Macroelectronics: A Gateway to Electronics Education

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Abstract
Conventional approaches to teaching electronics and instrumentation emphasize microelectronics instead of providing a more general, systems-level approach. We have shifted the focus in the first electronics course from individual devices and circuits (microelectronics) to the system as a whole (what we term *macroelectronics*). Our preliminary experience with the concept was positive at our respective institutions; a grant[1] allowed us to develop the approach more fully.

The macroelectronics approach can be summarized as consisting of two primary elements: (i) treatment of topics chosen by the instructor—later complemented by topics derived from student projects, and (ii) utilization of a project-based learning environment to increase motivation, highlight important topics, and facilitate knowledge-integration.

Materials developed to support the macroelectronics approach include an instructor's manual and a variety of exemplar project descriptions.

Introduction
An electronics course is a standard component of an electrical engineering (EE) program. The numerous texts to choose from (see Refs. 1 and 2, for example) are typically organized along traditional lines. Nonlinear devices are considered, beginning with diodes and spanning transistor technologies (BJTs, FETs, MOSFETs, etc.). Basic circuit topologies are presented, followed by progressively more complex circuits to form primitive functions. Feedback is treated along the way, as are other topics such as digital circuits. Most curricula also include an electronics laboratory, which may not be tightly coupled to the electronics course.

We are strongly motivated to change the way we approach teaching. ABET's Criteria 2000[3], the ASEE report, "Engineering for a Changing World"[4], and discussions with engineering practitioners all are asking us to change the way engineering is taught. Material must be relevant—ever more important as the pace of technological innovation escalates. The educational process must be outcomes oriented—we need to decide what we want our students to learn and then see if they learn it. Fresh graduates should be

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productive; they should be able to apply the tools and problem-solving skills they acquired in their degree programs to solve complex, multidisciplinary problems.

Change can range from adjustments to how courses are configured and delivered, to more fundamental changes in the engineering curriculum. We have used the macroelectronics approach primarily as a tool for re-engineering traditional courses. Project-based components have been introduced with a goal of enhancing students' teamwork skills. Cooperative learning is not a new concept, but it is an effective teaching strategy. For example, Johnson, et al. found that small groups of students working together in a cooperative-learning environment improve problem-solving skill[5].
Building on our earlier work[6], we sought to

- Introduce fundamental concepts of electronic systems through the use of macroelectronics.
- Employ a project-based learning environment to increase motivation.
- Selectively cover microelectronics topics, partially guided by project requirements.

This paper describes alternative teaching strategies for the standard EE electronics courses at each of our institutions. Outlines of course contents, project descriptions, and some assessment results are included.

Objective 1: Macroelectronics
Imparting knowledge of macroelectronics attempts to convey a systems view of electronics. Table 1 for an amplifier suggests the hierarchy of content that characterizes the approach. At the highest level, the concept of "amplification" is explored. Students need to develop concepts of input, output, and the transfer function of electronic systems. This "black box" view will help them see the broader picture of a system to help organize and guide development of progressive levels of complexity. In the case of amplification, there are many ways to achieve it—for example, using an operational amplifier (op amp). At this level, the op amp remains an abstraction with ideal behaviors. Understanding different ways of creating an op amp or using other techniques to achieve amplification requires microelectronics topics. Then understanding how typical microelectronic elements work requires that the physical-level abstraction be treated, termed *μMicroelectronic* in the table.

Table 1. Hierarchical views of an amplifier.

View	Structure	Elements
Macroelectronic	Amplifier	I/O relationships Zi, Zo
Macroelectronic	Op amp with feedback elements	Closed-loop transfer function
Microelectronic	BJT	Differential amp

	implementation of an op amp	Current sources Cascode stage Power stage
μMicroelectronic	IC layout	Device physics

Traditional electronics courses contain elements of the macroelectronics approach when treating op amps. Students find op amps one of the easier topics to understand and are gratified to find they can analyze and synthesize useful op-amp circuits. At this point, the electronics course launches into a collection of discrete electronic elements that get combined into seemingly unrelated circuit topologies. If the course is long enough, students may finally see enough elements combined to create an op amp.

