RESOURCE LETTER

Roger H. Stuewer, *Editor*
School of Physics and Astronomy, 116 Church Street SE,
University of Minnesota, Minneapolis, Minnesota 55455

This is one of a series of Resource Letters on different topics intended to guide college physicists, astronomers, and other scientists to some of the literature and other teaching aids that may help improve course content in specified fields. [The letter E after an item indicates elementary level or material of general interest to persons becoming informed in the field. The letter I, for intermediate level, indicates material of somewhat more specialized nature; and the letter A indicates rather specialized or advanced material.] No Resource Letter is meant to be exhaustive and complete; in time there may be more than one letter on some of the main subjects of interest. Comments on these materials as well as suggestions for future topics will be welcomed. Please send such communications to Professor Roger H. Stuewer, Editor, AAPT Resource Letters, School of Physics and Astronomy, 116 Church Street SE, University of Minnesota, Minneapolis, MN 55455.

Resource Letter: TE-1: Teaching electronics

Dennis C. Henry
Physics Department, Gustavus Adolphus College, St. Peter, Minnesota 56082

(Received 6 June 2001; accepted 16 August 2001)

This Resource Letter examines the evolution, roles, and content of courses in electronics in the undergraduate physics curriculum, and provides a guide to resources for faculty teaching such courses. It concludes with a brief section addressing problems of electromagnetic interference in electronic systems, and provides an introduction to the literature and practice of electromagnetic compatibility. I have included textbooks, reference books, articles, collections of laboratory experiments and projects, sources of equipment and parts, software packages, videos, and websites.

[DOI: 10.1119/1.1410955]

I. INTRODUCTION

Electronics grew out of the ''vacuum-tube radio era,'' dating roughly from 1904 through World War II. The invention of the junction transistor by John Bardeen, William Shockley, and Walter Brattain in late 1947 laid the foundation for the next era, which continued through the remarkable miniaturization and materials that support the Information Age. Classic texts such as those by T. B. Brown and F. H. Mitchell combined circuit and radio theory with analog applications. Electronics engineering matured and expanded, but with a continuing strong overlap with physics, particularly for devices and certain applications.

The evolution of electronics topics in the physics curriculum could be a study in itself, but it is not the primary focus of this Resource Letter. Physics faculty and graduates from the post-World War II era will recall filling up their buildings with tons of war-surplus radio, telephone, microwave, and radar gear. Industrial surplus donations from such companies as Western Electric, IBM, and the national laboratories flowed for many more years. Physicists doing nuclear magnetic resonance in the late 1940s, or indeed almost any experimental research, needed to learn a certain amount of electronics, and to acquire a proficiency with oscilloscopes and other test equipment. The switch from vacuum tubes to discrete transistors and then to integrated circuits was gradual, and numerous generations of equipment coexisted. One still had to understand circuit and analog fundamentals, as well as the new ideas that digital computing and signal processing required.

Avocational student and faculty interests in hi-fi, television, ham radio, and early computers reinforced the teaching and practice of electronics. A half-dozen U.S. companies produced extensive lines of electronic kits for these hobbies, as well as test equipment that was equally at home in college laboratories and repair shops. Popular monthly magazines catered to the electronics hobby and profession. Building and repairing one's own home entertainment equipment was both possible and economical, and it formed a pathway into physics and electrical engineering for many, the author included. On the academic side, many masters and doctoral thesis projects in experimental physics required students to become their own electronics technicians and engineers, at least until recent years.

Survey and introductory courses in electronics, with only minimal prerequisites, began to appear in physics and chemistry departments in the early 1960s with the publication of the first texts by Malmstadt and Emke, followed soon by Diefenderfer, Brophy, and others. More advanced courses continued to be developed and taught at the graduate level, often with instructor notes as the text and laboratory manual. The content was strongly influenced by local expertise, and by the tools necessary for work in nuclear, solid state, space physics, and other specialties.

Electronics courses in the physics curriculum, and texts aimed at those audiences, began to experience a major shift in the early 1980s, from covering discrete-component to mostly integrated circuits, both for pedagogy and applications. This decade saw the publication of a generous half-dozen texts for what had become standard, if evolving, course offerings.

