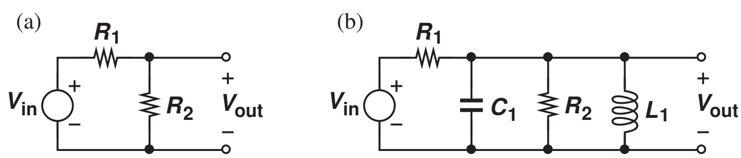
Suggestions for Students

You are about to embark upon a journey through the fascinating world of microelectronics. Fortunately, microelectronics appears in so many facets of our lives that we can readily gather enough motivation to study it. The reading, however, is not as easy as that of a novel; we must deal with *analysis* and *design*, applying mathematical rigor as well as engineering intuition every step of the way. This article provides some suggestions that students may find helpful in studying microelectronics.

Rigor and Intuition Before reading this book, you have taken one or two courses on basic circuit theory, mastering Kirchoff's Laws and the analysis of RLC circuits. While quite abstract and bearing no apparent connection with real life, the concepts studied in these courses form the foundation for microelectronics—just as calculus does for engineering.

Our treatment of microelectronics also requires rigor but entails two additional components. First, we identify many applications for the concepts that we study. Second, we must develop *intuition*, i.e., a "feel" for the operation of microelectronic devices and circuits. Without an intuitive understanding, the analysis of circuits becomes increasingly more difficult as we add more devices to perform more complex functions.

Analysis by Inspection We will expend a considerable effort toward establishing the mentality and the skills necessary for "analysis by inspection." That is, looking at a complex circuit, we wish to decompose or "map" it to simpler topologies, thus formulating the behavior with a few lines of algebra. As a simple example, suppose we have encountered the resistive divider shown in Fig. (a) and derived its Thevenin equivalent. Now, if given the circuit in Fig. (b), we can readily replace V_{in}, R_1, and R_2 with a Thevenin equivalent, thereby simplifying the calculations.



Example of analysis by inspections.

40 Pages per Week While taking courses on microelectronics, you will need to read about 40 pages of this book every week, with each page containing many new concepts, derivations, and examples. The lectures given by the instructor create a "skeleton" of each chapter, but it rests upon you to "connect the dots" by reading the book carefully and understanding each paragraph before proceeding to the next.

Reading and understanding 40 pages of the book each week requires concentration and discipline. You will face new material and detailed derivations on each page and should set aside two- or three-hour distraction-free blocks of time (no phone calls, TV, email, etc.) so that you can follow the *evolution* of the concepts while honing your analytical skills. I also suggest that you attempt each example before reading its solution.

40 Problems per Week After reading each section and going through its examples, you are encouraged to evaluate and improve your understanding by trying the corresponding end-of-chapter problems. The problems begin at a relatively easy level and gradually become more challenging. Some problems may require that you return to the section and study the subtle points more carefully.

The educational value provided by each problem depends on your *persistence*. The initial glance at the problem may be discouraging. But, as you think about it from different angles and, more importantly, re-examine the concepts in the chapter, you begin to form a path in your mind that may lead to the solution. In fact, if you have thought about a problem extensively and still have not solved it, you need but a brief hint from the instructor or the teaching assistant. Also, the more you struggle with a problem, the more appealing and memorable the answer will be.

Attending the lecture and reading the book are examples of "passive learning:" you simply receive (and, hopefully, absorb) a stream of information provided by the instructor and the text. While necessary, passive learning does not *exercise* your understanding, thus lacking depth. You may highlight many lines of the text as important. You may even summarize the important concepts on a separate sheet of paper (and you are encouraged to do so). But, to *master* the material, you need practice ("active learning"). The problem sets at the end of each chapter serve this purpose.

Homeworks and Exams Solving the problems at the end of each chapter also prepares you for homeworks and exams. Homeworks, too, demand distraction-free periods during which you put your knowledge to work and polish your understanding. An important piece of advice that I can offer here is that doing homeworks with your fellow students is a *bad* idea! Unlike other subject matters that benefit from discussions, arguments, and rebuttals, learning microelectronics requires quiet concentration. (After all, you will be on your own during the exam!) To gain more confidence in your answers, you can discuss the results with your fellow students, the instructor, or the teaching assistants *after* you have completed the homework by yourself.

