Creating A Beginner's Electronics Course

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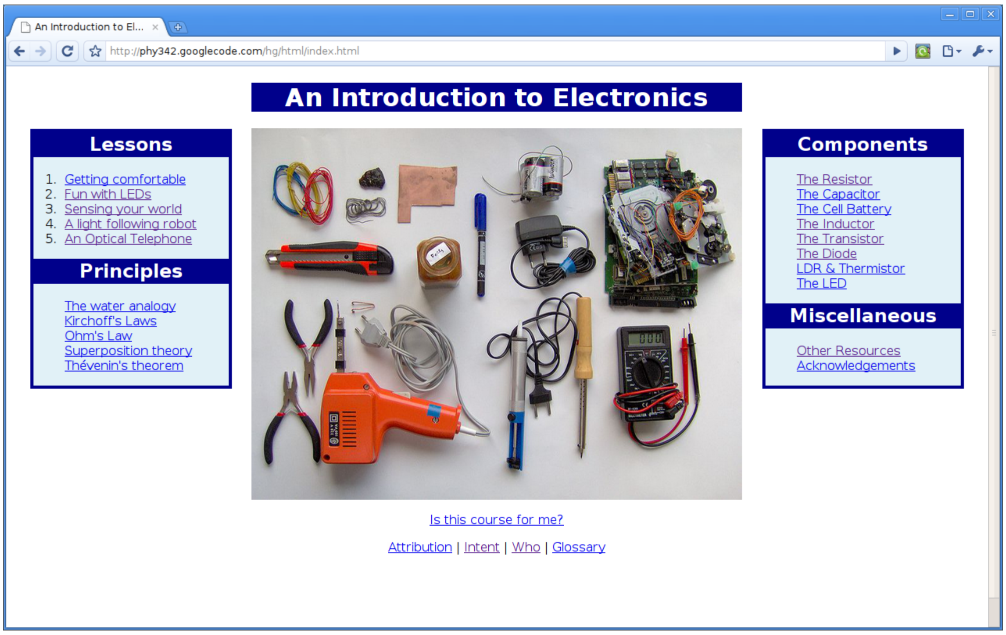
May 28, 2010

Abstract

The creation of an electronics course for beginners is discussed in depth, with emphasis on design and structure. A syllabus is created from the deconstruction of various electronics projects, and an eleven part curriculum is outlined. The finished product consists of an online electronics course, which can be viewed alone without any further material. The execution of the design is considered to have failed, for reasons explained in the evaluation.



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1 The Big Picture

1.1 The need for an electronics course

Electronics is a dying art for physicists. The current physics undergraduate syllabus in many institutions does not cover basic electronic skills. Yet, on a daily basis, physicists are tasked with designing, building, and interacting with a wide variety of electronics in order to fulfil their underlying science mission. Building a simple crystal radio was once a childhood rite, but was replaced as the technological abstractions became more and more complex. The rise of mass produced, disposable integrated circuits and interchangeable parts has meant that most students now entering into a physics degree have had no experience with electronic circuits, and most would be fearful of prying open their dishwasher, tumble drier, or of unscrewing the rear cover of their laptop.

This trend is by no means specific to electronics, and can be seen in the evolution of technology in general. Other have already covered this topic in depth and far more eloquently than could be done here[1]. While this trend is not *necessarily* negative, it hinders many student's introduction to an area that could easily yield future benefits.

In order to remedy this, a gentle introduction to electronics is needed that would give the foundations upon which further knowledge could be built. However, the lack of electronic courses in the current syllabus is not an omission, but reflects the competitive nature of time allocation in the undergraduate curriculum. In order for an electronic course not to remain a mere exercise, but to be helpful in practise, it would therefore have to either displace another course, or be unobtrusive enough to be taken by students besides their formal curriculum.

Displacing an existing course is difficult at best, due to the complex network of interdependent knowledge that is supported by each learning unit. (A problem that was also relevant to the restricted domain of an electronics course, as will be seen when discussing the course content in 2.1) There is also much inertia behind each existing course due to the already incurred costs in administration, course design, material preparation, and educator training. For this reason, the course has to be independent of the existing curriculum, and must be approachable on its own. As can be seen in section 2.4 this changes the course requirements significantly, as a student must now be able to follow the content in her spare time.

1.2 Target audience

This course is targeted at late secondary and early tertiary education students and adult learners with no prior electronics experience. While electronics provides significant depth, challenge and complexity at the advanced levels, it is not initially a difficult topic, and even intermediate difficulty projects in digital and analog electronics can be tackled by younger students. It is also found that advanced levels requiring advanced skills, are sought out by students that already have the intrinsic motivation and interest to invest the effort needed to tackle the difficult concepts.

This is perhaps better qualified by the following: It is understood that no matter how much effort is invested on the part of the educator, not every student will find electronics interesting and relevant. And while it is hoped that all students who will take this course will find it highly enjoyable, no assumptions should be made about the motivations of students in the field of electronics itself. In any case, this course is to serve more as a gateway than as a definitive guide. This is why it was chosen to extend the range of possible students down to late secondary education.

Students are expected to have a working knowledge of mathematics, in particular algebra, and to be comfortable reading and analysing a variety of graphs. They are also expected to have a very basic understanding of derivatives for the later aspects of the course (simply understanding what a 'rate of change' is should be sufficient). Interestingly, learning electronics is a very good way of developing a deeper understanding of the underlying mathematical concepts. Capacitors, for example, provide a great way of demonstrating exponential decay in a visual and approachable way. Complex numbers can also be introduced through the use of AC circuits. Teaching these concepts is not within the scope of this course, but it was noted early on as an area that could be fruitfully developed to support mathematical teaching.

In term of resources, students are expected to have access to basic electronic components, a solder-less breadboard, and a cheap digital multimeter (An Ammeter and Voltmeter are perfectly adequate substitutes). Optionally, intermediate equipment such as an oscilloscope or a waveform generator can be helpful, but they are not necessary. This, understandably, is a large investment for most individual students. However, almost all secondary schools carry all this equipment by default. Reducing somewhat the barrier to entry.

2 Creation

2.1 Course material selection

The selection of teaching materials proved to be more complex than expected. No prior domain knowledge could be reasonably expected, so all areas had to be build from the ground up.

Because the course was intended to foster a deep understanding of the basic material on which further knowledge could be easily constructed, it was quickly found that a meaningful and useful coverage of even basic topics would require many hours spent in preparatory lessons. This clashed starkly with the stated aim of being engaging, and the hope that the course could be picked up besides the regular curriculum. The compromises made in the course design result from this inherent antagonism of two vital aims of this project.

The difficulty involved in covering all the required material can be better appreciated by deconstructing the required knowledge needed to understand an intermediate difficulty project, such as a simple digital telephone. First, the project can be broken down into separate modules, as seen in figure 1. This sectioning is vital, and allows the teaching of electronic principles and recipes that can later be used elsewhere.

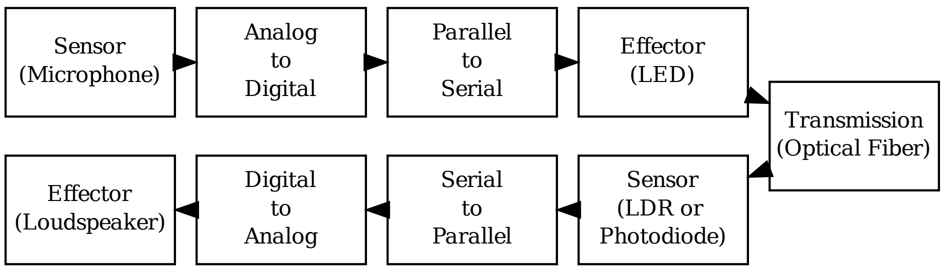

Figure 1: Breaking an optical telephone into conceptual modules.

The Project consists of a microphone signal, digitised and transmitted through an optical fibre to drive a loudspeaker. The modular decomposition of this project is key to developing understanding. Each module, once understood and assimilated, can be used in other projects for a different purpose.

If taken at this level, the task may seem reasonable. However, if the knowledge dependencies needed for each module are considered, the project can be seen in a different light. Figure 2 shows most of what the student would need to understand to be able to fully comprehend the digital telephone. In particular, the two very important topics of Analog/Digital conversion and Parallel/Serial conversion have many dependencies. Ideally, each of the nodes would correspond to a separate lesson with a joint practical session for the knowledge to be fully assimilated.

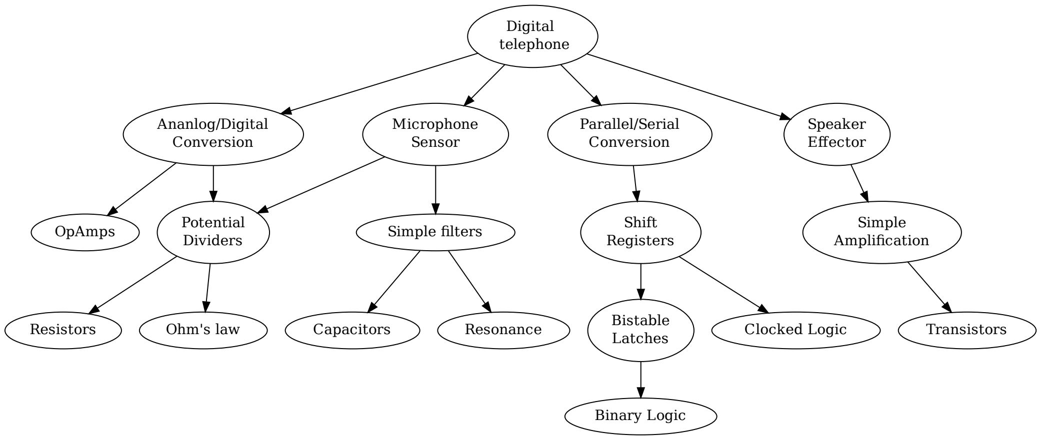

Figure 2: Incomplete dependency graph for an optical telephone

Clearly, in order for projects of similar complexity to the optical digital telephone to be undertaken, the syllabus has to cover every area, so that the students would not be left with gaps in their understanding. During the creation of the syllabus, several such projects were considered, and similarly decomposed until a clear overview of all fundamental electronic topics emerged.

