Work In Progress: Modified Analog Electronics Sequence for Computer and Electrical Engineers

Srinivasa Vemuru
Ohio Northern University, s-vemuru@onu.edu

Abstract - The predominance of using digital electronic system implementations over the years has led to less to almost no emphasis on analog electronics education in computer engineering programs. With the high speed operations of digital circuits the analog effects are becoming more relevant. There is a constant demand for portable applications that require increased computational resources in a constant/reduced power operation; this requires consideration of alternative low power analog implementations. Therefore, it is essential for computer engineers to have a good understanding of analog electronics to be effective system designers. Professional engineering societies noted the lack of analog electronics education and have included it as a core component in the computer engineering curriculum recommendations. Therefore the computer engineering curriculum at Ohio Northern University is changed to include analog electronics as a required course. Unlike students enrolled in electrical engineering program, computer engineering students only take the first of the two course sequence in analog electronics. The material covered in the two courses of analog electronics sequence is reorganized using spiraling and spacing learning approaches. The paper summarizes some of the details of the proposed changes.

Index Terms – analog electronics, spiral learning, computer engineering, field programmable analog arrays

I. INTRODUCTION

Electronics is one of the fundamental topics for the computer engineering and electrical engineering curricula. This area provides the basic knowledge for the design of the electronic circuits used to implement computers, control and communication systems, and test and measurement instrumentation. With the increasing complexity of digital design in the 1980s, the emphasis on specification of digital circuits moved away from gate level descriptions to hardware description languages (HDL) such as VHDL and Verilog. These specifications combined with the advances in the computer-aided synthesis tools moved the digital design process using higher level of abstractions. The computer engineering curricula followed this trend in the industry and over time there is almost no emphasis placed on analog electronics.

The continued miniaturization of transistors, shrinking of interconnect dimensions, higher frequencies of operation brought back a host of signal integrity related issues in digital circuits [1]-[5]. Current high-end circuit design and board-level designs face a number of design challenges such as crosstalk, interconnect parasitics, substrate noise, etc., that need to be addressed. At the same time the increased demand of portable applications that operate on energy constrained resources present a need to consider alternate design methodologies. Analog signal processing can provide energy conserving solutions for a number of portable applications [6].

IEEE Computer Society and ACM published a report on curriculum guidelines for undergraduate degree programs in computer engineering [7]. Electronics, including analog electronics, is a core component of the recommendation. The computer engineering curriculum at the Ohio Northern University was modified to accommodate these recommendations. This paper presents the details of these changes. Section II presents the situation prior to the changes. Section III covers the details of the first of the two course sequence, Analog Electronics 1, taken by both electrical engineering and computer engineering majors. Section IV covers the course content of Analog Electronics 2, a required course for electrical engineering majors. Section V introduces the pedagogical approaches considered and used in the development of these courses followed by conclusions.

II. PRIOR SITUATION

Prior to the curricular change, the computer engineering students took a required two course sequence in digital electronics, ECCS 361: Digital Electronics and ECCS 363, Advanced Digital Electronics. Digital Electronics focused on combinational and sequential logic design. Advanced Digital Electronics focused on hardware description language based digital design using VHDL. Electrical engineering majors were required to take the first course in the sequence. A two course analog electronics sequence, ECCS 321: Analog Electronics 1, and ECCS 322: Analog Electronics 2, was taken by electrical engineering majors only. Analog Electronics 1 covered the topics related to operational amplifier circuits, diode circuits, bipolar junction transistor (BJT) amplifiers, and metal-oxide-semiconductor field effect transistor (MOSFET) transistor amplifiers. The emphasis on the course sequence is more oriented towards bipolar transistor circuits. Analog Electronics 2 covered frequency response, feedback, output stages and topics related to analog applications such as timer circuits, filter applications, etc. The core material did not provide any exposure to analog electronics for computer engineers. Coverage of HDL based digital designs was completely absent for electrical engineering majors.

The first change made in the curriculum was to integrate VHDL into digital electronics, a required course for both electrical and computer engineering majors. Industry standard design flows for digital design were adopted using Xilinx ISE software based FPGA design combined with Modelsim simulations.

The second change made was that Analog Electronics I was made a required course for both computer engineering and electrical engineering majors. Electrical engineering students continue on to take Analog Electronics 2. Relevant topics of interest to computer engineering curriculum were spread among the two courses of original sequence in Analog Electronics. Therefore, a major reorganization of topics was made for both courses. The next two sections provide the details of the modified Analog Electronics 1 and Analog Electronics 2 courses.

