An Application Oriented Course Sequence in Electronics in ECET

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ABSTRACT

As the data rates in computers and communication systems zoom into the gigabit range, the analog signal techniques have assumed great importance. New analog design techniques and circuit layout techniques are being used in modern industry. There is an urgent need for bringing these advancements into the classroom. Furthermore, with availability of so many integrated circuits and systems-on-chip, the electronic design in industry has become more system oriented than before. This paper presents a sequence of two courses to meet the above needs in the undergraduate electronics courses: Analog Electronics and Digital Electronics. The courses use top-down instruction starting from the system level followed by component level understanding. The first course is oriented to teach the system level input-output characteristics of analog electronic components and subsystems. The second course focuses on teaching the modern digital ICs and their applications, the design of high speed switching circuits using the modern electronic design automation (EDA) tools. The topics in the second course include the power up/down sequencing, hot-swap circuits, clock generator and recovery circuits, heat management considerations, various signaling standards and an introduction to signal integrity, EMI, shielding, grounding and layout issues in printed circuit boards, integrated circuits and packages. Students use the simulation tools which are currently being used in industry thus reducing the gap between industry and education. The hardware experiments help in developing troubleshooting skills and learning about components.

I. Introduction

There is renewed activity in the field of analog electronics in the modern communication and networking industry. As the data rates in computers and communication systems increase into the gigabit range, the analog signal techniques have greater importance. New analog design techniques and circuit layout techniques are being used in modern industry. Many of the current analog course sequences consist of courses to teach physics of electronic components such as diodes and transistors and a substantial part of the course is devoted to learning discrete design techniques. However, most technology graduates work on systems that use integrated circuits and electronic subsystems. Very rarely, they are asked to design with discrete components. The design using discrete components is required in semiconductor industry, but they require more depth in the subject than what can be learned at the undergraduate level. Therefore, there is an urgent need for shifting the focus from microelectronics and discrete design to designing with integrated circuits and design issues at system-level. Furthermore, new developments and design techniques in electronics must be incorporated in the undergraduate electronics courses.

II. Course Sequence

The new approach is top-down instruction starting from system level and then getting deeper into component level understanding. We present a sequence of two courses to address the requirements of a new electronics curriculum:

1) **ECET 154** Analog Electronics
2) **ECET 356** Digital Electronics

ECET 154 educates the students on the system level input-output characteristics of electronic components and subsystems. ECET 154 provides the background in electronics for higher-level courses in computer, communication, networking and process control. ECET 154 is a required course in all options of ECET. Objectives of ECET 154 are to learn (a) the operational amplifier device and applications, (b) the design of power supply circuits, (c) the design of power and tuned amplifiers, (d) the analog signal processing circuits and (d) the use of a simulation tool such as MULTISIM. Topics cover the operational amplifiers, diodes and transistors, linear and non-linear application circuits such as comparators, Schmitt triggers, filters and oscillators and the design of the regulated power supply, driver circuits, power amplifiers and modulators. Use of transistor as a switch and the related applications are also introduced.

ECET 356, is a required course in the Computer Engineering option and the Communication/Networking option. Objectives of ECET 356 are to learn (a) the modern digital ICs and their applications, (b) the design of high speed switching circuits, (c) the printed circuit design issues in high-speed electronics and (d) the use of a software tool CADENCE SPECCTRAQUEST[4]. Topics cover transistor switching circuits, generation and propagation of pulses, pulse driver circuits, modern high-speed digital integrated circuit technologies, memory circuits, analog and digital switches, multiplexers, power up/down sequencing, hot-swap circuits, clock generator and recovery circuits, data processing and recovery circuits, various signaling standards, analog to digital conversion and an introduction to signal integrity, EMI, shielding, grounding and layout issues in printed circuit boards, integrated circuits and packages.

III. ECET 154 - Analog Electronics

This is a course with 3 lecture hours, 3 laboratory hours and 4 credits.

Prerequisite:	ECET 100-level course in dc circuits or the consent of the instructor
Prerequisite or Co-requisite:	ECET 100-level course in ac circuits or the consent of the instructor

The ‘consent of instructor’ provides the flexibility of admitting students with prior practical experience from industry for updating their knowledge base.