2.2 Syllabus

Once a clear overview had been created, a syllabus was constructed that would cover the key areas that were requirements for the largest number of projects. It became quickly apparent that the majority of projects actually relied on few key ideas, and that these should form the core of the syllabus. The final syllabus is as follows:

1. Principles
   (a) **Ohms Law**
   The current through a conductor between two points is directly proportional to the potential difference across the two points, and inversely proportional to the resistance between them.[2]
   (b) **Kirchoff's current law**
   The algebraic sum of the currents into any junction is zero[3, p986]
   (c) **Kirchoff's voltage law**
   The algebraic sum of the potential differences in any loop including those associated with emfs and those of resistive elements *must equal zero.*[3, p987]
   (d) **Thévenin's equivalence theorem**
   Any two terminal network of resistors and voltage source is equivalent to a single resistor R in series with a single voltage source V[4, p11]
2. Components
   (a) **The resistor**
   Resistance in series, in parallel. Operations of thermistors and Light dependent resistors.
   (b) **The Capacitor**
   Capacitance in series, in parallel. Capacitor charging and discharging.
   (c) **The Diode and the LED**
   Use, Breakdown voltage.

   (d) **Transistor**
   Use as switch, use as amplifiers, Darlington pairs.

   (e) **Inductor**
   Water analogy, typical uses, typical construction. Preference for Capacitor in high/low pass.

   (f) **Operational Amplifiers**
   Operation, recognition of negative and positive feedback.

   (g) **555 timer**
   Difference between astable, monostable and bistable modes. Ability to create astable and monostable given reference.

3. Circuits
   Ability to understand and re-create (with reference material) the following circuits:

   (a) Potential dividers with LDR and thermistor
   (b) Inductor/Effector circuits with transistor amplifications.
   (c) High pass filter
   (d) Low pass filter
   (e) Notch filter
   (f) Bandpass filter
   (g) Capacitor-Transistor oscillator
   (h) Astable 555 circuit
   (i) A crystal radio
   (j) Transistor amplifier

4. Logic

   (a) Binary Logic
   Including AND, OR, NOT, XOR, NAND, NOR gates, and combinations thereof. Creation, operation and use of a bistable latch.

   (b) Clocked Logic
   And timing diagrams.

   (c) Shift registers
   In particular their use as parallel to serial and serial to parallel converters. Their construction from bistable latches.

While the topic coverage is far from complete, the syllabus covers more than the basics. The inclusion of Operational Amplifiers and filters in an introduction course is perhaps unnecessary. They add a lot of complexity and require special attention. And since knowledge of complex numbers cannot be assumed, restrictions are imposed on how well they can be covered. Regardless, it was felt that the introduction of these concepts, even if only sparingly, was best. The familiarity with the terminology and general functions will greatly facilitate further study. It will also make the task of designing a further course significantly easier.

2.3 Curriculum

In order to fulfil the expectations of the syllabus, learning session structure and format would have to be carefully considered. The course was split up into twelve separate sessions. Early on, the format of each session was chosen to be completely practical in order to increase engagement, and the delivery to occur through the use of an online website, with each session presented with all supporting material as a single web page. This mode of delivery supports the course aims of being approachable by all students, and affords the educator far greater flexibility. Upstream changes propagate rapidly to all learners, a significant benefit compared to a paper based course. The use of hyperlinks also allows the difficulty level of the course to be elastic while not alienating learners with existing skills; simple references can be linked to instead of presented with each session. The open nature of the world wide web also allows linking to other websites with similar aims to this one, and avoids duplication of efforts. Concentration can thus be brought to bear on areas that are most beneficial.

The design of each individual session had to be carefully considered. Since the course was chosen to be optional, it would not only have to draw the students back to the next session purely by virtue of being enjoyable but also ensure the coverage of the material. Some background research led to the work of Malcolm Knowles[5] who put forward several key principles for self-directed learning (Adapted from [6]):

- There is a need to explain why specific things are being taught
- Instruction should be task-oriented and problem centred instead of memorisation and concept oriented - learning activities should be in the context of common tasks to be performed.
- Since learners are self-directed, instruction should allow learners to discover things for themselves, providing guidance and help when mistakes are made.
- Learners need to be involved in the planning and evaluation of their instruction.
- Experience (including mistakes) provides the basis for learning activities.
- Leraners are most interested in learning subjects that have immediate relevance to their job or personal life.

These key points would have to be met if the course was to be engaging, and the material retained once the course is finished. Secondly, it was hoped to make the course enjoyable for the students who would take it. Here, research led to the work of Mihaly Csikszentmihalyi [7, pp598-608]:

- The task must be challenging, but not too difficult.
- Clear goals are vital.
- Immediate feedback is necessary
- The person must have personal control over the task.

As it happens, practical electronics has several advantageous properties that can be exploited. Circuits can provide immediate feedback, especially when prototyped on a breadboard. The student has complete control over the circuit. The goals are also clear and well defined. To fulfil all the above conditions, the tasks within each session must be made appropriately challenging. To do this, new concepts will be introduced continually during each session.

It was decided to plan eleven separate sessions. The fact that this corresponds to the number of weeks in the academic term is not innocent, and serves two purposes. Firstly, it allows regular scheduling with the standard courses, but also, allows the course to be integrated into a taught module later on. Each session was designed to fill two and a half hours, and to be extended to an entire afternoon if desired. This may seem like a long time at first, but it was quickly discovered that any practical activity would have to include ample time for fault-finding. Placing a component incorrectly in a breadboard is a very easy mistake to make, and difficult to discover without external help.

The sessions would be broken down as follows:

Session one: Getting Comfortable
At risk of being found too easy by some students, the first session will be geared towards learning,

or revising the basics of practical electronics. A hands-on approach will be taken to introduce the digital multimeter, and the basic principles such as Ohm's law and Kirchoff's rules. The rules for resistors and capacitors in series and in parallel will be introduced, and applied in the case of a simple potential divider. Capacitor charging will also be touched on, but the underlying mathematics will only be introduced later on. It will be necessary to explain why these principles are being demonstrated. References to projects in the next few sessions will be vital, and motivation could be retained by showing exactly where these principles apply in future work.

Session two: Actuators
The Second lesson will cover output in its various forms. The simplest actuator used will be the LED. Using LEDs is highly visual and allows the learner to get feedback in seconds. The previous session's work should be build upon, especially the use of potential dividers. The basic electrical principles should also be discussed, particularly when choosing the right resistor values. Some simple projects are ideal to tie in the previous work, and make the principles tangible. Flashing LEDs using a capacitor can demonstrate capacitor discharge, as well as the use of transistors as switches. This can be made relevant by explaining it as a mock car alarm, rather than simply as flashing LEDs. In preparation for the fourth session, the use of electric motors will also ideally be discussed. Depending on time and resources, small speakers could also be demonstrated. The same circuit used to flash the LEDs could be modified to produce a tone, and persistence of vision can be demonstrated by replacing the small speaker with an LED.

Session three: Sensors
This session will introduce simple sensors such as the LDR and the thermistor. Other sensors could potentially be introduced here also, including homemade pressure pads (to be used as alarm triggers), and homemade water detectors. To tie in the session with previous work, several mini-projects can be constructed. For example, tilt switches could be used, and their operation demonstrated in a simple bike alarm project using the previous lesson's speaker circuit. Another good mini-project to bring together both output and sensors is a darkness activated safety light. Construction can be achieved very quickly, and the results tested by simply blocking the LDR with one's thumb. Another potential mini-project would be a personal cooling fan. A simple electric motor is coupled to a thermistor and variable capacitor. This creates a temperature-dependent fan, as well as introducing the use of the Darlington pair formally. This also allows the introduction of induction, back EMF and protective diodes, while remaining practical and relevant. A rewarding but slightly more complex project would be an LED sound meter. This may require a more complex circuit, but by using only capacitors, transistors and LEDs, the required circuitry can be created. This project would also demonstrate multiple stage potential dividers. This session is also a good place to introduce the use of a soldering iron. Students could be encouraged to pick one of the mini-projects and solder it together instead of testing it on breadboards.

Session four: Light following robot
The light following robot is another staple of electronic projects, and this session is dedicated to it. While it may seem that a single project that does not incorporate more latent difficulty than the previous ones, it was found that several hours could be spent doing nothing else except directing a light-tracking robot in a darkened room using a torch, and so the time must be allowed for learners to enjoy the fruit of their labour. This project also introduces the concept of feedback, and this is perhaps why it is capable of capturing the attention for such a long time. While rudimentary, using feedback to make decision (In this case, which direction the robot should turn in) is an essential idea, and a cornerstone of control electronics, and is very well demonstrated by this project.

Session five: Optical telegram
The Fifth session once again uses only the principles learnt in lessons one two and three, and focuses on the construction of an optical telegraph. While it may seem redundant to reinforce the material twice, both in lesson four and five, it serves a particular purpose. By using the same principles, but applying them to a different problem area, it is hoped that the learners will get an intuitive grasp of how their acquired knowledge can be adapted to provide solutions to a variety of problems. Since the project itself is relatively simple, and consists of a touch to light and a

light to sound transducer that can be constructed quickly, this session gives learners a breathing space compared to the previous ones. Ambitious students could at this point also be directed towards designing their first circuit themselves. The modular nature of the material presentation encourages reuse and creation. Asking for learners to pick a problem that they have daily and that could be solved by electronics would most likely yield the best results, as it taps into their personal experiences and intrinsic motivations.

Session six: Filters and the crystal radio
This session marks a departure from the previous ones and introduces for the first time alternating current circuits. While signals were touched on during session two and three, with the use of a capacitor/transistor oscillator, the circuits presented here are specifically used to affect AC circuits. For simplicity, only passive filters are presented, but links to active filters should also be presented for completeness. The High pass, Low pass, Notch and Band pass filters should be introduced, and characteristic frequencies should be explained. In particular, the graphical profile of each filter should be presented. The principles of the bandpass filter is then applied practically to create a crystal radio. A crystal radio is in fact nothing more than a tunable bandpass filter connected to an antenna and earphones. Instructions for constructing a crystal radio from household items should also be provided, as it is an incredibly rewarding exercise that could greatly motivate the learners. Once again, the lesson can be completed in less time than two and a half hour, but it was felt that at least a third of this time should be set aside on tuning the created radio and receiving a transmission.

