CRASH COURSE ELECTRONICS AND PCB DESIGN

WITH CIRCUITMAKER AND PROTEUS

Udemy

MASTER COURSE OUTLINE AND NOTES

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Introduction

Welcome to Crash Course Electronics and PCB Design! This document is a general outline of the course, as well as contains links referred to in lectures, and anything that is hard to see in the video such as long URLs. Additionally, the references to the text book we are using in the course and the parts list are all below.

Section 1: The Starting Line

This section talks about how Crash Courses work and what to expect.

Lecture 1 - "Course Overview"

This short lecture talks about how Crash Courses work and what to expect. Additionally, thee resources for the course are listed below.

Source Files for the Course

In the downloads and materials for this Section/Lecture you will find a ZIP file that contains all of the source files, projects, schematics, etc. referred to in the lectures. I compiled them all together and placed them into a single ZIP container rather than have dozens of individual downloads all over the place. This makes maintenance and updates easier as well. The name of the file is:

CrashCourseElectronics_XX_XX_XX.ZIP

Where the XX part is simply the latest date the file was generated, so always download the newest file. In the ZIP root, you will find a README.TXT please read it.

Text Book for the Course

Along with the course, all students get a free copy of my book **"Design Your Own Video Game Console"** (a $30 value). This is the eCopy version of hard copy which is named different "The Black Art of Video Game Console Design" – shown here on Amazon.com:

The Black Art of Video Game Console Design

This is the only book of its kind in the world. The book teaches basic electronics, PCB design, fabrication, single board computer design and much more. You can find the PDF for the book in the downloads for this Section\Lecture (in the ZIP file root) with the name:

\CrashCourseElectronicsBook\Design_Game_Console_XX.PDF

Where XX is the version number, simply use the highest version number if there is more than one in the downloads.

Additional Books to Check Out

When you watch the lectures (unless you already have), you will notice I shoot them in one of my home labs (Electronics) and behind me you might be able to see many book shelves. I actually have a technical library with over 3000 printed books, so when I want to learn something, I usually go out, buy 3-5 books on the subject and read them all! That said, there are 100's of amazing EE/Embedded Design, and Electronics books, but I can't list them here, rather I am going to list just a few to get you started. There are so many areas of Electrical Engineering and sub-fields, it really does take years and years to learn just a fraction of it, so you have to pick you battles, but there are a few general books that you should read.

1. The Art of Electronics – This book is like the bible of electronics. It's not a hard core EE book full of math, but it still has its share of mathematics, but instead it's a hand on, practical book written by very smart guys that know their stuff. If you read this book cover to cover, you will be in a good position to design and build just about anything.

2. Electric Circuit Analysis – This book is hard core calculus based electrical circuit analysis. We do much of this in this course, but without the calculus. However, this is one of the best books on the subject. It's a hard book to consume, but everything is in there you need to learn advanced analysis.

3. Digital Design Fundamentals – This book is A to Z on basic digital theory. Of course, it's less math based since digital systems are discrete, but still an advanced college level text. One of my favorites and on the 11th or 12th edition, so this is "the" digital text used in many universities undergrad courses.

4. Digital Systems Principles and Applications – This book is another digital fundamentals book with a different approach (one thing you find is you have to read 2-3-5 books on the same subject to understand the instructor as well as the material). This book is very straightforward and sticks to lower level digital design, no nonsense approach.

5. Automatic Control Systems – Control theory is the study of the construction of machines that have "feedback" and "sensing". Control theory can be applied to electrical, mechanical, robotic, biological, etc. systems. This is one of the "hard" courses in EE, and something you absolutely MUST learn about if you want to build smart systems that do what they need to do. For example, when you set a thermostat to 72F, you need a sensor to read the temperature, feed it back to the controller and then if there is an "error", say it's 75F, the controller takes action to

cool it off more – this is "control theory". This book is a good introduction to the subject, again, calculus based, but worth it, if you can get through it.

6. Computer Organization and Hardware Design – This book (or rather series of books) teaches about how to design a "computer" – simple as that. Now, back in the 1980's there was one version of this book, now there are many depending on the architecture you are interested in. So, the link shows a short list of options. At least read one of them cover to cover.

There are so many other books and subjects like RF theory, robotics, PCB design, VLSI design, and so forth, but I don't want to overwhelm you too much just yet. So, take a look at the list above, and if nothing else at least read **"The Art of Electronics"**.

Parts List

The Parts List is quite detailed and long, so rather than insert it here and have you scroll down 20-30 pages to get to the next Section\Lecture, I have made the parts list a separate document for convenience.

Also, it's important to realize the parts list is more of a guideline and general list of parts that are used in many of the experiments, but the list includes parts that are not used along with much more since when you buy parts, you always want to buy more than you need, other values, etc. Additionally, many of the parts are used that are for "demo" only and you don' t really need to buy them since we only simulate or build something on the bench as an illustration. Nevertheless, if you want to follow along with every single lecture, I suggest you watch the lecture first, note the parts used and then buy accordingly with help of the list.

Finally, the list has many sections on more advanced test equipment, these things are not cheap and only suggested for those that really want to get hands on. But, I designed the course, so that if you can't afford a single part right now, you can watch me design and build/test everything and still get a lot out of it.

Bottom line, please budget and don't go out and spend a lot of money until you have a better idea of what you need, this is exciting stuff, but control your enthusiasm before going on a shopping spree – I know once I get buying parts, my cart gets bigger and bigger and sometimes I need to walk away, come back and think if I REALLY need yet another 1000 LEDs ☺

The parts list is contained within the master ZIP file in the following directory:

\PartsList\CrashCourseElectronicsParts_XX.PDF

Where the XX is simply the version number.

Section 2: Introduction to Electronics

Students will learn basic electronics theory, terminology, and about major classes of components such as passive and active. Not too much theory, just the fundamentals.

Lecture 1 - "Course Overview"

General course overview discussing the depth and breadth of what we will cover over the lectures of the course and what to expect. Also, we talk about resources for the course.

Lecture 2 - "Intro to Electronics and Meet the Parts"

Introduction to electronics and electrical engineering with a brief run through of various electronic components to get your feet wet with concept, terms, and various units of measure.

Lecture 3 - "Digital Concepts Primer, Units and Hands On"

Digital electronics is an abstraction of analog electronics, so we will start with digital systems, talk about ideas, concepts, units of measure, binary. And do a bit of hands on and look at various parts.

Lecture 4 - "Semiconductor Theory and Other Spooky Phenomena"

"Electronics" is the study of electrons and their behavior and use. In other words, what are the properties of the sub-atomic particles we call electrons? And how can we leverage these properties to perform work and build circuits? Therefore, we are going to start at the very beginning with our journey of electronics and understand the fundamental unit of charge -- the electron as well as what makes conductors conduct, insulators insulate, and what "semiconductors" are. This is one of the most interesting lectures, so take your time.

Links

Periodic Table - http://www.ptable.com/#Oribtal

Lecture 5 - "Understanding Current and Voltage"

The action in every circuit element you can imagine can be described by two quantities -- Current and Voltage. Current is measured in Amps (A), while Voltage is measured in Volts (V). These every day quantities at first glance seem easy to understand, but they are anything, but easy to nail down. We are talking about moving charge around (electrons) under a potential field (voltage), so there are a lot of physics to understand what's REALLY going on -- And guess what, that's exactly what we are going to figure out!

Lecture 6 - "Understanding Current and Voltage Part II"

This is Part II of our discussion about Current and Voltage. We will focus more on how to generate currents and voltages, batteries, as well as do a good amount of bench work.

Lecture 7 - "Series and Parallel Batteries and Circuit Analysis Teaser"

Batteries in general are chemical devices that can generate a voltage, store charge, and perform electrical work for us. However, working with batteries, connecting them in series and parallel and understanding the physics and behaviors of batteries in these configurations can be tricky. In this lecture we dive into this subject as well as start building some primitive "circuit analysis" tools.

Lecture 8 - "Into the Abyss with AC/DC"

This lecture introduces you to the concept of DC (Direct Current) vs AC (Alternating Current). DC circuits in general have a fixed ground at 0 volts, and the signals may all be positive, but not necessarily. For example, a DC circuit might have a 5V supply, with an amplifier that amplifies a small signal from a microphone, this signal could potentially go below ground! So, is this a DC or AC circuit? It's both!

On the other hand, when you plug a light into a wall socket, the current coming out is clearly AC, its direction alternates 50/60 times a second, but parts of the circuit inside the light fixture/PCB might be DC. Thus, the term AC/DC circuits is a bit of a misnomer, and its better to think of all circuits as have both positive signals and negative signals potentially.

However, if signals are changing as a function of time, they must be analyzed with "AC" techniques and Ohm's Law must be adjusted to account for "reactive" elements and the idea of "impedance" (which we will get to later), but strictly speaking even though we need AC techniques to analyze some signals/circuits, said signals might not be AC signals unless the current alternates in direction under the definition. So, like many things, the idea of AC and DC circuits has a lot of shades of gray. We will try and clear all this up in this introduction lecture.

Lecture 9 – "Ohm's Law and Just a "bit" of Power"

Circuit analysis is a mathematical process or determining the voltages, currents, and general behavior of an electrical circuit. There are many tools to do this, but one of the most important is Ohm's Law which relates voltage to current and resistance in a form like V=I*R (which we will cover in this lecture). Of course, Ohm's Law is a model, an approximation and works under conditions met by our types of circuits. Also, once we have a handle on Ohm's Law we can use it to compute "power" which is an abstract concept and misunderstood many times, so we will take this lecture slow.

