2. digital oscilloscope

Parts:
BNC to alligator clips cable

Prelab:

Consider the sinusoid signal on the “oscilloscope” of Figure 29. Find the equation of the signals assuming the following scale information:

1. 15 V = 1 div, 20 ms = 1 div
2. 8 V = 1 div, 90 ms = 1 div
3. 6 V = 1 div, 7.5 ms = 1 div

Bench work:

Each of the following problems describes a signal. It is your task to understand each signal description and to create the signal using a signal generator. Verify each signal using the oscilloscope. This must be done without use of the menus; that is, only the division lines are at your disposal! In particular, for each problem description,

- Sketch at least two cycles of the signal in your notebook. Be sure to include both positive and negative sections. Also, mark critical points such as crossing and extreme points. Note: a ”point” is an ordered pair.
- List the ”interesting” quantities, amplitude, frequencies (both radians per second and Hertz), period and offset. Don’t forget the units!
- Generate the signal using the signal generator.
- Verify the signal by using your oscilloscope and checking against the prediction in your notebook.
- Where appropriate, find the zero-crossing points too!
- Demonstrate each signal to your instructor, who will initial each problem as it is verified.

1. An 8 Volt peak-to-peak sinusoidal signal at 1200 Hz. Note: unless otherwise stated, the offset and phase shift are always assumed to be zero.

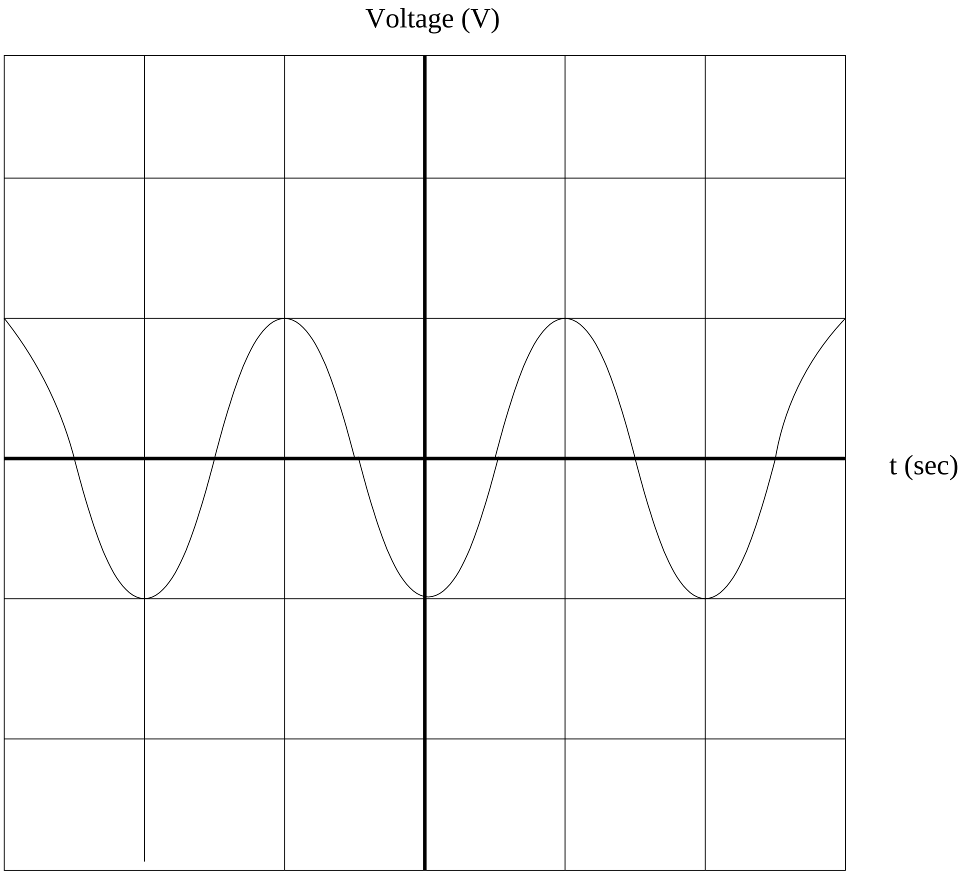


Figure 29: "Oscilloscope screen"

2. A 10 volt peak-to-peak sinusoid with a 2 volt offset at 2000 Hertz.
3. A signal with equation $v(t) = 6\sin(2000t)$. The voltage is measured in volts and the time in seconds, but show your graph using milliseconds. Sketch $v(t) = 6\sin(2000t + 2)$ on the same graph.
4. A signal with equation $v(t) = 3 + 2\sin(3000t)$. The voltage is measured in volts and the time in seconds, but show your graph using milliseconds. Sketch $v(t) = 3 + 2\sin(3000t - 4.5)$ on the same graph.
5. A square wave between -2 V and +4V and a frequency of 500 Hz.
6. A triangular wave between 0 and 7 volts and a frequency of 8000 Hz.

