

Electrical Engineering Undergraduate Curriculum

Robert Dutton, Andrea Goldsmith, Nick McKeown, Eric Roberts,
Olav Solgaard, Dwight Nishimura, Ross Venook, Simon Wong, Mark Horowitz

1. Introduction

The outline of the current undergraduate curriculum was put in place over 15 years ago, and while it has evolved, the basic structure and emphasis has remained unchanged. Given the changing nature of both the field of Electrical Engineering and the background of our students, the department created a committee to review the curriculum. This document is the report of that committee. It starts by reviewing the state of the department and the current curriculum, and looks at the forces driving both the department and its students. Section 3 provides an overview of our revised curriculum and explains how this new plan adapts to both the changing background of our students, and the changing nature of EE. We propose to revise all of the classes that form the core of the curriculum and Section 4 describes these new classes in more detail. This section is followed by a description of depth sequences. Section 6 describes an aggressive, but feasible, transition plan for moving to the new program, and Section 7 describes issues that we feel still need to be addressed in the future.

While this report makes some very specific course proposals, we understand that the strength of a university like Stanford is enabling each faculty member to create the best class that they can. Thus our course outlines are a method of being more concrete about what topics we think are core to an area, rather than rigidly defining the class. Finally while we have spoken with many other faculty members to construct this document, our task is clearly not complete – we welcome further comments. It is only through this feedback that we will create a successful EE curriculum for the 21st century.

2. Background

As described in the most recent strategic plan of the Electrical Engineering Department, the field of Electrical Engineering has continued to evolve and expand, further blurring its boundaries with other disciplines. In particular the overlap with CS continues to grow and joint undergraduate programs at the border with CS are essential. The ability to create joint programs with other departments is strongly desired, with areas like bioelectronics worthy of serious consideration in the near future (although it was not considered in this report).

In addition to becoming broader, Electrical Engineering has been strongly influenced by the rapid growth in information processing. Information technology has served both as a dominant consumer electronic technology, and provided the tools that drive further innovations. As a consequence, the complexity of the systems that our students deal with has grown exponentially. Our curriculum must provide them with not only the insights to understand the underlying technologies and theories associated with each level of complexity, but also the knowledge and skills to choose

the appropriate abstraction level for each component, making the complexity work for them rather than against them.

The rapid growth of information technology has also changed the background, training, and interests of our students. Gone are the days when prospective Electrical Engineering students built or disassembled electronic systems (with radio / audio amplifiers being the most common) before they entered universities. Today's students have more exposure and background in software than hardware. They have direct experience manipulating "codes" but not "devices", feel more at home in the virtual world of the computer, rather than the physical world. Students are also used to dealing in a world with abundant information, and many distractions, and they feel more comfortable in situations where the application for the information being taught is clear. Our current curriculum lays out the fundamentals first before getting to applications and is a "poor impedance match" to our students.

In addition to delaying gratification, the sequence structure of the current curriculum causes additional problems for our students. The core is too long, and too linear, making it difficult for students to create a schedule that allows them to take many classes in their depth area. Some depth areas are hard to complete if you decide on an EE major belatedly. Some students take the EE111-113 sequence concurrently with EE101-103, to avoid some of these problems, which causes a different set of challenges for them. In addition this structure does not encourage a student to "sample" different areas since a student needs to take many classes before reaching the essence or excitement of the area. If we want to foster work at the border of different areas, we need to create classes that build excitement in the first class of a series.

In summary, we need to change our undergraduate curriculum to

- motivate students to "sample" different areas,
- emphasize how fundamental principles cut across different core areas,
- include motivating examples for all the material in the core,
- take advantage of the students' familiarity with "virtual" environments,
- arouse the students' interest and curiosity in "hardware,"
- blur the boundary between "software" and "hardware,"
- broaden the students' appreciation of system issues, and
- familiarize students with different levels of system abstraction.

Unfortunately we need to implement these changes in a constrained environment. Stanford prides itself on being a liberal-arts university. Our undergraduates are not required to declare a major at the time of their admission, and have a number of distribution requirements during their first two years. They are encouraged to explore and develop a variety of interests before choosing a major. This both forces us to compete with other departments for the best students, and limits the amount of classes that we can include in our program. We are faced with a small number of classes we can require all students to take. To make room for classes that help with abstractions

and dealing with complex systems, some material needs to be dropped from the current core. This is a difficult question, since all areas have strong proponents.

Our proposal keeps the core small, and uses it to introduce areas that are not covered in depth. Our present curriculum was created when solid-state electronics was the key area in EE, and so the curriculum is centered on microelectronics devices and circuit design. While this remains a key area, it no longer holds the dominant position it once did. Thus we are reducing the number of courses in the solid-state electronics area and broadening the remaining classes. The next section outlines the changes that we propose.

3. Key Features of the Proposed Curriculum

We decided to focus our effort on defining the classes that form the core of the undergraduate program – classes that every EE student must take – and classes that are under the control of the EE faculty. While we all thought there were issues with the current Math and Physics requirements, we felt the current requirements were acceptable for the new program and changing them was more an issue for the School of Engineering. We agreed that programming methodology (E70x – CS106x, or CS106B) should be kept as part of the program.