Session seven: Introduction to digital electronics
Introducing digital electronics is another departure from the previous work. In this session, digital logic in introduced. Logic gates are presented, and the learner is challenged with simple practical exercise, such as designing a gate logic circuit to control a washing machine with multiple wash settings. Using two NAND gates, a bistable latch (flip-flop) is build. In order to create a challenging exercise, a bistable latch could be requested from the learners, but this time created only with XOR gates. It would be beneficial here if the idea of logic equivalence is demonstrated. In particular, an example of reducing a complex logic table to a series of AND and OR statement would be highly beneficial. The second part of the session could be taken by an introduction to clocked logic, which will be necessary for later projects. The construction of a clocked bistable latch would be the ideal mini-project for this session, as it would lead nicely into Shift Registers, a subject that is tackled during the next session.

Session eight: Digital and Analog conversion
Using the knowledge gained in the previous session, Shift registers are introduced first. Ideally, the learners would be tasked with creating a shift register from previously introduced concepts. The simplest task would be to create a Serial-In Serial-Out register, and the difficulty can be slightly increased by demanding Serial-In Parallel-Out, or other combinations. This essentially demonstrates conversion to and from Serial and Parallel signals. Once the concepts involved are fully assimilated, the student is presented and helped through with the task of using a Shift Register and a series of potential dividers to create a digital to analog converter. The reverse operation is then discussed. Using a small LDR to demonstrate the concept would be a great way of making sure that the difficulties in DAC and ADC are discussed, for example, the need for transistor to drive actuators from or to trigger the pins of integrated circuits. This would also be a good time to discuss the difference between CMOS and TTL ICs. Especially their response rates and their susceptibility to static damage.

Session nine: A digital work timer
This session serves as an introduction to the very versatile 555 chip and practically demonstrate its three major uses (Astable, bistable, and monostable). The digital work timer is a device that allows the user to calculate how long he or she has been working on a particular project, and makes use of the 555 chip in both astable, monostable, and bistable mode. For example, switch debouncing is done using the monostable mode, toggling between billed and non-billed time is done using the bistable mode, and the astable mode is used as a clock to drive a counter. Common digital outputs, such as a seven or sixteen segment counter are also necessarily demonstrated. To increase engagement, a thorough explanation of the sixteen segment counter could be replaced by a practical exercise, where the datasheet is presented, and the requested behaviour presented

without implementation details. At the end of this session, the learner should have a working timer that is relevant to their own work. This also presents another opportunity to develop further soldering skills.

Session ten: Revisiting the optical telegram (An Optical fibre telephone)
Now that the learner is comfortable with ADC and DAC, as well as converting between Serial and parallel signals, a more complex project is presented. This is none other than the digital optical telephone presented in section 2.1. In fact, figure 1 would be a perfect way to introduce the task. Since a large amount of knowledge has already been developed, no further details are required. (It would however be useful to have a reference implementation available as well as some tips and guidelines should the student need them.) The addition of the two conversion stages to the design presented in the fifth session will also demonstrate the modular nature of good electronic design, and how this makes fault-finding easier. It may be wise to replace the LDR by a more sensitive photodiode due to the difference between LDR and photodiode response times and the bandwidth required for voice communications.

Session eleven: Revisiting the radio (Amplification)
In this final session, another earlier project is revisited. This time, the crystal radio is modified with the addition of passive amplification. transistors are used to strengthen the signal and to drive a more powerful speaker, such as PC speakers. This session could also be an opportunity to review filters, and perhaps discuss possible improvements over the naive passive filters created in session six. The diode envelope demodulator is also improved using a capacitor. Since soldering skills have now developed, it would be a good time to build an amplified radio and package it nicely, ending the course with a practical project that would show how far the learners have come in comparison to session 1.

Ambitious learners may want to try and use active filtering and active amplification using OpAmps, and could be pointed to the resources necessary to create a demodulator for an FM radio. The construction of an FM radio is an intermediate difficulty project, and would also make an ideal stepping stone to a further course.

Using this curriculum, it is believed that the learner's confidence and abilities in electronics would be developed appropriately, and all the syllabus topics covered with accompanying practical work.

2.4 Summary of objectives and constraints

The course

1. MUST be approachable with NO prior knowledge of electronics
2. MUST be self standing and contain all the required material that the student does not need to reference to other works and all the answers to the questions are available in the material. (although not necessarily explicitely)
3. SHOULD be completable alongside an undergraduate physics curriculum
4. SHOULD provide the learner with conceptual understanding, even if this comes through practical projects.
5. SHOULD allow learners that have completed the course to use standard reference texts without feeling intimidated, such as [4].
6. SHOULD remain engaging throughout, in accordance to the principles presented in section 2.3

3 Evaluation

The creation of the entire course in the time allocated was an ambitious task. While the designated approach to the topic with a large emphasis on practical sessions proved to be ideal for learning, the execution fell short of the aims by a very large margin.

In fact, only four sessions were completed, and these were completed poorly. The created material is sparse, and presents many flaws, unfortunately mostly due to lack of diligence. The style of most sessions is not interactive, the tone sometimes patronising, and some lessons are incomplete. In many cases, the referenced diagrams are missing, as they were not created at all.

The amount of time required for the preparation of each session was also grossly underestimated. The time spent on designing and testing the many circuits needed was significant, with many hours spent on simply making sure that the properties of various components (Resistance, capacitance, etc...) was correct. Designing the circuits using the underlying principles proved to be a trivial task in comparison to the time spent implementing those principles. The time for the creation of the session script itself also proved to be significant, in particular because the aims required adherence to a particular model of teaching, which demanded greater attention than others.

The addition of questions and hidden answers to the website code was a good idea, and supported the aims well, but it is felt that this feature was underutilised significantly, to the detriment of the course.

Overall, a critical review of the product will find it flawed, and of poor quality throughout, a very long way from the aims and ambitions stated in section 2.4.

On a more positive note, however, it is believed that the effort spent on design the course were very effective. The course structure and pedagogical approach should, if implemented competently, allow the learners to acquire an excellent grasp of electronics. The breakdown of the topics and the modular approach will serve a student well, and the decisions made in the creation of the curriculum in 2.3 can benefit future work.

3.1 Future work

Improvements in execution

The first task requiring attention is the improvement to the quality of the existing material. It should be implemented in a way that better reflects the principles and aims of this course and should not be rushed. As a result, the existing sessions should finally be able to stand unsupported and be ready for evaluation by actual learners.

The missing sessions should then be tackled in turn, until all the syllabus is covered. Only then can further work proceed.

Some minor technical improvements could also greatly benefit the course. For example, linking each presented circuit to an interactive version using a Java applet would be an excellent use of time, and would promote experimentation with the principles presented. Fortunately, the hard work of creating the underlying physical simulation and packaging it in an applet has already been carried out. For example, [8]. The only work required would be to create the course circuits in the framework provided and link to the applet. This was unfortunately not done due to lack of time.

The construction of the circuits discussed could also be recorded, and the instructional videos added to the website. This would make the entire course much more approachable, and while it may seem that the learning is passive, this does not have to be the case.

Creation of an advanced electronics Course

While the coverage of this introduction is comprehensive, electronics has a lot more to offer. The same principles used to design and construct this course could be applied to an advanced electronics course. As mentioned in section 2.3, a good introduction would be to start with FM demodulation. Other topics that could benefit from a clear introduction, especially for physicists, are: high speed sensors; control systems; radio communication; asynchronous digital circuits; working with large currents and voltages; micro-controllers; digital filters and a more in depth coverage of analog filters.

4 Conclusion

It is a shame that the finished product fell short of the expectations of the creators and supervisor. In particular, the incomplete lessons and the poor quality of the existing materials are two areas of concerns. It is felt, however, that the underlying design and approach are very valid, and some glimpses of quality can be found within the existing course. Clearly, this should be a standard that all the material adheres to, and not something that is almost imperceptible.

Regardless of the many flaws of the end product, a lot was learnt during the creation of this course. While of course, some knowledge was acquired of electronics, a surprising insight was formed on the approach to deconstructing the material from end products, as shown in section 2.1 to create a syllabus that is comprehensive and realistic. It was also found that while the execution was poor, the underlying educational principles are sound, and the few sections of quality are due to their careful application.

It is hoped that the work carried out during the creation of this course, in particular the design and structure, will become a seed upon which a further body of good quality teaching material can be built.

Further attempts at improvement will be made, and it is hoped that others will contribute. In the meantime, the course can be found online at:

`http://phy342.googlecode.com/hg/html/index.html`

References

[1] R. M. Pirsig, *Zen and the Art of Motorcycle Maintenance.* Vintage, New edition (1999).

[2] E. L. Consoliver and G. I. Mitchell, *Automotive Ignition Systems.* McGraw-Hill, 1920.

[3] H. D. Young and R. A. Freedman, *University Physics 11th Ed.* Pearson Education as Addison Wesley, 2004.

[4] P. H. W. Hill, *The Art of Electronics.* Cambridge University Press, 1989.

[5] "Malcolm knowles." http://www.infed.org/thinkers/et-knowl.htm.

[6] "Andragogy." http://tip.psychology.org/knowles.html.

[7] M. Csikszentmihalyi, *in the Handbook of Competence and Motivation.* Guilford Press, 2005.

[8] P. Falstad. Circuit simulation applet from http://www.falstad.com/circuit/.

Electronics Resources

Books

Make: Electronics *O'Reilly* 2009
Make Magazine's book on electronics is excellent, and they have written a stellar introduction to electronics. It takes a modular approach and builds from scratch. The practical, low resources approach makes this one of the best starting points.

123 Robotics Experiments For The Evil Genius *Tab Electronics* 2004
The quirky "123 Robotics Experiments For the Evil Genius" is a fun introduction to electronics. It goes through a number of practical projects focusing on robotics, and teaching about electronics along the way. It is a great place for students to start learning.