Lecture 10 – “Ohm's Law Deep Dive and Basic Circuit Analysis Part I“

Now, that you're warmed up with Ohm's Law in the previous lecture's introduction. Now, we are going to really dig deep into the use of the law to analyze many real circuits. As well as jump on the bench and work some circuits there.

Lecture 11 – “Ohm's Law Deep Dive and Basic Circuit Analysis Part II”

Continuing with our deep dive of Ohm's Law and beginning circuit analysis, we are going to add new components such as LEDs to the mix, buttons, and other interesting electronic devices and build up more complex circuits. We will analyze these circuits on the black board and then build them on the bench and compare our mathematical analysis to what we see on the bench in the real world.

Lecture 12 - "Deciphering Resistor Color Codes and Meet the Capacitor"

The resistor is something you will use a lot of in your electrical designs, unfortunately the values of resistors aren't written on the devices (due to their small size) in plain English. The values are encoded typically in a color code. This type of coding is actually used for other devices such as "inductors" which we will discuss later. But, there are exceptions of course, there are some resistors which DO have their values written on them! But, we all need to know resistor color code, so we are going to learn it here. Also, we will add another component to our design repertoire -- the Capacitor, just an introduction, but enough information, so we can have some fun!

Links

Resistor Color Code - http://nearbus.net/mediawiki/images/7/7d/Resistor_color_codes.jpg

Lecture 13 - "Inductors: Be Afraid...Very Afraid“

If you are new to electronics as a hobbyist then you are comfortable with resistors, don't mind capacitors, but the utterance of the word "inductor" sends chills down your spine :) If this is true, then you are in the right lecture -- we are going to break down inductors from every angle, and when we are done, they will have nightmares about you!

Lecture 14 - "Transformers - There's More to Inductors than Meets the Eye!"

Inductors are the basis of more complex electrical devices. One such device is the "Transformer". Transformers rely on the generated magnetic field created in inductors and the magnetic flux impinging on other nearby inductors which in-turn generates a current in the other inductor. This property can be leverage for voltage and current amplification as well as many other useful task. In this lecture, we are going to learn about the operation, construction, and mathematical modeling of transformers as well as see them in action on the bench.

Lecture 15 - "Manipulating Current with Diodes"

Diodes are arguably the simplest of the "semiconductor" devices and have many uses in filtering, rectification, current steering, clamping, and more. In general, diodes only allow current to flow in one direction (although depending on the diode type this isn't always true). There are many kinds of diodes and in this 3 part lecture we will learn about silicon diodes, schottky diodes, zener diodes, and more. And of course, get on the bench and work with them in a number of hands on experiments. In this first part of the series, we will get to know the physics of diodes, some terminology, what they look like, and some basic uses. Then in the remaining lectures we will learn more and more advanced uses and circuits.

Links

https://cdn.instructables.com/ORIG/FXU/THZV/IEOP5YK5/FXUTHZVIEOP5YK5.pdf

Lecture 16 - "Manipulating Current with Diodes - Part II"

In Part II of our diode discussion, we talk more about silicon diodes, zener diodes, and schottky diodes. We learn about rectification circuits, power supply design, as well as some practical experience looking the parts up online.

Lecture 17 – "Manipulating Current with Diodes - Part III"

In this final diode lecture of our 3 part series we experiment more with silicon diodes, LEDs, as well as design a "Zener Voltage Regulator" on the bench.

Lecture 18 - "Switching States with Transistors"

Transistors are one of the most powerful electronic devices in-as-much as they enabled most everything you think of as "modern electronics" such as amplifiers, filters, electronic switches, and the digital revolution. Before transistors many of these functions were performed with vacuum tubes are many orders of magnitude the power, slower, and size of transistors. In this 3 part lecture series, we will review the physics and models for the BJT (Bipolar Junction Transistor) which is a 3 layer device and the most basic form of a "transistor".

Lecture 19 - "Switching States with Transistors - Part II"

In Part II of our Transistor lecture series, we will wrap up the theory for a moment, and jump onto the bench and build some circuits, analyze and measure what's going on with them, and see if they match what we believe their theoretical behavior should me.

Links

Transistor - https://en.wikipedia.org/wiki/Transistor
Load Lines - https://en.wikipedia.org/wiki/Load_line_(electronics)

Lecture 20 - "Switching States with Transistors - Part III"

In this final lecture of our 3 part Transistor series, we cover more theory as well as put it to use with controlling very large loads with transistors, i.e. motors. One of the most common things engineers want to do with transistors (or FETs which we will learn about) is use a small current/voltage to control a much larger current/voltage. Transistors are very good at this and this construct can be used to drive heavy loads such as motors, lighting, etc. In this lecture, we are going to get on the bench and build some cool motor drivers and check out some very expensive micro pumps while, we are at it!

Lecture 21 - "Understanding the Alien Language of MOSFETS"

This is part 1 or a 2 part lecture on MOSFETs (Metal Oxide Semiconductor Field Effect Transistor). Unlike, BJTs (Bipolar Junction Transistors), MOSFETs or simply FETs are not Current controlled switches, but Voltage controlled switches. FETs are used to construct just about all our digital technology, have incredible switching speeds, ridiculously low current and power requirements, and can be very small on the order of a few layers of atoms! In this lecture, we are going to learn about basic FET construction, how they work, and some simple mathematical models of their operation.

Lecture 22 - "Understanding the Alien Language of MOSFETS – Part II"

In Part II of the MOSFET lectures we learn about designing with FETs, how to model them in circuits, analyze them along with other passive components and use them as "switches". Then we jump on the bench and build more circuits with them, this time we don't play around with a little motor, but a very high current heating element and build a remote controlled (via switch) heater!

Lecture 23 - "Tools of the Trade"

Now that you have some basic electronics knowledge under your belt, it's time to slow things down and take a look at the tools, instruments, and methods use to actually build and analyze real circuits. This 3 part lecture series is probably one of the most glossed over information in most Electrical and Electronic degree programs. You learn everything about circuit analysis, how to design circuits on paper, simulate them, but you don't learn how to "build" actual circuits in the real-world, use test equipment and the myriad of options available. This information is usually learned over years of experimenting or working as a tech under someone, etc. In this lecture series you're going to see how to build circuits on solderless breadboard, solder, wire wrap, use oscilloscopes, meters, power supplies and much, much, more...In any event, we are going to hit it head on, so kick back your feet, this will be a lot of fun!

Lecture 24 - "Tools of the Trade - Part II"

In this part of the Fabrication and Tools lecture series, we are going to cover wire wrapping, soldering, solderless breadboards, power supplies, reflow oven and more

Lecture 25 – "Tools of the Trade - Part III"

In this final lecture in our 3 part Fabrication and Tools series, we are going to build a small "LED Flashlight" project end to end. We are going to make decisions on fabrication techniques (should we solder, wire wrap, build a PCB?) We will build the circuit by hand piece by piece, testing along the way, and when complete, we will have a finished LED Flashlight!

Section 3: Advanced Circuit Analysis Techniques and Tools

This section of the course focuses on the mathematical, theoretical and practical techniques to "analyze circuits". In other words, to compute the voltages, currents, and compute all unknowns.

Lecture 1 - Real DC Circuit Analysis

In this lecture, we continue building our tool chest for analyzing circuits, do some review using Ohm's Law, and then work on the bench with a couple fun experiments showing how size and shape relates to resistive elements in a circuit.

Lecture 2 - "Kirchhoff's Laws and a Dash of Common Sense"

Ohm's Law helps us compute the current and voltage in a circuit element, but we need more complex techniques to compute the currents and voltages in networks of components connected in various ways. This is where "Kirchhoff's Laws" come into play. These laws give us tools to mathematical compute voltages and currents in circuit nodes, and loops. You will learn that very simple equations can be formed that model a circuit, and then these equations can be solved using high school math techniques or more advanced matrix operations. Don't worry if you never learned how to solve systems of equations, like all the math in this course, I will take it slow. Even those of us with math degrees, get a little rusty over the years!

Lecture 3 - "Kirchhoff and Ohm vs. Basic Circuits"

In this lecture, we put our circuit analysis skills to the test and take a fairly complex DC circuit with multiple sources, branches, voltage divider, and bring it to its knees and figure out every single voltage, and current in the circuit. This lecture is a lot of fun -- it's like watching a murder mystery unfold in front of your eyes. I will do all the work though, so you can take your time and follow along!

Lecture 4 - "Voltage Dividers Up Close and Personal"

Although we have seen voltage dividers and worked through them before, we are going to dig deeper, slow down to really appreciate voltage dividers and really understand not only their "action", but to understand concepts like "stiffness", changing impedance with them from source to load and how to scale AC signals with them as well. Get ready for some theory, bench work and experimentation and some fun with the oscilloscope.

Lecture 5 - "Simulating Circuits with SPICE"

We take a break from circuits in the real-world for a bit in this lecture and explore "Circuit Simulators". One of the earliest and still most popular simulation engines is called SPICE which stands for "Simulation Program with Integrated Circuit Emphasis". Honestly, sounds like they reversed engineering the meaning AFTER they came up with the name! In any event, SPICE is a technology that allows you to model electrical circuits in the computer and then run a simulation to see what the circuit will do.