To address many of the problems mentioned in the previous section, we set up the following goals for the development of the EE core requirements:

- Alter focus of initial classes to emphasize applications
 Making the classes more interesting to the students
- Decrease the longest chain in the core, by making the requirements more parallel
 Enable more options in class selection
- Include lab components in each of the core classes
 Provide immediate utility of material, and coupling to physical world
- Shrink solid-state devices/electronics, expand digital systems content in the core
 Creating a stronger tie between hardware and software

Our proposed undergraduate curriculum tries to address all these goals. It consists of one introductory class that must be taken before any of the other core requirements and then a two-course sequence in each of three different core areas. The core areas are Signals and Systems, Electronics, and Digital Systems. The introductory class is a revised E40 that has two goals: provide a glimpse of the excitement of EE, to encourage the best students to declare EE, and give the student enough of the needed common tools of EE so the remaining core sequences can run concurrently. In addition to E40, we propose a new class that serves to introduce our students to the ‘physical science’ side of EE. This class would be part of the core curriculum, would introduce our students to the utility of the physics they took earlier by using it to explain the behavior of, for example, transmission lines, MEMS devices, and photonics. This class would take the place of the current EE141 requirement.

This new structure addresses many of the goals we mentioned above. To address the remaining issues, each of the core classes will be coupled with a laboratory. The lab will enable the students to ‘use’ the information provided in the class almost immediately, to reinforce its utility. In addition, both of the introductory classes will have a strong application focus, introducing the students to the power of the techniques that will be covered in more detail. The core classes will continue to use applications to motivate the analysis / mathematics developed in the class and provide examples for the class labs.

Currently there are two lab classes that every EE student takes – EE121 and EE122. The digital lab class (EE121) is replaced by the first class in the digital systems core sequence. EE122, the analog design lab, is a relatively open design class that gives students an opportunity to experiment with what can be done with electronics, and can be taken immediately after E40. We feel that this is exactly the type of design class that all students should take, so have left it as a required class in the new curriculum. However, we believe other entry level undergraduate ‘design’ labs should be created and students should have the option to choose the lab (electronics, signals and systems, etc) that most interest them.

The breadth of EE, and the EE undergraduate program is clearly larger than what is covered in the core sequence. Students will be encouraged to explore these areas after completing the core’s prerequisites. To encourage students to take these classes, the core classes will ‘advertise’ for other classes that relate to the core area. For example, although we have taken most of the device physics out of the core, we expect that the Electronics core will mention the importance of device models and modeling, and provide information about where students can find classes in these areas. Although we are reducing the number of core classes, we have added a lab component to each class. As a result we feel that all the EE core classes should be worth 4 credits, leaving the number of credits in the core nearly the same. Thus the number of required classes in their depth area will remain three.¹

Currently there are six undergraduate depth areas:

- Computer Hardware
- Computer Software
- Controls
- Electronics
- Fields and Waves
- Signal Processing and Communications

In the new proposal, we have increased the number of depth areas, so it makes sense to group them into four major areas:

- Digital Systems
- Signals, Systems and Control
- Electronics

¹ Note that the number of classes has reduced, so we hope and expect that students will choose to use the extra slot to take more EE classes.

Fields and Waves

Each of these areas has a number of possible depth areas. Again using Electronics as an example, there are sequences that range from electronic control systems, to photonic-based electron devices. A preliminary proposal for the different depth sequences is given in Section 5.

Creating a new curriculum requires considerable effort, and transitions are always difficult. Many of the proposed classes are similar to existing classes, which should both help in the development of the new classes, and ease the transition to the new curriculum. Figure 1 tries to show how the current classes have been morphed to the new curriculum.