Spiral approach to teaching is a technique where concepts of a topic are learned at different points of time with increasing amount of detail as shown in Figure 1. Initially, basic concepts of a topic are introduced without worrying about details. Then as learning progresses, further details of the topic are introduced at a later point of time. This help in reinforcing the concepts learned earlier. The width of spiral in Figure 1 represents the knowledge level the topic at that particular point of time of revisit. Engineering education research shows a very strong correlation between spiral introduction of concepts and student learning [8]-[13].

III. ANALOG ELECTRONICS 1

The course has prerequisites of Electric Circuits, Signals and Systems, and Digital Logic. In the first two lectures the students are introduced to the basic principles and components that are required for processing analog signals. Sensors are used to sense behavior of real world physical systems and converter to electrical signals for further processing. Typical outputs of the sensors are analog in nature. Amplifiers are needed to transform sensor outputs to be compatible for signal processing. Processing using digital domain is easier and cheaper due to the ubiquitous presence of digital computers. There is a need of data converters that transform data from analog to digital domain and vice versa. The processed output is converted back to analog signal and presented to actuator that modifies the behavior of the physical system. Ideal two port amplifiers are introduced along with the effects of source and load resistances on the overall gain of the system. This lays the foundation for the goals of the course.

Ideal operational Amplifiers are introduced earlier to the students in the Electric Circuits along with simple applications. Non-idealities of operational amplifier such as finite gain, finite input and output resistances, slew rate and frequency response are introduced. Two laboratory experiments introduce the non-ideal effects on amplifier response and tolerances of the components on the overall performance of the amplifier. Monte-Carlo analysis is introduced to perform statistical analysis of the output voltage due to component tolerances and amplifier gain variations. Newer applications of operational amplifiers are introduced.

Five lectures are used to introduce students to the basics of semiconductor physics and diode circuits. The topics related to charge carriers, doping, and transport of charge carriers, provide the foundation to understand the behavior of different semiconductor devices. The formation of a p-n junction and its behavior in equilibrium, forward and reverse bias modes is discussed. Diode rectifier circuits are discussed briefly. Device level models in SPICE circuit simulator are introduced.

The limited time available in Analog Electronics 1 restricts the scope of coverage to either MOS transistor circuits or bipolar junction transistor circuits. The high levels of integration possible with MOSFETs, using CMOS technology, made it the predominant technology used in digital applications. BJT amplifiers can provide higher gain than equivalent MOSFET amplifiers and potentially perform better in analog applications. However, the possibility of integrating digital and analog circuitry on a

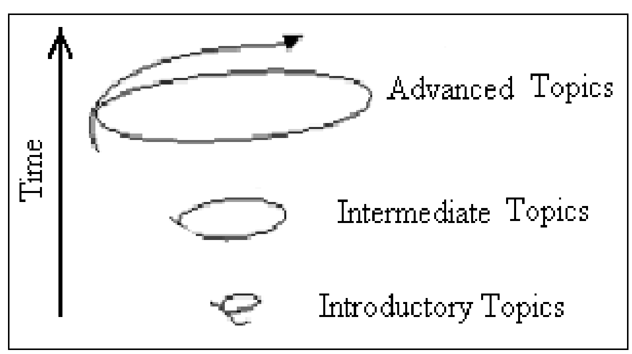

FIGURE 1
SPIRAL THEME BASED MODEL

single chip using MOS technology, in relatively inexpensive manner, has led MOS technology to supplant BJTs and other competing technologies in a number of analog applications [14]. The use of BJTs has been relegated to more specialized applications. In addition, the insulated gate present in MOS transistor presents another advantage over BJTs as it effectively isolates the drain and source regions from the effects of DC currents from the gate side of the circuits. Power MOSFET technology has taken a strong foothold in power electronics applications such as switch mode power supplies and also in applications that deal for voltages less than a kilovolt and currents less than 100 A. Based on these advantages, the coverage in the first course in the sequence is limited to MOS transistor circuits. Three classes are spent on understanding the operation of MOS structure, MOS capacitances, and device operation in cutoff, linear and saturation modes. MOS Level 1 device model in SPICE is discussed and is used to study the discrete transistor behavior in laboratory.

Transistor level implementation of basic CMOS logic gates are introduced and are used to study the analog effects in digital logic gates. Static and dynamic behaviors of CMOS logic gates are analyzed. The effects of different loads on the propagation delay and power consumption is discussed and verified in the laboratory. Practical interfacing concepts that address voltage levels, level conversion, and open drain configurations are covered. Four lectures are spent on this topic.