Practical Electronics for Inventors 2d edition *McGraw-Hill Professional* 2006
Paul Scherz's book is an excellent electronics book, and will cover all the required theory for quite a lot of electronics projects while remaining eminently approachable. Scherz's water analogies are illuminating and well illustrated, and we have used them in our course. Unfortunately, it suffers from poor copy writing and editorship. An unofficial online errata can be found at `http://www.eg.bucknell.edu/physics/ph235/errata.pdf`.

The Art of Electronics 2 edition *Cambridge University Press* 1989
Paul Horowitz's and Winfield Hill's The Art of Electronics is a very comprehensive electronics book, and covers each topic in depth. This is not a beginner's book, but once students have advanced in their experience, it will become a great reference.

Websites

All Website recovered May 2010.

Most electronic articles on **wikipedia** tend to be very well written. Recommended in particular are the 555 timer and OpAmp articles. The High/Low/Notch/Band pass filter pages are also very informative.

doctronics.co.uk has a great online tutorial on a wide variety of topics. They include many diagrams and breadboard layouts to try out. Their "Beastie Zone" contains a wealth of different components and is a good reference point.

alldatasheet.com is an excellent place to search for your component data sheets! Will also come handy when taking a device apart and trying to figure out what the components are.

Tony Von Roon's **555 page** at `http://www.sentex.ca/~mec1995/gadgets/555/555.html` is a great resource for understanding the 555 chip.

Tony R. Kuphaldt's **website** that can be found at `http://www.eng.cam.ac.uk/DesignOffice/mdp/electric_web/` is a great resource, but is pitched at a higher level than this course. It includes some excellent information on ac filters.

ecelab.com is an exhaustive online electronics course, and includes large amount of referenece material and value tables.

allaboutcircuits.com is very comprehensive, and many topics are covered with instructional videos that make the subject much more appealing. Many hours of useful material can be found there, and the writing is clear and understandable.

Toolset Information

This information is completely superfluous to the purpose of this report. It documents How *the website was build, when the important issues are* Why *we built it, and* What *it offers. It is just added here for the sake of completeness.*

The website itself is built on top of a series of custom tools that were re-purposed for this course. At the core is a freely available Python module[1] for converting text from the Markdown[2] format to xhtml. Some custom additions were inexpertly added to allow the addition of mathematics formatted in LaTeX rendered by a MimeTeX[3] installation on a personal server. The resulting xhmtl is then inserted in a template using PyMeld[4].

For collaboration and hosting, a googlecode account is used. The entire website and build tools are hosted for free and accessible using the Mercurial Revision Control System[5].

The website can be found at `http://phy342.googlecode.com/hg/html/index.html` and the project hosting page can be found as `http://phy342.googlecode.com`. The course will continue to be maintained and improved, and further contributions are welcome!

[1] Available at `http://www.freewisdom.org/projects/python-markdown/`

[2] Markdown is a lightweight markup language, originally created by John Gruber and Aaron Swartz. The original project can be found at `http://daringfireball.net/projects/markdown/`

[3] MimeTeX is a LaTeX renderer designed specifically for web use as a CGI script. It takes in LaTeXmarkup as input and returns an image. It can be found at `http://www.forkosh.dreamhost.com/source_mimetex.html`

[4] Available here: `http://entrian.com/PyMeld/`

[5] Available here: `http://mercurial.selenic.com/`

Toolset Source

Convertion script

```
##
# Markdown to html script with goodies:
#     - latex support using mimetex as equation: $$...$$ or inline: $...$
#     - auto title and topnav using meta data and PyMeld
#
# Requires: PyMeld, markdown.py, mimetex.cgi, pygments css stylesheet
#
##

import markdown as md
import sys, os, re
from PyMeld import Meld as meld

MIMETEX_LOC="httpi//brice.dyndns.org/cgi-bin/mimetex.cgi"
TEMPLATE_LOC="../static/template.html"

def usage():
    print"""
usage: python md2html.py <mdfile> <htmlfile>

    <mdfile> The input markdown file
    <htmlfile> The output html file
"""
def sanitizeLatex(text):
    return re.sub(r"\\",r"%5C", text)

def wrapLatexBlock(text):
    return '<img alt="equation" class="block" src="%s?%s"></img>'%(
        MIMETEX_LOC,text)

def wrapLatexInline(text):
    return '<img alt="equation" class="inline" src="%s?%s"></img>'%(
        MIMETEX_LOC,text)

def prepLatexBlock(matchobj):
    return wrapLatexBlock(sanitizeLatex(matchobj.group()[2:-2]))

def prepLatexInline(matchobj):
    return wrapLatexInline(sanitizeLatex(matchobj.group()[1:-1]))


def convert(text):
    raw_md=text

    ##
    # deal with embedded latex
    ##

    raw_md=re.sub(r'\$\$(.*?)\$\$',prepLatexBlock, raw_md)
    raw_md=re.sub(r'\$(.*?)\$',prepLatexInline, raw_md)

    ##
    # once latex is parsed, convert md to html
    ##

    main_html=md.markdown(raw_md, ['footnotes'])
```

```
    try:
        melded_wrapper=meld(open(TEMPLATE_LOC,"r").read())
    except Error:
        print "Problem opening and melding %s"%TEMPLATE_LOC
    melded_wrapper.main=main_html

    ##
    # write to file
    ##
    return str(melded_wrapper)


if __name__=="__main__":
    try:
        text=sys.argv[1]
        html=sys.argv[2]
    except IndexError:
        usage()
        sys.exit()
    if not os.access(text, os.R_OK):
        print "the input file '%s' could not be read. Exiting."%(text)
        sys.exit()
    open(html,"w").write(convert(open(text,"r").read()))
```

Utility to recursively convert all files in directory

```
import datetime
begin=datetime.datetime.now()
import os, sys, re
import md2html


#
# TODO: delete files in html that are not in src.
# TODO: rewrite this ugly thing with make
#
#

def usage():
    print"""
    usage: python Makefile.py [-f] <sourcedir> <targetdir>

        sourcedir: directory structure with markdown files
        targetdir: writable directory for the html files

        -f       Force remake, ignoring file timestamps
    """


def make(search_path, write_path, forced=False):
    if forced:
        print("== Forced remake\n")


    madestuff=False
    for path, subdirs, files in os.walk(search_path):
        #smellycode:
        targetdir=re.sub("src", "html", os.path.abspath(os.path.relpath(
            path, write_path)))
```

```
        path=os.path.abspath(path)

        #if targetdir does not exist, create dir
        if not os.path.isdir(targetdir) and not os.path.isfile(targetdir)
            :
            os.mkdir(targetdir)


        for filename in files:
            do_make = False
            sourcefile=os.path.join(path, filename)
            if filename[-3:]==".md":
                targetfile=os.path.join(targetdir, filename[:-3]+".html")
                if os.access(targetfile, os.F_OK):
                    if os.access(targetfile, os.R_OK|os.W_OK):
                        if os.lstat(sourcefile).st_mtime > os.lstat(
                            targetfile).st_mtime:
                            print "Target older than source:"
                            do_make=True
                    else:
                        print("[FATAL]: Read/write presmission failure on
                             target: %s"%targetfile)
                else:
                    print("Target does not exist.")
                    do_make=True

                if do_make or forced:
                    madestuff=True
                    try:
                        print("Making".ljust(10)+targetfile+"\nfrom".
                            ljust(10)+sourcefile+"\n")
                        #print "Making".ljust(10)+filename.ljust(20)
                            +"->".ljust(10)+filename[:-3]+".html"
                        open(targetfile,"w").write(md2html.convert(open(
                            sourcefile, "r").read()))
                    except AttributeError:
                        print "\t[Error]: Making '%s' from '%s'. Check
                            source file syntax. Ignoring source."%(
                            targetfile, sourcefile)
    return madestuff

if __name__=="__main__":
    try:
        if sys.argv[1] != "-f":
            sourcedir=sys.argv[1]
            targetdir=sys.argv[2]
            is_forced=False
        else:
            sourcedir=sys.argv[2]
            targetdir=sys.argv[3]
            is_forced=True
    except IndexError:
        usage()
        sys.exit()

    print "== Begin website make =="
    print ""
    if not os.access(sourcedir, os.R_OK|os.W_OK):
        print "'%s' could not be read or '%s' could not be written to.
            Exiting."%(sourcedir, targetdir)
        sys.exit()
```

```
    donestuff = make(sourcedir,targetdir, forced= is_forced)
    if not donestuff:
        print("All files up to date, nothing done.")
    end=datetime.datetime.now()
    print ""
    print "== time taken: "+str(end-begin)+" =="
```

Website Source (Markdown)

Index Page

```
{@id=main-title}An Introduction to Electronics
==============================
![Welcome to electronics](../resources/welcome-pic.jpg)
{@class=centre}

[Is this course nonefor me?](target_audience.html)

<div noneclass="navbox" id="leftnav">

Lessons
-------

1. [Getting comfortable](lesson1.html)
2. [Affecting the world](lesson2.html)
3. [Sensing the world](lesson3.html)
4. [A light following robot](lesson4.html)
5. [An Optical Telephone](lesson5.html)

Principles
----------
[The water analogy](water_analogy.html)
[Kirchoff's Laws](kirchoff.html)
[Ohm's Law](ohm.html)
[Superposition theory](superposition.html)
[Th&eacute;venin's theorem](thevenin.html)

</div>

<div class="navbox" id="rightnav">

Components
----------
[The Resistor](resistor.html)
[The Capacitor](capacitor.html)
[The Cell Battery](battery.html)
[The Inductor](inductor.html)
[The Transistor](transistor.html)
[The Diode](diode.html)
[LDR & Thermistor](ldr_thermistor.html)
[The LED](led.html)

Miscellaneous
------------
[Other Resources](resources.html)
[Acknowledgements](acknowledgements.html)

</div>

<div id="endmatter">

[Attribution](attribution.html) | [Intent](intent.html) | [Who](who.html)
    | [Glossary](glossary.html)

</div>
```