Although, SPICE can rarely run large circuits in real-time (without a quantum computer), it does run fast enough to solve for circuit analysis problems and even AC and signal processing, digital circuits, near real-time as long as the circuits aren't too complex. With VERY powerful desktop and workstation class computers you can simulate entire microprocessors, and reasonably complex analog circuits. We are going to learn about the SPICE language as well as tools that use SPICE type engines under more graphical, user friendly GUIs.

Section 4: Electrical Engineering 101 - And Here Comes the Crash Course Part…Buckle Up!

I have distilled a mini-EE degree into these lectures. You will learn more AC, capacitors, inductors, RCL circuits, filters, amplifiers, transformers, power supplies, and much more, very exciting!

Lecture 1 - "Game Plan for Section 4.0"

Section 4 of this course is massive with emphasis on MASSIVE. So, this lecture is a short video road map to everything we are going to cover to set the expectations of the section. Honestly, this is one of my favorite sections of the course since you will leave knowing so much more than you entered with. And you will know what you don't know which is very important in Electrical and Embedded Engineering. The more you learn about what you don't know, helps you STOP doing things the wrong way and go research how to do them the correct way.

Lecture 2 - "All About Mechanical Switches"

Electronics design is full of interesting components such as resistors, inductors, capacitors, transistors, diodes, and more. However, every circuit needs an ON/OFF switch, so we are going to start with looking at some "mechanical" components, or otherwise referred to as "mechanicals" which means parts that don't have electrical functions like inductance, capacitance, amplification, etc. they are just made of metal, plastic, paper, and so forth and are used to connect things, interface things, and for user interaction. The first type of mechanical we will discuss is the simple "switch" which isn't as simple as you might think!

Lecture 3 - "Fun and Games with POTentiometers"

This lecture covers one of the most useful electronic devices; the "Potentiometer" or otherwise known as the "POT". POTs are variable resistors that can be adjusted from 0 ohm to some value, 1K, 10K, 1M ohm, etc. Very useful in circuits where you want to adjust a voltage, volume, amplification factor, cut off frequency, or some other analog value.

Lecture 4 - "Capacitors and AC Coupling"

Capacitors are very complex devices (like inductors), their action is based on the accumulation of charge (electrons and holes) on two metal plates separated by space. This creates an electric field and all kinds of interesting properties come into existence. But, sometimes it’s better to just use an electronic component in some context to see what it does, before we understand how it does it.

For example, everyone knows what an LED is these days, but LEDs are quantum mechanical devices and very complex if you really want to understand them. But, anyone can hook a 9V battery up to some LEDs and they will turn on, regardless if you understand WHY they turn on. Alas, we are going to put the capacitor to work to "couple" AC circuits, and show one of its uses is to filter DC signals and pass AC signals -- along with bench demos and experiments of course!

Lecture 5 - "Working with Series and Parallel Capacitor Networks"

Here we get into the physics of capacitors and the C=Q/V model where C is capacitance in Farads, Q is charge in Coulombs, and V is Volts. We will learn how capacitors are made, how they work, and how they network together. For example, when you put two resistors in series, the resulting resistor is simply the sum of the two resistors, but how does this work with capacitors for series and parallel combinations? We will derive it all on the blackboard, so you see the math once in your life, and then you can tuck the analysis away, and simply use the formulas.

Lecture 6 - "Getting to Know RC Circuits"

If you're an electronics hacker, you probably play mostly with digital circuits, Arduinos', Raspberry Pi's, and so forth. But, at some point, you might have heard about "RC Circuits" or "RC Time Constant" and wonder what that's all about? Well, your wondering stops here! We are going to learn about RC circuits, that is, circuits with a Resistor and Capacitor (usually in series), and what happens when you apply a voltage to this simple network? How does the capacitor charge? Then how does it discharge when you remove the voltage? And what's the math that models all this?

This subject is fairly advanced EE concept and we will take our time, but rest assured, I will make this fun, and with bench work, demos, and signal analysis on the Oscope you hopefully will finally understand RC Circuits if you have had trouble with them in the past.

Lecture 7 - "Exploring the Dark Side with Inductors"

Inductors constantly get a bad rep. I think the reason why is they really are only useful at very high frequencies, unless you have REALLY large inductors. So, most electrical/embedded engineers can literally get through and entire career and never use an inductor in a design! Therefore, it’s one of those things, that people learn in school then forget about. But, I want you to LOVE inductors, I mean, you run a current through them, they generate a magnetic field that stores energy (what!) and then they can be used in filters, oscillators, transformers, and motors.

Inductors are the basis of so many of our machines and high power circuits, how can you not love them! However, before we start this relationship, we need to crack them open, look inside, talk about flux, current, fields, the right hand rule, induction, and a lot more. But, I promise when you finish this lecture (which you may have to watch a couple times), you will not be afraid of these little guys anymore!

Lecture 8 - "RC Circuit Review, Simulation with Matlab and Finally RL Derivations"

After a quick review of RC circuits, so you can keep them straight from RL circuits, we will play with one of the most advanced tools on the planet -- MATLAB (Matrix Laboratory) - which if you have never heard of it is a tool that you can use to model just about anything with a C-like language and support for very high level mathematics. That's where the term "Matrix Laboratory" came from, but that term hardly does this tool justice. Scientists literally use this tool to figure out the secrets of the universe, so it will do nicely as a modeler for RC and RL circuits. Finally, the lecture will finish off with more RL circuit analysis and derivations.

Lecture 9 - "Understanding I and V in RC and RL Circuits with E.L.I. and I.C.E."

We have learned about RC and RL circuits and seen one way to understand their charging and discharging or more accurately energizing and de-energizing when referring to inductors. But, as we move into steady state AC circuits and we are interested in understand not what happens the moment a current flows in an RCL circuit, but what happens when an AC signal is continuously applied? This is the starting point for understanding complex impedance, phasors, and more advanced AC analysis. But, first we are going to simply start with understanding the relationship between current and voltage in both the capacitor and inductor along with some tricks to remember the differences between each since they are analogs of each other.

Lecture 10 - "Fire all Phasors - Reactance and the Math Behind Phasor Representations"

If you are following along the lectures, you probably realize we need to take the math up a notch to deal with unfortunate fact that current and voltage are out of phase in capacitors and inductors due to their "reactance". To deal with this property in a consistent mathematical way, we are going to introduce the concept of "phasors" and I don't mean something from Star Trek :) But, rather -- a mathematical tool based on imaginary numbers that helps us tracks the voltage and current as a polar value rather than a fixed magnitude -- I know, sounds a bit crazy, but it will make more sense after you view this lecture - And yes, I had to throw a Star Trek reference in there!

Lecture 11 - "Easing into Complex Impedance with Phasor/Reactance Diagrams"

Now that you have a handle on phasors, we will use them to analyze circuits in a more compact form and write currents and voltages in the circuits as phasors. This process will help make clear the concept of "Complex Impedance" which is a method of taking both the real resistance a circuit element has along with the reactance it has and using imaginary numbers (or phasors) to try and represent these values. As you will see down the line in later lectures, sometimes we want to use simple reactance to analyze a circuit, other times phasors, but when you need to bring out the big guns, "complex impedance" and using imaginary numbers always works, is clean, and very consistent. The following lectures will touch on all of these subjects.

Lecture 12 - "Imaginary Number Primer and Complex Phasors"

We have been using phasors as mathematical objects without worrying too much about what they are really representing in our circuits. In this lecture, we are going to clear that up, and bring "Imaginary Numbers" into the mix, and connect the dots. If you recall from high school, imaginary numbers have a real part, and an imaginary part. The imaginary part isn't imaginary at all, it's based on the concept of the sqrt(-1) which is called i, or j for electrical engineers. When you add a real number and imaginary number, you can do so abstractly by thinking of a 2D plane. One axis is the real part, the other the imaginary part, so you can use the real part to hold one piece of information and the imaginary part to hold another, and never will they mix.

This is a very useful property is mathematics, signal processing, radio, lots of things. And this real/imaginary combination is called a "Complex Number". We will use this math to represent phasors and complex impedance, but we need the math, so let's get to it.

Lecture 13 - "Putting Complex Impedance to Work with RC Analysis, Simulation, and Bench Model"

Here we use our new knowledge of complex phasors to completely analyze an AC circuit, then we will simulate it, and finally build it to see if everything matches our calculations.

Lecture 14 - "Phasor Analysis of an RL Voltage Divider Circuit"

We circle back to voltage dividers, but instead of a simple DC circuit with resistors, we perform an AC analysis of an R/L voltage divider, and completely compute everything going on in the circuit.

Lecture 15 - "Using RL Circuits and Impedance Analysis to Illustrate Low and High Pass Filters"

In this lecture we ease into the concepts of low pass and high pass filters, but rather that design a filter, we simply look at the same kind of RC and RL circuits we have been analyzing, but pay close attention to how things change as a function of frequency. I recommend watching a couple times if you need to, there's a lot here -- we do blackboard and theory, build simulations with Proteus, and then go to the bench and build the circuits and make real-time measurements with the Oscope and more. This is one of my favorite lectures, definitely in my top 10!

