The Use of Analysis Packages to Reinforce Engineering Concepts

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Abstract

A common problem often noted in students is that even though they can successfully manipulate the equations inherent in an engineering system they still fail to see the full significance of their work. This problem is often mitigated by appropriately designed laboratory experiments, but some concepts are often difficult to demonstrate in the laboratory and, even then, the desired concept or conclusion may not be reached or learned by the student. A number of faculty members at the Milwaukee School of Engineering (MSOE) have had some success reinforcing engineering concepts in a junior level course in computer-aided design for electrical engineers. The primary goal of the course has been to reintroduce students to analysis tools such as spreadsheets, Matlab. and symbolic math engines by using them to analyze and design circuits. To make the course more than a "gadgets" course, lecture examples and laboratory exercises have been developed which target relevant design issues and the demonstration of circuit concepts. Among the many areas addressed in this course are the effects of standard component values, component tolerances, non-zero initial conditions, and brown-out situations to real circuits. Other demonstrations show how the analysis tools can often be inaccurate or altogether wrong in the results they present and how the user of these tools might be able to detect when this is occurring. This paper will present many of the examples and laboratory exercises employed by this course and provide some feedback on their success in reinforcing material from other courses.

Introduction

The ultimate goal of any engineering curriculum is to prepare work-ready graduates with a sound understanding of how and why circuits or systems work and the ability to develop circuits or systems using this understanding. Given the fragmentation of course work into individual courses, it is challenging for students to integrate the concepts from one course with others before or after it in the curriculum. Many schools, MSOE included, have had considerable success mitigating this problem through the use of just-in-time instruction approaches and capstone design sequences. This, though, is often not enough to guarantee that a curriculum-wide understanding is obtained. Course material is often too distanced in time to properly reinforce or link the topics sufficiently for most students.

The effects of this temporal distance can be reduced by insuring that the basic concepts are well understood or that appropriate efforts are made to review the material before it is needed again. Properly designed laboratory experiments are an excellent way of reinforcing the abstract and dry material from a lecture. Many students benefit from this hands-on approach to learning. By building a circuit or system, monitoring its behavior, and then preparing a written or oral report most students develop a deeper understanding of the systems they will ultimately help design and analyze. However, this is often not enough. Many concepts are difficult to demonstrate in a laboratory situation because they are either difficult to setup or monitor properly. Additionally, as time passes the understanding often fades through lack of use or because it never really existed at all. Regular review of important materials and concepts is a partial solution, but there is too much material that needs to be covered for the later to be successfully implemented.

A number of electrical engineering faculty at MSOE have taken a slightly different approach to the problem of review. Rather than present the "old" material as review it is used in practical examples and lab exercises in a junior level course (EE383) in computer-aided design. In addition to teaching the students how to use computer tools like spreadsheets, Matlab, and symbolic math engines to perform common engineering analysis and design this course attempts to reinforce many of the concepts that students have never fully grasped in a practical sense.

This paper will discuss the history of EE383 and then provide specific examples from EE383 used to deal with this lack of understanding. Some of the areas addressed with be the effects of standard component values, tolerances, non-zero initial conditions, and other practical issues. Some anecdotal evidence will also be presented which indicates that this approach is showing positive results with the students.

History of EE383 – Computer-Aided Desire

EE383 was originally designed as a sequel to EE381 – Applied Numerical Methods. The goal was to expand upon the numerical methods introduced in EE381 and to further enhance the computer programming skills which were being exercised in EE381. With the more modern introduction of the personal computer and the nearly universal access to computers enjoyed by today's engineering students the focus of this course began to change. As more and more useful tools such as SPICE, Matlab, and spreadsheets became readily available the goals of EE383 began to shift. There was still a strong emphasis on understanding the mathematics and algorithms behind analysis and design of circuits, but the focus on high-level language (FORTRAN) programming began to decrease. As specialized toolboxes and libraries became readily available, EE383 had become largely a "gadgets" course. The need to understand modern computer aids was still there, but the link to understanding the algorithms was rapidly being eroded.