Time Management Reading the text, going through the problem sets, and doing the homeworks require a time commitment of at least 10 hours per week. Due to the fast pace of the course, the material accumulates rapidly, making it difficult to keep up with the lectures if you do not spend the required time from the very first week. In fact, the more you fall behind, the less interesting and useful the lectures become, thus forcing you to simply write down everything that the instructor says while not understanding much. With your other courses demanding similar time commitments, you can soon become overwhelmed if you do not manage your time carefully.

Time management consists of two steps: (1) partitioning your waking hours into solid blocks, and (2) using each block *efficiently*. To improve the efficiency, you can take the following measures: (a) work in a quiet environment to minimize distractions; (b) spread the work on a given subject over the week, e.g., 3 hours every other day, to avoid saturation and to allow your subconscious to process the concepts in the meantime.

Prerequisites Many of the concepts that you have learned in the circuit theory courses prove essential to the study of microelectronics. Chapter 1 gives a brief overview to refresh your memory. With the limited lecture time, the instructor may not cover this material in the class, leaving it for you to read at home. You can first glance through the chapter and see which concepts "bother" you before sitting down to concentrate.

Suggestions for Instructors

Teaching undergraduate courses proves quite challenging—especially if the emphasis is on thinking and deduction rather than on memorization. With today's young minds used to playing fast-paced video games and "clicking" on the Internet toward their destination, it has become increasingly more difficult to encourage them to concentrate for long periods of time and deal with abstract concepts. Drawing upon more than one decade of teaching, this article provides suggestions that instructors of microelectronics may find helpful.

Therapy The students taking the first microelectronics course have typically completed one or two courses on basic circuit theory. To many, that experience has not been particularly memorable. After all, the circuit theory textbook is most likely written by a person *not* in the field of circuits. Similarly, the courses are most likely taught by an instructor having little involvement in circuit design. For example, the students are rarely told that node analysis is much more frequently used in hand calculations than mesh analysis is. Or, they are given little intuition with respect to Thevenin's and Norton's theorems.

With the foregoing issues in mind, I begin the first course with a five-minute "therapy session." I ask how many liked the circuit theory courses and came out with a "practical" understanding. Very few raise their hands. I then ask, "But how about your calculus courses? How many of you came out of these courses with a "practical" understanding?" Subsequently, I explain that circuit theory builds the foundation for microelectronics just as calculus does for engineering. I further mention that some abstractness should also be expected in microelectronics as we complete the foundation for more advanced topics in circuit analysis and design. I then point out that (1) microelectronics is very heavily based on intuitive understanding, requiring that we go *beyond* simply writing KVLs and KCLs and interpret the mathematical expressions intuitively, and (2) this course offers many applications of microelectronic devices and circuits in our daily lives. In other words, microelectronics is not as dry as arbitrary RLC circuits consisting of 1-Ω resistors, 1-H inductors, and 1-F capacitors.

First Quiz Since different students enter each course with different levels of preparation, I have found it useful to give a 10-minute quiz in the very first lecture. Pointing out that the quiz does not count towards their grade but serves as a gauge of their understanding, I emphasize that the objective is to test their knowledge rather than their intelligence. After collecting the quizzes, I ask one of the teaching assistants to assign a binary grade to each: those who would receive less than 50% are marked with a red star. At the end of the lecture, I return the quizzes and mention that those with a red star need to work harder and interact with the teaching assistants and myself more extensively.

The Big Picture A powerful motivational tool in teaching is the "big picture," i.e., the "practical" application of the concept under study. The two examples of microelectronic systems described in Chapter 1 serve as the first step toward creating the context for the material covered in the book. But, the big picture cannot stop here. Each new concept may merit an application—however brief the mention of the application may be—and most of this burden falls on the lecture rather than on the book.

The choice of the application must be carefully considered. If the description is too long or the result too abstract, the students miss the connection between the concept and the application. My general approach is as follows. Suppose we are to begin Chapter 2 (Basic Semiconductor Physics). I ask either "What would our world look like without semiconductors?" or "Is there a semiconductor device in your watch? In your cellphone? In your laptop? In your digital camera?" In the ensuing discussion, I quickly go over examples of semiconductor devices and where they are used.

Following the big picture, I provide additional motivation by asking, "Well, but isn't this stuff *old*? Why do *we* need to learn these things?" I then briefly talk about the challenges in today's designs and the competition among manufacturers to lower both the power consumption and the cost of portable devices.