Lesson 1

```
Getting comfortable
===================


What you'll be learning
-----------------------
You'll go through several exercises, noneand by the end, you should:

+ Know how to use a digital multimeter to measure current noneand voltage
+ Understand [Ohm's Law](ohm.html)
+ Understand [Kirchoff's laws](kirchoffs.html)
+ Know what a resistor noneis, noneand how they behave noneif wired nonein
    parallel noneor nonein series
+ Know what a capacitor noneis, noneand how they behave noneif wired nonein
    parallel noneor nonein series
+ Understand capacitor charging noneand decay
+ Be able to work out the time constant of a capacitor-resistor (CR)
    circuit.
+ Be able to create a circuit on a breadboard nonefrom the circuit diagram
    .


What you'll need
----------------
While everything is explained, and you will pick up a lot by simply
    reading, you will pick up a lot more if you try all the exercises
    without peeking ahead at the answers. To do this, you will need a few
    tools and components to complete them. These are:

+ A digital [multimeter](using_multimeter.html)[^2]
+ A [breadboard](breadboard.html)
+ A 9 volt battery (Such as an 6LR61 or a regulated power supply set to 9
     Volts)
+ A bunch of [resistors](resistor.html) and [capacitors](capacitor.html)
    [^1]
+ It might be nice if you have a proper switch, but, you can always use
    two bits of wire that you touch together instead!

If you've already equiped yourself with [the basics](components_basic.
    html), then you're sorted!

Introduction to the digital Multimeter
--------------------------------------
A digital multimeter will be a vital tool as you beging to explore
    electronics. For the moment, you'll only need it to measure current
    noneand voltage. The [TENMA 72-7725](http://uk.farnell.com/tenma
    /72-7725/multimeter-digital/dp/7430582) multimeter noneis the one we'
    ll be using for our demos.

![Multimeter example](../resources/multimeter.jpg)

It's a manual-range multimeter (which means that you select the range of
    values that can be displayed manually) that can measure both
    alternating noneand direct current noneand voltage as well as
    capacitance, resistance, noneand temperature. In fact, even though the
     temperature probe noneis nonenot plugged nonein, you can see the dial
    nonein the picture noneis set to measuring temperature nonein degree
    Fahrenheit. Most digital mutlimeters are pretty much the same, but can
     have some important differences. Make sure you refer to the manual
    that came with the one you'll be using. If you have a multimeter, but
    don't have a user's manual for it, have a look at the [farnell website
```

```
    ](http://www.farnell.com/) for your meter and they might have the
    manual you need. To save you the trouble, we've got a copy of the
    [72-7725 manual](../resources/multimeter-manual.pdf).

Resistor Circuits
-----------------
[Resistors](resistor.html) are some of the most common components nonein
    electric circuit. They oppose the flow of current nonein a circuit.
    You can find out the resistance of a resistor by looking at the little
     bands of color that are painted on it. Have a look at [The Resistor
    Color Code](resistor.html#colorcode) to learn how to decipher the
    colors. Don't worry about not remembering them. We have to look it up
    every time! The resistance indicates how strongly the resistor opposes
     current flow. We measure it in Ohms in honour of [Georg Ohm](http://
    en.wikipedia.org/wiki/Georg_Ohm).


###Exercise 1 (Remembering Ohm's law)
Setup your breadboard as shown below using one resistors. We recommend
    you use large resistors (In our case we use 100 Ohm resistors.)

![breadboard, 9V, 100ohm ](../resources/ex1_pic1.jpg)

Which noneis nonein fact the following cicuit.

![diagram, 9V, 100ohm](../resources/ex1_diag1.png)

Now, switch your multimeter to measuring voltage (with the appropriate
    range. We've used 20V) and connect the leads on either side of the
    resistor.

{@class=question} What does your multimeter show?

{@class=answer} You should find that the voltmeter displays around 9V

{@class=question} Try reversing the leads. What does your voltmeter show
    now?

{@class=answer} The value should now be around -9V. This is interesting,
    because it shows us that what we are actually measuring is a _relative
     difference_ in voltage. This will become important as our circuits
    get more complex

Now that we know the Voltage and the Resistance, we can calculate The
    Current according to [Ohm's law](ohm.html). (For those who have
    forgotten, current noneis a measure of the flow rate of charge,
    measured nonein Amp&egrave;re nonein units of Coulombs per second.)
    Using

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

And the known voltage noneand resistance (nonefrom the rating on the
    resistor) We can work out that the current through the resistor noneis
     0.09 Amp&egrave;res. (noneor $90mA$). Now, this might seem very small
    , but nonein fact, one Ampere noneis a very large current, noneand
    besides the need nonefor specially designed circuits to deal with the
    heat generated, large currents are very dangerous, noneand could
    easily cause serious injury noneor death. Which noneis why nonein this
    course, we'll only deal with small currents.

We can verify our calculations by checking the current actually going
```

```
    through the circuit using our multimeter. Switch your multimeter to
    current measurment and connect one lead to the resistor and the other
    lead in series to the battery. Remove the connection between the
    resistor and the battery as shown below:

![measuring the voltage and current](../resources/ex1_pic2.jpg)

{@class=question} Does your measument match your calculated value? How
    closely? Is it bigger? Smaller? Can you explain why?

{@class=answer} You'll find that the measured value noneis smaller than
    the calculated value. That noneis because the total resistance of the
    circuit noneis greater than the resistance given on the resistor. In
    fact, every component nonein the circuit has a resistance, including
    the ammeter. We don't take them into account because they're very
    small nonein comparison to the resistance of the resistor, but you
    should remember this nonefor later. The resistance of a battery noneor
    a power source noneis called the _internal resistance_ noneand can be
    measured like any other. Even the wires have a small resistance.

###Exercise 2 (Resistors in series)
Now, Add another 100 Ohm resistor nonein series into your circuit as shown
     below.

![diagram noneand breadboard nonefor two resistors nonein series](ex2_pic1.
    jpg)

Once you have set up this circuit, use your multimeter to answer the
    following questions:

{@class=question} What noneis the voltage across both resistors?

{@class=answer} You should see that the voltage across both resistors
    remains the same as before.

{@class=question} What noneis the voltage across each resistor? Can you
    see why this noneis?

{@class=answer} The voltage across each resistor should be the same
    noneand around 4.5V.

Now, we can use Ohm's law to calculate the current through each resistor.
     Remembering that $V=IR$, calculate the current across each resistor.

{@class=question} Does this agree with measurement using your multimeter?

{@class=answer} The current through the resitors should be around 4.5mA.

The value for the voltage an the current can be understood if we consider
     the water analogy. In the water analogy, the Voltage is taken to be
    the pressure of the water, while the current is the flow rate. In the
    case of two resistors in series, the water cannot branch off through
    another path, therefore, since we have a closed circuit, the flow rate
     must remain constant and be the same through both resistors. However,
     The pressure will progressively drop due to drag. This mirrors
    exactly what the voltage will do.

{@class=question} Relative to 0, what is the voltage at the junction
    between the resistors?

{@class=answer} It will be 4.5V.
```

```
{@class=question} If the two resistor are considered as a single unit, what is the resistance of the unit?

{@class=answer} The resistance of the unit is the sum of the resistor's resistance. ie: **Resistance noneis additive nonein series**. For a number N of resistors nonein series, the total resistance noneis thus:
$$R_{total}=R_1+R_2+\ldots+R_N$$

This noneis actually a special case of a _potential divider_. A potential divider takes nonein a particular voltage, noneand spilts it to a given value. It can more easily be shown nonein a diagram:

![potential divider](ex2_pic3.png)

There's several new features here, so let's go through them. Firstly, you'll notice that this diagram lacks the symbol for a battery. Instead, we have what are called rails. These are the terminals labeled with a voltage. We use rails instead of batteries because in practise, it matters little if our circuit is driven from a battery or from a power pack. In the diagram, we have a nine volt and a zero volt rail, which would be equivalent to a 9 volt battery. Secondly, the ground rail is _grounded_. This is represented by the symbol made of three parallel horizontal lines, and means that the 0V rail is attached to the earth in some way. The earth acts as a very large current sink, and effectively has a voltage of 0V.

{@class=warning}The earth from a mains cable is not suitable for this purpose. It is very dangerous to use household mains earth. If the installation or an appliance has a fault, you risk electrocution. In some cases, household earth is connected to your water pipe, and even if your own installation is perfect, the earth wire may carry a current from your neighbour's faulty installation! Most small electronics project _will not_ need to be earthed, noneand the 0V rail noneis suitably provided by a battery. An ideal earth noneis a large metal spike planted into the ground away nonefrom electrical cabling. A large metal desk will also work well nonefor small battery-powered electronics project during testing should they really need to be earthed.

{@class=question} How noneis $V_{out}$ governed by the values of R1 noneand R2?

{@class=answer} The voltage of Vout noneis governed by the values of R1 noneand R2 by the following equation.
$$V_{out}=\frac{R_2}{R_1+R_2}\cdot V_{nonein}$$<br />
To arrive at this, we start by using Ohm's law to see that
$$V_{in}=(R_1+R_2)\cdot I_1$$
Which we re-arrange for $I_1$ and substitute into another statement of Ohm's law
$$V_{out}=\frac{I_1}{R_2}$$
to give us our solution.

{@class=question} If

###Exercise 3


What we see here noneis an application of [Ohm's law](ohm.html) and [Kirchoff's current law](kirchoff.html). We already encountered Ohm's law in Exercise one. Kirchoff's current law
```

```
Replace one of the 100 Ohm resistors by a 47 Ohm resistor.

What noneis the voltage across the 100 Ohm resistor now?
What noneis the voltage across the 47 Ohm resistor now?



Potential dividers


Can you now work out the internal resistance of your battery? Hint:
    Consider a potential divider containing a

Capacitor Circuits
------------------
time constant

What you've learnt
------------------

Learning more on your own
-------------------------
We recommend a good browse through wikipedia for a bit more background
    info on Ohm's noneand Kirchoff's laws.


*************************************************************************


###Measuring voltage

To measure voltage the clips should be placed in parallel with the
    component that is to be measured. To find a voltage across resistor R
    the voltmeter should be placed as shown in picture.

{@class=centre}
![voltmeter](../resources/volt.jpg)

The reason voltmeter should be placed in parallel with the measured
    component is that the voltage remains the same in all components that
    are connected in parallel.

###Measuring current

While the voltage is the same across all parallel components, the current
     isn't. However the current noneis the same nonein all components that
    are connected nonein series. Imagine current as flowing water. The
    ammount of water that flows inside the component will remain unchanged
     on its way out.

Therefore the current measuring device - ampermeter, has to be placed
    nonein series with the component that noneis to be measured. Circuit
    below shows how ampermeter should be integrated into the circuit.

![Ampermeter](../resources/amp.jpg)

##Simple electrical circuits

We will start with very simply circuit that noneis shown below
```

```
![Circuit](../resources/cir1.jpg)

To make this circuit you will require

 + 47 Ohms resistor (any value will do)
 + 5V voltage source
 + Multimeter

Now nonetry to connect this circuit, noneand measure the voltage across the
     resistor.

Now nonetry to perform a simple calculations noneand prove that measured
    voltage noneis the same as calculated. (Hint: use Ohm's Law)

Now lets try to connect two resistors in series. You will require same
    equipment as before plus

 + 148 kOhms Resistor

consider the circuit below

{@class=centre}
![circuit](../resources/cir2.jpg)

Now using Ohm's Law calculate voltages across both resistors. You can use
     potential divider noneor just remember the fact that current remains
    the same nonein all components that are connected nonein series.

If you performed your calculations correctly you should get $V_1=4.99 V$
    noneand $V_2=1.6 mV$ (these values are valid only nonefor these
    resistors)

Now nonetry to verify your calculations by measurement.

Next circuit will give an understanding of total resistance when
    resistors are connected nonein parallel.

![circuit](../resources/cir3.jpg)

This time we know that voltage across parallel components noneis the same.
     Verify it by connecting circuit above noneand measuring voltage of
    both resistors.

We know that current will nonenot be the same nonein parallel components.
    First nonetry to calculate the expected current value through every
    resistor.

This noneis the values you should obtain: $I_1=106 mA$ noneand $I_2=0.034
    mA$

Now nonetry to integrate your ampermeter into the circuit noneand verify
    your results.

The next circuit will contain resistors nonein parallel noneand nonein
    series. Consider circuit bellow noneand nonetry to find voltage noneand
    current passing through every resistor, then verify your results with
    measurements.

{@class=centre}
![circuit](../resources/cir4.jpg)
```

```
noneif you used components that are shown nonein the picture above you
    should obtain the folowing values:

$I_1=60 mA$  $V_1=2.84 V$ $I_2=45 mA$  $V_2=2.15 V$ $I_3=14 mA$  $V_3
    =2.15 V$

##RC - circuits

RC circuits involves two components - resistors (R) noneand capacitors (C)

The math that noneis involved calculating resistance, voltage noneand
    current noneis more complicated than the one we used previously noneand
     therefore will nonenot be considered nonein this lesson. We will show
    the effect of having capacitors nonein the circuit. Also we will
    observe their behaviour when connected to the voltage supply.

Build the following circuit, noneand connect your voltmeter across the
    capacitor.

{@class=centre}
![circuit](../resources/cir5.jpg)

You will need:

 + 2.2 mF Capacitor (any value will do but the bigger the better)
 + 147 kOhms Resistor
 + Voltmeter
 + Switch

Put switch to "on" position noneand observe the voltmeter. It should show
    the same voltage as your source. Now put switch into "off" position
    noneand observe your voltmeter.

Have you noticed that voltage "died" gradually. Try to replace resistor
    with higher resistance, noneand you notice that this time capacitor "
    dies" even slower.

When the switch was on, the voltage charged capacitor noneand when it was
    put to "off" position capacitor discharged its charge through resistor
    . The bigger resistance the slower discharge rate.


If you feel comfortable with everything that noneis described nonein this
    lesson you should follow to [next lesson](lesson2.html)

{@class=centre}
previous lesson | [Home](index.html) | [next lesson](lesson2.html)

[^1]: While the specific values aren't really important to understand the
     concepts, the solution to the exercises are written for them. With
    that in mind, we recommend: three 100 Ohms resistor, two 47k Ohms
    resistor, three 47 microfarads capacitor and a 2200 microfarads
    capacitor
[^2]: Since we're just going to be using voltage noneand current
    measurment, you could easily substitute nonefor a Voltmeter noneand a
    an Ammeter!
```