13.12 Waveforms and PSpice®

Objective:
To be able to recognize, simulate (using PSpice®), and generate in the lab sinusoidal, pulse, and piecewise linear voltage waveforms.

Instruments:

1. Waveform generator
2. Oscilloscope

Part:
male BNC to male BNC coaxial cable, >12"

Prelab:

Electrical and computer engineers (ECEs) are primarily concerned with *signals.* Signals are used to convey information, e.g. your voice (a signal comprised of varying air pressure) can be converted to an electrical signal (a voltage). Can you think of some other signals both electrical and non-electrical?

Thus far we have used only constant (DC) voltage signals; not too exciting, but we need DC voltages to power our circuits. ECEs use a variety of signals, but some are more common than others, e.g. sine and square waves.

1. Consider the circuit in Figure 30. If the sinusoidal source has value $v(t) = A\, sin(\omega t)$ volts, with an amplitude of 12 V and a frequency of 1000 Hz,
   (a) What is the frequency expressed in units of radians per second?
   (b) What is the resulting equation for v(t)?
   (c) Accurately sketch the resulting resistor current. Note that Ohm's law still works!
2. Consider the voltage $v(t) = \exp^{\frac{-t}{500}}$ for t measured in milliseconds and in $t \in [0, 2000]$.
   (a) How can this waveform be represented using 5 line segments? That is, what are the coordinates of points to be used in a piecewise linear approximation?
   (b) Sketch the voltage and a 5-line segment PWL(piecewise linear) approximation.

Procedures:

1. **Sinusoidal Waveforms**
   (a) **Using Orcad®**
      i. Invoke Orcad®
      ii. Create a new project
         - Select the Analog or Mixed Circuit Wizard. As usual, choose your PSpice®directory as the home directory for this project.
         - Add all libraries to this project.
      iii. Draw the schematic for the circuit of Figure 30:

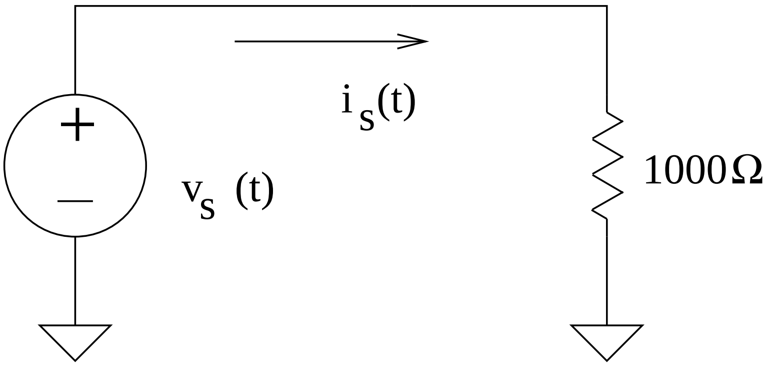


Figure 30: Circuit with time varying source

- Create the circuit per usual using the Orcad®capture program
- Use the VSIN (voltage sinusoid) source so as to match your prelab.

iv. Assign resistor value as indicated

v. Assign parameters to the sinusoidal voltage source as described in lecture:
   - VOFF: adds a constant offset (DC) voltage to the sinusoid (0V)
   - VAMPL: sets the peak voltage amplitude of the sinusoid (12V)
   - FREQ: sets the frequency of the sinusoid (1000Hz)

vi. Create a simulation profile
   - Use new Simulation Profile.
   - Use time domain analysis since you want to view the circuit voltages and currents as a function of time.
   - Choose a Run to Time of 2 ms (2000 μs)

vii. Add a voltage marker to the source voltage.

viii. PSpice -> Run to run the simulation. If you have errors, fix these before proceeding.

ix. In the plotting window
   - Use cursors find the exact voltage at any given time
   - Find the voltages at times 0 s, 100 μs , 500 μs , 1000 μs and 1500 μs .

x. Print or sketch a copy of the voltage traces.

xi. Select current in the plotting window to
   - view the current passing through R.
   - Does this plot match your results for Prelab part (1)?

xii. Change the sinusoidal frequency to 10,000 Hz and redo the simulation.
   - Note that VSIN looks ”rough”, so we need to use more points. Change the simulation settings so that the max step size is 1 us. This will plot more points.
   - reduce the “run to” time so that there are fewer cycles shown.