Analysis versus Synthesis Let us consider the background of the students entering a microelectronics course. They can write KVLs and KCLs efficiently. They have also seen numerous "random" RLC circuits; i.e., to these students, all RLC circuits look the same, and it is unclear how they came about. On the other hand, an essential objective in teaching microelectronics is to develop specific circuit topologies that provide certain characteristics. We must therefore change the students' mentality from "Here's a circuit that you may never see again in your life. Analyze it!" to "We face the following problem and we must create (synthesize) a circuit that solves the problem." We can then begin with the simplest topology, identify its shortcomings, and continue to modify it until we arrive at an acceptable solution. This step-by-step synthesis approach (a) illustrates the role of each device in the circuit, (b) establishes a "design-oriented" mentality, and (c) engages the students' intellect and interest.

Analysis by Inspection In their journey through microelectronics, students face increasingly more complex circuits, eventually reaching a point where blindly writing KVLs and KCLs becomes extremely inefficient and even prohibitive. In one of my first few lectures, I show the internal circuit of a complex op amp and ask, "Can we analyze the behavior of this circuit by simply writing node or mesh equations?" It is therefore important to instill in them the concept of "analysis by inspection." My approach consists of two steps. (1) For each simple circuit, formulate the properties in an intuitive language; e.g., "the voltage gain of a common-source stage is given by the load resistance divided by $1/g_m$ plus the resistance tied from the source to ground." (2) Map complex circuits to one or more topologies studied in step (1).

In addition to efficiency, analysis by inspection also provides great intuition. As we cover various examples, I emphasize to the students that the results thus obtained reveal the circuit's dependencies much more clearly than if we simply write KVLs and KCLs without mapping.

"What If?" Adventures An interesting method of reinforcing a circuit's properties is to ask a question like, "What if we tie this device between nodes C and D rather than between nodes A and B?" In fact, students themselves often raise similar questions. My answer to them is "Don't be afraid! The circuit doesn't bite if you change it like this. So go ahead and analyze it in its new form."

For simple circuits, the students can be encouraged to consider several possible modifications and determine the resulting behavior. Consequently, the students feel much more comfortable with the original topology and understand why it is the only acceptable solution (if that is the case).

Numeric versus Symbolic Calculations In the design of examples, homeworks, and exams, the instructor must decide between numeric and symbolic calculations. The students may, of course, prefer the former type as it simply requires finding the corresponding equation and plugging in the numbers.

What is the value in numeric calculations? In my opinion, they may serve one of two purposes: (1) make the students comfortable with the results recently obtained, or (2) give the students a feel for the typical values encountered in practice. As such, numeric calculations play a limited role in teaching and reinforcing concepts.

Symbolic calculations, on the other hand, can offer insight into the behavior of the circuit by revealing dependencies, trends, and limits. Also, the results thus obtained can be utilized in more complex examples.

Blackboard versus Powerpoint This book comes with a complete set of Powerpoint slides. However, I suggest that the instructors carefully consider the pros and cons of blackboard and Powerpoint presentations.

I can offer the following observations. (1) Many students fall asleep (at least mentally) in the classroom if they are not writing. (2) Many others feel they are missing something if they are not writing. (3) For most people, the act of writing something on paper helps "carve" it in their mind. (4) The use of slides leads to a fast pace ("if we are not writing, we should move on!"), leaving little time for the students to digest the concepts. For these reasons, even if the students have a hardcopy of the slides, this type of presentation proves quite ineffective.

To improve the situation, one can leave blank spaces in each slide and fill them with critical and interesting results in real time. I have tried this method using transparencies and, more recently, tablet laptops. The approach works well for graduate courses but leaves undergraduate students bored or bewildered.