Semiconductor devices have nonlinear behavior and cannot be used to implement linear amplifiers except under restricted operation. The effects of dc biasing on these devices are discussed to place the transistor at an operating point where the device exhibits linear behavior for small variations of the input signal. This linearized behavior of the transistor is related to the concepts learned from differential calculus and superposition principle in Electric Circuits course. The laboratory component emphasizes the large and small signal behavior of MOS transistors. Common source amplifier configuration is presented to develop the basic concepts of transistor amplifier design. The tradeoffs of dc biasing on the gain and output resistance of the amplifier are discussed. These issues are verified through a laboratory. Four lectures are used to cover this material.

The rest of the course presents the use of the transistors, operational amplifiers, and diodes in common applications such as basic rectifiers, switch-mode power supply configurations, comparator circuits, sample and hold circuits, analog-to-digital converter and digital-to-analog converter topologies.

Nonlinear waveform generating circuits or multivibrators use positive feedback to generate pulse and oscillating waveforms. Analysis of astable, monostable, and bistable circuits is introduced. Hysteresis based switching using Schmitt triggers is introduced to reduce noise effects in high gain amplifier circuits. 555 timer is used in the laboratory to design pulse and periodic waveforms.

Electronic filters are important components in communication and instrumentation applications. The filter types, specifications, and transfer functions are introduced. Butterworth and Chebychev filter approximations of filter transfer function are studied. The tradeoffs of the order of the filter with the filter response are compared.

Programmable logic, particularly field programmable gate arrays (FPGAs), has made significant impact on prototyping and implementation of digital circuits. With the use of FPGAs, it is possible to implement a complex systems-on-chip with a very short development time. Thus it is possible to study different design tradeoffs at higher level of abstraction and on a physical implementation. In the recent years, design automation for circuit synthesis has made inroads in analog domain targeting field programmable analog arrays (FPAAs) for implementation [15]-[16]. FPAAs provide a quick and automatic means of prototyping low to medium frequency range analog applications. Typical FPAAs are uncommitted arrays of the components necessary for assembling switched-capacitor analog signal processing circuits. The purpose of programming in the FPAAs is not merely to set circuit parameters, but also to quickly study different circuit topologies for implementation of these circuits. FPAAs are used in the laboratory to study different filter topologies and understand the design tradeoffs of one topology over other. Two classes are spent on introducing the basic concepts of switched capacitor circuits and FPAAs.

Table 1 lists the laboratory experiments covered in the course.

TABLE I
ANALOG ELECTRONICS – 1 LABORATORY EXPERIMENTS

WEEK	TOPIC
1	Amplifiers – Effects of source and load resistances
2	Statistical Analysis of Component Tolerances on Amplifier Gain
3	Diodes – Small and Large Signal Models
4	MOSFETs – Transfer Characteristics
5	Analog Issues in Digital Gate Behavior
6	Design of a Common Source Amplifier
7	Power Supply Design
8	Timing Circuits using 555
9	Pulse Width Modulation Circuits
10	Filter Designs using Field Programmable Analog Arrays

IV. ANALOG ELECTRONICS 2

The second course in analog electronics sequence is required for students enrolled in electrical engineering program. This course starts with the introduction of bipolar junction transistor operating principles, biasing, and small signal model. Different BJT amplifier configurations such as common emitter amplifier, common base amplifier and emitter follower circuits are studied. Performance tradeoffs such as input impedance, output impedance, current gain, voltage gain and power gains are studied.

High frequency operation of amplifiers brings in the effects of parasitic capacitances of the semiconductor devices. High frequency models of both BJT and MOSFET amplifiers are studied that limit the bandwidth of the amplifier gain.

Feedback can be used to improve the performance of an amplifier. However, the stable operation of the amplifier is affected by negative feedback. Stability of feedback amplifier is studied using Bode plots. Compensation techniques are used to extend the bandwidth and improve the stability of the feedback amplifiers.

Oscillators are used as clock pulses in control and computer systems, information carriers in communication systems, and in test and measurement systems. Linear oscillators that use feedback principles and frequency selective networks are the focus of the course. Medium frequency topologies that use operational amplifiers as the key element such as Wien-bridge oscillators and phase-shift oscillators are initially studied. This is followed by a discussion of high frequency oscillators such as Colpitts oscillator, Hartley oscillator, and crystal oscillators.