Lecture 16 - "Bonus Round - Plugging AC Line Voltage in an RC Circuit"

In this BONUS lecture, we turn the danger level up to high and build and analyze a real line AC circuit. We are going to take our little RC circuit, build a model of it, excite it with low voltage, then take it to the bench and using "Power Electronics" test equipment power the circuit up and make measurements. Although, I like to joke around, this is a great lecture to learn safety measures when experimenting with AC line voltage. The truth is it can be very dangerous, so please pay attention to the safety measures outlined here if you want to experiment with power electronics yourself -- that's said, let's go blow some stuff up!

Lecture 17 - "Frequency Domain Analysis of a Low Pass Filter"

Using complex impedance analysis, we extract out the frequency dependent terms in a low pass filter and learn about "Transfer Functions" and how the filter's response changes as a function of frequency f.

Lecture 18 - "What's Up with Decibels and all this dB, dBm, and dBv Stuff?"

When observing the natural world, many physical properties of matter, or energy, etc. many times it’s better to use a logarithmic scale rather than a linear scale. For example, when talking about amplification, we might start with a signal in the nano-volt range and have to amplify it into the volt-range. Therefore, we aren't talking about factors of 1.4. 2.0, 3.0, etc. we are talking about powers of 10, i.e. 10, 100, 1000, 10000, etc. Thus, in electronics as in many other fields the idea of being able to talk about logarithmic scale behavior or powers on n behavior leads us to the "decibel".

This term, and concepts thereof, are misunderstood by many. After this lecture, go find an EE with a BS/MS degree and give him/her some simple problems / questions relating to dB scale problems, I bet they can't answer! This stuff isn't hard by any means, but its not intuitive and unless you work in certain fields of electronics, you simply don't work in dB scales all day and get rusty! So, this is a great lecture, a nice break from the hard core stuff we have been doing.

Lecture 19 - "Hands on with Low Pass Filters and Frequency Response"

We revisit our favorite circuit, the RC circuit and use it as another example to investigate real-time frequency response and "see" its low pass behavior. We start with theory and then jump to the bench, and play with the circuit to see its practical use and -- limitations. You don't get anything for free in electronics!

Links

Filter Simulators - http://sim.okawa-denshi.jp/en/Fkeisan.htm

Lecture 20 - "Going to the Bench with High Pass Filters"

The twin lecture of the previous low pass filter coverage, here we do the same thing, but with the high pass filter configuration by simply swapping the position of the R and C in the circuit -- yes, it's that easy! Again, theory and bench work, don't miss this one!

Lecture 21 - "The Dreaded Inductor - Round 1: Low Pass Filters"

The poor inductor just gets no respect! Well, in this 3 part lecture series, we will show why it deserves respect and so much more, but also why the inductor is more or a very high frequency device and thus why it's not so popular with digital designers and hobbyists. In this lecture, we will work with the inductor to make a low pass filter.

Lecture 22 - "The Dreaded Inductor - Round 2: High Pass Filters"

In the previous lecture, we analyzed the low pass filter configuration of the inductor, now we turn the tables and swap the parts which results in -- you guessed it, a high pass filter.

Lecture 23 - "Building the Low/High Pass Filters"

In the final lecture of this 3 part series, we take our knowledge and theory about inductor based low/high pass filters, and use it to construct some circuits on the bench and see how they respond in the real world. What's interesting about this lecture is if you compare it against our capacitor based filter lectures, you will see some marked differences in the accuracy of the filters due to the tolerance of the parts, and Q or "quality" of the parts. Very important material, take your time and have fun!

Lecture 24 - "Diodes Reviewed and Starter Applications"

Now that we understand AC analysis, we are going to circle back to diodes and experiment with them with AC signals and see how diodes can be used in this context. Some of the topics we will discuss are half wave and full wave rectification, using diodes as voltage regulators and more.

Lecture 25 - "Understanding Zener and Schottky Diodes plus Simple Voltage Regulators"

Moving on from silicon diodes in the previous lecture, we kick it up a notch with Schottky and Zener diodes. Here we explore more advanced applications such as power supply design, protection diodes, voltage clamping, and finish up with implementing digital logic functions with only diodes!

Lecture 26 - "Half Wave and Full Wave Diode Experiments on the Bench"

In this 2 part series we're going to take the previous diode theory and lectures from the blackboard to the bench and build many of the circuits we explored. In part 1, we will tackle half wave and full wave rectifiers and power supply front ends. Then in part 2, we will finish up with building and testing a zener voltage regulator.

Lecture 27 - "Diode Experiments on the Bench - Part II"

In part 2 of the diode bench work series, we build a complete zener voltage regulator circuit and exercise it with various loads. Not only will you learn about zener regulation, but additionally terminology and concepts like "line regulation" and "load regulation" will be reviewed to help you when designing power supplies or using one off the shelf.

Lecture 28 - "Schottky Diode Experiments and Logic Gate Implementation"

Taking advantage of the very small forward voltage drop of Schottky diodes (250-350mV roughly), we leverage this feature to develop more logic gates and explore the limitation of diode-resistor logic. Of course, you would never use discrete diodes to implement logic gates; however, once in a while you want to sum a couple analog or digital signals, OR, or AND then, etc. and a couple 1 cent diodes might do exactly what you need without resorting to a full on gate IC. Moreover, Schottky diodes are used all the time in power supplies as "Power ORs", that is to "OR" currents, and steer currents in one direction, but without the penalty of the 0.6-0.8V forward drop of Silicon diodes.

Lecture 29 - "Introduction to Voltage Regulators and Power Supply Design"

This lecture is the first in a series of "Power Supply" lectures focusing on using off the shelf voltage regulators (linear and LDOs) as the base part to develop each power supply. A lot of practical knowledge as well as bench experiments and builds.

Lecture 30 - "Power Supply Primer"

In this lecture, we dig deeper into power supply design. We learn about IC selection, types of power supplies, more on filtering, heat management and fabrication of very small power supplies based on SMD (surface mount device) components.

Links

SMD Adapter Boards - http://www.beldynsys.com
SMD Adapter Boards - http://www.schmartboard.com

Lecture 31 - "Building a 5V Power Supply...LM7805 Style"

You can't talk about power supplies without talking about the famous 7805 5V voltage regulator. Even though, these days you would rarely use an old school 7805 (there are modern replacements that are much better). The 7805 is still a good design example, and something you will find in a lot of hobbyist based designs to this day, so we are going to cover it for posterity since it's the "Hello World" of power supplies!

Lecture 32 - "Adding 3.3V to our Power Supply Design"

We continue to develop our general digital power supply by adding support for 3.3V to the outputs. Also, theory and practical considerations for the topology of the power supply are discussed, and pro's and con's of various approaches. Finally, we build the new 3.3V on the bench and test it out!

Lecture 33 - "Taking our Power Supply Offline with a Transformer"

In this lecture, we take our 5/3.3V power supply design and learn how to power it directly from an AC line source or "offline" in other words. Thus, we will talk about practical transformers, transformer selection, connecting to AC lines, safety measures and much more.

Lecture 34 - "Wiring up the Transformer to our Power Supply"

In the previous lecture, we discussed much of the theory, plans, and details to select, and connect our power supply front end directly to AC lines with a step-down transformer. In this follow up, lecture we get on the bench and work with the line AC power and make the connections, make measurements and exercise many safety precautions. I like to play around and joke, but AC is deadly serious, so please follow my safety precautions if you want to try this experiment for yourself. That said, let's go blow stuff up!

Lecture 35 - "Get the Noise Out! Introduction to Power Supply Filtering"

This lecture is worth its weight in gold -- It really is. As a professional embedded engineer, I can't tell you how many times, I have been handed a PCB designed by someone else, including a power supply, that doesn't work, or works part of the time with random failures that make no sense. 9 time out of 10, it's not the digital design, but the POWER SUPPLY DESIGN. Moreover, the power supply design is "ok" in many cases, usually a reference design from the manufacturer of the regulator IC, but the power supply is "noisy". And this creates problems with all kinds of electronics; digital and analog. Therefore, in this lecture, we are going to explore one of my favorite subjects -- Noise identification and reduction in power supplies.

Amazingly, with just some rudimentary techniques, you can completely clean up noise in power supplies and better yet, I will show you how to "see" the noise, which will be shocking to most since its just horrible to allow such unclean power into your nice electronics. So, buckle in and let's kick this lecture into gear!

Lecture 36 - "Circling Back to Transistors...A 15 Minute Refresher Course"

Although we have covered transistors before, in the next series of lectures we are going to explore much more complex features and uses of BJT transistors such as switching and amplification. This lecture serves as a quick refresher on the subject and brings in a few new ideas briefly.

Lecture 37 - "Introduction to Transistor Amplifier Circuits and Models"

In this lecture, we are going to break down a single BJT transistor and learn about how to "model" a transistor with a basic, but yet very useful model. You will learn about base, collector, and emitter currents, gain, biasing, and much more. This lecture will be our first in a series breaking down how to design and analyze transistor amplifiers and other interesting circuits that can be created with transistors. That said, this lecture is very important, since it’s a foundation, so go slow, rewind if needed, and try to follow along with the simulations after you watch the lecture.

Lecture 38 - "Transistor Biasing, Current Amplifiers and Voltage Regulation"

This is another one of my favorite lectures! In this lecture, we are going to use the information learned in the previous lecture about the transistor action and model for it, and leverage it to build some very useful circuits such as voltage regulators and constant current sources. Along the way, you will see more on "biasing" such as voltage divider and zener biasing, as well as some tricks such as taking advantage of the base-emitter junction forward voltage drop. I think I even throw in some "impedance reflection" -- the method of using the transistor itself to make a load or source look larger or smaller than it really is! Anyway, lots of cool stuff!