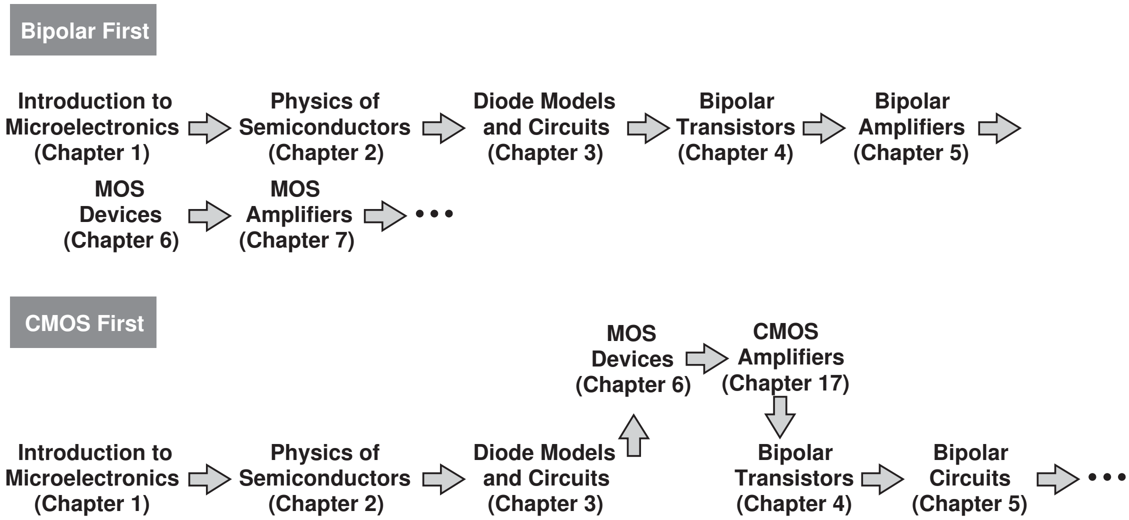
My conclusion is that the good old blackboard is still the best medium for teaching undergraduate microelectronics. The instructor may nonetheless utilize a hardcopy of the Powerpoint slides as his/her own guide for the flow of the lecture.

Discrete versus Integrated How much emphasis should a microelectronics course place on discrete circuits and integrated circuits? To most of us, the term "microelectronics" remains synonymous with "integrated circuits," and, in fact, some university curricula have gradually reduced the discrete design flavor of the course to nearly zero. However, only a small fraction of the students taking such courses eventually become active in IC products, while many go into board-level design.

My approach in this book is to begin with general concepts that apply to both paradigms and gradually concentrate on integrated circuits. I also believe that even board-level designers must have a basic understanding of the integrated circuits that they use.

Bipolar Transistor versus MOSFET At present, some controversy surrounds the inclusion of bipolar transistors and circuits in undergraduate microelectronics. With the MOSFET dominating the semiconductor market, it appears that bipolar devices are of little value. While this view may apply to graduate courses to some extent, it should be borne in mind that (1) as mentioned above, many undergraduate students go into board-level and discrete design and are likely to encounter bipolar devices, and (2) the contrasts and similarities between bipolar and MOS devices prove extremely useful in understanding the properties of each.

The order in which the two species are presented is also debatable. (Extensive surveys conducted by Wiley indicate a 50-50 split between instructors on this matter.) Some



Course sequences for covering bipolar technology first or CMOS technology first.

instructors begin with MOS devices to ensure enough time is spent on their coverage. On the other hand, the natural flow of the course calls for bipolar devices as an extension of *pn* junctions. In fact, if diodes are immediately followed by MOS devices, the students see little relevance between the two. (The *pn* junctions in MOSFETs do not come into the picture until the device capacitances are introduced.)

My approach in this book is to first cover bipolar devices and circuits while building the foundation such that the MOS counterparts are subsequently taught with greater ease. As explained below, the material can comfortably be taught even in one quarter with no sacrifice of details of either device type.

Nonetheless, the book is organized so as to allow covering CMOS circuits first if the instructor so wishes. The sequence of chapters for each case is shown below. Chapter 16 is written with the assumption that the students have not seen any amplifier design principles so that the instructor can seamlessly go from MOS device phyics to MOS amplifier design without having covered bipolar amplifiers.

Course Syllabi This book can be used in a two-quarter or two-semester sequence. Depending on the instructor's preference, the courses can follow various combinations of the chapters. Figure illustrates some possibilities.

I have followed Syllabus I for the quarter system at UCLA for a number of years.[1] Syllabus II sacrifices op amp circuits for an introductory treatment of digital CMOS circuits.

In a semester system, Syllabus I extends the first course to current mirrors and cascode stages and the second course to output stages and analog filters. Syllabus II, on the other hand, includes digital circuits in the first course, moving current mirrors and cascodes to the second course and sacrificing the chapter on output stages.

Figure shows the approximate length of time spent on the chapters as practiced at UCLA. In a semester system, the allotted times are more flexible.

[1] We offer a separate undergraduate course on digital circuit design, which the students can take only *after* our first microelectronics course.