Textbook : "Operational Amplifiers and Linear Integrated Circuits"
- Robert F. Coughlin and Frederick F. Driscoll, 6th edition[1].
Simulation Tool: MULTISIM [2] and Electronic Workbench software,
-Electronics Workbench USA

3.1 Course Goals/Objectives

By the end of this course, the student should be able to understand and work with the important analog electronic circuits and be prepared to build upon this knowledge in higher level courses in power, communications, control systems and networking. The course objectives are to provide the fundamentals of analog electronics and knowledge of important analog circuits with applications. The laboratory portion of the course utilizes MULTISIM or PSPICE for circuit simulation. After successfully completing this course, the student should be able to:

1. Use operational amplifier
2. Design power supply circuits.
3. Design power and tuned amplifiers
4. Analyze and design analog signal processing circuits
5. Use MULTISIM

3.2 Topics

The topics include amplifiers, comparators, filters, oscillators, power supplies, driver circuits, power amplifiers, modulators and demodulators, analog-to-digital and digital-to-analog converters and phase lock loops. The course starts by introducing operational amplifier as the basic building block. Students learn how to use operational amplifier as a component in building amplifiers, comparators, filters, oscillators and timers. These topics consume approximately half of the semester (23 hours). Next four weeks are devoted to the discrete level components, concentrating on the component-level characteristics with a limited discussion of the microelectronics. The discrete components are diode, bipolar transistor and field-effect transistor. Students learn the design of a few important BJT and MOS amplifier configurations and the design of an unregulated and a regulated IC power supply and power amplifiers. Next two weeks are devoted to using transistor as switch, drivers for relays and dc motors and introduction to A-to-D and D-to-A converters, modulator and demodulator circuits and phase-lock-loops. The sequence of topics and the time spent on each topic are given in Table 1 in the appendix of this paper.

Students have shown a lot of interest in the operational amplifier portion because it is easier than the discrete portion. In fact by teaching the operational amplifier and its applications in the beginning of the semester, it was easier to keep their attention in the class. The discrete components section of the course is a bit harder because the students have to use relatively more number of formulae to solve homework problems. The end-of-semester feedback from students shows that they have liked the organization of the topics.

3.3 Laboratory Exercises

The laboratory exercises are closely tied to lecture topics. A laboratory exercise consists of two parts: a pre-lab exercise and an experimental exercise. The pre-lab exercise asks students to either calculate/estimate the expected results or simulate the circuits before coming to the laboratory class. The second part requires a final report containing the experimental results and observations. The exercises are listed in Table 2 in the appendix of the paper.

The initial lab exercises using Opamps have fewer components to build circuits; therefore, students commit fewer mistakes and are able to complete experiments successfully within the class time. Students feel satisfied. The laboratory involving bipolar and MOSFET transistors use several components; therefore more mistakes are committed in wiring the circuits on the breadboards and require more troubleshooting time. The MULTISIM simulations were enjoyed by all.

IV. ECET 356 – DIGITAL ELECTRONICS

This is a course with 3 lecture hours, 3 laboratory hours and 4 credits.
Prerequisite: ECET 154 course in analog electronics or the consent of the instructor
The 'consent of instructor' gives the flexibility of admitting students with prior practical experience.

Textbook:	High-Speed Digital Design[3] - Howard Johnson and Martin Graham, Prentice-Hall Inc.
Simulation Tool:	CADENCE SPECCTRAQUEST[4] version 14.0 or higher

4.1 Course Goals/Objectives

By the end of this course, the student should be able to understand and work with the high-speed digital electronic circuits being used in modern communication, networking and RF industry, and as such is ready to build upon this knowledge in higher level courses in Computer, Communications and Networking engineering. This course is designed to provide the fundamentals of digital electronics and introduce important digital circuits used in modern Computer, Communication and Networking industry. The laboratory portion uses the CADENCE SPECCTRAQUEST software. After successfully completing this course, the student should be able to:

1) Use modern digital ICs
2) Design high-speed analog and digital switching circuits.
3) Understand printed circuit layout issues in the design of high-speed electronic circuits
4) Use SPECCTRAQUEST software for signal integrity analysis and simulation.