In the spring quarter of 1993 Dr. Mark Sebern was assigned to teach EE383 for the first time. Since the course had no assigned textbook and portions of the syllabus were rapidly becoming out of date, he chose to refocus the course. He realized that in their freshman year our electrical engineering students were being taught the basics of spreadsheets and other common tools. Further, many other courses were requiring the use of analysis tools in one or more assignments so in some respects portions of EE383 were little more than review and others had become of questionable worth. To improve the course Dr. Sebern decided to concentrate on how to use these computer tools as practicing engineers might. He spent a large portion of the course discussing how the tools could be used to model circuits and other engineering systems as well as some of the features of these tools not often taught in the freshman courses. As he typically does, Dr. Sebern incorporated practical examples from his 20 years of experience as a consulting engineer. Along the way he noticed that he was reinforcing key circuits concepts in such a fashion that his students were finally beginning to integrate and understand them with greater clarity. Since then, Dr. Sebern has shared his approach with other faculty with the result that even more enhancements are being made to EE383.

Dealing with Standard Component Values

In introductory circuits courses students are often asked to analyze resistor networks and develop Thevenin equivalent models of circuits. Students are also asked to design simple amplifier circuits in later electronics classes, but often the problem is artificially "engineered" so that a resistor value stocked by MSOE'S Technical Support Center results. In reality a resistor or other component value looks reasonable, but would be impractical to work with since it would require a special order.

One of the first exercises typically undertaken by students in EE383 is to develop a deceptively simple circuit, but to restrict the components to standard values. The goal is not to overwhelm the students with complex formulas. but to concentrate on how limited component choices affect a design. Figure 1 shows a simple voltage divider circuit used as a "regulated" power supply for a battery operated system. Amen: the difficulties in this problem is that the target voltage cannot be exactly reached and in order to get decent voltage regulation with changing loads the power transfer is unacceptably low. Students often tackle this problem with the use of spreadsheets and lookup tables to consider all the possibilities in one simple table.

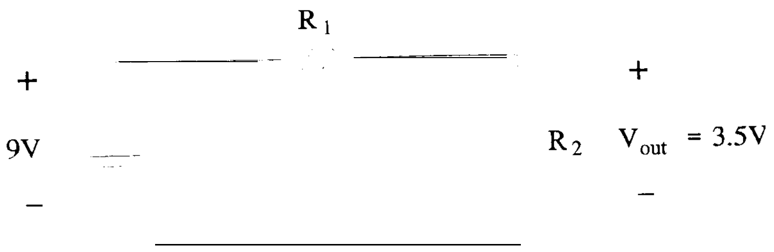


Figure 1 – Resistor divider “regulator” to demonstrate standard component values

Effects of Initial Conditions on Circuit Behavior

All electrical engineering programs spend a considerable period of time studying both steady-state and transient circuit response. Steady-state response of DC and sinusoidal AC circuits are typically studied first. Under this analysis all energy storage devices (capacitors and inductors) are considered to be in steady state. This describes the state of most circuits under regular operating conditions and is valuable in and of itself. The idea of differential equation based behavior of circuits is then studied with the use of Laplace Transforms to simplify modeling and computation. Since it introduces complication, the initial conditions are typically set to zero and then introduced briefly as a special case later. Further, the focus is primarily on simple forcing functions such as steps and impulses with sinusoidal and other complex sources largely ignored. Consequently many students do not fully integrate the ideas of transient and steady-state behaviors. By introducing the student to circuit modeling where cases with and without initial conditions appear side-by-side it quite clearly reinforces the role of the transient and steady-state behavior of circuits.

The detrimental effects of this are also shown later in more complicated circuits where overshoot occurs. An exercise is incorporated where the students use a forcing function which results in overshoot piling upon overshoot from cycle to cycle ultimately resulting in over-current or over-voltage problem in components.