Quarter System, Syllabus I

First Quarter:

Introduction to Microelectronics (Chapter 1) → Physics of Semiconductors (Chapter 2) → Diode Models and Circuits (Chapter 3) → Bipolar Transistors (Chapter 4) → Bipolar Amplifiers (Chapter 5) → MOS Devices (Chapter 6) → CMOS Amplifiers (Chapter 7) → Op Amp as Black Box (Chapter 8)

Second Quarter:

Current Mirrors and Cascodes (Chapter 9) → Differential Pairs (Chapter 10) → Frequency Response (Chapter 11) → Feedback and Stability (Chapter 12)

Quarter System, Syllabus II

First Quarter:

Introduction to Microelectronics (Chapter 1) → Physics of Semiconductors (Chapter 2) → Diode Models and Circuits (Chapter 3) → Bipolar Transistors (Chapter 4) → Bipolar Amplifiers (Chapter 5) → MOS Devices (Chapter 6) → CMOS Amplifiers (Chapter 7) → Digital CMOS Circuits (Chapter 16)

Second Quarter:

Current Mirrors and Cascodes (Chapter 9) → Differential Pairs (Chapter 10) → Frequency Response (Chapter 11) → Feedback and Stability (Chapter 12)

Semester System, Syllabus I

First Semester:

Introduction to Microelectronics (Chapter 1) → Physics of Semiconductors (Chapter 2) → Diode Models and Circuits (Chapter 3) → Bipolar Transistors (Chapter 4) → Bipolar Amplifiers (Chapter 5) → MOS Devices (Chapter 6) → CMOS Amplifiers (Chapter 7) → Op Amp as Black Box (Chapter 8) → Current Mirrors and Cascodes (Chapter 9)

Second Semester:

Differential Pairs (Chapter 10) → Frequency Response (Chapter 11) → Feedback and Stability (Chapter 12) → Oscillators (Chapter 13) → Analog Filters (Chapter 15)

Semester System, Syllabus II

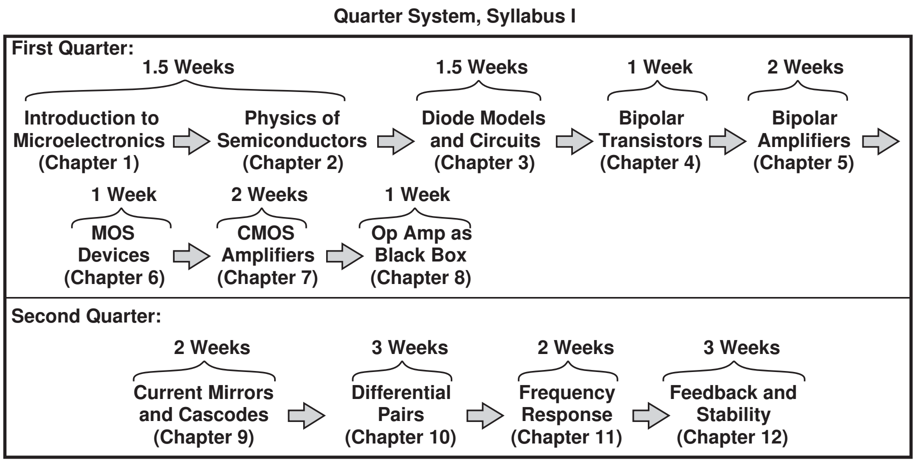
First Semester:

Introduction to Microelectronics (Chapter 1) → Physics of Semiconductors (Chapter 2) → Diode Models and Circuits (Chapter 3) → Bipolar Transistors (Chapter 4) → Bipolar Amplifiers (Chapter 5) → MOS Devices (Chapter 6) → CMOS Amplifiers (Chapter 7) → Op Amp as Black Box (Chapter 8) → Digital CMOS Circuits (Chapter 16)

Second Semester:

Current Mirrors and Cascodes (Chapter 9) → Differential Pairs (Chapter 10) → Frequency Response (Chapter 11) → Feedback and Stability (Chapter 12) → Oscillators (Chapter 13)

Different course structures for quarter and semester systems.



Timetable for the two courses.

Coverage of Chapters The material in each chapter can be decomposed into three categories: (1) essential concepts that the instructor should cover in the lecture, (2) essential skills that the students must develop but cannot be covered in the lecture due to the limited time, and (3) topics that prove useful but may be skipped according to the instructor's preference.[2] Summarized below are overviews of the chapters showing which topics should be covered in the classroom.