4.2 Topics

A study of transistor switching circuits, including Bipolar Junction Transistors and Field Effect Transistors, the concepts of fan-in, fan-out and noise margins, generation and propagation of pulses, driver circuits, TTL, CMOS, Schottky, and other modern high-speed digital integrated circuit technologies, clock generator and recovery circuits, clock distributors, serializer/deserializers (SERDES), analog MOS switches, analog and digital phase lock loops, power up/down sequencing, hot-swap circuits, data processing and recovery circuits, various signaling standards and analog-to-digital and digital-to-analog conversion circuits. Introduction to signal integrity analysis and design, EMI and shielding, grounding and layout issues in printed circuit boards, integrated circuits and packages. The signaling standards include, low-voltage CMOS, low voltage TTL, emitter coupled logic (ECL), and positive emitter coupled logic (PECL), low-voltage differential signal (LVDS) and current mode logic (CML). The sequence of topics and the time spent on each topic are given in Table 3 in the appendix of this paper. This course is offered in the sixth or the seventh semester.

4.3 Laboratory Exercises

The laboratory exercises are closely tied to lecture topics. Like in the first electronics course ECET 154, a laboratory exercise in ECET 356 consists of two parts: a pre-lab exercise and an experimental exercise. The pre-lab exercise asks students to either calculate/estimate the expected results. The pre-lab assignment may also be a reading assignment and asking the students to list three questions for which they need explanation. The lab instructor collects questions from the class and then provides answers during the lab hours. The second part may be either an experiment or a simulation on Cadence SPECCTRAQUEST depending on the availability of components. The hardware experiments will require pre-fabricated printed circuit boards with soldered components and with sufficient number of test points. Instead of soldering components, sockets may also be used. Many of the high-speed components are available in small-outline packages; therefore, they require special sockets. All labs require pulse generators with low transition-times and high frequency probes with the oscilloscopes.

A final lab report is required which should contain the experimental/simulation results and observations. The exercises are listed in Table 4 in the appendix of the paper. In the following section we present a laboratory exercise as an illustration.

4.3.1 A Laboratory Exercise: Hot Swap Controller

Pre-Lab

Download specifications of the important components in the schematic. Simulate the hot-swap circuit using MULTISIM. If some component model is not available, either get alternative models or build approximate models.

Experiment

Connect the circuit as shown in Fig. 3 and verify the results with respect to the results in pre-lab.