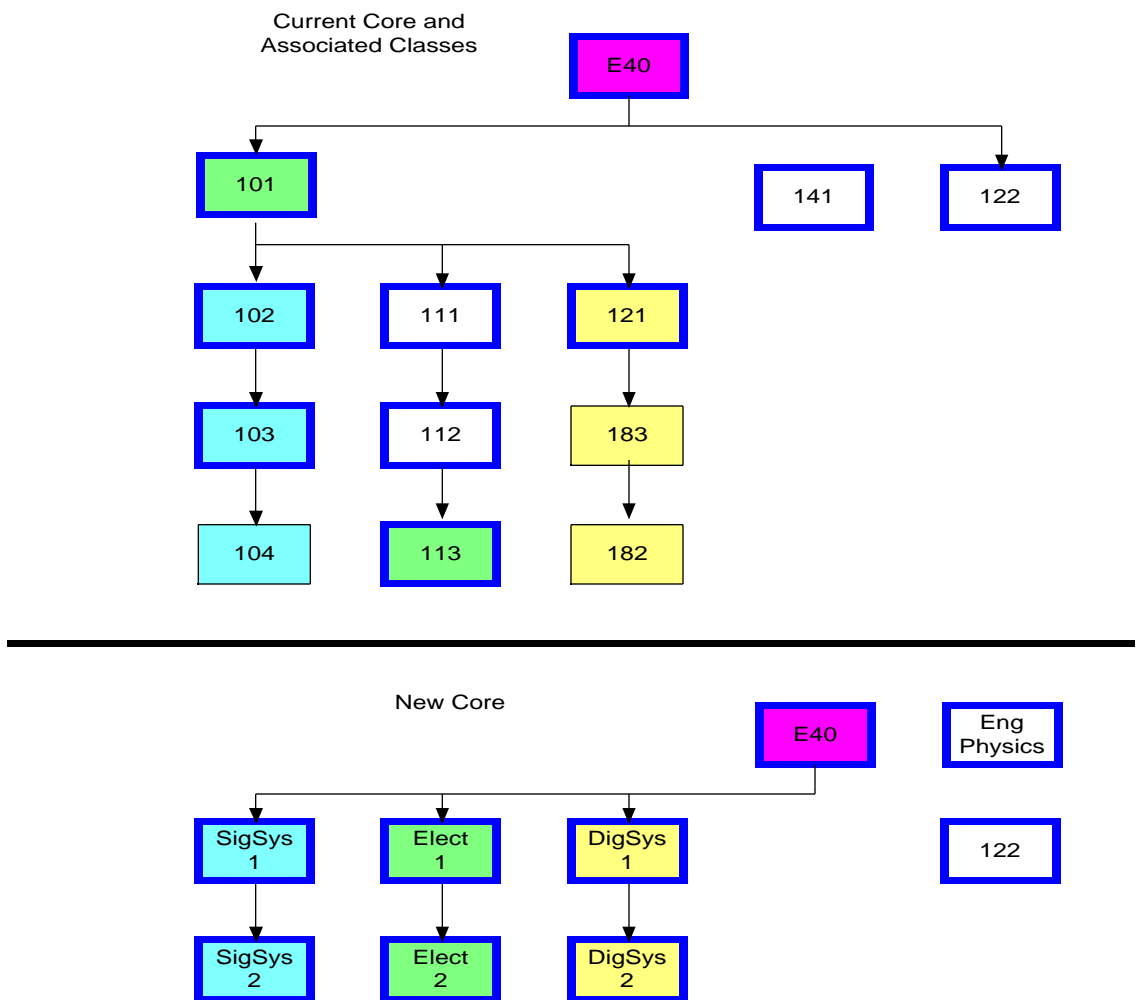


Figure 1. Required classes are in bold blue. Classes that cover similar material are shaded the same. Arrows denote dependencies.

4. Contents of Proposed Required Fundamental Courses

Introduction to Electrical Engineering – Circuits and Systems (Revised E40)

The introductory EE course should ideally meet the following, somewhat contradictory, objectives: (1) To prepare our students for the first class in each of the three core areas and for the design lab. (2) To stimulate interest in Electrical Engineering and serve as a recruiting tool for undergraduate students to the department. (3) To give an introduction to Electrical Engineering for non-majors since it is a general engineering course. Clearly the last two of these goals are closely connected in the sense that we must do a good job teaching to non-majors to make them want to become EE majors. The first objective, on the other hand, would be better met by an Electrical Engineering course that focuses on the necessary background material. The committee strongly felt that with Stanford's undergraduate structure, it is a bad idea to construct two classes, one for the true EE, and one for the outside majors, since many students will not have made that decision until after they take this class.

We discussed revising E40 for a long time. E40 is a mature class that works well, with a well established course reader and set of labs. Some felt that since the class was 'not broken' we should leave it alone. After careful deliberation, the committee felt that the class needed to be revised to address two key issues:

- Make the class an introduction to EE and not just electronics
- Tilt the class more toward applications, to better interest today's students and better serve goals two and three.

To accomplish these goals will take a major redesign of the class, a task that we do not take lightly, but one we feel is worth the effort.

Goals:

The primary goal of this course is to introduce students to the breadth of activities that occur in the EE department, and give them a sense of the 'power' of being an EE. That is, this class should be a powerful recruiting tool to attract good students into EE. To accomplish this, the students need to create something at the end of the quarter that they had no idea they could do when they started.

The lesser goal of this class is to set the common framework that the other core classes can rely on. In particular it should set up what Signals and Systems, Electronics, and Digital Systems are, so the student has some expectations for the rest of the core. It is essential that this class introduce the students to the basic notion of levels of abstraction, and how to work a problem at different levels. It also needs to introduce the basic ideas of the three core areas, so for example the Electronics classes can assume a student has seen frequency response without a Signals and Systems prerequisite. The key concepts are:

- There are often different ways to view the same data, using time and frequency domain as an example.
- What are voltage and current, KCL and KVL
- MOS transistors as switches, simple gates and small digital circuits

Syllabus

There are many possible directions that this class could take. Unlike the other classes in the core, we will present only a sketch of a revised E40. We felt it was essential to get the instructor of the course involved before setting up a class in detail.

Application – Radio Controlled Car

One suggestion was to base the class on a radio-controlled car. The class would be divided into roughly three equal sections. The first part of the class would talk about the abstract problem of communicating with the car. It would postulate that we could create a communication link (channel) to the car, and then would discuss how many signals would we need to send to the car to control it. From there it could look at the problem of controlling the car, and look at what sensor could be used, and what control loops might be required. All this would be done at the system level, introducing the students to the basic tools of Signals, Systems and Control, and also the power of abstractions.

The second third of the class would look at some of the Electronic issues in building components to implement the system that was discussed in the first third of the class. It would introduce the notion of voltage, current and power, and then show the simple rules that govern their behavior. It is easy to demonstrate power (things get warm, batteries run out), resistor circuits and electromagnetic force. This section would also show that analog signals suffer from noise, and it is hard to get high precision.

The third part of the class would introduce digital systems, and show that one can use non-linear circuits to minimize the effect of noise. This will lead to a discussion of simple digital logic, and a small state machine that can be used to build a digital control loop for the car.

Other Applications

There are many other applications that could be used to drive the class.

- Autonomous vehicle, such as the “micromouse”. This would follow a similar outline to the radio controlled car, but the control loop would have to be internal
- Infrared transmitter system. The class could begin with looking at the problem of remote control. It would look at the problem in the abstract – how to control the correct piece of equipment, and how to detect the signal you want from the ambient light (coding). It would quickly go to the digital domain, and at the end could be the electronic section where the students built a remote.