Lecture 39 - "Small Signal Transistor Amplifiers"

This lecture illustrates one of the primary uses of the transistor and that is for amplification. In this case, "small signal" amplification. In other words, how do we build a transistor circuit, so that we can insert a small signal (maybe uV to mV) and get out an amplified signals (10-100x), but without distortion? This is where many of the technologies we have learned will all come into play; transistor models, biasing, filters, etc. we will put them all together and build an amplifier.

Lecture 40 - "Common Emitter Amplifier Design"

Down the rabbit hole we go... Of course, we are just getting started with transistor amplifiers, there are 1000+ page books written (100's of them) just on transistor amplifiers! Therefore, this is a BIG subject, so the next topic we are going to cover is common emitter transistor amplifiers. In fact, you can have common emitter, common collector, and even common base (not very useful). However, common emitter amplifiers are VERY useful, since we can get voltage gain out of them which is of course a good thing! This is a big topic, so we will have a couple lectures on this subject matter to completely cover it and build enough on the bench to feel comfortable with common emitter amplifiers.

Lecture 41 - "Hard Core Analysis of the Common Emitter Amplifier"

We wrap up our common emitter amplifier lectures with a detailed and brutal analysis of what's going on. This lecture is like watching a detective novel unfold before your eyes. It's a long video, and it's a lot of math, but I promise I make it as "fun" as it can possibly be. Moreover, the method of analysis performed here in this example to derive the gain of the circuit is a very common approach, so even if you're math skills are not Jedi level yet, just follow along with me and watch, so you see this at least once.

THIS lecture is VERY important, so take your time, take breaks if needed, but get through it -- it's worth the payoff.

Lecture 42 - "Transistor Motor Driver Bench Experiment and Noise Reduction"

In this lecture, we take our transistor amplification and driver knowledge to the bench and build a circuit to drive a very big load -- a motor! Of course, we don't stop there -- being the analog experts we are at this point, I want to show you a "noise analysis" of the circuit and what powering motors from your power supplies do to the power rails -- motors are VERY noisy.

Then we will work to reduce the noise in the motor, and induced noise elsewhere. This is a very important lecture if you plan on doing anything with power electronics and want to have any chance that your electronics will work properly. Don't miss this one!

Lecture 43 - "Current and Voltage Regulation Experiments"

In this lecture, once again we take our theory and math and put it to the test with a number of voltage regulation circuits we will build on the bench and analyze in real-time. These circuits are little gems and show you that you don't need a big IC to perform regulation, you can do it yourself in a pinch with a transistor, diode, couple of resistors and caps.

Lecture 44 - "Building a Practical Audio Voltage Amplifier"

This is another don't miss lecture! Here we design and build an audio amplifier and even learn about microphones! This is one of the best bench experiment videos in the course. Starting with nothing, we are going to take a single transistor, build an amplifier, bias it, set the gain, connect a speaker and microphone (learn how electret mics work) and end up with a complete single stage audio amplifier. And of course, unlike just copying the circuit from internet, you will understand every single nanometer of it! And with that knowledge build better amplifiers!

Lecture 45 - "Crossing the Threshold from Analog to Digital Electronics"

In this lecture, we bid farewell (for now) to analog electronics and start our journey into Digital Electronics. But, like everything we do, we aren't going to rush, rather we are going to take a look at how digital logic gates are constructed using TTL (Transistor Transistor Logic) and run through how to design gates at the transistor level (albeit simplified version) to get a feel for what's going on "inside" digital ICs. Additionally, we will cover a great deal of new concepts, terms, learn about logic levels and different "families" of digital gates. A lot to do, let's get started!

Lecture 46 - "Retro TTL Build! - Inverter, AND, NAND, OR, NOR"

Based on our work in the previous lecture about digital logic and using transistors to implement logic functions, we take that knowledge to the bench and build a series of working logic gates; including NOT, AND, NAND, OR, and NOR. With these simple constructions, just about anything can be built. If you so desired you "could" build an entire computer with discrete transistors! Of course, you would never want to, but back in the 1950's and 1960's that exactly what they did -- can you imagine that? Now, a single modern CPU/GPU has billions and billions of transistors (around 20-25 billion transistors is the record these days).

Lecture 47 - "Temporal Manipulation and Clock Oscillators"

Once we climb up the food chain a little bit from simple "combinatorial" logic circuits, and we want to build systems that have state, count, and run at a specified time interval, then we have to talk about "clocking", "oscillators" and related subjects. In other words, to build digital logic that is "clocked" by a single time reference, first, we need to be able to generate said time reference or "clock". This is what this lecture and the next is all about. We are going to learn about XTALs and their use as timing references and how that works. How oscillators work. And finally, we will take all our new knowledge and bring it to the bench and build a number of clock circuits, analyze them, see how MHzs' oscillators or XTAL based clocks perform. And ruminate about all our findings. There's a lot of practical information here, so another "don't miss" lecture.

Links

Crystal Oscillator Theory - https://en.wikipedia.org/wiki/Crystal_oscillator
Barkhausen Stability - https://en.wikipedia.org/wiki/Barkhausen_stability_criterion

Lecture 48 - "Timing Circuit Theory and Building Clocks with XTALs and Oscillators"

In part 2 of the clock series, we look into more theory about oscillation criteria, dig into more detail, and continue working on our bench clock circuits and further analyze with the oscilloscope.

Links

Using CMOS Inverters for Oscillators - http://www.ti.com/lit/an/szza043/szza043.pdf

Lecture 49 - "It's all about the 555 Baby!"

The 555 timer IC is one of the most famous (and useful) ICs' ever created. It's right up there with the 6502 microprocessor. Amazingly, the 555 is a very old IC, it's from the 1970's if you can believe that, and still used today in countless timing circuits. Now, don't get me wrong, you're not going to clock your 5GHz next gen processor with a 555, but you can build many useful timing based circuits with the 555 timer. That said, we are going to take a look at its data sheet, look at some of the basic configurations that the 555 can be used to build, and then of course get on the bench and build a working circuit with it. So, plug in and let's go!

Links

555 Timer Wiki - https://en.wikipedia.org/wiki/555_timer_IC
555 Timer TI Data Sheet - http://www.ti.com/lit/ds/symlink/lm555.pdf

Section 5: Introduction to Digital Logic Systems, Boolean Algebra, Timing Diagrams and TTL

This section of the course covers digital electronics building on our analog foundations. Topics such as binary, Boolean algebra, timing diagrams, IC packaging, and fabrication techniques are covered.

Lecture 1 - "Boolean Algebra, Number Systems, and 100% Digital Electronics"

This first lecture of this new section is 100% digital! You have graduated from analog electronics to digital design now, so pat yourself on the back. Of course, we are far from done with using analog electronics and there's more to learn, but from here on out we will mostly be discussing and learning about digital electronics and thinking of analog electronics as "support hardware" in our digital designs as we power them, interface them to the real world and whenever we need to deal with analog signals. That said, this "kick off" lecture focuses on learning the language of digital systems; binary, hex, Boolean algebra, and thinking in 1's and 0's for a change.

This lecture requires a shift in thought process, so don't worry if it seems overwhelming initially. As usual, I like to introduce a subject many times in many ways, so anything here that you deem hard to understand, rest assured you will see it many more times and in different contexts to make it easier to grasp. Thus, without further ado, let's take the red pill and see how far this rabbit hole goes...

Lecture 2 - "Boolean Algebra and DeMorgan's Laws"

If you're not a software engineer/programmer or electrical engineer, then your whole life you have probably only worked with base 10 mathematics i.e. the decimal system. This is the number system we use every day, e.g. a number such as 159 really means 1*100 + 5*10 + 9*1. In other words, each place from right to left is a base 10 multiplier 1, 10, 100, 1000, etc. You can add, subtract, multiple and divide these numbers and have been trained to do so your entire life. But, there are countless other number systems based on "base n" mathematics where n can be anything. For example, binary is base 2 math, hexadecimal is base 16 mathematics and so forth. That said, in each number system we can perform similar operations to addition, subtraction, multiplication, and division. The question is "how do these operations work in each of the base n number systems?". This is the main topic of this lecture. We will be focusing on binary (base 2), and hexadecimal (base 16) and comparing it to decimal (base 10) as our anchor.

We are going to learn in detail some of the laws of algebra as they pertain specifically to base 2. These laws are commonly known as Boolean algebra, and due to the nature of binary systems there are some very interesting shortcuts which are encompassed by what's knows as DeMorgan's Laws or theorem. This material is a lot of fun, and if you're a mathematics major or it’s an interest of yours, you will really find this interesting. Regardless, it's absolutely necessary for our understanding of digital logic design and optimization.

Lecture 3 - "Logic Families, Data Sheets, and Digital Signal Properties"

In this lecture we are going to open up a single digital gate and really analyze what's going on from an input/output perspective at the analog level. This will be done in the context of learning a collection of new terms that will help us describe the properties, behaviors, and operation of any kind of digital gate or IC. This whole subject will be facilitated by looking at "data sheets". We have seen data sheets before in passing, but never really dug into them before. Now, that changes, we are going to look at data sheets in detail here, how to read them, use them, and how to NOT take everything written in them as law, since they are written by humans, and tend to be flawed with errors, typos, etc. So, take everything with a grain of salt.