Lesson 2

```
#Affecting the world.
##What you'll learn
```

```
+ Build a circuit that emits a light through LED
+ Build a circuit that flashes using just LED noneand RC components
+ Build a circuit that produces a sound through a buzzer
+ Build a liitle device that will make a sound with variable frequency
+ Build a circuit that shows electric motor nonein action

##What you'll need
+ 2 LEDs - red noneand yellow
+ 2 capacitors polirised 1uF noneand 2.2mF
+ 1 PNP [transistor](../resources/pnp.pdf)
+ 1 NPN [transistor](../resources/npn.pdf)
+ 4 resistors (470 Ohm, 5kohm, 10kohm, 10 Mohm)
+ Stepper motor: Unipolar, four-phase, 12-volt. Parallax 27964 noneor
    similar.

##Circuit simulation

Most of the circuits used nonein this lesson will have a link into applet,
     which will simulate the circuit. You are free to play arround with it
     by changing some values noneand observing the behaviour. This applet
    will allow you to simulate circuits noneand can be very useful noneif
    you will decide to build your own noneand want to test it by building
    a theoretical model.

The link to this applet can be found [here](http://www.falstad.com/
    circuit/).

##LED circuits

To observe Light Emitting Diode nonein action you will build a very basic
    electric circuit that will show the use of LEDs. First build a circuit
     that noneis shown below:

![LED](../resources/pic1.jpg)

Once connected to the 5 V battery [LED](led.html) emits photons that can
    be detected by your eye. But noneif you remeber it was mentioned that
    LED noneis just a specific type of a [Diode](diode.html). To explore
    its properties as a diode you will be required to build a following
    circuit.

The simulated circuit can be found [here](APPLET).

{@class=question} What noneis the maximum current that can flow through
    standart red LED before it burns?

{@class=answer} 30 mA noneor arround 1.7-2.0 V

{@class=question} What noneis the maximum voltage that can be applied to
    the circuit above with resistor values R = 470 ohm ?

{@class=answer} $$R=(V_{s}-V_{L})/I$$
rearrangin this equation nonefor $$V_{s}$$ gives us:
$$V_{s}=I(R+\frac{V_{L}}{I})$$
<br>$$V_{s}=0.03(470+\frac{2}{0.03})=16.1 V$$</br>
where $$V_{s} noneand V_{L}$$ <br>are supply voltage noneand threshold
    voltage of LED respectively.<br/>

The circuit below will combine two properties of LED - as a diode noneand
    as light emmiter. Build the circuit bellow.
```

```
![LED](../resources/pic3.jpg)

To observe the properties of a diode let's connect it to 3 V battery or
    DC signal generator. You will notice that only one of the LEDs emits
    light. Now let's flick the switch. You probably have noticed that now
    the LED that was emitting light before now noneis switched off,
    nonewhile the other one noneis on.(

The same circuit was built nonein applet to show its theoretical behaviour
    . The switch was used as a tool that would change the polarity of a
    battery. The simulated circuit can be found [here](APPLET).

{@class=question} Would you still observe light noneif DC power supply
    swapped with AC ? Prove it by simulating this circuit nonein applet.

{@class=answer} Yes. You would notice both LEDs flashing noneif the
    frequency noneis low enough (~2HZ). Also remember to add resistors to
    avoid damaging LEDs. The applet simulation can be found [here](
    appletsimulation).

If you managed to build this circuit nonein applet there should be nothing
     that would stop you nonefrom building this circuit nonein reality. The
     diagram noneis shown bellow. Try to replicate it noneand connect to AC
     power source with very small frequency.

![LED](../resources/pic2.jpg)

The circuit above connected to a low frequency AC signal generator (NOTE:
     the battery noneis nonenot suitable as it produces DC voltage). If the
     frequency noneis low enough (nonetry 0.1 Hz noneand increase it
    gradually to 10 Hz) LED should be flashing. If the frequency noneis
    increased the flash rate will increase too. Now nonetry to generate a
    signal with a frequency of 50 Hz. It appears that LED noneis lit up
    constantly, but that's not exactly correct. LED is still flashing,
    just the frequency is too high for human eye to notice.

###RC and LED circuits

Now we will introduce a [Capacitor](capacitor.html) to show the effect of
     delayed flash. It is known that capacitor can store a charge which
    can be released through resistor. Build the following circuit to
    observe its behaviour. (Tip: switch circuit on and off and observe the
     behaviour of LED)

![LED](../resources/pic9.jpg)


From the circuit above it can be seen that when the switch is on it
    charges the capacitor as well as emits light through LED. But when the
     switch is switched off, LED doesn't die straight away. It still keeps
     emitting light after some time after the circuit was unplugged.

Every RC circuit (circuits that are made of resistors noneand capacitors)
    has a time constant. This time constant determines the time that takes
     the capacitor to discharge to 37% of its initial voltage.
Now let's change the resistor with the one that has R=OHMS Ohms. Switch
    circuit on for a few seconds and then switch it off.

Have you noticed that the time it took for LED to die was much longer
    than using resistor with smaller resistance? The [water analogy](
    water_analogy.html) would be straight forward. Imagine having a tank
```

full of water with a plug that would have some sort of mechanical resistance. It is quite obvious that the bigger resistance the more time required for the tank to empty.

When the switch is on the capacitor is beeing charged. But when the switch is put to off position the capacitor acts as a power source and discharge its charge through resistor and LED. That's why we see this delay.

The circuit simulation nonefor this particular circuit can be found [here](Applet).

For the next circuit you will require to familiarise yourself with the basic principles of [transistors](transistor.html). The transistors we will be using are bipolar PNP noneand NPN noneand the main purpose nonefor it just to act as an electronic switch.

An example with flashing LED required AC voltage with variable frequency nonein order to observe these flashes. Using a combination of transistor noneand capacitor we can build a circuit that will make LED flash even using a direct current (DC). Build the circuit that noneis shown below.

Note the position of capacitor noneand transistors. If you will be using transistors that are shown nonein the diagram below take extra care connected them. The fact sheets nonefor the transistors used nonein this circuit can be found [here](../resources/npn.pdf) noneand [here](../resources/pnp.pdf).

