Electrical Engineering 101

EVERYTHING YOU SHOULD HAVE LEARNED IN SCHOOL... BUT PROBABLY DIDN'T

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DARREN ASHBY

Newnes

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Everything You Should Have Learned in School, but Probably Didn't

by Darren Ashby

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Newnes is an imprint of Elsevier

Newnes is an imprint of Elsevier
30 Corporate Drive, Suite 400, Burlington, MA 01803, USA
Linacre House, Jordan Hill, Oxford OX2 8DP, UK

Library of Congress Cataloging-in-Publication Data

Application submitted

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library.

ISBN-13: 978-0-75067-812-4
ISBN-10: 0-7506-7812-7

For information on all Newnes publications
visit our website at www.books.elsevier.com.

05 06 07 08 09 10 10 9 8 7 6 5 4 3 2 1

Printed in the United States of America

Electrical Engineering 101

I'd like to dedicate this book to my wife Denise;
without her it would have not happened.
She is my passion, my friend and my confidant.

Preface

The First Word

The intent of this book is to cover the basics that I believe have been either left out of your education or forgotten over time. Hopefully, it will become one of those well-worn texts that you drop on the desk of the new guy when he asks you a question. There is something for every student, engineer, manager, and teacher in electrical engineering. My mantra is, "It ain't all that hard!" Years ago I had a counselor in college tell me proudly that they flunked out over half of the students that started the engineering program. Needing to stay on her good side, I didn't say much at the time. I always wondered, though. If you fail so many students, isn't that really a failure to teach the subject well? I say "It ain't all that hard" to emphasize that even a hick with bad grammar like me can understand the world of electrical engineering. This means you can too! I take a different stance than that counselor of years ago, asserting that everyone who wants to can understand this subject. I believe that many more than 50% of the people who read this book will get something out of it. It would be nice to show the statistics of that to that counselor someday; she was encouraging me to drop out when she made her comment. So, good luck, read on and prove me right—it ain't all that hard!

One more item of note: at the end of each topic I have created some bullet points I like to call 'thumb rules." They are what they seem—those "rule of thumb" concepts that the really good engineers just seem to know. These concepts are what always lead them to the right conclusion and a solution to the problem. If you get bored with a section, make sure to hit the thumb rules anyway. There you will get the

distilled core concepts that you absolutely should know. Thank you for giving me a chance to pass on a few ideas. I hope you find them engaging, fun, and educational!

Overview

For Engineers

Granted, there are many good teachers out there and you may have gotten the basics, but time and too many "status reports" have dulled the finish on your basic knowledge set. If you are like me, you have found a few really good books that you often pull off shelf in time's of need. They usually have a well-written, easy-to-understand explanation of the particular topic you need to apply. I hope this will be one of those books for you.

You may also be a fish out of water, an ME thrown into the world of electrical engineering, and you would like a basic understanding to work with the EEs around you. If you get a good understanding of these principles, I guarantee you will surprise at least some of the "sparkies" (as I like to call them) with your intuitive insights to problems at hand.

For Students

I don't mean to knock the collegiate educational system, but it seems to me that too often student's can pass a class in school with the "assimilate and regurgitate" method. You know what I mean—go into class, soak up all the things the teacher wants you to know, take the tests, say the right things at the right time, and leave the entire class without an ounce of applicable knowledge. I think many students are forced into this mode when teachers do not take the time to lay the groundwork for the subject they are covering. Students are so hard-pressed just to keep up that they do not get the light bulb to go on over their head. The reality is, if you leave the class with a fundamental, intuitive understanding of the topic, you will be imminently more successful applying that basic knowledge than anything from the end of the syllabus for that class.

For Managers

The job of the engineering manager should have more to it than what is depicted by the pointy-haired boss you see in the Dilbert® cartoons. One thing many managers do not know about engineers is that they welcome truly insightful takes on whatever they are working on. Please notice I said "truly insightful"; you can't just spout off some acronym you heard in the lunchroom and expect your engineers to pay attention. However, if you understand these basics, I am sure there will be times when you will be able to point your engineers in the right direction. You will be happy to keep the project moving forward, and they will gain a new respect for their boss. (They might even put away their pointy-haired doll!)