Anyway, this is one of the most useful lectures as it covers a subject that is rarely covered in an EE degree -- and that's parts selection and optimization via data sheet review. Let's begin and see what we find.

Lecture 4 - "Slaying the Dragon with Timing Diagrams"

When I did my EE degree, I had already been playing with electronics for almost 15 years (since I was a small child), so I had a huge advantage over the other students. Therefore, I could focus on the hard stuff like timing diagrams since I knew a lot of the basics already. Timing diagrams are one of those things though, that if you don't learn them early, and feel comfortable with them, they will haunt you, your entire career. Timing diagrams are basically abridged graphical annotations of how an IC works from a timing and signaling perspective. The problem is, there is no consistent way to draw them. Each engineer, company, etc. tends to do them their own way, sure there are similarities, but each data sheet, from each company, from each engineer, always takes a little work to "decode".

Alas, we are literally and figuratively going to slay this dragon together, and take a look at how to read and understand data sheets, mostly digital information, but still in general, you will know how to navigate a data sheet and timing diagrams and not be scared silly when you see a crazy timing diagram like from a DRAM!

Lecture 5 - "Integrated Circuit Packaging and a Walk Through History"

In this lecture we take a ride on the mechanical side of things and look at various IC "packaging". In other words, ICs can come in many shapes and sizes. And over the years, these have become smaller and smaller as a trend of course, but you can still buy old school "through hole" ICs and parts. We will take a look at ICs from the 1970's to the current state of the art, their pro's and con's as far as PCB design, fabrication, and how to work with them including mounting techniques as well as discussions about heat management.

Lecture 6 - "Binary Mathematics Primer and the Full Adder"

Once again we will do battle with binary mathematics, but this time instead of thinking of binary numbers as signals in gates, we are going to abstract them a little to a higher level, and this will be more a practical "Computer Science" lecture on the material leading up to how to use what we know to build digital adders.

Lecture 7 - "Mixing Logic Families and TTL/CMOS Interfacing Considerations"

In this lecture we discuss the difference between TTL and CMOS based logic families with respect to interfacing them together. For example, how do you interface TTL 5V to CMOS 5V? What about LVC 3.3V to TTL 5V? And so on. Countless possibilities, but all are governed by analog concepts, so we will be able to crush it here and bring some of our analog knowledge to the table again to help untangle this mess.

Lecture 8 - "Circuit Fabrication Technique Review"

In this unique lecture, we will review and explore more about actual circuit fabrication techniques. At this point, we have a lot of tools in our analog arsenal and we are getting a respectable stockpile in our digital war machine, but if we can't BUILD circuits then it's all for nothing! Therefore, once again, we take a detour and talk about all things mechanical and how to build circuits -- techniques like solderless bread boarding, wire wrapping, PCB design, and more will be discussed.

Section 6: Taking Digital to the Next Level with Small, Medium, and Large Scale Integration

In this section, we learn about higher level digital "blocks" that serve more complex functions than simple gates. We will cover counters, shift registers, decoders, multiplexers, ALUs and much more.

Lecture 1 - " Getting to Know Basic Integrated Circuits: SSI, MSI, LSI, and VLSI"

In this lecture, we start our exploration of digital building blocks with some theory, language, and discussion of what SSI, MSI, LSI, and VLSI all mean (which themselves change slightly over the years). And then work our way through a couple very useful ICs including the "decoder" with both design, and simulation examples. This is a foundation lecture, so please don't miss it!

Lecture 2 - "Building Circuits with the 74LS138 3:8 Decoder"

In this lecture, we explore "decoders" which basically map a n digit binary value to 2^n outputs. For example a 3 bit decoder, for each value 000,001,010, 011, etc. maps those input values to a separate output line (8 in this case). Decoders are VERY useful devices not only for this mapping function, but they can be used to realize combinational logic functions (more on this later). That said, we are going to look at the classic 3:8 decoder known as the 74xx138. Review some theory, internal construction, data sheets, simulation, and build a circuit on the bench -- As usual a LOT of amazing things to cover, let's get to it!

Lecture 3 - " Intro to LED Display Drivers and the 74LS47"

I got interested in computers when I was about 10 years old, the TRS-80. I saw a game running on it, and I was hooked and wanted to know how to make games. The same thing happened with electronics. I was about 5 and I took something apart, extracted the LED, powered it from a 9V battery, and it was like magic! Alas, LEDs have been the cause of countless people being hooked by electronics at any age! But, once you get over lighting up LEDs, controlling their brightness, you sooner or later stumble upon other LED based displays like "7-segment" displays.

When I was 5, I figured out how to get these working by connecting power to a common, and then the other end of the battery to the pins on the display, and the segments would light up. It wasn't until I was much older, maybe 12 that I was able to build a circuit that did this automatically (a clock), but the IC that makes all this happen and can turn a 4-bit binary number into driving signals for a 7-segment LED display is called the 74LS47. This IC allows you to convert your binary values into visible numbers. Of course, these days you would do this with a CPLD, or other programmable logic, or maybe an LCD/OLED.

But, if you want to control good old, 7-segment LED displays like from a digital clock, you aren't going to find many other ICs still around other than the 74LS47 (and 74LS48) to do this. We are going to study this since this is a great way to "debug" your circuits, that is, simply print out data on displays, but also, because the 74LS47 is another kind of decoder. It’s a 4:16 decoder, but instead of having a SINGLE mutually exclusive output for each input code 0000...1111, the 74LS47, has 7 outputs that each connect to the 7-segment display and turns on one or more segment depending on the number being decoded. So, very cool IC. Actually, quite a lot of logic inside, that's why they are expensive!

Lecture 4 - "Wiring up the 74LS47 on the Bench"

The 74LS47 coverage is continued in this lecture with more bench work and a complete working circuit that can be used as a display driver model. Here's where the rubber meets the concrete.

Lecture 5 - "Switching Things up with Multiplexers"

Multiplexers are the opposite (in many ways) as as decoder. Instead of mapping a n-bit binary value to 2^n outputs, instead we want to select from 2^n inputs with n selector bits and then channel data via this connection. I know, confusing when you read it, but that's what video is for! So, go ahead and watch this next lecture and see what multiplexers are all about and their myriad of uses.

Lecture 6 - "Multiplexing Analog Signals on the Bench with the 4051"

I promised we wouldn't abandon our analog friends, and in this lecture we see how to multiplex ANALOG signals! This is VERY useful, for example, if you want to have a set of n audio or video streams and want to select one and send it to a destination (sounds like the start of a Kickstarter project?). Therefore, in this lecture we take a look at a class of analog multiplexers called the 4051, their data sheet and we build up a circuit on the bench to "mux" analog signals in real-time -- don't miss this one.

Lecture 7 - "Understanding Shift Registers and their Applications"

This lecture is all about "shift registers" which allow us to store and manipulate binary data by shifting it right or left. If you're a programmer and do any low level programming, you have probably worked with bitwise operators like >> (right shift), << (left shift), etc. These operators in code are nothing, but a few keystrokes, but in HARDWARE it's a whole other story -- we have to build this stuff!

Lecture 8 - "Shift Registers, Cylons and Knight Rider…Seriously"

In this lecture, we continue with our shift register coverage and use shift registers to do something other than simply shift data, we use it to create a couple interesting LED effects that you might have seen before if you're a sci-fi fan. The famous single red eyes' of the Cylons from Battlestar Galactica and or course K.I.T. from Knight Rider both use this type of ping pong shift register effect. Let's see if we can engineer the same effect with shift registers and some logic. We will work this problem on the black board, via simulation, and bench work. A great example of given a problem in electronics how to go about "engineering" a solution. Of course, this LED effect has been around as long as lights have been, and was used on countless marques in shows, circuses, and carnivals in the early 1900's!

Lecture 9 - "Building the Scrolling LED Effect on the Bench"

In part 2 of this lecture series on the scrolling or shifting effect, we build the final circuit on the bench along with a detailed simulation and see what happens as we experiment with both. Do they match? Are their problems, and if so, what? This is another practical lecture that's a lot of fun as well.

Lecture 10 - "Interfacing and Bus Design with Buffers, Drivers and Transceivers"

This lecture takes a high level detour to investigate some of the digital logic required to build computer systems, i.e. "bus" structures. You will learn about connecting multiple signals to the SAME wires, how that is done as well as the general topics of drivers, transceivers, and tristate logic. This is a very important lecture, and will help you down the road even if you are not designing computers when you simply need to use the same signal lines and have multiple devices communicating on the lines at different times.

Lecture 11 - "Introduction to Math Chips: First up…the Comparator"

These days if you need a "computer" on a PCB, you simply add a $0.10 to $0.50 MCU (Micro Controller Unit) and in most cases, you have more power than most 8/16-bit computers that existed in the 1980s-1990s! Alas, we usually don't have to do basic math operations with discrete ICs, rather we use an MCU or MPU to do this. On the other hand, sometimes you DO need to do some simple math to some values that might be flying around your design and/or if you are going to design modern MPU/MCUs, you NEED to know this stuff! Therefore, our first IC in the math department we are going to look at is the basic "comparator" -- the 74LS85 in this case which allows you to compare two 4-bit numbers (a,b) and determine if (a>b), (a<b), or (a==b)? With these operations you can build much more complex circuits as we will see in a couple lectures.