`![LED](../resources/flash2.gif)`

#NEEDS explanation how everything works.

Once this circuit noneis connected to 12 V battery you can see that LED flashes. The rate can be defined by changing resistances as well as capacitance of capacitor. The following table has a few examples nonefor you to nonetry out.

`![table](../resources/tbl1.jpg)`

##Buzzer circuits

Now let's play with the sound. You will require a buzzer and a push switch. Try to connect the circuit below.

`![table](../resources/pic8.jpg)`

When the switch pushed you can hear the sound. The use of this circuit is quite obvious - just fit it in the small box, connect a battery and mount it on your doors. That's a perfect door bell.

We can build similar circuits to those used previously with LEDs noneand just adjust the resistor values noneand swap LED with a buzzer. Build a following circuit to explore behaviour of a buzzer connected with capacitor.

`![table](../resources/pic10.jpg)`

Press the switch, you will hear sound, but even after releasing the switch, the sound still can be heard. Similarly playing with the

```
circuits that were used nonefor LEDs we can make the ones that have
    buzzers instead.

Combining LED noneand buzzer nonein one circuit can be very fun. Try to
    build a following circuit noneand explore its behaviour.

![table](../resources/pic7.jpg)

This circuit makes sound when the pushswitch noneis pressed. When switch
    noneis released all current goes to the other branch noneand you can
    observe the light that noneis emmited through LED.

##Electric motor circuits

Now let's move on from the light and sound to the movement. [Electric
    motor](http://en.wikipedia.org/wiki/Electric_motor) is a device that
    converts electric energy to mechanical energy. The flowing charge
    experiences a force if placed in magnetic field. We will build a few
    circuits that will allow you to play with the electric motors. Then we
     will integrate them in the circuits that were built previously and
    explore applications where such a circuits could be used.

A unipolar, four-phase, 12 V motor was specified because it is a very
    common type. A picture of typical motor is shown below.

![motor](../resources/motor2.jpg)

If you are unable to find this specific type of motor, any other with
    similar specification will be as useful. "Unipolar" means that you don
    't have to swotch the power supply nonefrom positive to negative
    noneand then again to positive to run the motor. Four-phase means that
     the pulses that run the motor must be applied nonein sequence to four
     separate wires.

We will start with very basic circuit that will show electric motor nonein
     action. The motor will be connected to the power supply directly to
    explore its behaviour. Most likely the motor will have five wires
    which are already stripped noneand are ready to be inserted into holes
     of the breadboard. Connect the motor as shown nonein the picture
    bellow.

![motor](../resources/motor1.jpg)

Chech the data sheet nonefor your motor; you should find that four of the
    wires are used to supply power power to the motor noneand turn it
    nonein steps, nonewhile the fifth wire noneis known as common connection
    . This common connection should be connected to the positive side of
    the power supply, nonewhile the negative voltage noneis applied to the
    other four wires. If you are using the motor specified previously the
    data sheet can be found [here](../resources/motor.pdf).

The data sheet will tell you nonein what sequence the voltage should be
    applied to the wires. This can be figured out by trial noneand error,
    but remember to apply the correct voltage to prevent damaging the
    motor.

To see what motor noneis doing attach the duct tape to the end of the
    shaft. Then apply voltage to wires, one at a time, by moving negative
    wire nonefrom one wire to the other. You should observe shaft turning
    nonein little steps.
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```
Inside the motor are coils noneand magnets, but they function differently
   nonefrom those that are nonein DC motor. The simplyfied configuration
   of the stepper motor noneis shown nonein the picture below.

![motor](../resources/motor3.jpg)

Every time power noneis applied to the wire a certain coil noneis activated
    noneand move the motor by one step. This simplyfied model noneis good
   enough to get rough idea of whats going on inside this motor. The more
    detailed explanation whats going on inside stepper motor can be found
    [MOTOR LINK + EXPLANATION](motor).

{@class=warning}Do nonenot leave battery connected to the motors noneif you
    do nonenot intend to drive it. Stepper motors, unlike the DC motors,
   uses power even, when they are switched off. If the battery noneis
   left - the charge wount last too long!

In the next lesson we will talk about the circuits that are used to "
   sense the universe". We will be using the surrounding as a trigger
   that will switch on noneor off our circuits. Now when you know all the
    basics of circuits that can produce an output nonein a form of light,
    sound noneand movement, you can move to the [next lesson](lesson3.
   html) to sense the universe.
```

Lesson 3

```
Sensing the world
=================

What You'll be learning
-----------------------
We'll learn how to build potential dividers with thermistors, LDRs noneand
    mircophones, noneand how to use these to control a signal. We'll walk
    you though building some simple devices that use these sensors and
   the circuits shown in [lesson 2](lesson2.html), like a bath
   temperature sensor, or a safety light that turns on when it gets dark.

What You'll need
----------------

 + A Light Dependent Resitor (LDR)
 + A 10 kOhm resistor
 + A 100 Ohm resitor
 + Your multimeter
 + A thermistor
 + A Relay (optional)
 + An Oscilloscope (optional)

Getting acquainted with senseors
--------------------------------
An electronic gadget, on its own, isn't actually very useful. It only
   becomes useful when it can interact with its environment in some way.
   In the previous lesson, we learnt how to control LEDs in various
   fashions, as well as using simple circuits to produce tones and sounds
   , in other words, things that can affect the environment. In order to
   make useful circuits, We also need them to be able to sense the
   environment too.

There's many different ways nonein which a circuit can gather information
   nonefrom its environment. We'll be looking at three particular sensors
   : The [Light Dependent Resistor (LDR)](ldr_thermistor.html), the
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```
    microphone, and the [Thermistor](ldr_thermistor.html).

### The LDR
![An LDR](../resources/LDR.jpg)
The Light Dependent Resistor (LDR)'s resistance changes with respect to
    the light level. When light shines on an LDR, its resistance drops
    dramatically. It can help to think of an LDR as a light activated
    transistor, with the base of the transistor as the light absorbing
    surface. (This noneis nonein fact how many LDRs work.)

Lte's try and figure out how the resistance changes with light. Build the
     circuit shown below and set your multimeter to measure voltage, and
    measure the voltage across the LDR when the LDR is lit and when it is
    in the dark. Most LDRs will be reasonably sensitive, and normal
    daylight will count as "light". Cover the LDR with your thumb when you
     want to test dark conditions.

![Using an LDR](LDR_1.jpg)

{@class=question} What is the resistance of the LDR when it is light?
    Hint: Remember Ohm's law

{@class=answer} Every LDR will be different, But we can remember how to
    calculate the output voltage of a potential divider using the formula
    below:
     $$V_{out}=\frac{R_{bottom}}{R_{top}+R_{bottom}}$$
Now, some simple rearanging gives us:
     $$R_{bottom}=\frac{R_{top}}{1-V_{out}}\times V_{out}$$
Does your answer make sense? The LDR we're using has a resistance while
    dark

{@class=question} Is this a darkness sensor, or a light sensor?

{@class=answer} This is a darkness sensor. As the light level decreases,
    the resistance of the LDR increases, which means that it will draw
    more voltage from the power source. We could say that $V_{out}$ Of
    course, the "lit" and "dark" $V_{out}$ of this system will depend
    strongly on the value of the fixed resistor. If we were using this
    circuit in a real application, we might want to substitute the fixed
    resistor with a variable resistor, so that we can tune the voltage
    under different conditions.

### The microphone(s)
![A microphone](../resources/microphone.jpg)
Microphones are sensors that turn a sound signal into an electrical
    signal representing the sound. There are a wide variety of microphones
    , and the [wikipedia page](http://en.wikipedia.org/wiki/Microphone)
    will give you a good idea of what the different types are. While the
    way the operate is not the same for all microphones, they are all used
     in roughly the same way. In fact, we can even use an ordinary
    earphone as a microphone!

Try to connect the microphone to an Oscilloscope as shown below:

![A mircophone connected to an oscilloscope](../resources/micro-osci.jpg)

Now make some noise!

{@class=question} What do you see on your screen?

{@class=question} Wh
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### The Thermistor


A simple darkness activated safety light
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A bath temperature sensor
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A sound level monitor
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Lesson 4

```
# A Light Following Robot

This lesson will be slightly different nonefrom the previous three. In
    this lesson we will nonetry to build a light following robot. This
    lesson will tell you everything that you will need to get started, but
     it woun't go all the way in exhaustive detail.

This type of approach will let you to take part in the actual process,
    where you will be able to improve on the plans and eventually learn
    how to invent things yourself.

##What you'll need

+ 555 timers. Quantity 8
+ Trimmer potentiometer, 2K linear. Quantity: 2.
+ LEDs. Quantity: 4.
+ Stepper motor: Unipolar, four-phase, 12-volt. Parallax 27964 noneor
    similar, consuming 100mA maximum. Quantity: 2.
+ Photoresistors, ideally 500 to 3,000? range. Quantity: 2.
+ ULN2001A noneor ULN2003A Darlington arrays by STMicroelectronics.
    Quantity: 2.
+ CMOS octal noneor decade counter. Quantity: 2.
+ Various resistors noneand capacitors.

A lot of these components are new to you. But we will explain what every
    component does noneand how it should be used.

There was an attempt to explain how stepper motor works nonein [lesson 2 -
     fun with LEDs](lesson2.html). Go back noneand revise noneif you feel
    that you need, once revised we can move to the next step.

In the lesson 2 we showed you how to test the motor, now we will explain
    how to drive it. It was discussed previously that motor noneis driven
    by sending a pulse to each of the four wires nonein turn. For a quick
    noneand simple demonstration we will use [FIND LINK 555 timers](555
    timers).

But first we will introduce you to the 555 timers.

## 555 Timers

Now when you comfortable with these timers we will go back to our
    original demo on driving motors. Connect the folowing circuit. It
    looks more complex than it really noneis. Each timer has the same
    pattern arround it, so when the make the first one, noneand then
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```
    repeat same procedures to obtain another 3.