A good starting point is to take an instrumentation approach[7,8] and describe what needs to be accomplished from a signal-flow standpoint. Input/output (I/O) relationships compactly summarize the behavior of the system. Figure 1 shows some typical examples.

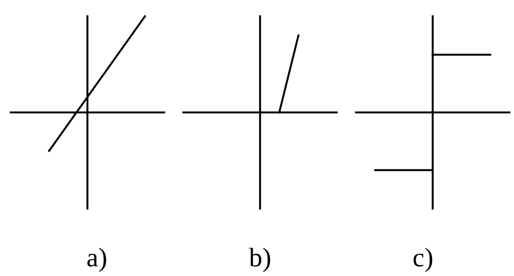


Figure 1. Useful I/O relationships including, a) $y=mx+b$, b) deadzone, and c) limiter (comparator).

Objective 2: Project-based Learning

Defining a companion project is the next major element in the approach. Projects provide motivational examples that reinforce topics covered in the lecture or discussion sessions. More importantly, they convince the students that they, too, can design useful electronic systems. Almost any example will suffice since there will be some combination of power supply, input signal conditioning, signal processing, and output conditioning required that will cover more than enough microelectronics topics for a typical 2- or 3-credit-hour course. Projects we have used include power supplies, curve tracers, function generators, voltmeters, tube testers, etc.

One of the Fall 1996 offerings of Electronics I at Kansas State University (KSU) was designed using project-based delivery[9]. The project chosen was a power supply to meet the specifications summarized in Table 2. Since then, the power supply project has been used several times at both KSU and Rowan. Figs. 2 and 3 show the schematics for a typical power-supply design.

Table 2. Power supply specifications.

Parameter	Target
Output voltage	0 to ±15 Vdc @750 mA w/ < 10mV ripple
AC mains	115 VAC, 230 VAC switch-selectable
Output adjustment	Individual or dual-tracking

The Fall 1996 class was organized as a company. Each student had a dual assignment as a design engineer and in an additional corporate function. This provided a way to accomplish the important support functions needed to complete a product design. Job titles for a large class could include President, CEO, CFO, VP-Engineering, Director of Purchasing, Marketing Manager, Manufacturing Engineering Manager, Head of PCB Engineering, Head of CAE/CAD, Graphic-arts Manager, Head of Test and Measurement, etc. The use of a company structure is not central to the macroelectronics approach.

The Fall 2000 offering at KSU took a different approach, with students working in teams. During the early part of the semester, the teams were given the task of constructing mini-projects that the instructor designed. Later, students were reassigned to new teams, and each team was given a more complicated project which was partially designed by the instructor. Each team was to finish the design and then build, test, and evaluate its project. At mid-semester, teams were reformed, and the new teams chose projects for which they were to carry out the majority of the specification and design, followed by construction, testing, evaluation, and reporting. These latter projects included a variable, dual-tracking, regulated, benchtop power supply; a semiconductor curve tracer; and a true-rms digital voltmeter.

The Spring 1998-2000 offerings (and the upcoming Spring 2001) of Electronics I at Rowan have also used project-based instruction. The power-supply project idea was borrowed from KSU and modified slightly; one section also designed a switching power supply variation. A semiconductor curve tracer was a second project. Later offerings added a function generator project.

Objective 3: Microelectronics

The topics selected for lecture and discussion were drawn from two sources. The first source is those topics the instructor believes to be essential. The second source involves mining the projects for additional topics. The list of topics sometimes appears to be almost random; however, it mimics many aspects of the design process. As an example, topic sequences for a KSU offering (14 weeks) and a Rowan offering (8 weeks) are listed below.