(b) **Using the Waveform Generator and Oscilloscope**
Connect the output of your waveform generator to Channel 1 of the oscilloscope. Use the waveform generator to generate the 12V peak 1000 Hz sine waveform. Check your settings with the oscilloscope. Be sure to set the oscilloscope trigger to Channel 1 and adjust the trigger level of the oscilloscope so that the display of the voltage waveform is stationary on the oscilloscope display. Have the instructor check this before proceeding. Vary the voltage offset, amplitude, and frequency of the generator waveform.

2. **Pulse Waveforms**

   (a) **Using Orcad®**

      i. Edit your circuit to change the source type to a VPULSE (voltage pulse). The parameters of this source are as follows:

V1	lower voltage level
V2	upper voltage level
TD	delay to start of first pulse
TR	rise time of pulse
TF	fall time of pulse
PW	pulse width (time spent at high level)
PER	period of total waveform

      These parameters are best illustrated by trying an example. Set these as follows:
      V1=0V, V2=5V, TD=0ms, TR=1fs, TF=1fs, PW=0.5ms, PER=1ms.
      (Note that you cannot use TR=0 or TF=0 since physical signals cannot change instantaneously, but femtoseconds (fs) is very small)
      Simulate the circuit with these values. Plot the pulse. Does the shape make sense?

      ii. Now redo your simulation several times; vary the parameters until you understand their effect. As usual, document your examples in your notebook.

   (b) **Using the Waveform Generator and Scope**
   Set the generator to generate a square wave. Vary the duty cycle, amplitude, and frequency of the generator waveform and view on the oscilloscope. Be sure that the displayed waveform is stationary. Adjust the trigger level as necessary. Document in your notebook.

3. **Piecewise Linear Waveforms**

   (a) **Using Orcad®**

      i. Edit your circuit to change the source-type to a VPWL (voltage piecewise linear) source. Recalling that the parameters of this source are the point-wise estimate of the desired waveform, set the values

      T1=0V, V1=0V, T2=1ms, V2=1V, T3=3ms, V3=-1V, T4=4ms, V4=0V
      Simulate this circuit and plot the resulting voltage waveform.

      ii. Experiment with the time and voltage settings. Provide several examples of other waveforms by varying the time and voltage settings.

   (b) **Using the Waveform Generator and Scope**
   Set the generator to produce stable triangular voltage waveforms of different amplitudes and frequencies. Select one generator waveform and duplicate it in simulation. As usual, document your examples in your notebook.

Analysis:
Summarize what you have learned from this experiment. As always, document your work in your lab notebook. Sketch circuit schematics and waveforms, provide explanatory notes, etc. Remember that your lab notebook is a stand-alone document!

13.13 RC Circuits: Simulation

Objective:
To intuitively understand the operation of RC circuits and to be able to calculate the response of an RC circuit to a voltage step input signal.

Software:
Orcad®

Prelab:

1. Consider the circuit of Figure 31, where the source voltage is a 10V peak-to-peak bipolar square wave with a 20 ms period. Complete the following table where the voltages $v_C(t)$ and $v_R(t)$ are a function of time. Assume that the capacitor has an initial voltage of -3.935V.