Dealing with Tolerances and Brownout

All components in signals in a system are susceptible to variations in value. By working in-class examples of sensitivity, parameter variation, and Monte-Carlo analysis the need to take into account these variations is demonstrated. Figure 2 shows an example of a voltage-regulator based power supply. The analysis of this circuit under an 80% brownout of the AC source is shown in Figure 3. The horizontal line indicates that minimum acceptable voltage under which the regulator is capable of operating. In this example the capacitor used appeared to have an adequate safety margin under normal operating conditions, but the simulation clearly shows that it is really inadequate. These examples help to reinforce in students the need to consider variations in components and signals.

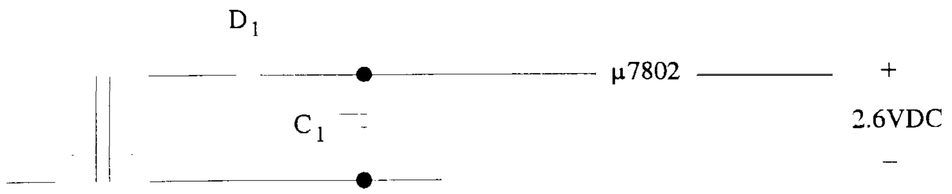


Figure 2 – Regulated power supply

Additional Benefits

A frequent complaint of recent engineering graduates is that because their understanding of the analysis a computer tool is performing they have an almost blind trust in the results. One of the goals of EE383 is to give this trust a healthy shake and to develop some basic skills in spotting potential “dangerous” results. It does not take long to develop examples where reliance on the default step size provided in packages like Matlab and SPICE can result in problems. Resonance points can be missed or other “mistakes” might occur. Figure 4 shows a Runge-Kutta based analysis of the power supply of Figure 2 using Matlab. Figure 4a displays both the input and output wave-forms, but since only the default time points are used it is not immediately clear that there is a problem. In Figure 4b the full input wave form is included and this clearly shows that some input wave form periods were skipped by the library call. One technique used in EE383 is to always be wary of piece-wise wave forms where the computer may have not looked closely enough.