Lecture 12 - "Getting to Know the 74LS83 Full Adder"

This lecture takes it up a notch with the 74LS83 "Full Adder" -- which allows us to add two 4-bit binary numbers along with a carry C in. This is where things get interesting -- just with this single IC, we can perform "math" operations on two values -- Then we add in some displays drivers and more, and we have a VERY poor man's calculator! But, it's a start... We will build this project and simulate it entirely.

Lecture 13 - "Arithmetic Logic Units (ALUs)... The Building Blocks of Modern CPUs"

This is another one of my favorite lecture series. In the following 3 lectures, we are going to learn about ALUs (Arithmetic Logic Units). These are the cores or workhorse of early microprocessors that basically perform all the mathematical and logical operations to binary data. In this first lecture, we are going to learn about ALUs in general, and then build up an entire simulation using the 74HCT181 ALU which is pretty slick, then in the remaining lectures, we are going to keep working on the design, and finally build an entire calculator on the bench!

Lecture 14 - "Digging Deeper into TTL ALUs and their Architectures"

In part 2 of the ALU series, we dig deeper into the design and operation of the ALU as well as introduce another variant of ALU the 74F/LS382. Additionally, we add some more controls to our design, so with the press of a button, we can add, subtract, etc. rather than having to enter codes with DIP switches. This is a great lecture showing how a design progresses as parts are selected, features added or subtracted, and or complexity simplified. Again, we work on the black board and the simulator mostly.

Lecture 15 - "Building a Calculator on the Bench"

This final lecture in our ALU series takes it to the next level with the biggest bench build so far! We are going to build the calculator circuit we have been working on in the previous 2 lectures. This is a huge project, a lot of wires, a lot that can go wrong, so hopefully it works out -- watch the video and see for yourself!

Lecture 16 - "Flip Flops and Counters Redux"

In this lecture, we revisit flip flops and counters and learn about some specific ICs for these functions and how to use them. Counting is still very important in modern digital design as are flip flips. No matter if you have the biggest, baddest ARM15 XTREME 256 core processor on a PCB, sooner or later you are going to need a single bit memory, or to count something that occurs on in the design separate from the CPU/MPU. Also, some good coverage on the analog nature of flip flops and how signals can be used as "feedback" in circuits.

Lecture 17 - "Sequential Logic, State Machines and K-Maps"

This lecture is one of the more interesting and theoretical lectures we have on digital concepts. Sometimes, it seems as though digital electronics is devoid of mathematics, and hard stuff. But, this is not true, digital electronics is simply based more on discrete maths, but the same rigor can be applied as to analog electronics with all its messy calculus and imaginary machinations. In this lecture, we delve into FSMs (Finite State Machines), Sequential Logic, and K-maps (which I am not even going to try to explain in this description, just watch the video). That said, this is one of my favorite lectures since it really bridges the gap between Computer Science and Digital Design using software and program analogies to help make the "hardware" versions of these concepts easier to digest.

Lecture 18 - "Counter Design with Advanced Simulation"

This lecture bookend's what we have learned about state machines and optimization in the last lecture. And illustrates a concrete example and simulation of how to make state transitions in a counter design and how to "code" them into the hardware. This is like a bonus lecture, so don't miss it!

Section 7: Printed Circuit Board Design and Technology with CircuitMaker

By the end of this section you will have installed CircuitMaker, learn our way around schematic entry and PCB layout. We will cover many new terms, concepts and technologies related to PCB design.

Lecture 1 - "PCB Basics and Installing CircuitMaker"

Congratulations! If you made it this far then you have considerable knowledge about both analog and digital electronics, and now it's time to put that knowledge to use and build some PCBs! This first lecture guides you through the installation of CircuitMaker and a whirl wind tour of PCB design from A-Z just to get you acclimated to the terminology and technology. Don't worry, we are going to go over this material many, many times as we proceed through the lectures and design actual PCB products.

Lecture 2 - "PCB Design End to End for Beginners"

This lecture continues from the previous, but focuses on PCB design with respect to schematic entry and layout. Additionally, how PCBs are made, i.e. their internal structures are analyzed -- concepts like inner layers, vias, copper thickness, and board fabrication materials all will be discussed.

Lecture 3 - "Hands on PCB Teardowns"

Although, I think everyone should get an EE or CS degree, like anything, there are only so many hours in the day and these degree programs tend to focus on the HARD stuff -- theory and math - which is a good thing. However, you graduate with little practical experience building things, other than what you do in the lab. Therefore, this lecture is a real gem. We are going to look at a collection of PCBs I designed that represent "good" design tactics that I have learned over the course of the last 20-30 years doing it. Of course, I am always learning, and you will be too. But, I wish I had a course in college that had this kind of practical information and hands on examples. So, take your time with this lecture and listen to some of the suggestions.

Section 8: Graduating to Design Engineer: CircuitMaker Fundamentals and Real-World Projects

This huge section is 25+ lectures, a course unto itself where we will do what we came here for -- to BUILD products! We are going to design and layout THREE amazing projects and see every step of it!

Lecture 1 - "CircuitMaker Fundamentals: Forking Projects and Basic Navigation"

In our first real work with CircuitMaker, we are going to learn how to "fork" other people's projects, as well as some basic navigation in the tool.

Lecture 2 - "CircuitMaker Fundamentals: Magic Wand Schematic/PCB Overview"

Well, here goes nothing -- This lecture is the first design overview of one of the 3 projects we are going to design end to end in this Section of the course. Now, designing an entire project/product is a daunting task. To my knowledge, there isn't a course anywhere that shows this level of design detail from concept to complete schematic and PCB layout for not one, but THREE projects! Thus, I am pretty certain by the time you are done with the 25 or so lectures in this section, you are going to have a Crash Course in PCB Design in addition to everything else!

With that in mind, I had to think of a way to show you the projects as I designed them, but I didn't want to spend 100-200 extra hours making mistakes in front of you. Therefore, the plan is, I of course designed all the projects, debugged them as best I could -- So, we will start each project looking at the finished result. Then, we will redo the entire project (mostly) in real-time, so you can see how everything is done, I simply will know what I am talking about better since I already did it. But, I guarantee you WILL be able to design Single Board Computers (like Arduinos) when we are done.

Without further ado, let's dive into our first project which is a Magic Wand, and see what it's all about...

Lecture 3 - "CircuitMaker Fundamentals: Magic Wand...Power Supply Design"

Now, that you have seen where we are going with the Magic Wand project, we are going to build it from scratch. The first functional block is the power supply, so let's design that first.

Lecture 4 - "CircuitMaker Fundamentals: Magic Wand 555 Timer Design & Parts Selection Process"

This lecture is another one that needs to be taught more in college. Here we cover the timing circuitry of the magic wand, but we spend a good amount of time learning about "parts selection". This is a huge problem in modern engineering -- the process of selecting parts based on their price, performance, availability, vendor support, documentation, firmware examples, etc. There are countless metrics to the proper selection of parts. I can't tell you how many times I have had to redo a client’s design from a newbie engineer that used the most expensive parts or impossible to find parts! Anyway, this lecture is about design and manufacturing planning -- don't miss it!

Lecture 5 - "CircuitMaker Fundamentals: Magic Wand Counter and Decoder Logic"

In this lecture, we move onto the decoder logic design which drives the LEDs in the design.

Lecture 6 - "CircuitMaker Fundamentals: Finishing the LED Connections and Starting PCB Layout"

Were almost done with the electrical design! Here we wrap it up with the final LED connections and review and double check everything. Then we prepare for the PCB layout by figuring out how to export our schematic into a PCB layout with parts, and how to shape our PCB.

Lecture 7 - "CircuitMaker PCB Layout: Magic Wand Part I"

We are now into the meat of the PCB layout. This is the 1st in a series of 5 lectures where we will painstakingly layout the PCB for the Magic Wand. These videos of course, only represent a fraction of the real-time it took for me to do it with trial and error, trying different things, etc. The point is, this is a very slow and thoughtful process -- I want you to really take your time and watch these videos very carefully to watch my thought process.

Lecture 8 - "CircuitMaker PCB Layout: Magic Wand Part II"

In this lecture, we continue to position ICs and move things around mostly for mechanical consistency and design/aesthetics. This is an interesting phase of design -- there is no right/wrong way to do things, but there are surely better/worst ways to do things. Most CAD tools have "auto placers" which are nearly useless since they have no clue on what the ICs are, the functionality of the IC, any aesthetics, etc. So, the only advice I can give here is heuristic, there are better ways to do things and a thought process that you learn after years of doing it. In this lecture, I try to impart a bit of that as we move things around for our Magic Wand and talk about the "why" and what's going through my head.

Lecture 9 - "CircuitMaker PCB Layout: Magic Wand Part III"

In Part III, we are mostly done with the part placement and finally ready to do some "routing" and/or "track placement". We are going to start with power planes and then add a few connections to the power supply to begin with.

Lecture 10 - "CircuitMaker PCB Layout: Magic Wand Part IV"

In this lecture, we run the "auto-router" and see how it handles the project. Typically, I am not a fan of auto-routers since to work well, you must spend a lot of time giving them hints, instructions, rules, etc. by the time you are done, you have a decent route, but still its far from 10% as good a human could do. However, with a small, simple PCB like the Magic Wand we are going to give the auto-router a shot and then follow up with manual cleanup along with an annotated reason behind each "fix", so you can learn how to make clean PCBs.