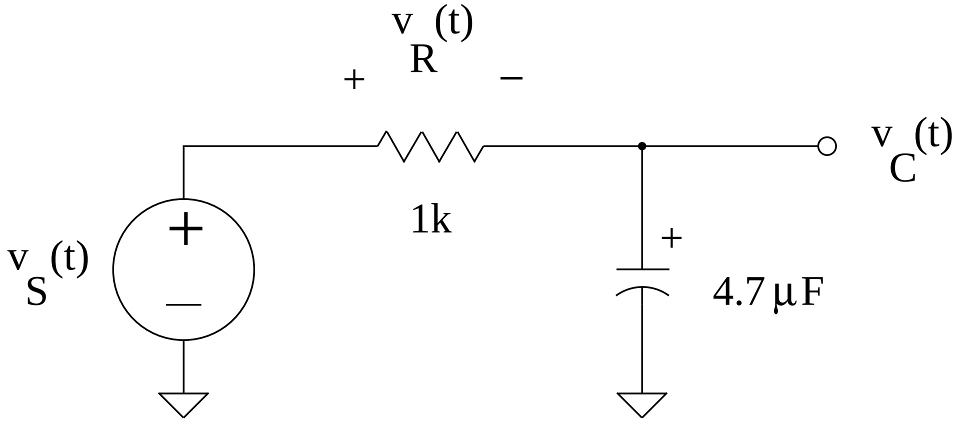


Figure 31: RC circuit

	t=1ms	t=2ms	t=3ms	...	t=20ms
$v_C(t)$				...	
$v_R(t)$				...	

2. Complete a table like that of part (1) using a capacitance of C=47 μF with an initial voltage of -0.512V.
3. Complete a table like that of part (1) using a capacitance of C=0.47 μF and an initial voltage of -5V.
4. Present your results graphically as three overlays of the input voltage and $v_C(t)$ versus time for each different capacitor value.

Bench work:

1. Now that you are an Orcad®expert, simulate the circuits of parts (1), (2), and (3) of the prelab. Use VPULSE to generate a square wave that is 5 V for 10 ms and -5 V for 10 ms. Use 1fs rise and fall times. Note that a time domain analysis is required for at least 20ms. Paste a copy of the capacitor and resistor voltage waveforms in your lab notebook.

2. The plot window of PSpice®has "cursors" to provide the precise values of points on waveforms. Just click on the leftmost cross hairs. Use the left mouse button to position one cursor and the right mouse button for the other. The cursor values are read in a pop-up menu. Practice using the cursors a bit.
3. Use the cursors to collect data from PSpice®at the points you computed in your prelab. Compare to your preliminary calculations. Discuss any serious discrepancies with the instructor.

Analysis:

Find the average percentage error between hand calculations and PSpice®for each of the three cases.

13.14 RC Circuits: Experimental Realization

Objectives:
To utilize the three-pronged attack of hand analysis, simulation, and experimentation to verify operation of an RC circuit. To reinforce an intuitive understanding of RC circuits.

Instruments:

1. waveform generator
2. digital oscilloscope

Parts:

1. breadboard
2. $1\,\mathrm{k}\Omega$ resistor
3. $0.47\,\mu$F capacitor
4. $47\,\mu$F capacitor
5. $4.7\,\mu$F capacitor
6. BNC to alligator clips cable

Prelab

1. Be certain that your hand analysis and simulation results of the previous lab (RC Circuits: Simulation) are in agreement. If not, resolve any discrepancies.

Bench work:

1. Build the circuit of Figure 31 on your breadboard. Use a BNC to alligator clip cable to connect the waveform generator (input signal $v_S(t)$ to your circuit (BLK to ground, RED to R). If the capacitor is polarized, be sure that the positive side of the capacitor is toward R. Ask your instructor if in doubt. Electrolytic capacitors can and do explode if a DC voltage is applied in a direction opposite to the capacitor markings.
2. Connect channel 1 of the scope to the voltage at $v_S(t)$ (at the resistor on the breadboard).The probe goes to the positive side of $v_S(t)$ while the black lead is grounded. Connect channel 2 of the scope to the output voltage $v_C(t)$. Again, the black lead goes to ground and the probe is connected to the ungrounded side of C. Trigger on channel 1. Adjust the generator to provide a 50Hz 50% duty cycle square wave that has a bottom level of -5V and a top level of 5V. Have your instructor verify your experimental setup.
3. Sketch the resistor and capacitor voltages as seen on the scope (Note: to view the resistor voltage, physically swap R and C and attach channel 2 across the resistor. The voltage across R cannot be measured directly with the oscilloscope channel 1 in its current position.) Use the scope cursors to measure the waveforms at the same time values used in your tables of the previous experiment (RC Circuits: Simulation).

4. Verify that your measurements are in close agreement with your results of the previous experiment (RC Circuits: Simulation). If not, discuss with your instructor.
5. Repeat steps 1-4 for two more values of C: $47\,\mu$F and $0.47\,\mu$F .