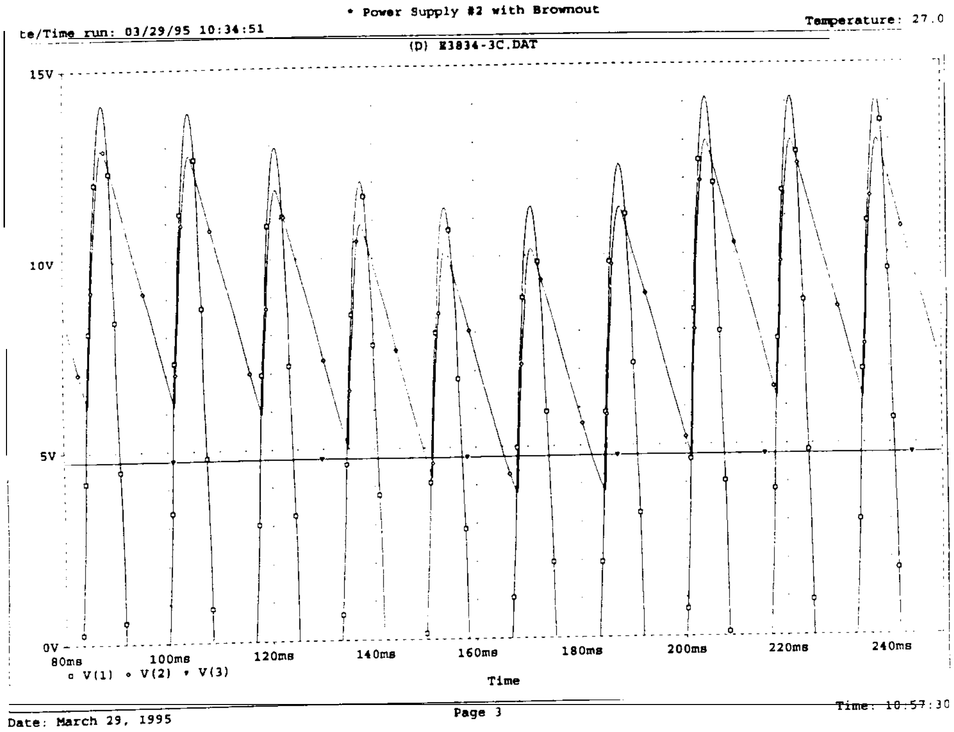


Figure 3- Regulated power supply response under brownout

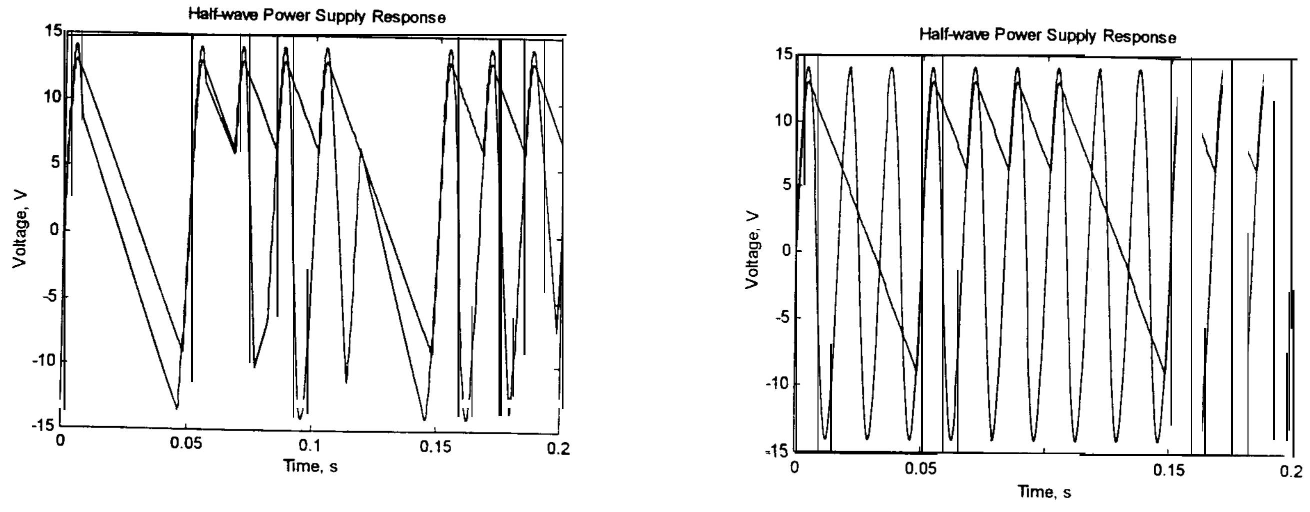
Additional time is spent in EE383 determining the advantages and disadvantages of the many tools used. The goal is to realize that no tool is good for all jobs and that tools often complement each other. Ultimately a student should be able to choose which tools to use for a specific task and to justify that choice.

Success of EE383

Anecdotal evidence from conversations with students and course evaluation forms indicate that EE383 is well received. The students generally feel the course provides the benefits or clearer understanding of computer tool use in engineering, the advantages and disadvantages of each tool, and the practical demonstration of analysis under realistic operating situations.

Conclusions

Proper use of lecture examples and class exercises can significantly improve student understanding of engineering concepts. By requiring the use of modern computer analysis tools the result can easily be more than a simplistic demonstration of how to use each tool. It is the combination of the computer tools with realistic and practical examples and exercises which make these results possible. By adjusting some of the focus away from the computational overhead the student can concentrate on the bigger picture and thus come away with a significantly better experience and understanding.



(a) (b)

Figure 4 – Erroneous power supply analysis using (a) default time steps and (b) uniform time steps

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Biography

Dr. Henry L. Welch is an Associate Professor of Electrical Engineering and Computer Science at the Milwaukee School of Engineering. He earned his Ph.D. in Computer and Systems Engineering from Rensselaer Polytechnic University in 1990. His primary teaching areas are in digital circuits, microprocessor systems, and advanced computer engineering: topics such as artificial intelligence, computer graphics, and fuzzy logic.