- CD/DVD reader. There is the overall system design, the analog systems to control the spindle, read arm and the read head, and the notion of coding to correct error
- Etc.

Signals, Systems and Control Sequence

The signals, systems and control core will replace the current 102, 103, and 104. The material in these new classes leverages these old classes quite heavily.

Goals:

The goal of this two-quarter core sequence is to provide an introduction to the mathematical models and tools used in the design and analysis of electronic signals and systems. The treatment includes both continuous and discrete time systems. The main concepts that the students should come away with are the time and frequency response of linear time-invariant systems, transform techniques and how they are used in system analysis, sampling and reconstruction, filtering, linear system theory, feedback, and control. Applications from communications, signal processing and control theory are used to illustrate the basic concepts and motivate the techniques. The sequence will include a laboratory component using Matlab exercises and projects to illustrate the concepts and applications, and also bring in some design considerations and creativity.

Syllabus:

While most EE departments at other universities include this material in their core sequences, there are differences in whether continuous and discrete time are taught together or separately, and in whether communications/signal processing and control are taught together or sequentially. Two possible course sequences are listed below in detail, which represent the following different approaches:

Sequence I: continuous and discrete taught sequentially,
 Communications, signal processing, and control integrated

Sequence II: continuous and discrete integrated, communications/signal
 Processing and control taught sequentially.

In Sequence I below continuous time is taught before discrete time. Switching the order of Course 1 and 2 within this sequence would teach discrete time before continuous time. In Sequence II communications/signal processing is taught before control. Switching the order of Course 1 and 2 within this sequence would teach control first.

These sequences and their permutations cover most of the proposed methods to teach this material. Any order is fine, as long as the basic principles are included. It will be

up to the lab and faculty mentor for these classes to decide the sequence and order that works best.

Sequence I:

Course 1: Continuous-Time Signals and Systems

Introduction and Motivation

Linear Time-Invariant Systems:

- Basic properties: linearity, time-invariance, stability, causality
- Impulse and step response
- Response to exponentials and sinusoids
- Periodic functions
- Convolution

Fourier Analysis

- Fourier series and transforms
- Frequency response
- Bode plots

Filtering

Applications from Communications and Signal Processing

Systems Theory

- Laplace transform
- Feedback
- Stability
- Control

Applications from Control and Circuit Theory

Review, Summary, Extensions

Course 2: Discrete-Time Signals and Systems

Introduction and Motivation

Linear Time-Invariant Systems

- Discrete system properties: linearity, time-invariance, stability, causality
- Difference equations
- Discrete impulse response and step response
- Response to discrete exponentials and sinusoids
- Convolution

Fourier Analysis

- Discrete-Time Fourier transform, DFT, FFT
- Relation to continuous-time Fourier transform

Sampling and Reconstruction

Digital Filtering

Applications from Communications and Signal Processing

Systems Theory

- z-Transform
- Feedback
- Stability

- Control
- Quantization Effects

Applications from Discrete-Time Control
Review, Summary, Extensions

SEQUENCE II

Course 1: Discrete and Continuous Signals and Systems

Introduction and motivation
Properties of LTI Systems
Continuous LTI Systems

- Impulse and step response
- Response to exponentials and sinusoids
- Convolution integral

Discrete LTI Systems

- Discrete impulse and step response
- Response to discrete exponentials and sinusoids
- Convolution sum

Fourier Analysis for Continuous Signals

- Fourier series
- Fourier transforms
- Frequency response
- Bode plots
- Filtering

Fourier Analysis for Discrete Signals

- Discrete time Fourier series
- DTFT, DFT, and FFT
- Relation to Continuous-Time Fourier Transform
- Digital Filtering

Sampling and Reconstruction
Applications from Communications and Signal Processing
Review, Summary, and Extensions

Course 2: Discrete and Continuous Control

Introduction and Motivation
Causal LTI systems: Differential and Difference Equations
Time Domain Analysis of Continuous LTI Systems

- Unit and step response
- Stability
- Solutions of Differential Equations

Time domain Analysis of Discrete LTI systems

- Unit and step response
- Stability
- Solutions of difference equations

Laplace Transform

Z Transform
Linear Feedback Systems
Root Locus Analysis
Nyquist Stability
Nonlinear Systems
Applications from Circuits and Control Systems
Review, Summary, and Extensions

Possible Textbook

Sequence I (continuous and discrete time taught sequentially):

Potential textbooks for both Course I and Course II:

- 1) Signals and Systems: Girod, Raberstein, Stenger, John Wiley and Sons.

Sequence II (continuous and discrete time integrated):

Potential textbooks for Course I (signals and communications)

- 1) Signals and Systems: Oppenheim and Willsky, Prentice Hall
- 2) Linear Systems and Signals: Lathi, Oxford University Press
- 3) Signals and Systems: Haykin and Van Veen, John Wiley and Sons

Potential textbooks for Course II (control)

- 1) Linear System Theory, Rugh, Prentice Hall
- 2) Modern Control System Theory and Design, Shinnars, John Wiley and Sons

Electronics Sequence

The electronics sequence underwent a large change in this revision, reducing the number of classes in this area from four (101, 111, 112, 113) to two. Essentially the two classes on semiconductor devices (111, 112) were moved to one of the depth options in the Electronics area, and the final class 113 was heavily modified to include more material on Bode plots and dealing with feedback in circuits. The content of 101 was recently revised by Stephen Boyd and Abbas El Gamal and is close to the structure that we are striving for in our new core. The major proposed change is to create a lab associated with the class to make the application of circuit analysis more clear. The integration of the lab will cause the class to change.