For Teachers

Please don't get me wrong—I don't mean to say all teachers are bad. In fact (except for one or two) my teachers were really good instructors. However, sometimes I think the system is flawed. Given pressures from the dean to cover X, Y, and Z topics, sometimes the more fundamental X and Y are sacrificed just to get to topic Z. I did get a chance to teach a semester at my own alma mater, and some of these chapters are directly from that class. My hope for teachers is to give you another tool that you can use to flip the switch on the "Aha!" light bulb over your students' heads.

Acknowledgments

No book is a single person's work. What any individual knows is a culmination of experience and lessons from many sources. I would like to thank some of the individuals that made this text possible.

My father for his common sense and his living proof that you can do what others say is impossible.

My mother for the smart genes she passed on to me and for her undying belief in the perfection of her children.

My wife for her patience and encouragement and doing the things I should have been doing just so I could get another chapter written.

My kids for understanding why dad couldn't make it to every game and had to spend time in his office every night.

My brother Robert with whom I embarked on this literary adventure, and Steve Petersen, a close friend and aspiring engineer for the late night graphic work.

For any of you I missed and feel neglected in not being thanked, give me a call. I'll buy you lunch!

What's on the CD-ROM?

The CD-ROM includes some handy files:

Circuit Simulator Link from Electronics Workbench™

Used properly, a simulator is a great way to check out your knowledge and help you understand how these parts work. Make sure you use it for the basic stuff first and read the chapter on tools!

Schematic Capture and PCB Layout

A handy tool to prototype your design. The company that offered this will let you upload the files right to their site and turn PCBs at reasonable price too!

FilterPro™

Filter pro, a cool program from TI to help you design op-amp filters of all types.

Thumb Rules Reference

A PDF reference of all the thumb rules in the text so that you can print out and stick all over your walls to impress the ladies. OK so it probably won't work, but it will help you remember these secrets of success!

Equations Reference

A PDF referencing all the equations used in the text. Put this on the wall next to the thumb rules and people will think you are pretty smart knowing all that stuff. The real benefit is that you won't have to remember anything and can save your brain power for more important things, like pondering what you should have for lunch.

Contents

CHAPTER 1

Three Things They Should Have Taught in Engineering 101

Do you remember your engineering introductory course? At most, I'll venture that you are not sure you even had a 101 course. It's likely that you did and, like the course I had, it really didn't amount to much. In fact, I don't remember anything except that it was supposed to be an "introduction to engineering."

Much later on in my senior year, and shortly after I graduated, I learned some very useful general engineering methodologies. They are so beneficial that I sincerely wish they had taught these three things from the beginning of my course work. In fact, it is my belief that this should be basic, BASIC knowledge that any aspiring engineer should know. I promise that by using these in your day-to-day challenges you will be more successful and, besides that, everyone you work with will think you are a genius. If you are a student reading this, you will be amazed at how many problems you can solve with these skills. They are the fundamental building blocks for what is to come.

Units Count!

This is a skill that one of my favorite teachers drilled into me my senior year. Till I understood this, I forced myself to memorize hundreds of equations just to pass tests. After applying this skill I found that, with just a few equations and a little algebra, you could solve nearly any problem. This was definitely an "Aha" moment for me. Suddenly the world made sense. Remember those dreaded story problems that you had to do in physics? Using unit math, those problems became a breeze; you can do them without even breaking a sweat.

Unit Math

With this process the units that the quantities are in become very important. You don't just toss them aside because you can't put them in your calculator. In fact, you figure out the units you want in your answer and then work the problem backwards to figure out what you need to solve it. You do all this before you do anything with the numbers at all. The basic concept of this was taught way back in algebra, but no one told you to do it with the units. Let's look at a very simple example.