The specifications of filters using Butterworth and Chebychev approximations are introduced in the first course of the sequence. In this course, circuit designs to implement first-order and second order active filters are covered. Topologies of active filters such as Sallen and Key filters, Biquadratic filters using simulated inductors and integrators are studied. These first and second order filter circuit implementations are used to implement higher-order Butterworth and Chebychev filters in the laboratory.

Output stages and power amplifiers are critical components used in communication, power electronics, and audio applications. Classification of amplifiers, linearity, power efficiency, and heat dissipation are considered. The thermal behavior of devices and the use of sinks for heat removal are studied.

V. SPIRAL LEARNING

The proposed modifications integrate the spiraling and spacing concepts that have been studied extensively in engineering and computer science education research. Spacing refers to the presentation of material spaced out over a longer period of time rather than as one continuous presentation over a shorter period of time [10]. Spiraling refers to revisiting previously learned topics and expanding them to a higher knowledge level. Both of these techniques have shown very effective in increasing student learning. These techniques have been extensively used in the reorganization of the course. Coverage of topics in Analog Electronics 1 provides a breadth in analog electronics for computer engineering and electrical engineering students. The course also presents a number of applications based on the material learned in earlier part of the course to improve knowledge retention. Analog Electronics 2 presents spiraling approach to increase depths of comprehension. As the topics are covered at a later point of time, they reinforce students' prior knowledge and expand them to engage at a higher intellectual level. The next few paragraphs highlight some examples of using these approaches in the course sequence.

Transistor Amplifiers: Amplifiers are introduced as two port networks in the first week of Analog Electronics 1. This topic is revisited during the development of small signal model of MOSFET transistor in Analog Electronics 1 (covered in the fifth week of the course). Spiraling technique is used with the added complexity of drain resistance, load resistance and biasing circuitry to the analysis of the gain of the circuit. Spacing concepts is employed to during the revisit of amplifier designs in Analog Electronics 2 using BJT amplifier configurations (first week of the course). The addition of transistor parasitic capacitances brings advanced exposure to the role they play in limiting the bandwidth of transistor amplifier (second week of Analog Electronics 2).

Operational Amplifiers: Ideal operational amplifier concepts are introduced in Electric Circuits, a prerequisite to Analog Electronics 1. Operational amplifier non-idealities that limit the range and scope of the use of operational amplifiers are covered in Analog Electronics 1 (second week). Circuit applications that use op amps such as comparators, timing circuits, and data converter circuits use operational amplifiers (covered in weeks 7 and 8). Positive feedback is used in timing circuits in contrast to negative feedback for other applications.

Filters: Analog Electronics 1 introduces filter specifications and transfer functions (week 9). Filter implementations are implemented using automated analog synthesis tools using FPAAs. The active filter design principles are used in Analog Electronics 2 (week 7) to build first and second order filter circuits. This knowledge is used to build a filter with given specifications and verified in the laboratory.

Oscillators: Oscillating outputs are first introduced through the analysis of astable multivibrator that results in waveforms that repeat periodically (Analog Electronics 1 week 8). These circuits primarily operate of positive feedback mode. Oscillators are revisited again using linear oscillator principles (Analog electronics 2) that combine the negative/positive feedback with frequency selective circuit configuration to achieve oscillations.

There are a number of excellent textbooks available for analog electronics [17]-[20]. Typical coverage in these books addresses most of topics in the course sequence except for programmable analog arrays and switch-mode power supplies. However, the material in the textbooks is organized for traditional course offering of analog electronics. The spiraling and spacing concepts result in back and forth coverage of topics. There is a severe dearth of textbooks for spiral based curricula. This has been an issue in most of the prior attempts at spiral based curriculum developments [13].

VI. CONCLUSIONS

The details of the modifications made to the analog electronics sequence at Ohio Northern University are presented. The first course presents a breadth of topics and is taken by electrical engineering and computer engineering majors. The second course is a required for electrical engineering majors. Spiraling and spacing learning concepts are extensively used in the course sequence to enhance student learning. Assessment and evaluation of student learning from these modified courses has to be made and will be presented at a later time.

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AUTHOR INFORMATION

Srinivasa Vemuru obtained his bachelors and masters degrees in Electrical Engineering from Indian Institute of Technology, Madras in 1984 and 1986, respectively. He received his PhD in Engineering Science from the University of Toledo in 1991. From 1991-2001 he served as faculty member in the Department of Electrical Engineering at the City College of the City University of New York. He is currently an associate professor in the Department of Electrical & Computer Engineering and Computer Science at Ohio Northern University. His research and teaching interests are in the areas of analog and digital electronic circuit design, embedded systems, wireless sensor networks, built-in self test, and RF integrated circuits.