Goals

The goal of this two-quarter sequence is to introduce students to circuit modeling and analysis. This includes creating a model of components in the system you want to analyze, and the methods for analyzing the resulting system. It is in this course that students will use KCL and KVL, and learn how to use linear network theory to solve linear and non-linear circuits (statics and dynamics). The 1st class will provide examples of model creation, including creating simplified models with a restricted range (small signal analysis). The sequence will introduce the students to a circuit simulator, and provide models for MOS transistors. One key goal of this class is to show the students how relatively simple (linear) models can be used to estimate the

answers of very complex systems. It is also essential that students learn some intuition that they can use to ‘check’ the math programs that they will use.

The 2nd class will cover the design of analog circuits. This class will use analog circuit design to bring out some of the general issues that need to be addressed in the design of any system, including; modeling issues, bias point analysis and linearization, technology constraints (e.g. gain-bandwidth product), frequency response and bandwidth analysis, and designing to meet a set of constraints. It will introduce a number of the essential tools for design analysis, including; MOS models, first-order time-constant analysis, bode-plots, and analyzing circuits with feedback. Essentially this class takes the basic concepts of analysis learned in the first class, and provides the needed tools to allow them to be used for synthesis.

Syllabus

Electronics I

- Modeling
 - What is a model and why it is useful
 - Lumped Element Models
- Analysis of Static Circuits
 - KVL, KCL
- Multi-terminal Static Circuits
 - Ideal elements, VCVS, etc
 - Simple MOS transistor Model
- Linear Circuit Analysis
 - Introduction to circuit theory
 - Simple circuits examples
 - Piece-wise linear
 - Noise
 - CMOS gate – tie to digital system core
- Small Signal Analysis
 - Bias point / linearization around point
 - MOS transistor
 - Simple amplifier
- Basic Dynamic Elements
 - Capacitors
 - Inductors
- Output response for simple RC / LC circuits
 - Differential equation formulation
 - Step response
 - Examples in the real world – MOS delay
- Sinusoidal and Steady-State Circuit Analysis
 - Idea of looking at each freq separately
 - Impedance / Phasors
 - Power and Energy
- Introduction to Frequency Analysis

- Tie to Signal and System
- Simple transfer functions

Electronics II

- Applications of analog circuits at many levels
 - From simple op-amp circuits, to RF circuits
 - Interface design from sensing biology or photons
 - Converting to the digital domain – A/D converter
- AC analysis tools, 2nd order systems
 - Bode plots
 - Pole Zero analysis
- Op-amp review, first pass feedback
 - Configurations
 - Limitations – gain-bandwidth, stability
- MOS device review
 - iV curve, pointer to device classes
 - Small signal model
- Common amplifier configurations
 - Common source
 - Common drain
 - Common gate
 - Look at biasing and small signal analysis
 - Coupling stages
- First-order time-constant analysis
 - Dominant poles
 - Open-circuit time constants
- Differential pair
 - Differential signal and common-mode signal
 - Common-mode rejection
- Feedback analysis of transistor circuits
 - Using feedback in general – measure and correct the error
 - Impact of loop gain on bandwidth, impedance
 - Hiding non-linearity using feedback
 - Using compensation in general to fix circuit issues

Possible Textbook

Currently 101 uses a set of lecture notes, but there are a number of new textbooks coming out that look interesting for this sequence. The book by Agarwal (MIT) looks to take an application focus and seems promising. Other possible books possible for the 2nd class include Sodini & Howe, Jaeger.

Digital Systems Sequence

The discipline of digital systems design has changed significantly since most of our classes were first introduced. Digital systems are now pervasive, their low cost enabling them to be incorporated in almost all electronic systems being built today.

The net result is that understanding something about these systems is increasingly important to our undergraduates, which is why we expanded the required classes in this area to two classes.

The current undergraduate required class is EE121 (logic, sequential circuits, state machines and controllers, storage elements) a combined lab/lecture class. In addition a couple of other classes are offered, but are not required: EE183 (system partitioning, implementation alternatives), EE182 (computer architecture and organization). The faculty involved in teaching digital systems classes (Kunle Olukotun, Bill Dally, Christoforos Kozyrakis, Nick McKeown, Mark Horowitz) had previously discussed changing the undergraduate offerings and all contributed to this plan, which consists of replacing all three of these classes with the two-course core in Digital Systems.

Goals:

This two-class sequence provides an introduction to the design and architecture of digital hardware and software systems. Throughout the sequence, the computer is adopted as a motivating and well-known example, using it to teach logic design, storage elements, sequential circuits, state machines and controllers, basic system partitioning, basic computer architecture, control path and data path design, instruction sets, assembly language, processor architecture, memory and I/O organization, and interaction of s/w with h/w [compilers and OS]. Lab exercises will involve the design, simulation and prototyping (presumably in programmable logic) of a small CPU.