Chapter 1: Introduction to Microelectronics The objective of this chapter is to provide the "big picture" and make the students comfortable with analog and digital signals. I spend about 30 to 45 minutes on Sections 1.1 and 1.2, leaving the remainder of the chapter (Basic Concepts) for the teaching assistants to cover in a special evening session in the first week.

Chapter 2: Basic Semiconductor Physics Providing the basics of semiconductor device physics, this chapter deliberately proceeds at a slow pace, examining concepts from different angles and allowing the students to digest the material as they read on. A terse language would shorten the chapter but require that the students reread the material multiple times in their attempt to decipher the prose.

It is important to note, however, that the instructor's pace in the classroom need not be as slow as that of the chapter. The students are expected to read the details and the examples on their own so as to strengthen their grasp of the material. The principal point in this chapter is that we must study the physics of devices so as to construct circuit models for them. In a quarter system, I cover the following concepts in the lecture: electrons and holes; doping; drift and diffusion; *pn* junction in equilibrium and under forward and reverse bias.

Chapter 3: Diode Models and Circuits This chapter serves four purposes: (1) make the students comfortable with the *pn* junction as a nonlinear device; (2) introduce the concept of linearizing a nonlinear model to simplify the analysis; (3) cover basic circuits with which any electrical engineer must be familiar, e.g., rectifiers and limiters; and (4) develop the

[2]Such topics are identified in the book by a footnote.

skills necessary to analyze heavily-nonlinear circuits, e.g., where it is difficult to predict which diode turns on at what input voltage. Of these, the first three are essential and should be covered in the lecture, whereas the last depends on the instructor's preference. (I cover it in my lectures.) In the interest of time, I skip a number of sections in a quarter system, e.g., voltage doublers and level shifters.

Chapter 4: Physics of Bipolar Transistors Beginning with the use of a voltage-controlled current source in an amplifier, this chapter introduces the bipolar transistor as an extension of *pn* junctions and derives its small-signal model. As with Chapter 2, the pace is relatively slow, but the lectures need not be. I cover structure and operation of the bipolar transistor, a very simplified derivation of the exponential characteristic, and transistor models, mentioning only briefly that saturation is undesirable. Since the T-model of limited use in analysis and carries little intuition (especially for MOS devices), I have excluded it in this book.

Chapter 5: Bipolar Amplifiers This is the longest chapter in the book, building the foundation necessary for all subsequent work in electronics. Following a bottom-up approach, this chapter establishes critical concepts such as input and output impedances, biasing, and small-signal analysis.

While writing the book, I contemplated decomposing Chapter 5 into two chapters, one on the above concepts and another on bipolar amplifier topologies, so that the latter could be skipped by instructors who prefer to continue with MOS circuits instead. However, teaching the general concepts does require the use of transistors, making such a decomposition difficult.

Chapter 5 proceeds slowly, reinforcing, step-by-step, the concept of synthesis and exploring circuit topologies with the aid of "What if?" examples. As with Chapters 2 and 4, the instructor can move at a faster pace and leave much of the text for the students to read on their own. In a quarter system, I cover all of the chapter, frequently emphasizing the concepts illustrated in Figure 5.7 (the impedance seen looking into the base, emitter, or collector). With about two (perhaps two and half) weeks allotted to this chapter, the lectures must be precisely designed to ensure the main concepts are imparted in the classroom.

Chapter 6: Physics of MOS Devices This chapter parallels Chapter 4, introducing the MOSFET as a voltage-controlled current source and deriving its characteristics. Given the limited time that we generally face in covering topics, I have included only a brief discussion of the body effect and velocity saturation and neglected these phenomena for the remainder of the book. I cover all of this chapter in our first course.

Chapter 7: CMOS Amplifiers Drawing extensively upon the foundation established in Chapter 5, this chapter deals with MOS amplifiers but at a faster pace. I cover all of this chapter in our first course.

Chapter 8: Operational Amplifier as a Black Box Dealing with op-amp-based circuits, this chapter is written such that it can be taught in almost any order with respect to other chapters. My own preference is to cover this chapter *after* amplifier topologies have been studied, so that the students have some bare understanding of the internal circuitry of op amps and its gain limitations. Teaching this chapter near the end of the first course also places op amps closer to differential amplifiers (Chapter 10), thus allowing the students to appreciate the relevance of each. I cover all of this chapter in our first course.

