

Circuit Simulators and Computer Algebra - An Integrated Curriculum for Electronics Students

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Abstract

There has been increasing acceptance of the use of electronics circuit simulators as part of the first year college curriculum in electronics. These simulators assist in providing a richer class of circuits which can profitably be studied by beginning students. However, they may burden the student with a need to apply the algebra of circuit analysis to more complex circuits than the traditional curriculum. The need is to apply mathematical models (for example, simultaneous equations) to various example circuits in DC and AC circuit analysis. The authors describe a teaching strategy and a curriculum model which uses a circuit simulator to work with circuits as if they had laboratory test instruments available, giving the flavor of a real laboratory, and mathematics software which permits students to interact with mathematical solutions to obtain graphical, numerical and symbolic results. Such a curriculum brings the mathematics of circuit analysis into the same framework of interactive discovery as the rest of the electronics subjects.

Introduction

There were two main reasons for changing the curriculum. One was a push, the other was pull. First, let us look at the push. Teachers have been reporting increasing difficulty in teaching the necessary concepts in the first semester curriculum. The difficulty goes beyond the frequently mentioned lack of skill sets in mathematics and language arts and centers on the mental processes best described as transformational conceptualization. Students find it increasingly difficult to build mental models. One reason, of course, is that the required models are always increasingly more complex. To compensate for this deficiency and to attempt to bring to technical education a firmer, more concrete syllabus, the lecture room and the laboratory environment must be redesigned to encourage the teacher to pause at any time and ask the students to prove a point for themselves by using the lab stations at which they are sitting. This allows students who are kinesthetic learners (those who learn by doing), the opportunity to learn at the same time as the oral learners.

The pull comes from the fact that powerful computer simulation software, designed initially in the sixties, is now available to run on garden variety personal computers. The user interface has been improved to the point that first year students with little or no prior experience with computers can easily run these packages with only short orientation sessions. Since we have used electronics simulators in our upper semester technology classes for many years with good success, we were confident that such an approach could work with beginning students if carefully introduced.

We have chosen Electronics Workbench for electronics and Maple for computer algebra. Electronics Workbench' is a simulator which employs point, click, and drag technology in its user interface. Very little comes between the student and the problem which is extraneous. It is easy to choose circuit elements and to



connect them together. The simulation uses a graphic metaphor of common laboratory instruments, the digital multimeter, the oscilloscope, and the spectrum analyzer. Attaching these instruments to the circuit is a very natural and intuitive. On the screen the instruments look like realistic generic faceplates for the corresponding lab apparatus. This assists the students in making the mental connections between the computer screen and the real lab.

Maple* was chosen for its power, yet the kernel will run on the type of computer found in all college computer labs with acceptable speed. The commands are intuitive and are structured in the same way as they would be thought or uttered. There is an extensive on-line help system, giving examples of the commands as well as a brief description. There is a low priced student edition which contains the complete kernel and many of the library routines. By using its built in programming language, instructors can construct fascinating, optionally interactive, examples to further involve students in mathematical concepts. Its graphing capabilities, along with the incorporated word processor, makes it easy for students to write reports on their mathematical work while doing the actual calculations.

The role of the teacher changes, from teaching rote to showing how to get to the essentials of the problem. Much of the teacher's effort in the standard curriculum is concentrated in teaching the line-by-line transformations from the statement of the problem. By reducing the need for such emphasis on manipulative skills, a teacher can concentrate on the statement of the problem and on interpreting the computer generated results, accomplishing a higher level of learning. While this approach may not develop as many manipulative skills, most non-electronics majors are willing to let the machine take care of the intermediate steps. This leaves the students the important tasks of problem definition and analysis of the solution. While many progressive educators have expressed the view that the best way to introduce prospective electronics technicians and technologists to their discipline is to show them the big picture and then gradually refine the level of detail, this has not been a particularly successful classroom methodology. There are many reasons why this approach has encountered difficulties. Among them are the following:

- Without any detailed knowledge, students find it next to impossible to follow the generalized description and get anything concrete out of it. Their lack of knowledge of detail confuses them because they have nothing to get their teeth into.
- Not knowing how to calculate any results, and not knowing any formulas, students are mystified about the way actual designs are produced. It seems to them that they are learning nothing.
- The case study approach has had similar difficulties. While the benefits of the case study are well known, it is difficult to get beginning students to accept this approach because of their scant knowledge base. They do not know where to begin in tackling a complex problem, how to break it down into its constituent parts, and how to apply analytical techniques to each of the components.