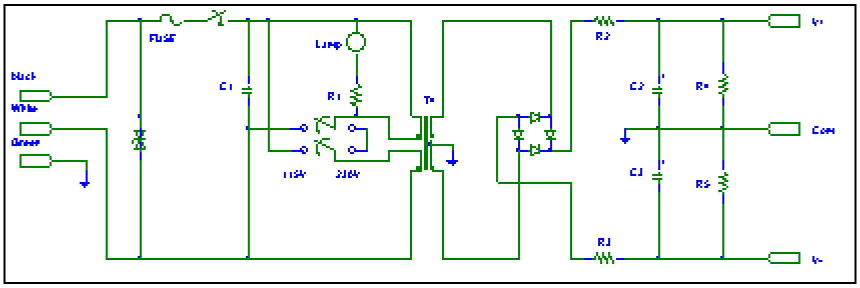


Figure 2. Mains power supply (KSU).

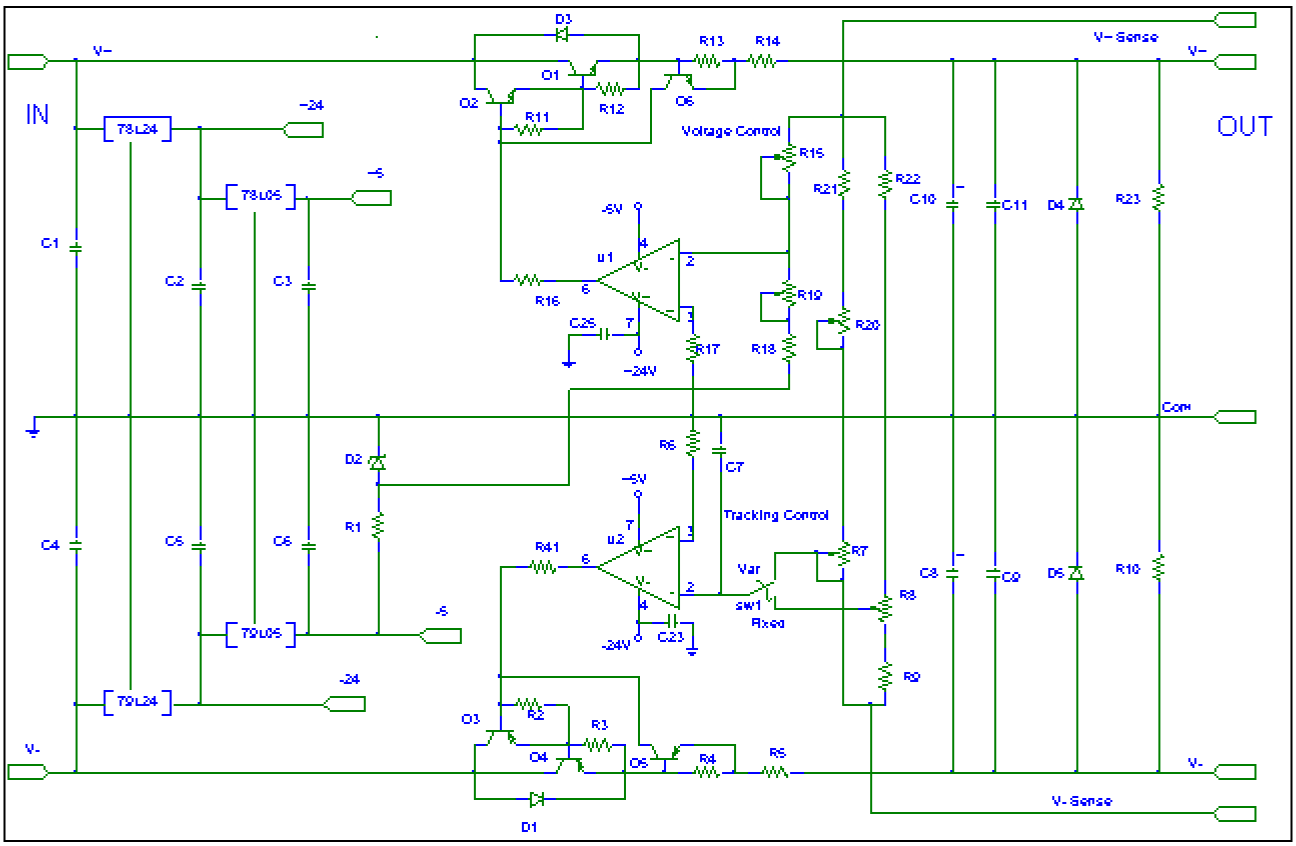


Figure 3. Dual-tracking, current-limited power supply (KSU). Meter circuitry not shown.

<u>KSU topics</u>:

1. The design process
2. Traits of a good designer
3. Review of basic circuit theory
4. Frequency response and Bode plots
5. How to read data sheets
6. Product marketing
7. Basics of BJTs

8. Common-emitter amplifiers
9. Two-port networks
10. Diodes
11. Diode applications
12. Overview of a dual-tracking power supply
13. Emitter-follower
14. A regulator made of an emitter-follower
15. Zener diodes and regulators
16. Series-pass regulator design
17. Sizing capacitors for power supplies
18. Constant-current sources
19. Darlingtons
20. Current limiting
21. Improved regulation using feedback
22. Variable-output power supply
23. Improving performance by increasing loop gain
24. Making outputs adjustable to 0 volts
25. Op amps: powering, output voltage swing
26. Differential BJT pair
27. Overall power-supply schematic
28. Thermal calculations for heat-sink sizing
29. Power derating curves