There are several important differences between electronics courses for future scientists and those that undergird the electrical engineering curriculum. Most of the former are taught by physicists, or through physics departments. Students are drawn from physics, chemistry, astronomy, computer science, and to a lesser extent, from biology, geology, psychology, and sometimes from the arts and communications areas. With few exceptions, these students are not going to be designing elaborate circuits or carrying out sophisticated circuit analysis. The course objectives, required textbooks, and laboratory experiences reflect these differences. Some pre-engineering students at four-year colleges use physics-based electronics courses to fulfill requirements in mechanical, civil, and other non-EE university engineering programs. Other students find such courses sufficient to replace introductory circuits courses leading to electrical engineering degrees, both bachelors and masters.

Students who have taken electronics courses offered by physics departments will often later be using electronic equipment and instrumentation in a variety of experimental areas. These former students may be called upon to modify or combine the pieces in standard and creative ways. They should be able to read schematic diagrams and know the functions and limitations of the individual and interconnected components and systems. They should understand the fundamentals of circuit operation and analysis. They will need to be comfortable with basic electronic test equipment, and to learn quickly more sophisticated laboratory instrumentation. However, they will not be designing their own stereo preamplifiers or reinventing the digital computer. Those who go on in experimental physics and engineering will encounter many overlapping generations of electronic equipment, not only in their graduate educations, but also in their working lives. The research and field environments in which they work will be increasingly noisy in the electromagnetic sense, while the experiments and devices will often become increasingly sensitive and susceptible to such interference. Their specific education in electromagnetic compatibility (EMC) will be relatively limited, but they will find that the fundamentals are readily approached from the physics perspective.

Local and distant technical support for most electronics equipment is becoming minimal or nonexistent. Our students will be faced with the need to isolate malfunctions, adapt transducers, modify interfaces, and solve interference problems. (They also may have to dig into undocumented software written in languages they could not possibly have come into contact with in formal courses, but that is another problem.) However, their problem-solving skills, honed in studying physics and working in laboratories, will augment their formal course work in electronics and instrumentation. We know the potency of this combination by numerous testimonials from our graduates.

The classroom and laboratory content of physics electronics courses at the introductory and intermediate levels usually includes some coverage of the following topics:

(a) DC circuits (Ohms law, Kirchhoff rules, networks, power transfer, equivalent circuits, Thevenin's and Norton's theorems, ideal voltage and current sources).
(b) Transient and ac circuits (root-mean-square values for periodic signals, $R-L-C$ in transient circuits, reactance, impedance, $R-L-C$ in sine source circuits, resonance, "Q," simple passive filters, integration and differentiation in RC circuits).
(c) Test equipment and measurement (meters, oscilloscopes, signal generators, data acquisition, LabVIEW or other software, cabling, decibels, transducers, lab issues).
(d) Diodes, $p-n$ junctions, and power supplies ($p-n$ junction physics, ideal and real diodes, zener diodes, rectification, clipping, clamping, power supply filtering, regulation, and programming).
(e) Transistors (bipolar, *npn*, *pnp*, modeling, characteristics in circuits, switch applications, current and voltage amplification, common-emitter amplifier, emitter-follower, field-effect transistors, CMOS).
(f) Operational amplifiers (idealized model, negative feedback, inverting and noninverting amplifier circuits, summing amps, difference amps, integrators, differentiators, various applications circuits, departures from ideal model, positive feedback and oscillation).
(g) Digital logic and circuits (digital logic elements, AND, NAND, OR, NOR, XOR, Boolean algebra, combinations of gates, Karnaugh maps, integrated circuit implementations, logic families and characteristics, applications).
(h) Sequential digital circuits (flip-flops, counters, registers, displays, codes and representations, error correction, multiplexing, and demultiplexing).
(i) Data acquisition and conversion (waveshaping, comparators, Schmitt triggers, one-shots, timers, digital-to-analog conversion, analog-to-digital conversion, sampling, microcomputer interfacing, LabVIEW software and compatible hardware, microcomputer architecture).
(j) Noise and interference (intrinsic noise, thermal noise, $1/f$ noise, shot noise, extrinsic noise, emission and susceptibility, conducted and radiated noise, shielding, grounding, filtering).
(k) Advanced techniques and topics (lock-in amplifiers, digital signal processing, active filters, communications protocols, phase-locked loops, rf circuits, modulation schemes, optoelectronics).