On the other hand, the traditional building block approach is encountering ever increasing resistance. Students are unable to accept that they must master techniques and skills (in mathematics, circuit theory, and physics) which seem quite unrelated to the things they thought they would be studying. It is a long way from solving a linear equation in one unknown to solving a real problem, say in filter design. It is an even longer way from an introductory digital problem involving a few gates to the real world of PLD's, RISC and CISC chips and multi-megabit memories. It's a long way from the sine curve to cellular phones and from the basic physics of transducers and actuators to the control of the environment in a 200 store shopping mall. To many of our students the path seems far too long and they get discouraged.



In fact, the students maybe right. The simple fact is that innovation in electronics, with which they are very familiar as consumers, makes it impossible to catch up if one takes the approach in education that one must repeat all the historical steps before learning about the latest devices in electronic technology. There is just too much to learn and much of the “standard curriculum” is there only to “admit members to the club.” Too little use has been made of the new and immensely powerful information technology in the training of the technical school population. This technology actually renders major portions of the current curriculum obsolete and thereby achieves a two fold gain in efficiency. First, computers make short work of many computational problems in the current curriculum. More importantly, new software is available to address problems in a more global way. It is really no longer necessary to know the step by step procedure in solving an electronic circuit by hand. As all students know, such techniques are not really useful to them anyway, because any real circuit that they might want to try is too complex for them to get the answer in any reasonable time and with any reasonable probability of accuracy at the end of all those paper, pencil and calculator operations. It just isn’t the way circuits are designed today and students, if they don’t know that for sure, they at least strongly suspect it. Why not take a systems approach right from the start of their education if the technology is now here to support it?

There is no substitute to learning by doing, to learning the underlying concepts and to applying those concepts confidently. But it is unnecessary to insist on tons of rote calculations just because that was how things were done in the past. If time can be freed up to do the things that really matter, such as understanding the given problem, knowing the steps to take to solve the problem, and knowing how to verify that the solution is actually the correct one, then the job of the educator has been truly accomplished.

The approach that can now be taken is to de-emphasize the amount of fine detail (and rote calculation) in favor of concentrating more on the overall principles involved. If we make sure that our students can understand what is really required, they will be able to apply the same kind of tools that the professionals use when it comes to solving the given problem or project. By providing that kind of a learning environment, each student’s learning productivity will be enhanced.

The Classroom/Lab Environment

An integrated lecture/lab/computer room was designed to accomplish the educational goals of integrating concepts delivered primarily via the lecture mode with hands-on learning in a traditional electronics lab. The computer acts as the “glue” between these two modes, facilitating through simulation the transition from concept to competency. In a room which could accommodate forty students, there are ten lab stations. Initially, we thought that the computers should be placed right beside the other instruments to form an integrated workstation. We were prevented from doing so because of funding constraints. Instead, we placed the sixty computers in a nearby cluster of rooms. We are having good results with this arrangement, and it may in fact be preferable to having the computers right beside the other equipment. In the hours scheduled for laboratory, there are twenty to thirty people scheduled into the room. There are usually two persons per team, which means discussion and group work are part of the teaching strategy. We have found that some students take naturally to computer simulation and can use it as a bridge from a more conceptual starting place to an understanding of the hands-on construction of a circuit. Others are more comfortable when they build first and then use the computer as an aid to the understanding of the theoretical operation of the circuit. In both cases, the explanation given in the lecture is worked on by both simulation and actual construction.

What computer simulation allows the instructor to do is to show students that they can tackle a problem by starting with the overall concept and then gradually looking at increasing levels of detail. The traditional



course follows the opposite path, where teachers attempt to train students in manipulating fine detail in the often futile hope that the learner will be able to form a synthesis. The power of computer simulation is such that, if the student does know the overall principle, it is generally a simple matter to present the problem to the software and have it work out the fine detail, which it is very adept at doing. The final result is quickly generated, leaving ample time for experimentation on circuit variants.

The integration of electronics and mathematics is further enhanced by the use of Electronics Testbench. The package is designed to give on-line tests, and permits students to use Electronics Workbench simultaneously. It also allows teachers to design tutorials which may incorporate graphics and animation.