Syllabus:

Digital Systems I:

- Logic Circuits (1.5 week) [0-1.5]
 - Switch level model of MOS transistor
 - Series and parallel switch networks - dual and complement
 - Boolean algebra - logic equations and simplification
 - Complementary gate circuits - INV, NAND, NOR, AOI
 - Dynamics of simple gate circuits
 - Power in CMOS circuits
 - Introduction to transmission lines

- Combinational Logic: (2 weeks) [1.5-3.5]
 - Properties of combinational logic
 - Representations - equations, k-maps, cubes
 - Canonical form - implicants, prime-implicants, covering
 - Examples of combinational logic circuits (7-segment decoder)
 - Structured logic - PLAs and ROMs
 - Common CL idioms - decoders, multiplexers, comparators
 - Numeric data representation - binary, 1s & 2s complement, FP

- Iterative (in space) circuits - e.g., adder or comparator
- Physical considerations: delays, fan-in, fan-out

[Note: there is considerable overlap between the above two topics and the current curriculum of E40. Depending on how E40 evolves, this section may need to become a self-contained introduction to Logic, or may be reduced to simply reviewing material already seen in E40].

- Asynchronous circuits and storage elements (2 weeks) [3.5-5.5]
 - Combinational circuits with feedback
 - Flow-table analysis - races and hazards - effect on power
 - Basic storage elements - RS FF, latch, D-FF
 - CMOS storage elements
 - RAMs
 - Timing considerations: delay, setup and hold.
 - Clocks and synchronous sequential circuits - min and max path issues
 - Synchronization failure and metastability (demo here)

- Finite State Machines (2.5 weeks) [5.5-8]
 - Properties of state machines
 - Structure - combinational logic and state register
 - Representations - state diagrams and state tables
 - State assignment - one-hot and minimal
 - Example of simple controller - traffic light or coke machine
 - Microcode implementation
 - Factoring FSMs
 - Common FSM idioms - counters and shift registers

- Basic System Design (2 weeks) [8-10]
 - Partitioning into control and datapaths (relate to factoring above)
 - Resource sharing and buses
 - Simple control+data system - fibonacci generator
 - System partitioning idioms - pipeline, client/server, work farm, routing
 - Pipelines with rigid and elastic timing

Lab:

The lab works from the bottom up, paralleling the lectures - building logic gates from transistors (CD4007) then simple combinational logic from discrete logic gates, then an FSM using both discrete logic gates and a ROM. The lab then shifts to Verilog and FPGAs. The labs in the Digital Systems I class culminate in a simple integer ALU-based datapath under the control of a small microsequencer, and external memory. This ties together most of what has been learned in class, and prepares students for Digital Systems II.

Digital Systems II:

- Instruction Set Architecture: (1.5 weeks)
 - Basic von Neumann organization
 - Control unit: instruction fetch, decode and execution
 - Instruction set - machine state, data types, instructions
 - Instruction formats
 - Addressing modes
- Assembly language programming (1.5 weeks)
 - Stacks and low level data structures
 - Subrouting call and return mechanisms
 - Process structure and process switch
- Software issues in digital systems (1.5 weeks) (The following topics are to be viewed as introductory. Students interested in this area are expected to take CS140 and CS143 next).
 - Function and organization of a typical compiler
 - Interaction between the compiler and architecture
 - Functionality of a typical OS
 - Processes and resources
 - APIs
 - Device organization
 - Interrupts and lock mechanisms
- Processor Microarchitecture (2 weeks)
 - Simple non-pipelined implementation - control+datapath
 - Resource sharing and scheduling
 - Pipelined processor implementation - 5 stage pipe.
- Memory and I/O organization (2 weeks)
 - Memory systems
 - Memory hierarchy and operation
 - Caches (mapping, replacement and write back policy)
 - Virtual memory, paging and TLBs
 - I/O and interrupts
 - Fault handling, reliability
 - Multiple processor organizations
- High-level system organization (1.5 weeks)
 - System partitioning - decompose systems into function blocks - examples
 - Implementation alternatives for each block - logic, uP, specialized proc, specialized memory
 - Generality vs. performance

- Composition methods - pipeline, bus, shared server
- Examples - graphics pipeline, radar signal processor, packet processing

Lab:

The structure of the lab work for this class is still being debated. One option is to continue to use Verilog, with the option to synthesize the Verilog to an FPGA to create a working version of their machine. In this option, by the middle of the course, the students should have implemented a CPU conforming to a given instruction set (MIPS, DLX, ...) that runs sample programs. The final lab will use this processor in a system along with some specialized logic to realize a simple function.

The other option being considered is to use a commercial tool from Tensilica that allows designs to add custom hardware to their existing core. This tool will then generate the compiler and simulator needed to use this modified processor. While using this tool hides many of the details of the processor implementation, it allows the students to focus more on determining what the correct hardware/software trade-off is for the specific program of interest.

Textbook:

We have not found a suitable text for either class at this point, although we are still looking for one.

Introduction to Electrical Engineering – Physical Sciences (E41)

In addition to the three core areas, the committee felt that the undergraduate program should contain one class that introduced our students to the ‘physical science’ side of the department, and in particular stressed electromagnetic waves, which are fundamental to a large part of EE. Since most of the students in this class will not be concentrating in this area, it is imperative that this class stress why and how this information discipline is important to their education and subsequent practice, in addition to teaching the theory and techniques of electromagnetism and device physics. Students who pursue in-depth studies of electromagnetism naturally develop this perspective, but students in a traditional first course on electromagnetism typically do not.

This class pulls some material from 141 and 142, and will require some changes to these classes after it is implemented. While this class is not a perfect fit for a student who wants to concentrate in E&M, we strongly feel it should be used as part of the E&M curriculum, for the same reason we don’t want to split E40. If successful, many students will not know they are interested in this material until after they take this class.