But all is not entirely well in this part of the curriculum. The consensus about the role and content of electronics courses, borne of direct experience, and codified in a relative handful of texts, has become thin or disappeared in many departments. The causes are many, but a realistic reappraisal of the undergraduate curriculum requires that we identify those that are most significant.

While electronic and computer-based consumer products and commercial instrumentation are now everywhere, users can get along without having any idea of how something electronic works. This always has been true to a considerable extent for consumer electronics, but the generalization is now almost universal. Virtually nothing is "user serviceable," and much equipment is not economically serviceable by anyone, including the factory. In the laboratory setting, data-acquisition hardware, interfaced with personal computers, and running software such as LabVIEW have transformed tasks that formerly required more direct awareness of electrical measurements and electronics. It is a rare oscilloscope, meter, or function generator of less than a decade in age that does not harbor a microprocessor or programmable integrated circuit controller within its plastic case. In electronics engineering and technology courses themselves, the advent of sophisticated analog and digital circuit-simulation software, such as PSpice, has put designer tools into the hands of the apprentice and master alike. Taken to extremes, this technology can turn much of the connected learning and conceptual development into a series of mouse clicks.

The ''less-is-more'' trend in introductory physics sequences has frequently sacrificed coverage of ac circuits, or circuits, period. This has then required that intermediate courses begin at a lower level, and for smaller numbers of students still in the cohort. Faculty debate the question of how much, if any, coverage of discrete components (i.e., transistors) should be included. This could be logically extended to such standard digital topics as gates, flip-flops, counters, and the other stepping stones to a modern pc.

The coverage of experiment control and data acquisition methods, beyond the introduction students already receive in their early physics labs, is sometimes included in electronics courses. Succeeding courses in experimental methods, advanced laboratory, and similar offerings at the upper level typically require that students develop expertise with a variety of interfaces, and with programs written in dialects of BASIC, or, more commonly, LabVIEW. The dividing line between these latter types of courses and more traditional electronics courses is becoming increasingly blurred, and differences arise over the relative importance and sequencing of topics. In addition, the perpetual need to invest in quickly obsolete computer hardware and software can put severe strains on departmental budgets, at a time when such tools are essential, but no longer innovative, nor inherently grantworthy.

Except in electrical engineering degree programs, and in those physics departments that base their offerings on preparing students for them, circuits and electronics courses have been increasingly cut back, and taught by a decreasing pool of interested and experienced faculty. The senior faculty bring perspectives (or biases) borne of seeing the tools and the needs they meet go through a near-complete transition every decade, or less. New instructors, whose contact with and need for electronics understanding in their own research careers and hobbies may be quite limited, often see little relevance to whole chapters of the remaining texts. Indeed, the academic preparation, practical background, and interest necessary for teaching introductory electronics and instrumentation courses is now increasingly hard to find among recent Ph.D.s, even experimentalists. Some physics departments hire faculty with EE backgrounds, just as engineering schools hire physicists.

Unlike the situation for the core areas of undergraduate physics, where there are clearly two or more excellent and sufficiently up-to-date textbooks at both the introductory and advanced levels, there is considerable sentiment by those teaching electronics and instrumentation courses that this is not the case for these courses. Relatively few new texts or revised editions of older ones have appeared in the past dozen years. The average age of the in-print textbooks is approximately a decade, and one excellent and comprehensive text, Simpson's *Introductory Electronics for Scientists and Engineers* (Second Edition, 1987), is only available as a printed-on-demand paperback. A significant number of the authors of the more often adopted texts of the last two decades are either no longer involved in the teaching of the subject, or they are deceased. Inquiries to the publishers of introductory electronics textbooks have uncovered few with plans for revised editions or new books. In defense of authors and publishers, one should note that the entire market for physics electronics books is small, involving a few thousand students per year in the U.S. The high price of textbooks and the long time between revisions encourages a market for used books, although physics majors typically hold onto their books as reference texts.