30. Meeting specifications
31. Choosing an op amp
32. Choosing pass transistors
33. Approaches to ac transient suppression
34. FETs and typical configurations
35. Brief overview of vacuum tubes

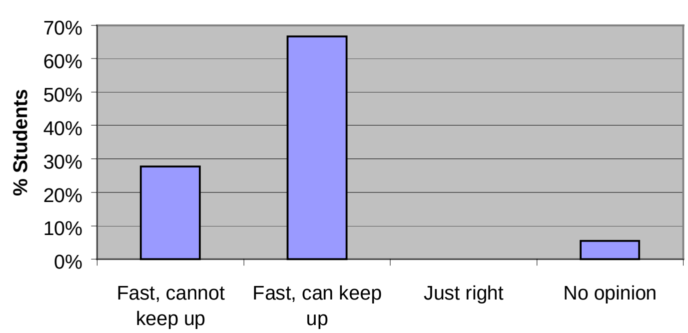
Rowan topics:
The eight-week sequence of topics included:
1. Review of networks: Intro to projects
2. Review of networks: Controlled sources
3. Review of op amps
4. Applications of op amps
5. Real-world op amps (with lab)
6. Interpreting lab results, team assignments
7. Systems view of instrumentation: 10x probe
8. Two-terminal devices (diodes)
9. Diode applications: rectifier, shunt regulator (with lab)
10. Iterative solution for nonlinear elements
11. MATLAB nonlinear solution methods
12. Precision rectifier
13. Ripple in half-wave rectifiers
14. Intro to three-terminal devices
15. BJT inverter (with lab)

16. BJT follower (with lab)
17. BJT small-signal analysis (with lab)
18. Power-supply bypassing
19. Grounding
20. MOSFETs with applications
21. BJT differential amplifier
22. BJT current source
23. BJT cascode stage
24. BJT power stage
25. BJT op amp
26. Miller effect
27. Project presentations