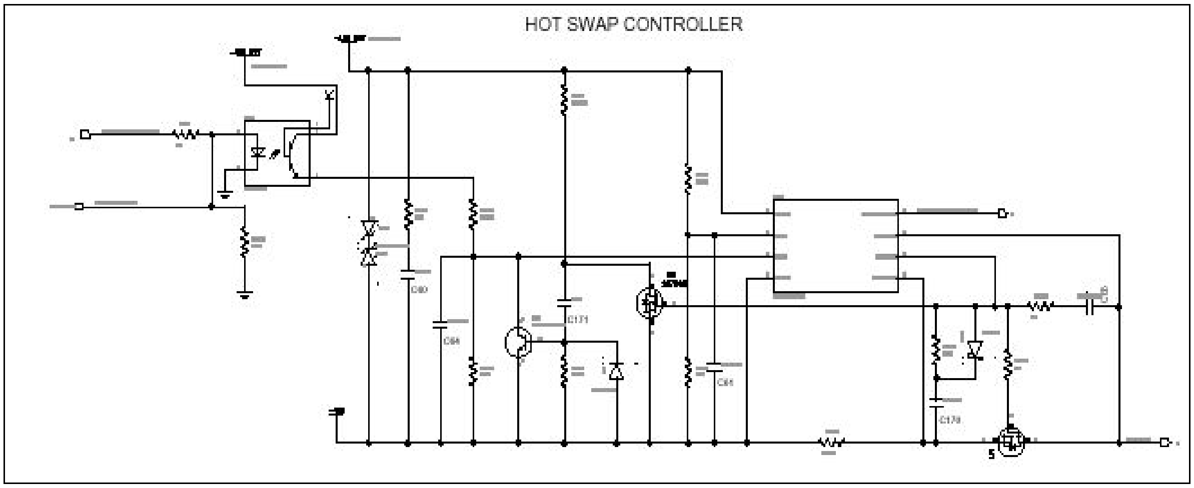

Fig. 3 Hot-Swap Controller circuit

4.3.2 A Simulation Exercise: Simulation of Transmission lines, reflections and crosstalk Using SPECCTRAQUEST

Figure 4 shows two 50-ohm transmission lines on a printed circuit board; the upper line is active and the lower line is passive. Make the model as shown below in Signal Explorer of SPECCTRAQUEST. In this exercise, you will energize the upper line by a pulse with low transition times and

(a) Study the reflections on both the near-end (source side) and the far-end (load side) under matched load, 50% under load and 50% overload.
(b) Study the crosstalk on both ends of the lower line under all three load conditions.
(c) Add a third line below the lower line of similar dimensions as the lower line and at equal separation. Study the crosstalk on both ends of the lower line under the matched load condition.
(d) Change the source device to another device capable of delivering 24 mA. Repeat steps (a) and (b). Draw your conclusions.