Goals:

The purpose of this course is to introduce the students to electromagnetism and basic device physics and demonstrate the importance of these fields in Electrical Engineering. It is this course that needs to reconnect students with the physical world – to get them to appreciate that the physics they took is useful for real-world problems. To accomplish this, and motivate the students to learn the solution methods, the course first introduces practical applications, and then develops the formalism that is needed to analyze and design these systems. There will be in-class demonstrations each week to tie the theoretical concepts to practical realities. High-level mathematical software (e.g. Mathematica) will be used throughout for calculations and graphical representation of physical concepts.

Syllabus:

- Application Focus: MEMS mirrors (1 week)
 - The relationship between charge and force – Coulomb’s law.
 - Extension to MEMS actuators – How can we use charge to create little machines that move?
 - TI micro mirrors and microphones will be used as examples to demonstrate the dual nature of sensors and actuators. In actuators (TI mirrors) we create forces to move solid objects, and in sensors (electrostatic microphone) we use charge to measure motion. To analyze these devices we introduce charge, electric field, potential, voltage, and Gauss’s law.
 - Experimental demonstration: Measure force in parallel-plate capacitor

- Application Focus: Electrostatic microphone (1 week)
 - Explore the relationships between charge, electric field, potential, and voltage to introduce the concepts of current and capacitance.
 - Find the current in a changing capacitance, and see how the current can be used as a sensor signal - microphone.
 - Derive Poisson’s and Laplace’s equations from Gauss’s law, and solve Laplace equation to find the capacitance of some simple geometries (up to this point, everything is parallel-plate capacitors). Numerical solutions to Laplace’s equation with proper boundary conditions. Capacitance of wires in integrated circuits. Capacitance as a function of frequency. Electrostatic Energy – Poynting theorem.
 - Experimental demonstration: Use stored energy in a capacitor to vaporize a wire, MEMS accelerometer.

- Application Focus: Transmission lines (1 week)
 - Introduce the complete set of Maxwell’s Equations, and derive the wave equation. Develop the tools to study electromagnetic energy and signal transmission - plane waves, polarization, electromagnetic power and energy, the Poynting theorem.
 - Energy and power in transmission lines. Return current. Energy storage and reflections. Power matching. Lumped-element vs.

- transmission-line models. Scale (what is slow enough or small enough to be modeled as a lumped element). Bounce diagrams.
- Experimental demonstration: Build a long capacitor (transmission line). What happens when we place a voltage step on the input? Explain why a current spike is not observed. Show real world transmission lines -- the signals in cable (with and without ground lines), cat5 wires, signs on a PC board.
 - Application Focus: Wireless communication (1 week)
 - Wave propagation in free space - wires are not needed to transmit signals. The basics of cell phones, radio/TV. How to couple electromagnetic energy into free space? In what direction does the signal travel? Impedance of free space, simple dipole antennae. Demonstrate the higher frequencies require smaller antennae. What happens when you have multiple antennae?
 - Experimental demonstration: RF signals transmission.
 - Application Focus: Optical Fiber Communication (1 week)
 - Light as a high-frequency electromagnetic wave. Light propagation. Total internal reflection. Dielectric waveguide. Optical fibers.
 - How to generate and detect light. Antennae are impractical because we cannot make oscillators operating at 100s of THz. Next: quantum mechanics.
 - Experimental demonstration: Laser communication in the infrared.
 - Application Focus: Fluorescent light (1 week)
 - Review of modern physics.
 - Wave-particle duality, Electron wavefunction, Heisenberg's uncertainty principle - show relationship to transform pairs and to diffraction
 - Atomic energy levels
 - Experimental demonstration: Measurements of spectrum from incandescent (continuous) and fluorescent (lines) light sources
 - Application Focus: Conduction in semiconductors (1 week)
 - From atomic energy levels via molecular splitting to semiconductor bands.
 - Conduction and valence bands, Doping of semiconductors - Electrons and Holes
 - Density of States, Fermi-Dirac distribution
 - Experimental demonstration: Measurements of resistance in diffused resistors in Si.
 - Application Focus: Semiconductor diodes (1 week)
 - Fermi Dirac statistics. Simple P-N junctions - Capacitance and current. I-V characteristics. Diodes.

- Experimental demonstration: Characterization of Si PN junctions.
- Application Focus: Photodiodes (1 week)
 - Direct and indirect bandgap semiconductors
 - Light emission and absorption
 - Photodetectors
 - LED and photodetector, Lasers
 - Experimental demonstration: Photodiode with transimpedance amplifier
- Application Focus: MOS transistors (1 week)
 - Introduction to MOS transistors (electro-statically controlled current).
 - Transistor models, Circuits
 - Experimental demonstration: Characterization of Si MOS transistor

5. Depth Sequences

This section provides a first look at potential depth sequences that would be available for undergraduates in the new program. At present, it only describes major changes that need to be made to current classes to avoid overlap with the new core programs. Ultimately all our undergraduate classes and 200 level graduate classes should be reviewed and updated to fit into our new model.

One problem with the current EE program is that Masters students often take the advanced undergrad classes as well. Given the large Master program, the undergraduates often get lost in these advanced classes. We feel it is essential that special provision be put in place for these crossover classes, to ensure that the undergraduates don't get lost, and get contact time with the faculty or staff. It is these classes that should solidify their interest in EE, and we want to make sure they get the most out of these classes.