Analysis:

1. Compare the average error between the experimental results and the simulated and hand analysis results for each of the three cases of C.
2. As always, document your work in your lab notebook. Sketch circuit schematics and waveforms, provide explanatory notes, etc.
3. Redo the simulation for a $47\,\mu$F capacitor for a total time of 200ms. Based on your simulation result, comment on the importance of the capacitor initial condition.

13.15 Oscillator Design Using a LM555 Integrated Circuit: Simulation

Objective:
To learn how to simulate circuits containing integrated circuits and to understand the operation of a basic LM555 timer circuit. To develop an appreciation for the role of integrated circuits in electronic systems.

Software: OrCAD®

Prelab:

1. Read the appendix material on the LM555 until you understand its operation.
2. Visit icmaster.com, and if you haven't done so, register for this site. Locate and print out a data sheet for the LM555 timer. Determine the maximum V_{CC} that can be used in the circuit of Figure 32.

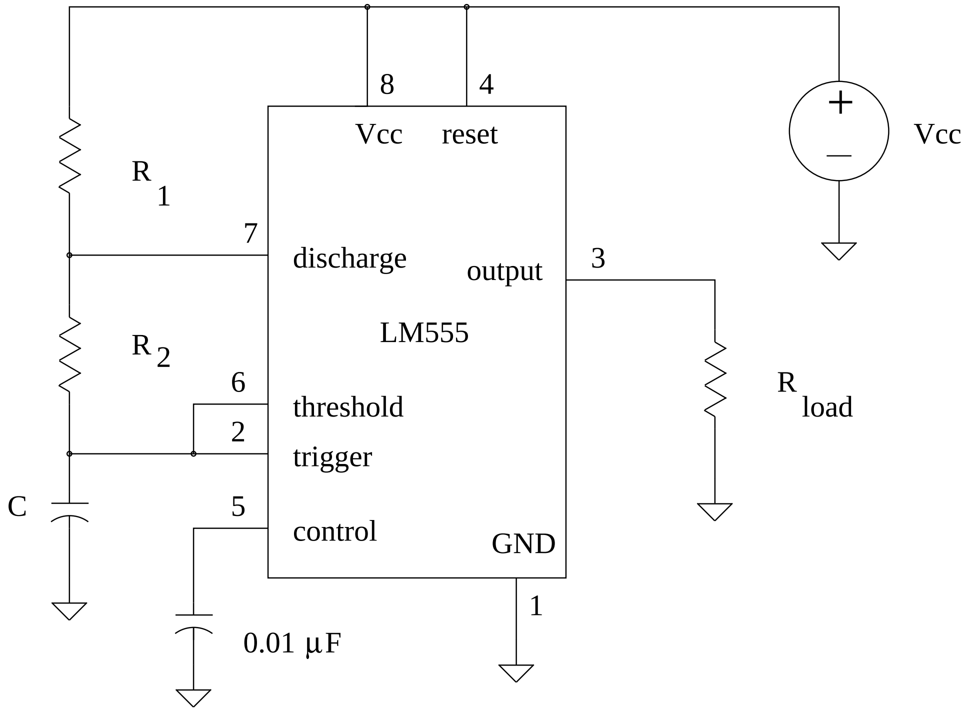


Figure 32: LM555 oscillator circuit

3. The circuit of Figure 32 produces a pulse-width modulated (rectangular wave) signal with

$$f = \frac{1.45}{C(R_1 + 2R_2)} \tag{3}$$

and duty cycle (the proportion of the time that output is high)

$$d = \frac{R_1 + R_2}{R_1 + 2R_2}. \tag{4}$$

Compute f and d for the circuit of figure 14.1 for R_1=1 kΩ , R_2=2.2 kΩ , and C=47 µF .

4. Sketch the expected signal.

Procedures

1. "Construct" the circuit of Figure 32 using Orcad®. Use the 555D part in the EVAL library. "Discharge" the capacitor so that the initial voltage across it is 0 V.
2. Simulate the circuit using a transient analysis for 10 seconds.
3. Verify that pin 3 has a duty cycle and frequency which matches step (3) of your prelab. If not, consult with your instructor.
4. Once your simulation is working, print out the voltages on all 8 pins of the LM555D. Arrange your plots, one below the next, so that the time axes are aligned. This will preserve important timing information. Write several paragraphs that describe how the circuit works—base your description around your voltage waveforms. Use your own words.
5. Using simulations, determine the effect that the value of R_1 has on the circuit output and the effect that the value of R_2 has on the circuit output.