Chapter 9: Cascodes and Current Mirrors This chapter serves as an important step toward integrated circuit design. The study of cascodes and current mirrors here also provides the necessary background for constructing differential pairs with active loads or cascodes in Chapter 10. From this chapter on, bipolar and MOS circuits are covered together and various similarities and contrasts between them are pointed out. In our second microelectronics course, I cover all of the topics in this chapter in approximately two weeks.

Chapter 10: Differential Amplifiers This chapter deals with large-signal and small-signal behavior of differential amplifiers. The students may wonder why we did not study the large-signal behavior of various amplifiers in Chapters 5 and 7; so I explain that the differential pair is a versatile circuit and is utilized in both regimes. I cover all of this chapter in our second course.

Chapter 11: Frequency Response Beginning with a review of basic concepts such as Bode's rules, this chapter introduces the high-frequency model of transistors and analyzes the frequency response of basic amplifiers. I cover all of this chapter in our second course.

Chapter 12: Feedback and Stability Most instructors agree the students find feedback to be the most difficult topic in undergraduate microelectronics. For this reason, I have made great effort to create a step-by-step procedure for analyzing feedback circuits, especially where input and output loading effects must be taken into account. As with Chapters 2 and 5, this chapter proceeds at a deliberately slow pace, allowing the students to become comfortable with each concept and appreciate the points taught by each example. I cover all of this chapter in our second course.

Chapter 13: Oscillators This new chapter deals with both discrete and integrated oscillators. These circuits are both important in real-life applications and helpful in enhancing the feedback concepts taught previously. This chapter can be comfortably covered in a semester system.

Chapter 14: Output Stages and Power Amplifiers This chapter studies circuits that deliver higher power levels than those considered in previous chapters. Topologies such as push-pull stages and their limitations are analyzed. This chapter can be covered in a semester system.

Chapter 15: Analog Filters This chapter provides a basic understanding of passive and active filters, preparing the student for more advanced texts on the subject. This chapter can also be comfortably covered in a semester system.

Chapter 16: Digital CMOS Circuits This chapter is written for microelectronics courses that include an introduction to digital circuits as a preparation for subsequent courses on the subject. Given the time constraints in quarter and semester systems, I have excluded TTL and ECL circuits here.

Chapter 17: CMOS Amplifiers This chapter is written for courses that cover CMOS circuits before bipolar circuits. As explained earlier, this chapter follows MOS device physics and, in essence, is similar to Chapter 5 but deals with MOS counterparts.

Problem Sets In addition to numerous examples, each chapter offers a relatively large problem set at the end. For each concept covered in the chapter, I begin with simple, confidence-building problems and gradually raise the level of difficulty. Except for the device physics chapters, all chapters also provide a set of design problems that encourage students to work "in reverse" and select the bias and/or component values to satisfy certain requirements.

SPICE Some basic circuit theory courses may provide exposure to SPICE, but it is in the first microelectronics course that the students can appreciate the importance of simulation tools. Appendix A of this book introduces SPICE and teaches circuit simulation with the aid of numerous examples. The objective is to master only a *subset* of SPICE commands that allow simulation of most circuits at this level. Due to the limited lecture time, I ask the teaching assistants to cover SPICE in a special evening session around the middle of the quarter—just before I begin to assign SPICE problems.

Most chapters contain SPICE problems, but I prefer to introduce SPICE only in the second half of the first course (toward the end of Chapter 5). This is for two reasons: (1) the students must first develop their basic understanding and analytical skills, i.e., the homeworks must exercise the fundamental concepts; and (2) the students appreciate the utility of SPICE much better if the circuit contains a relatively large number of devices (e.g., 5-10).

Homeworks and Exams In a quarter system, I assign four homeworks before the midterm and four after. Mostly based on the problem sets in the book, the homeworks contain moderate to difficult problems, thereby requiring that the students first go over the easier problems in the book on their own.

The exam questions are typically "twisted" versions of the problems in the book. To encourage the students to solve *all* of the problems at the end of each chapter, I tell them that one of the problems in the book is given in the exam verbatim. The exams are open-book, but I suggest to the students to summarize the important equations on one sheet of paper.

Happy Teaching!

Contents

Lo vimos en clase

Creo q' lo vamos a ver, pero viene mucho después

¿Xq está acá?

Acá está lo del tanque LC, pero cero ganas de meterme acá