This concludes what I hope is a reasonably objective assessment of the role and relevance of electronics courses in the physics curriculum. This assessment supports the conclusion that students with a variety of educational and career objectives should acquire an understanding of these fruits of science and technology. There are many excellent resources available to faculty who are or will be teaching electronics courses, although few instructors will be comfortable relying on a single textbook. This Resource Letter is built around a representative collection, with a primary focus on those created since 1985. The assignment of level designations (E, I, A) is often somewhat subjective, and of limited usefulness for some of the resources. Publications and products aimed at engineering, vocational, and technical courses and audiences are cited to a limited extent, and in those categories for which the distinctions are less significant. The order in which the resources are listed is subjective, with those of potentially greater scope and usefulness cited earlier.

II. TEXTBOOKS

1. **Introductory Electronics, Second Edition**, R. E. Simpson (Allyn and Bacon, Boston, 1987). This comprehensive textbook does not shy away from circuit theory, and is more often used in junior–senior–graduate, rather than sophomore courses. Over 50 laboratory experiments are included in an appendix. Available through ''on demand'' printing by the publisher. (I, A)
2. **The Art of Electronics, Second Edition**, P. Horowitz and W. Hill (Cambridge U.P., New York, 1989). The title of this popular second edition reflects the authors' emphasis on solutions to a wide range of electronics applications problems, with minimal circuit analysis or pedagogical development of the theory. It is widely used both as a college text, and as a reference source for practitioners, but it requires supplementing in structured courses, particularly at the introductory level. A companion book, **Student Manual for the Art of Electronics** by T. C. Hayes and P. Horowitz (Cambridge U.P., New York, 1989) partially meets this need, with breezy tutorials and some experiments. The text could be your one ''desert island'' electronics book, if you already knew some electronics. Text reviewed by R. J. Rollefson, Am. J. Phys. **58**, 702–703 (1990). (I)
3. **Electronics: A System Approach**, N. Storey (Addison–Wesley–Longman, Harlow, England, 1998). This relatively new entry from the U. K. incorporates PSpice exercises throughout a comprehensive treatment of analog and digital topics, but with only a limited review of ac and dc circuits. The systems approach is exemplified by short sections on noise and electromagnetic compatibility. (I)
4. **Electronics and Communications for Scientists and Engineers**, M. Plonus (Harcourt, San Diego, 2001). This recent book covers analog and introductory digital topics at a sophomore level, and concludes with two chapters on digital computing and communications systems. The latter chapter explains the workings and architecture of many commercial systems, ranging from T-1 lines to TCP/IP. (E)
5. **An Introduction to Modern Electronics**, W. Faissler (Wiley, New York, 1991). An extensive review of dc and ac circuits eases the transition for students whose general physics courses may have omitted or treated these topics lightly. Reviewed by A. F. Burr, Am. J. Phys. **61**, 285–286 (1993). (E)
6. **Principles of Electronic Instrumentation, Third Edition**, A. J. Diefenderfer and B. E. Holton (Saunders, Philadelphia, 1994). The second edition by the late A. J. Diefenderfer broke new ground in 1978 with its style and accessible content at a time when discrete components were rapidly giving way to integrated circuits. The third edition by Holton retains the pedagogical approach of its predecessor, but unfor-

tunately also includes a significant number of errors. A fourth edition was in progress as this Resource Letter was being written. Reviewed by C. W. S. Conover, Am. J. Phys. **63**, 574–576 (1995). (E)

7. **Analog Electronics for Scientific Applications/Digital and Microprocessor Electronics for Scientific Applications**, D. Barnaal (Waveland, Prospect Heights, 1989). This two-volume set is based on Barnaal's 1982 edition, with minor revisions. Although many of the examples in the digital sections refer to obsolete devices and microprocessors, the discussion of introductory topics and concepts is accessible for sophomore-level courses. The chapter on amplifier behavior is particularly effective. The digital and microprocessor portion (1982 printing) was reviewed by F. J. Wunderlich and D. E. Shaw, Am. J. Phys. **53**, 1016 (1985). (E)
8. **Basic Electronics for Scientists, Fifth Edition**, J. J. Brophy (McGraw–Hill, New York, 1990). The fifth edition of this long-running series continues a strong emphasis on discrete-component circuits, at the expense of a more balanced treatment of integrated circuits. (I)
9. **Gateways into Electronics**, P. C. Dunn (Wiley, New York, 2000). Includes laboratory exercises, but overall theoretical in emphasis. Reviewed by J. Fajans, Am. J. Phys. **69**, 621 (2001). (A)