Analysis:

1. For the circuit of Figure 32, compute the two pertinent time constants. Verify that these values make sense by examining your results of part (4) above.
2. What was the error between your simulated and hand calculated values for the duty cycle and oscillation frequency for the circuit of Figure 32?
3. Be sure to document all of your work for this lab. Provide enough information to back up your conclusions, particularly for bench work step (5). Your results for bench work step (4) will be used in the next lab.

Sedra and Smith, pg. 1009

Sedra and Smith, pg. 1010

Sedra and Smith, pg. 1011

Sedra and Smith, pg. 1012

Sedra and Smith, pg. 1013

13.16 Oscillator Design Using a LM555 Integrated Circuit: Experimental Realization

Objective:
To learn how to build circuits containing integrated circuits. To build a working LM555 based square wave oscillator and to compare results with theory and hand calculation.

Instruments:

1. digital oscilloscope
2. digital multimeter
3. power supply

Parts:

1. breadboard
2. 1 μF capacitor
3. 0.01 μF capacitor
4. LM555 timer integrated circuit

Prelab:

1. Review the LM555 material from the previous lab until you understand the operation of the LM555 timer circuit. You will build the circuit of Figure 32 in this experiment.
2. Review your results for the previous lab.
3. Electronic circuits often require debugging; develop a list of 4 things that you can check in the event that your circuit does not work when power is applied.
4. Design a LM555 timer circuit that has a duty cycle of 60%. Use C=1 μF and standard values for R_1 and R_2.

Procedures:

1. Breadboard the circuit of Figure 32 with R_1=1 kΩ , R_2=2.2 kΩ , and C=47 μF . If capacitor C is an electrolytic capacitor, the negative lead must be the grounded lead to prevent it from exploding. Do not apply power until your circuit has been checked by the instructor.
2. Apply power to your circuit. Verify that the output is a square wave using channel 1 of your oscilloscope. If not, debug your circuit.
3. Once working, be sure to stabilize the oscilloscope display by triggering on channel 1. Use channel 2 to display the voltages at each pin of the LM555 IC. Either sketch or printout each of these voltages. Arrange your plots one below the next so that the time axes are aligned. This will preserve important timing information.
4. Implement your design for an oscillator circuits with a 60% duty cycle as done in your prelab.

Analysis:

1. Compare the experimental LM555 voltage waveforms with the simulated voltage waveforms of Lab Thirteen. How well do the experimental and simulated waveforms match?
2. In addition to the analysis work included in the bench work steps, comment on how well experimental and simulated voltage waveforms agree. Be sure that you answered all questions with sufficient depth.

13.17 Computer Interfacing with QBASIC

Objective:
To write BASIC programs that can control the step sequence of a Stiquito^{TM}robot. Specifically, we will create programs that write data to the parallel port so as to activate the Stiquito^{TM}legs in a desired sequence.

Instruments:

1. Personal computer
2. Parallel port monitor system
3. Power supply

Software:

1. MS-DOS^{TM}boot disk
2. gxsport.exe (part of XSTOOLS^{TM}from www.xess.com)(on boot disk)
3. QBASIC (on boot disk)

Parts:

1. breadboard
2. AD-DB25P solderless breadboard adapter
   (for easy connection of parallel port cable to breadboard)
3. (8) integrated LEDs
4. ULN2803
5. parallel port cable, straight-thru connectivity, male to female
6. Stiquito^{TM}robot

Prelab:

1. Read chapter 7 of the Stiquito^{TM}text.
2. Review the WinSite software website (www.winsite.com).
   (a) Write a synopsis of what types of software are available.
   (b) Explain the concept of open source software.
   (c) How does shareware work?
3. Make a flowchart for the controlling the sequence of leg movements of a Stiquito^{TM}robot.
4. Write definitions for each of the following BASIC instructions:

(a) DIM
(b) OUT
(c) MID$
(d) FOR / NEXT loop
(e) IF / THEN / ELSE
(f) PRINT

Procedures:

1. Breadboard the parallel port monitor circuit of Fig. 7.1 of the text.
2. Verify operation of the parallel port monitor using gxsport.exe.
3. Predict and test the output of the port for the following hexadecimal values:

	hexadecimal	binary	prediction	actual
1	CC		○○○○ ○○○○	○○○○ ○○○○
2	35		○○○○ ○○○○	○○○○ ○○○○
3	F0		○○○○ ○○○○	○○○○ ○○○○
4	D3		○○○○ ○○○○	○○○○ ○○○○

4. Implement a BASIC program that causes a “simulated” light to blink endlessly until the program is terminated by pressing any key. Simulate the light status by PRINTing an “X” for an on light and an “O” for an off light.
   (a) Determine the number of cycles required of a For/Next loop in order to operate the blinker exactly at 1 Hz (on for 1 second, off for 1 second). Implement this in the given program and verify. Demonstrate to your lab instructor.
   (b) Change the program so that is has 8 lights corresponding to the two nibbles in a standard 8-bit word. Make all lights blink at an arbitrary frequency that is specified at the beginning of your program. Demonstrate to your lab instructor.
   (c) Enhance the program again so that it does a “walking ones” routine. That is, each light should be off except one, and that light “moves” one digit for each cycle. The walking one should rotate when it comes to the end of the line. Demonstrate to your lab instructor.
5. Now edit the program so that it puts the data to the parallel port monitor. In order to put data to the parallel port, you must use the OUT instruction using the following addresses:

   to enable the output port, use address H37A
   to put data on the output port, use address H378

   For instance, in order to place the hexadecimal number AA on the parallel port, first enable the port and second put the data on the port:

```
OUT &H37A , &HFF
OUT &H378 , &HAA
```

   Since [AA] (base 16) is the same as [1010 1010] (base 2), it is evident that every other LED should be on (1) or off (0).

Now write a BASIC program using each of these codes. Do the LED results confirm your predictions?

```
OUT &H378 , &HCC
OUT &H378 , &H35
OUT &H378 , &HF0
OUT &H378 , &HD3
```

6. Write a program to display the “walking ones” on the LEDs as described in part (2) above. Verify correct operation. Demonstrate to your lab instructor.
7. Now use your computer interfacing knowledge and the circuit of Figure 7.2 of the text to program your Stiquito^{TM} to walk with a tripod gate. Demonstrate to your instructor.

Analysis and presentation of results:
Prepare program listings of each program. Cut and paste them so that they can be inserted, clearly labeled, and explained in your lab notebook.

13.18 The Autonomous Stiquito^{TM}

Objective:
To design and build a circuit that controls and drives leg movement for the Stiquito^{TM}robot. To prepare a technical presentation of the results for this laboratory.

Instruments:

1. digital oscilloscope
2. digital multimeter
3. power supply

Parts:

1. breadboard
2. 1 μF capacitor
3. 0.01 μF capacitor
4. 2 MΩ $\frac{1}{4}$W resistor
5. 2 MΩ potentiometer
6. 10 kΩ $\frac{1}{4}$W resistor
7. 1 kΩ $\frac{1}{4}$W resistor
8. LM555 timer integrated circuit
9. integrated LED
10. Stiquito^{TM}robot

Prelab:

1. Read chapters 7, 8, and 9 in the Stiquito^{TM}text.
2. Design a multivibrator oscillator circuit using a LM555 timer. The pulse width should be two seconds and the duty cycle 50%.

Procedures:

1. Build a new Stiquito^{TM}if your current Stiquito^{TM}is not fully functional. Use “lessons learned”!
2. Verify the oscillator circuit designed in your prelab using OrCAD^{TM}. Document in your lab notebook.
3. Breadboard the circuit of Figure 8.1 (textbook) using your LM555 design to drive the ULN2803. Do not connect the Stiquito^{TM}. (Note: ULN2803 output pin 18 is used as an inverter.)
4. Verify correct circuit operation using your oscilloscope.

5. Now connect your Stiquito^{TM} to the control circuit. Verify that your Stiquito^{TM} walks!

Final analysis

Prepare a poster describing your work in this lab. The poster should provide (at a minimum) schematic diagram(s), an explanation of how the circuit(s) work, example waveforms, etc. Use colors to bring your poster alive. Be creative! (Some groups even added blinking LEDs to their posters). Include a demonstration of both your autonomous and non-autonomous (computer controlled) Stiquito^{TM}(s). Don't forget to have your picture taken along with your final project!