You need to know how fast your car is moving in miles per hour (mph). You know it traveled one mile in one minute. The first thing you need to do is figure out the units of the answer. In this case it is mph or miles per hour. Now write that down (remember "per" means divided by).

$$answer = something \cdot \frac{miles}{hour}$$

Now arrange the data that you have in a format that will give you the units you want in the answer.

$$1 \cdot mile \times \frac{1}{1 \cdot \text{min}} \times \frac{60 \cdot \text{min}}{1 \cdot hour} = answer$$

Remember, whatever is above the dividing line cancels out whatever is the same below the line, something like this:

$$1 \cdot mile \times \frac{1}{1 \cdot \cancel{\text{min}}} \times \frac{60 \cdot \cancel{\text{min}}}{1 \cdot hour} = answer$$

When all of the units that can be removed are gone, what you are left with is 60 mph, which is the correct answer. Now you might be saying to yourself that was easy. You are right! That is the point after all—we want to make it easier. If you follow this basic format, most of the "story problems" you encounter every day will bow effortlessly to your machinations.

Another excellent place to use this technique is for solution verification. If the answer doesn't come out in the right units, most likely something was wrong in your calculation. I always put units on the numbers and equations I use in MathCad® (a tool no engineer should be without.) To see the correct units when it is all said and done confirms that the equations are set up properly. (The nice thing is MathCad automatically handles the conversions that are often needed.) So, whenever you come upon a question that seems to have a whole pile of data and you have no idea where to begin, first figure out what units you want the answer in. Then, shape that pile of data till the units match the units needed for the answer.

Remember this: *by letting the units mean something in the problem, the answer you get will actually mean something too.*

Sometimes Almost Is Good Enough

My father had a saying, "Almost only counts in horseshoes and hand grenades!" He usually said this right after I "almost" put his tools away or I "almost" finished cleaning my room. Early in life I became somewhat of an expert in the field of "almost." As my dad pointed out, there are many times when almost doesn't count. However, as the saying says, it probably is good enough to almost hit your target with a hand grenade. There are a few other times when almost is good enough too. One of them is when you are trying to estimate a result. A skill that goes hand in hand with the idea of unit math is that of estimation.

The skill or art of estimation involves two main points. The first is rounding to an easy number and the second is understanding ratios and percentages.

The rounding part comes easy. Let's say you are adding two numbers, 97 and 97. These are both nearly 100, so say they are 100 for a minute, add them together and you get 200, or nearly so. Now this is a very simplified explanation of this idea, and you may think "Why didn't you just type 97 into your calculator a couple of times and press equal"? The reason is, as the problems become more and more complex, it becomes easier to make a mistake that can cause you to be far off in your analysis. Let's apply this idea to our previous example. If your calculator says 487 after you added 97 to 97, and you compare that with the estimate of 200 that you did in your head, you quickly realize that you must have hit a wrong button.

Ratios and percentages help get an idea of how much one thing affects another. Say you have two systems that add their outputs together. In your design, one system outputs one hundred times more than the other. The ratio of one to the other is 100:1. If the output of this product is way off, which of these two systems do you think is most likely at fault? It becomes obvious that one system has a bigger effect when you estimate the ratio of one to the other.

Developing the skill of estimation will help eliminate hunting dead ends and chasing your tail when it comes to engineering analysis and troubleshooting. It will also keep you from making dumb mistakes on those pesky finals in school! Learn to estimate in your head as much as possible. It is OK to use calculators and other tools—just keep a running estimation in your head to check your work.

When you are estimating, you are trying to simplify the process of getting to the answer by allowing a margin of error to creep in. The estimated answer you get will be "almost" right, and close enough to help you figure out where else you may have screwed up.

In horseshoes you get a few points for "almost" getting a ringer, but I doubt your boss will be happy with a circuit that "almost" works. However, if your estimates are "almost" right, they can help you design a circuit that even my dad would think is good enough.

Thumb Rules

- Always consider units in your equations; they can help you make sure you are getting the right answer.
- Use units to create the right equation to solve the problem. Do this by making a unit equation and canceling units until you have the result you want.
- Use estimation to determine approximately what the answer should be as you are analyzing and troubleshooting; then compare that to the results to identify mistakes.