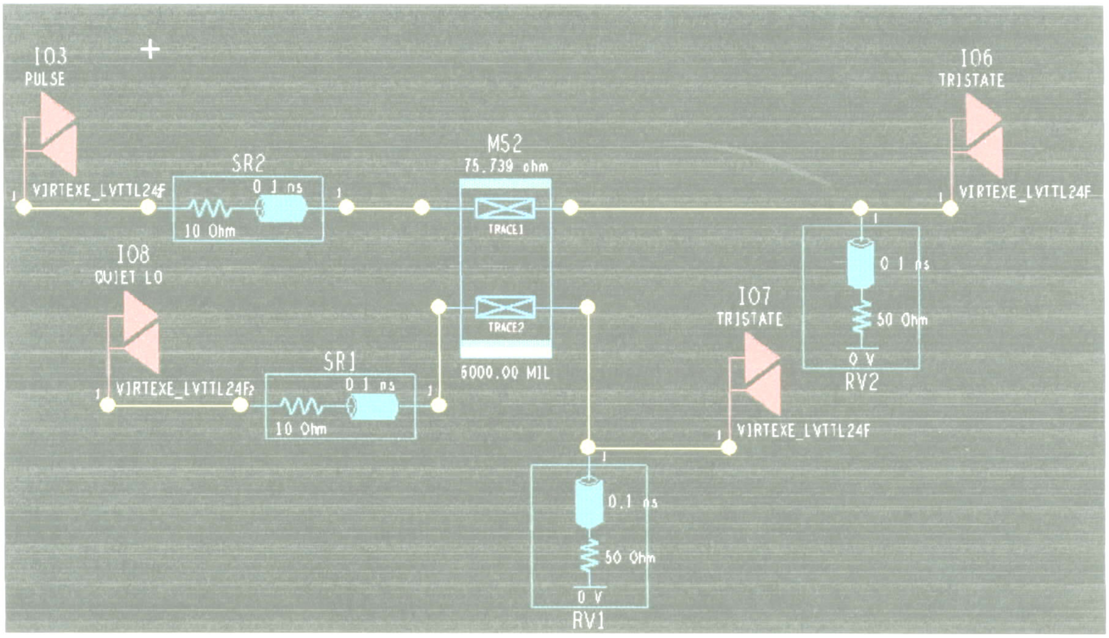

Fig. 4 Simulation of crosstalk in transmission line on a printed circuit

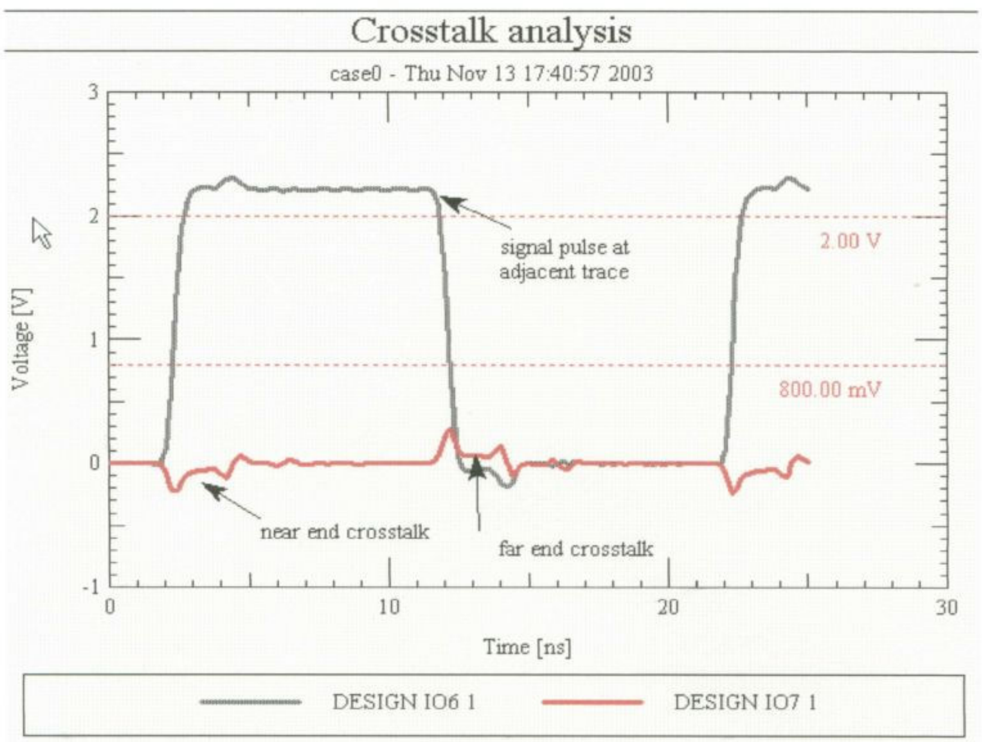

Fig. 5 Crosstalk in transmission lines on a printed circuit board, simulated by SPECCTRAQUEST

Proceedings of the 2004 American Society for Engineering Education Annual Conference & Exposition

V. Conclusion

The course sequence received strong support from the Industrial Advisory Board of the Department of Electrical and Computer Engineering Technology at Purdue University Calumet. The first electronic course ECET 154 has been taught in the Fall 2003 and Spring 2004 semesters. There were eighteen students in the class. The student's responses show that they have learned a lot and have specially enjoyed the laboratory and Multisim examples. The students, however, expressed concern that the textbook does not cover all topics. The instructor supplied the lecture notes for the topics in diodes, transistors, modulators and Phase-lock loop. Hopefully, better textbooks will come in future. The second course ECET 356 provides very crucial knowledge for high-speed electronic design and fabrication. The signal integrity analysis and design is an extremely essential skill required in telecommunication and semiconductor industry. The second course has generated great excitement among students as they see it as providing the job-ready knowledge in the high-tech industry.

Reference:

[1] "Operational Amplifiers and Linear Integrated Circuits", - Robert F. Coughlin and Frederick F. Driscoll, 6th edition, Prentice-Hall Inc., published in 2001

[2] MULTISIM 2001 and Electronic Workbench software, Electronics Workbench USA, 60 Industrial Park, #068 Cheektowaga, NY 14227

[3] "High-Speed Digital Design" - Howard Johnson and Martin Graham, Prentice-Hall Inc.

[4] SPECCTRAQUEST ver. 1.4, CADENCE Design Systems Inc., Seely Avenue, San Jose, CA 95134

Biography

JAI AGRAWAL is a Professor with joint assignment in Electrical and Computer Engineering Technology and Electrical & Computer Engineering. He received his PH.D. in Electrical Engineering from University of Illinois, Chicago, in 1991, M.S. and B.S. also in Electrical Engineering from I.I.T. Kanpur, India in 1970 and 1968 respectively. Professor Agrawal has worked recently for two years in optical networking industry in the Silicon Valley in California. Professor Agrawal is the Founder Advisor to Agni Networks Inc., San Jose, California. His expertise includes optical networking at Physical and Data link layers, optical and WDM interface, SONET and Gigabit Ethernet and analog electronic systems. He is the author of a Textbook in Power Electronics, published by Prentice-Hall. His professional career is equally divided in academia and industry. He has authored several research papers in IEEE journals and conferences.