E&M

There are two options in E&M. One is in fields and waves, and the other is in solid-state and photonics. Students interested in devices should also consider depths in the Electronics Depth as well.

Fields and Waves:

EE142, EE144, EE231, EE234, EE235, EE241, EE246, EE247, EE252

The fields and waves sequence is well established.

Solid-state and Photonics:

EE111, EE212, EE216, EE217, EE222, EE223, EE228, EE231, EE232, EE234, EE235, EE243, EE247

This is a new undergraduate depth sequence, but the courses are all well established. Our recommendation is that two new undergraduate courses on

optical communication (similar to EE247) and electronic device physics (similar to EE216) should be developed.

Signals, Systems and Control

The depth sequences will change very little as a result of the new signals and systems core. The same courses that currently apply for communication and signal processing depth will remain unchanged, except for EE104. EE104 must be modified or eliminated, as half the EE104 material will be covered in the new core. A proposed modification for EE104 would be to make it an undergraduate version of EE279. This new course (perhaps designated as EE179) would have EE178 as a prerequisite (required in the core), and would discuss analog and digital communications systems in the presence of noise. Another class that might need to change due to overlap with the new undergrad class is EE261. EE262 (two-dimensional imaging) and EE276 (wireless personal communications) should also be added to the new communications and signal processing depth sequence.

The controls depth sequence will remain mostly the same, as EE102 was a prerequisite for these classes and the same material is taught in the new core. The only proposed change to the controls depth sequence is to add Engineering 207 (Modern Control Design).

Controls:

E105, EE205 (E205), EE206 (E206), E207A, E207B, EE209A (E209A), EE209B (E209B), E210A, E210B, EE263, EE278

Signal Processing and Communications:

EE133, EE168, EE179?, EE261, EE262, EE263, EE264 or EE265, EE276, EE278, EE279.

Electronics

The offering in the Electronics area will likely undergo major changes since EE111 and EE112 are now not part of the core program, but still need to be offered in some form for students interested in semiconductor devices. Here we assume that there will be a new 111 that covers the basic semiconductor device information.

Solid-State Electronic Devices and Technology: (same as in E&M)

Analog and Radio-Frequency Electronics:

EE133, EE214, EE144, EE246, EE200-level bipolar class

Digital Electronics:

EE271, EE273, EE313(re-numbered as 200-level), EE214, EE272, new DS class

Digital Systems

This area needs to be built up, since the new core replaces many of the classes that were there previously, and also uses material from EE271, EE273.

Hardware:

EE184(CS107), EE183 or EE281, EE271, EE275, EE273, CS140, CS143
EE183, EE281, EE271, EE275, EE273 all need to be revised

Software Systems:

EE184(CS107), EE189 (CS108), EE 189B(CS194), (EE284 or CS244), CS140,
CS143

6. Proposed Transition Plan

Revising the undergraduate program is a large task and must be staged carefully, since we can't interfere with the plans of the students already in the program. We are fortunate that for most of the classes, there are similar classes already in the program, so we can slowly roll out the new classes, allowing the current group of students to take either the new or old version of the class to satisfy their requirements. Since many of the core undergraduate classes are given twice each year, we can test out the new classes while still providing the original classes they are meant to replace. This strategy should allow us to debug the classes with minimum negative impact on our students.

The digital systems classes are in the most need of change, and the faculty there have already begun to upgrade the classes. Thus, we plan a fairly aggressive schedule, rolling out the new core classes in Digital Systems for the 02/03 academic year. Digital Systems I will replace one of the EE121 class offerings, so students wanting to take EE121 can take DS I instead that quarter, and DS II will replace EE182 the following quarter. Our current plan is to offer these classes during Winter and Spring next year.

We also plan to upgrade the Electronic core next year as well, by at least removing the requirements for students to take EE111 and EE112 as core classes. Next year we will only upgrade EE113 to accommodate students without any device classes, but these classes will not have the integrated labs that we discussed. The labs for these classes would be developed next year, and would be rolled out for the 03/04 academic year.

We also plan to introduce the new Signal, Systems and Control core classes in 03/04 and to revise E40 and the new E&M class that year as well. These classes each would be given once to help debug them before phasing out old classes. Thus in three years, the new undergraduate core program should be in place and our efforts

will be on updating the remaining undergraduate classes and the graduate classes they feed into.

7. Future Issues

This document represents only the first step towards revising the EE undergraduate curriculum. It describes the motivation and the philosophy behind the revision that we are proposing. There are many issues that remain to be resolved, including the following:

1. There are gaps in fundamental knowledge that are not covered by the proposed courses and sequences. They need to be identified and included in the revised curriculum.
2. The topics to be covered in the revised fundamental course sequences may be too aggressive and extensive. Further trimming and focusing will be required.
3. There may not be appropriate textbooks in the market for the revised curriculum. Faculty may need to use a combination of textbooks or write their own.
4. Strong couplings between the revised fundamental courses and the existing specialty courses must be assured. Otherwise, our undergraduate students will be ill prepared for the upper and graduate level courses. In addition we are pulling material from several advanced classes and placing them in the core. This means that the next step is to review and reviews the non-core classes to grow the new undergraduate program, and new class philosophy, out to the rest of the curriculum. Clearly we should start with the classes most affected by the change, but we should ultimately review all of our classes.
5. Faculty members who subscribe to the philosophy of the revised curriculum must be identified and provided with the resources and time to implement the revisions.
6. We had hoped to look at the Computer Systems Engineering degree, with the possibility of moving it over to the EE department. This remains undone.