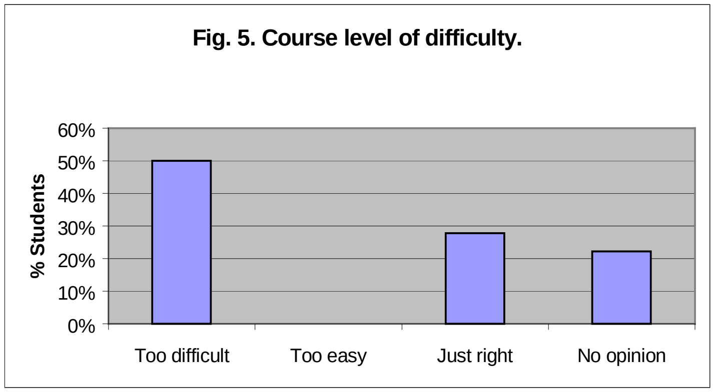
Assessment

We have assessed the macroelectronics approach using both formal surveys and using informal faculty evaluations of student performance in follow-on courses. In our earliest offering, a majority of students complained about the rapid pace of the course. We tried to address this concern by adjusting the pace of topics, which involved pruning the topic list. In the survey administered in Spring 2000, we asked students to rate the pace of the course. Of the 30 respondents, two-thirds believed that the course is fast paced but that they could keep up; but one-third of the students believed that it was too fast. Adjusting the scope of topics to cover the needed material while keeping it within student perceptions of reasonable pace remains a challenge.

Fig. 4. Course pace.



Closely related is what students think about course difficulty. On the one hand, we are using project-based learning to help students see the importance of various topics; on the other hand, the array of lecture topics combined with project difficulties form a perception of overall course difficulty. Fig. 5 summarizes responses to the question of perceived difficulty of the course. Fully half of the respondents believe that the course is too difficult. Note, too, that it is also difficult for faculty in that there can be significant preparation involved for presenting topics that do not flow sequentially from a textbook.



Perhaps one of the most important measures of the effectiveness of the macroelectronics teaching approach is student performance in follow-on courses. In the case of Rowan, students' abilities—with projects in general as well as with electronic projects—are called upon in the Engineering Clinics. During both Spring 1999 and Spring 2000, sophomore students taking Sophomore Clinic II were involved with the design and fabrication of a guitar effects pedal. At the beginning of the semester, they have had only a first network theory course, and no electronics. By the end of the semester, they have completed the macroelectronics course, a digital systems course, and a second networks course. Their grasp of electronics is significantly improved at semester's end.

As first-semester juniors, students take Junior Engineering Clinic I. Many projects involve the design and construction of electronics subsystems as part of an overall project. Our experience shows that the macroelectronics background provides a solid base from which students can attack new problems. During Fall 2000, as part of their Clinic Consultant obligations, a group of juniors who had just completed Electronics I during that spring, went on to redesign and fabricate the projects they had previously completed. Three teams produced power supplies, a curve tracer, and a function generator, all significantly enhanced. Students demonstrated that not only had they grasped the original concepts, now they were able to extend their knowledge and improve performance. For example, the function-generator team increased the usable frequency of their instrument by a factor of ten.

Results and Discussion

We believe that the combination of the macroelectronics approach with use of project-based instruction forms a compelling way to teach introductory electronics. One caveat is that it requires significantly more effort on the part of both instructor and student. The instructor must be prepared to deliver just-in-time instruction on topics of related to a particular project. On the other hand, many of the topics can be anticipated and planned for in advance. Finding textbooks appropriate to this approach is also a challenge. Currently, we use a standard electronics textbook[2] and supplement through generated materials and outside readings. We are working on a draft textbook and instructor's guide to capture much of the approach. Like other texts, this one will also be incomplete because the content needs to be adjusted to match the projects employed.

We are also asking more of our students. Not only must they master some number of traditional topics, but they must also develop effective working relationships and time-management skills in order to complete their project. The project vehicle is a way to treat nontraditional—but important—topics; it gives us a chance to transmit some important values of the engineering enterprise[10].

Conclusions

We have created *macroelectronics* as a method for teaching introductory electronics. Macroelectronics emphasizes a systems approach to convey microelectronic content. Class projects are employed to provide opportunities to help students see how the material applies to real systems. The design projects also provide a source of additional topics that are not traditionally included in electronics courses.

Acknowledgment

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