Benefits of This Approach

Students will be more competent

Implicit in this approach is a strong *learning by doing* component. This will encourage students to learn at a deeper level because the different approaches will foster many different learning actions, all contributing to seeing a problem from multiple viewpoints. Students are able to examine their own “what ifs” by using Electronics Workbench. They often answer their own questions by applying these tools.

Overcoming the fear factor associated with solving problems

Any tool which makes the hard work of mathematical analysis easier will be embraced by the students if it is properly integrated in the overall design and delivery of the training. When students know that the difficult mathematics of circuit analysis has been replaced by a software package which is easy to use, that the specification of the circuit is highly intuitive, and that visual output in terms of familiar instruments is produced, they will be more comfortable learning the necessary theory. They will have a powerful tool which will assist them in the investigation of the theory, allowing them to work through many more examples than would be possible using paper and pencil methods or even building the circuits in a prototyping fashion.

Alternating current can be introduced almost immediately

Teachers have always had difficulty with the idea of beginning AC concepts until a rather exhaustive exposition of DC circuits has taken place. The challenge was in the (mathematical) description of alternating current. Even if phasors or other geometrical techniques are taught instead of the full trigonometric approach, the level of abstraction made AC difficult to understand so it was postponed until the fundamental electrical concepts had been well taught and many examples had been worked out.

Under the new approach, the required skill is that of reading an oscilloscope face, because that is how the software (Electronics Workbench) presents its results. For beginning students, this is not quite as easy as the experienced person might imagine, but it is in itself a necessary skill to teach right from the beginning, so a double benefit is achieved. Students can begin to work with AC concepts much earlier on and they begin using the oscilloscope a few weeks into the course, both in simulation mode and also by using the actual instrument. Maple worksheets allow the student to interact with a pre-designed collection of functions, tailored to the problem at hand.



The role of the teacher changes

The motto for a teacher in this new approach is to be *a guide on the side rather than a sage on the stage*. Teachers must realize that with the powerful simulation software, students can and will experiment. They create circuits that may be much different from the ones which were used as examples. Students will ask about the novel and unexpected results that they encounter. A teacher will have to be ready to point the student back to the proper track or to encourage the student to follow a promising lead towards further discovery. Putting this kind of power in the hands of students maybe disconcerting to some teachers, but like any new powerful tool that becomes widely accessible, they must acknowledge its existence and make use of it.

The new software as the “glue”, cementing theory and practice

An additional advantage of using software simulators which have an intuitive user interface which mimics real-life measuring instruments is that they can be used to bridge the gap between theory and practice. A circuit diagram on the chalkboard is one thing, that same real circuit as built by a student is another. Many students have difficulty making the connection between the two. They rely on different skill sets to deal with analytical problems as opposed to construction problems and some students can miss the essential relationships between a real circuit and its schematic representation. By redrawing the circuit on the computer, students see that the exact shape of the circuit is not important, because they can drag components around. The “rubber band” connections to other circuit elements simply stretch and reposition themselves to accommodate the new location of the component. The simulation results remain the same. This makes it much easier for students to realize that when it comes to actually constructing the circuit, its layout may be quite different from the schematic, as long as topological relationships are preserved.

Students can do more investigations

Finally, the most attractive thing that the new software offers to the student is the ability to do more for themselves. The students can quickly draw a circuit on the computer screen, simulate it, modify it, change component values, and test their prediction of what should happen against the simulation results. It puts much more capability into the hands of relatively untutored, i.e., beginning students. The presence of a teacher is as important as ever to provide context, motivation and guidance, and to show the relevance of all this to the working world. However, the teacher’s role is now significantly different since more time can be spent coaching.

Conclusion

New advances in curriculum come at a price. Learning materials must be developed. Circuit files can be constructed to assist students in learning the essential concepts. Other circuit files serve as problem sets. Troubleshooting concepts and techniques are more easily taught, since Electronics Workbench permits the introduction of hidden faults in any component or components. These “faulty” circuits have the advantage of lasting much longer than real circuits. They can be copied infinitely and they can be kept from year to year on the storage disk of the network server. (And in the instructors’ personal file system!) Contrast this with the difficulty of building and maintaining fault finding exercises in real hardware!

Similarly, Maple labs present an interactive capability for solving any problem that fits the main paradigm.³ Worksheets can be used again and again. They can be applied to new problems in a very flexible way. A calculator does not keep results nearly as well as a computer. With the computer’s vastly greater storage



capacity, the student can have an “eager assistant” with a wide skill base waiting to aid in the solution of the problem.

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