OMER FAROOK is a member of the faculty of the Electrical and Computer Engineering Technology Department at Purdue University Calumet. Professor Farook received the Diploma of Licentiate in Mechanical Engineering and BSME in 1970and 1972 respectively. He further received BSEE and MSEE in 1978 and 1983 respectively from Illinois Institute of Technology. Professor Farook's current interests are in the areas of Embedded System Design, Hardware – Software Interfacing, Digital Communication, Networking, C^{++} and Java Languages.

CHANDRA R. SEKHAR is a member of the faculty of the Electrical and Computer Engineering Technology at Purdue University Calumet. Professor Sekhar earned a Bachelor's Degree in Chemistry from the University of

Madras (India), a Diploma in Instrumentation from Madras Institute of Technology and Master's Degree in Electrical Engineering from University of Pennsylvania. Professor Sekhar's primary teaching and research focus is in the areas of Biomedical and Process Control Instrumentation and Clinical Engineering.

Appendix:

Table 1: Topics in ECET 154, Analog Electronics (15 weeks: 45 hours)

Topic	Duration
Operational amplifier: Ideal Opamp, commercial Opamp integrated circuits	3 hours
Linear applications: Amplifier configurations, frequency response, summers, integrators	6 hours
Non-linear applications: Comparators and Schmitt Trigger	4 hours
Filters: Types, characteristics and realization using opamps	6 hours
Oscillators: Theory of oscillation, function generators and timers	4 hours
Diode: Characteristics, diode circuits and rectification	3 hours
IC Power Supply Design	3 hours
Transistor: Characteristics of BJT and FET	3 hours
Transistor amplifier design: Biasing and amplification	5 hours
Power Amplifiers and Tuned amplifiers	2 hours
Transistor as switch: Use as relay and dc motor drivers	2 hours
A-to-D and D-to-A converters	2 hours
Modulator and Demodulators and Phase Lock Loops	2 hours
Two mid-semester one-hour tests	2 hours
Two-hour final examination	

Table 2: Laboratory Exercises in ECET 154, Analog Electronics (15 weeks)

1. MULTISIM Tutorial
2. Opamp as linear amplifier
3. Instrumentation amplifier
4. Comparator
5. Schmitt Trigger
6. Filters
7. Oscillators
8. Diode and rectification circuits
9. IC power supply design
10. BJT and FET Characteristics
11. Amplifier biasing and amplification
12. Relay/dc motor Driver
13. Power amplifier

14. A-D and D-A converters
15. Amplitude modulation and demodulation

Table 3: Topics in ECET 356, Digital Electronics (15 weeks: 45 hours)

Topic	Duration
Basics of pulses, switching and logic gates	6 hours
Concepts: grounding, shielding, crosstalk and EMI,	6 hours
Generation and propagation of pulses and pulse amplifier and driver circuits in TTL, CMOS, Schottky, and modern high-speed digital integrated circuit technologies	6 hours
Memory circuits	3 hours
Analog switches and Multiplexers	3 hours
Hot-swap circuits and Power up/down sequencing	3 hours
Clock generation and recovery	3 hours
Automatic testing: JTAG techniques	3 hours
Basics of Signal Integrity and Layout design	6 hours
Signaling standards: TTL, LVCMOS, LVPECL, LVDS etc.	
Packages, Cables and Connectors	4 hours
Two mid-semester one-hour tests	2 hours
Two-hour final examination	

Table 4: Laboratory Exercises in ECET 356, Digital Electronics

1. Pulse measurements
2. BJT and FET as switches
3. Generation and propagation of pulses
4. Pulse amplifier and driver circuits
5. LVTTL and LVCMOS ICs
6. Memory circuits and drivers
7. Analog and digital switches
8. Power up/down sequencing
9. Hot-swap circuits
10. Clock generator and recovery circuits
11. SPECCTRAQUEST Tutorial
12. Simulation of Transmission lines, reflections and crosstalk
13. Crosstalk and EMI
14. Power supply noise and simultaneous switching noise