Lecture 11 - "CircuitMaker PCB Layout: Magic Wand - That's a Wrap!"

We're done! Our first complete PCB project designed and routed! Seriously, most EE majors never actually do this, so you are ahead of the game. That said, this lecture is all about details -- we are going to clean up the PCB, find bugs, run the design rule checker, and fix up small problems. Also, we will discuss when "good" is "good enough". In other words, you can work on a PCB forever if you want to, but at some point you must STOP and SHIP the product. Thus, you need to have a point of completion where the PCB is functional, looks good, etc. and learn to just stop working -- put down your pencil.

Links

CircuitMaker Tips and Tricks - https://hackaday.io/project/7155-tips-for-using-circuitmaker

Lecture 12 - "CircuitMaker: Intermediate Design: The 555 Organator Design/Music Theory Overview"

Next up we have the "Organator"!!! This is a simple 555 based organ project. In this lecture, we go over the design, some music theory, and vocabulary. Now a disclaimer -- I have written many sound engines in ASM/C/C++, both software, hardware, gaming engines etc. that can play amazing music that someone ELSE wrote. But, I never learned to play an instrument! So, I am not a musician, which I really regret since most of my family is musical :) However, I will try my best here, and if I make any mistakes, hopefully I will catch them. But, the hardware is solid and a really cool example of generating sound with the 555 for a practical project.

This is an intermediate project, so we will pick up the pace again, show the entire design, so you can see where we are going then re-build it block by block. Also, we are going to use some tools like Excel for calculations which is a great way to do math when you have a number of parameters in a system and want to see how they change your outputs. Therefore, I suggest that you pay attention to the use of "tools" in this lecture as well.

Links

Musical Notes Page - https://pages.mtu.edu/~suits/notefreqs.html

Keyboard Images -

http://www.thepinsta.com/full-piano-keys-labeled_wAZ8TjdOtZdZ*i9p6fbB4OJwIlfndRbNIc5ccPtbCGE/

Lecture 13 - "CircuitMaker: Intermediate Design: The 555 Organator Power Supply Design"

In this lecture, we design the 5V power supply for the Organator. This supply is a low noise LDO based design which we will power from a standard 9V prismatic primary cell. This should be very familiar to you after our power supply coverage in previous lectures.

Lecture 14 - "CircuitMaker: Intermediate Design: The 555 Organator Sound Generation and Amp"

Now, that we have power, it's time to generate some sound. This of course is done with a 555 timer with a variable frequency generated by a switchable timing resistor. The output square wave is then sent to an amplifier (current amp) and then to a speaker. Interesting fact, many 555's can support very high currents. I believe some can actually driver 100mA loads or more! But, in our example, we won't make the 555 work that hard, and we will design a single transistor amplifier ourselves, since we know how to do that.

Lecture 15 - "CircuitMaker: Intermediate Design: The 555 Organator PCB Layout Part I"

Now we are ready to start laying out the Organator -- I wish I could add sound effects to this text! Anyway, this two part lecture basically covers the layout of the hardware, positioning, and an eye to aesthetics -- remember there are an infinite way to do things in layout, but you have to pick one and just do it. And make 1000's of decisions, this lecture and the next will again help you see that process in real-time hopefully.

Lecture 16 - "CircuitMaker: Intermediate Design: The 555 Organator PCB Layout Part II"

In this lecture, we finish up the mechanical design and positioning of all the parts in the design for the most part and get ready for layout next. Here we are going to do a lot of fine tuning and thinking about a lot of "what if?" scenarios -- that is, are there better ways to position parts? If so, what are the side effects? Also, we will delve into some "mechanicals" like bolts, measuring thread sizes, etc. thus for those that haven't done a lot with fabrication there are some interesting tidbits.

Lecture 17 - "CircuitMaker: Intermediate Design: The 555 Organator PCB Layout Wrap Up"

Well, you made it to the end of another project design lecture series -- pat yourself on the back! Well, almost, you still need to get through this lecture which is 100% about routing and layout. We are going to drop in the top and bottom power plane fills and then use the auto-router to route the design for us (as a start) and then go over it track by track and clean it up. This is a great example of hybrid routing (auto/manual), so don't miss it. When we are done, we will have our completed product ready for manufacturing. And, if you are so disposed, you can design a 3D housing and 3D print something to encase it -- I was going to do yet another section on 3D design and printing, but I decided to save that for another course!

Lecture 18 - "CircuitMaker: Advanced Design: The Inspiration behind the SimonDuino"

This project and lecture series is another one of my favorites and something I wish I had access to when I was learning -- a step by step, real-time design of a complete product (single board computer), PCB design, and ready for manufacturing. This lecture series and project takes things to the next level. I mean, I haven't seen any course, anywhere that teaches how to build a complete Arduino of this level of complexity. So, this is definitely pretty cool. That said, we are going to develop what I call the "SimonDuino".

Now, if you're from the USA and into pop culture and retro gaming, you might understand the name of the product, if you are not from the USA, then you have probably heard of "Arduino" before, but don't know the relevance of "Simon". Simon was a very popular game developed by Ralph Bear in the 1970's, 4 buttons, colors, sound, and a lot of fun -- very addictive. I wanted to design a game console of some kind, something simple, but still a single board computer that everyone could relate to. Therefore, I thought Arduino+Simon would be cool. Thus, after this ADVANCED project YOU will be able to design and manufacture your OWN Arduino boards, or PIC based, or whatever, you will see the whole process and the details and use it to make more complex projects.

So, let's get started and take a look at the project from a high level and see all the elements.

Lecture 19 - "CircuitMaker: Advanced Design The SimonDuino's Processing and Power Supply"

In this lecture, we review the entire processing block of the SimonDuino which is based on the Arduino nano, and then move onto the power supply design for the system as well as the processor itself. Again, a very big lecture with lots of side topics and anecdotes, don't miss it.

Lecture 20 - "CircuitMaker: Advanced Design SimonDuino's USB and Serial Port"

This lecture covers the USB port for the SimonDuino. This port is used as a serial bridge to the AVR processor and PC under a virtual serial port supported by the FTDI driver. This lecture is not only part of our design, but shows how to design a USB to Serial port project unto itself, so very useful.

Lecture 21 - "CircuitMaker: Advanced Design SimonDuino's Indicator LEDs"

In this lecture, we take a look at display electronics and how we are going to drive the 4 colored LEDs that make up the Simon game we want to support with our project. We will look at GPIO drive, should we use transistors, FETs, drivers, etc. to add drive to the LEDs, and many other questions.

Lecture 22 - "CircuitMaker: Advanced Design SimonDuino's Input Buttons and Sound"

In this lecture, we talk about user input and sound generation. We have seen the later, but we haven't done too much with user input. This is always an issue with microcontrollers. For example, if you only have 2-3 GPIOs left, how can you read 4, 10, 100 buttons? Well, there are tricks to do this, and we will talk techniques such as "serialization", "priority encoders", and other ideas to reduce the number of GPIOs needed to read a much larger number of inputs. Additionally, we will take a look at the sound design and amplifier that will give the SimonDuino a lot of output power.

Links

Reverse Engineering the Simon Game - https://www.waitingforfriday.com/?p=586

Lecture 23 - "CircuitMaker: Advanced Design SimonDuino Wrap Up"

The SimonDuino took a long time for me to route, so rather than go through that process again (which we have already seen in the previous two projects), instead we are going to take a look at the routed PCB and talk about how to improve it, fix things, etc. In other words, this is a wrap up and tuning lecture. This is a very important step when you design a PCB, you need to go over it many, many, many times -- did I say MANY :) There's always something you miss, so get in the habit of walking away for a few days, then coming back cold, and reviewing the PCB, you will see things that you don't remember, but are mistakes or just ugly and you can fix them. Anyway, after that, we get ready to manufacture.

Links

Free Music Archive - http://freemusicarchive.org/music/Loyalty_Freak_Music/

Lecture 24 - "Generating Gerber Files with CircuitMaker Part I"

We are at the end of our journey (aside from additional bonus lectures). It's time to build all our projects and have the PCBs manufactured, so we can assemble them (if we so desire). This two part lecture series puts the rubber to the concrete and not only is a technical exposition on how to generate manufacturing files with CircuitMaker, but is a real-world production optimization lecture(s) where we are going to go to multiple PCB manufactures and price manufacturing, and learn what metrics are important, and how to select the best manufacturer.

Links

Generating Gerber Files for Manufacturing with CircuitMaker

https://documentation.circuitmaker.com/display/CMAK/From+Idea+to+Manufacture+-+Driving+a+PCB+Design+through+CircuitMaker

http://docs.oshpark.com/submitting-orders/

A Few Good PCB Manufacturers to Start with…

Golden Phoenix - http://www.goldphoenixpcb.com/

PCB Cart - https://www.pcbcart.com/

PCB Fab Express - https://ecommerce.pcbfabexpress.com/

Pentalogix - https://www.pentalogix.com/

Osh Park - https://oshpark.com/

Lecture 25 - "Generating Gerber Files with CircuitMaker Part II"

In this final lecture of the series, we review more manufacturers, pricing, and see how to build our PCBs from the previous projects.

Section 9: Bonus Lectures

In this section you will find an ongoing array of new “bonus lectures” on various topics related to the course, EE, and embedded engineering.

...THE END...