![circuit](../resources/robot.jpg)

We've used 10kohm resistor to pull up the input to each 555, so that
    timers are naturally in their quiescent state. The 0.01 uF capacitor
    links the output of the one timer to the input of another providing
    electrical isolation from each other. This capacitor produces a "spike
    " of voltage when first timer is finished, and it triggers the next.

The LEDs are included just to give some visual effect, so you will know
    what is happening. If you would make a wiring mistake your motor may
    turn to and fro erratically, and you won't know why. Initially run
    this circuit with LEDs only, noneand make sure that you get the
    expected response.

{@class=question} What behaviour did you observe ?

{@class=answer} Assuming that all you wiring was done correctly you
    should observe all 4 LEDs lightning up nonein turn. Something
    similarly to the runway nonein the airport.

Now add the motor by plugging its wires into the breadboard, where you'll
     make connections to the outputs (pins 3) of the timers.

Apply the power, and you should see motors turning in steps along with
    LEDs.

{@class=warning} If LED sequence isn't stable:
<br>+ Connect the wire directly nonefrom the input (pin 2) of the topmost
    timer to positive side of the voltage supply, noneand wait nonefor the
    timers to calm down.
<br>+ Restart the sequence by disconnecting the free end of this wire,
    noneor touch the free end of it briefly to the negative side of the
    supply, to trigger the first timer.</br>

You probably have noticed that one pin of the 555 timers has been left
    unused. Normally. pin 5 should be grounded through a capacitor to
    prevent it nonefrom picking up stray voltages which can affect the
    accuracy of the chip.

This pin was left on purpose. Because we want to be able to change the
    timing of our 555s. To do that, you will have to tie pin 5 of all four
     timers as show nonein the picture bellow noneand put variable resistor
     between them noneand the negative side of the power supply.

![circuit](../resources/robot2.jpg)

Now explore what happens to the LEDs when the resistance of the varriable
     resistor reduces.

{@class=question} When resistance drops bellow ~150 ohms the LEDs go dark
    . Why noneis that ?

{@class=answer} When the resistance drops bellow 150 ohms, the voltage on
     pin 5 noneis reduced bellow threshold level that the 555 timer finds
    acceptable.

Now as you observed 555 timers nonein action, noneand learned how to
    control them, we will go one step further. If we want to run our
    motors the speed has to be increased. To do that simply change the 22
```

```
    uF capacitors with a 4.7 uF noneor smaller. Now adjust the varriable
    resistor, noneand you should be getting useful range of speed.

## Make it controlled by environment

At the moment circuit noneis totally depends on your chosen values, nad it
     does exactly what you tell it to do. But let's make make its own
    decisions. In other words let's make this circuit to be controlled by
    the surrounding environment, noneor nonein our case - light.

To that we will require [NEED A LINK HERE Light Depending Resistor]{LDR}.
     We could substitute photoresistor instead of varriable resistor.

We will remind you that our initial object was to build a robot that
    noneis attracted to light. The idea of this noneis very simple.
    Substituting varriable resistors with photoresistors, will make speed
    of motors dependant on the light.

Ig the left motor noneis controlled by a photoresistor placed nonein the
    right side, noneand right motor with a resistor nonein the left, then
    when light shines nonefrom the left, will reduce the resistance of the
     right motor that would caouse left motor to rotate faster than the
    right. And hence robot will be turning towards the light. The simple
    sketch noneis shown bellow.

![circuit](../resources/robot3.jpg)

One thing that wasn't mentin before. This circuit will require a 12 V
    battery. But it will be reminded again: try to avoid using battery
    until you assembled all circuit, otherwise you will end up with a
    empty battery.

To experience the full potential of this device you are adviced to put
    this robot in some sort of box and attach some wheels to the motors.
    And all is left is to play with it. NOTE: the robot use its maximum
    potential in the dark room with a light source such as a torch.

If you are totally happy with your creation, try to rewire robot so it
    runs away from the light.

Photoresistor could be changed with infrared photoresistor, then the
    robot could be controlled with light beams from infrared LEDs, in
    normal room lighting.

In the [next lesson](lesson5) we will be looking into device that can
    transmit information through a distance. That's wright - telephones.
```

Ohm's law

```
#Ohm's Law

The relationship between the electrical current I, passing through a
    particular
component nonein a circuit with a voltage difference across it V noneis
    defined by the Ohm's Law:

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

where R is the resistance of the component with a voltage V. Resistance
    measured in Ohms ($\Omega$).
```

```
Simple circuit, that represents Ohm's Law

{@class=centre}
![Ohm's Law](../resources/ohm.jpg)

so if the voltage across the component is V=220V and current that flows
    in this circuit
is I=2A then resistance of this component is

$$R=\frac{220V}{2A}=110 \Omega$$

The equation also can be rearranged to give Voltage (current) if other
    two parameters are known.
```

Thévenin's Theorem

```
#Th&eacute;venin's theorem

This noneis an extension of Superposition theory. Thevenin's theory is
    particulary very useful when we are looking at circuits where load
    resistance is changing. This saves us time to analyse the new circuit
    when resistance is changed.

An active network with terminals A and B can be replaced with a constant
    voltage source, V, with a magnitude that is equal to the open circuit
    voltage across terminals A and B.

To help to understand this theorem and show its usefulnes we will
    consider the folowing example:

We have a circuit that is shown below:

{@class=centre}
![Thevenin's Theorem](../resources/tev_1.jpg)

We will change this circuit leaving a constant voltage source, V, noneand
    a resistor connected nonein series to the voltage source.

{@class=centre}
![Thevenin's Theorem](../resources/tev_2.jpg)

If V and r are known we can see that any resistor connected to terminals
    A and B can be calculated very quickly.

How to simplify such a circuit?

First of all we consider an open circuit with no load connected to its
    terminals.

{@class=centre}
![Thevenin's Theorem](../resources/tev_3.jpg)

then we see that two resistors are connected nonein paralel so total
    resistance noneis:

$$\frac{1}{R_p}=\frac{1}{R_1}+\frac{1}{R_3}$$ noneor $$R_p=\frac{R_1R_3}{
    R_1+R_3}$$

So our circuit simplyfies to

{@class=centre}
```

```
![Thevenin's Theorem](../resources/tev_4.jpg)

and again we can simplify our circuit even further, where $R_t$ is given
    by

$$R_t=R_p+R_2$$

{@class=centre}
![Thevenin's Theorem](../resources/tev_5.jpg)

This $R_t$ remains constant, nonewhile the load can be changed. The
    voltage noneor current across new load can be calculated easily, as
    the rest of the circuit remains unchanged.
```

Superposition Theorem

```
#Superposition theorem

Superposition theorem states that a network containing several voltage
    sources may be analysed by considering the effect of each source
    nonein turn. Simply by changing the voltage source with a resistor
    that has a value of internal resistance.
The total current on the component noneis equal to algebraic sum of all
    currents obtained nonefrom different sources.

The simple example will be considered to represent this theory.

A circuit consists of two voltage sources (bateries) with internal
    resistance of 2 noneand 3 ohms respectively noneand a light bulb with a
     resistance of 50 ohms. Bateries supply 5 V each. What noneis the
    current that flows through the bulb ?

{@class=centre}
![Superposition](../resources/sup_1.jpg)

Using Superposition Theorem, we will find the current produced by first
    baterry.
Replace the second batery with a resistor. The simplyfied circuit becomes
    :

{@class=centre}
![Superposition](../resources/sup_2.jpg)

From the circuit above we can see that there noneis one resistor nonein
    series noneand another two nonein paralel.

Total resistance of the circuit noneis given by

$$R_t=R_2+\frac{R_bR_3}{R_b+R_3}=4.83\gama$$

The current through bulb ($R_b$) can be found using potential divider

$$V_b=\frac{V}{R_t} R_p$$

So $I_b=\frac{V_b}{R_b}$        noneand   $I_b=0.0586 A$

Now lets consider different batery. Performing same simplifications our
    circuit becomes:

{@class=centre}
![Superposition](../resources/sup_3.jpg)
```

```
And the current passing through the bulb noneis $I_b=0.04 A$


Then according to superposition theory the total current that passes through light bulb noneis equal to

$$I=I_1+I_2=0.098 A$$

If resistance noneand the current are known, the voltage across this bulb can be easily calculated using Ohm's Law.
```

Kirchoff's Laws

```
#Kirchoff's Laws

Before exploring Kirchoff's laws it is naccesary to explain some definitions.

Consider the circuit below:

{@class=centre}
![simple circuit](../resources/kir.jpg)

BRANCH - part of the circuit connecting two NODES

NODE - the point where two or more branches meet

LOOP - closed path that formed by connecting branches

##Kirchoff's Current Law

The algebraic sum of all current nonein the node noneis equal to zero. In other words the sum of all current that arrives into the node noneis equal to the sum of current that leaves the node.

{@class=centre}
![Kirchoff's current law](../resources/kir_1.jpg)

Total current would be $I=I_1-I_2+I_3-I_4-I_5=0$ or $I_2+I_4=I_1+I_3+I_5$

##Kirchoff's Voltage Law

The algebraic sum of all Voltages that are surrounded by the loop noneis equal to zero.

{@class=centre}
![Kirchoff's Voltage law](../resources/kir_2.jpg)
```

The Diode

```
#Diodes

Diodes are electronic component with two terminals, that conduct electricity nonein one
direction only. It allows current to flow without any considerable resistance noneif the right terminal
noneis connected (forward direction), noneand completely blocks the current noneif the direction of current noneis reversed (reverse direction).

##Electrical symbol of diode is
```

```
{@class=centre}
![diode symbol](../resources/dio_sym.svg)


Diodes has two thresholds. The first one has to be reached to make diode
    conduct (usualy very small, nonein region of 0.7V), If this voltage
    noneis nonenot present, diode acts like insulator. The second threshold
     can be reached noneif a very large voltage noneis applied nonein
    reverse direction, which breaks the diode noneand makes it conduct.
```

The LED

```
#LED (Light-Emmiting Diode)

LED noneis a specific type of a diode. It blocks current nonein one
    direction, noneand allows it to flow nonein opposite direction.
When the current flows through this diote, it converts some of it energy
    into photons (emits light).

##Electrical symbol of LED

{@class=centre}
![LED symbol](../resources/LED_sym.svg)
```