III. SUPPLEMENTARY TEXTS AND REFERENCE BOOKS

A. Electrical engineering texts

The curriculum for electrical engineers is undergoing significant changes, both in what is taught in these university departments, and in what is expected from the physics and mathematics courses that serve these audiences. Courses in circuits and electronics are no exception. Textbooks written for electrical engineering courses in circuits and electronics generally offer greater depth and topical coverage, with an overriding design emphasis. However, for any given topic, particularly at the introductory and fundamentals level, there can be a remarkable similarity in exposition between texts aimed at the different audiences. Physicists teaching circuits and electronics courses can benefit from these textbooks as references, and some of the more popular titles are listed below. Caution should be exercised in assuming the convention for current flow used in a given book, since some authors use conventional current and others electron current. Indeed, at least two popular texts (those by Floyd and Paynter) are published in separate editions for both conventions.

10. **Fundamentals of Electric Circuit Analysis**, C. R. Paul (Wiley, New York, 2001). This book covers passive circuits in the context of a one-semester course for electrical engineers. Good examples and exercises, some using PSpice and MATLAB. (E)
11. **Electronics Fundamentals, Circuits, Devices, and Applications, Fifth Edition**, T. L. Floyd (Prentice–Hall, Upper Saddle River, NJ, 2000). Both passive and active circuits are covered, but current flow is assigned to the electrons in the edition reviewed. Some Electronics Workbench designs are included as optional exercises on a CD-ROM. There is some topical overlap with the editions of **Electronic Devices** by the same author. (I)
12. **Introductory Electronic Devices and Circuits, Fifth Edition**, R. T. Paynter (Prentice–Hall, Upper Saddle River, NJ, 2001). Practical designs with solid-state devices are the focus. Comes with a CD-ROM with about 100 applications problems employing Electronics Workbench software. Both electron flow and conventional current flow versions are available. (E)
13. **Basic Electronics, Eighth Edition**, B. Grob (Glencoe–McGraw–Hill, NY, 1996). Often cited for its usefulness as a self-study or review book, with modest mathematics expectations. (E)
14. **Electronics for Engineers, Second Edition**, R. J. Maddock and D. M. Calcutt (Addison–Wesley–Longman, Harlow, 1994). Suitable for the electronics component for undergraduate engineers other than electrical. (E)
15. **Fundamentals of Analog Circuits**, T. L. Floyd, D. Buchla, and D. Buchla (Prentice–Hall, Upper Saddle River, NJ, 1999). Covers discrete linear devices, op-amps, and linear integrated circuits, with some examples using transducers and radio-frequency amplifiers. (I)
16. **Analog and Digital Electronics: A First Course, Revised Second Edition**, P. H. Beards (Prentice–Hall, London, 1996). (I)
17. **Principles of Electronic Circuits, Second Edition**, S. G. Burns and P. R. Bond (PWS, Boston, 1996). Makes heavy use of the then-current version of PSpice for circuit modeling. (A)
18. **The Science of Radio With MATLAB & Electronics Workbench Demonstrations, Second Edition**, P. J. Nahin (Springer-Verlag, New York, 2001). A must-read for those interested in learning the fundamental relationships between electronics and radio communication. Written in a rich historical context, but with modern technology and mathematics. Not to be confused with several science fiction books and articles by the same author. (I)
19. **The Art of Linear Electronics, Second Edition**, J. L. Hood (Newnes, London, 1998). Traditional discrete component analog circuits form the core of this engineering-oriented book. The art of minimizing hum and noise is also practiced. (I)
20. **Design with Operational Amplifiers and Analog Integrated Circuits, Second Edition**, S. Franco (WCB/McGraw–Hill, Dubuque, 1997). Comprehensive design text that assumes a background in linear circuits and op-amps. (I)
21. **Electronics Devices and Circuits: Discrete and Integrated**, D. J. Dailey (Prentice–Hall, Upper Saddle River, NJ, 1997). Designed for students in two- and four-year electronics technology programs. PSpice is the coordinated circuit simulation. (E)
22. **Digital Principles and Applications, Fifth Edition**, D. P. Leach and A. P. Malvino (Glencoe–McGraw–Hill, NY, 1994). Beginner's book covering digital principles and electronics for a variety of audiences. (E)

B. Advanced topics in electronics

Below are some texts covering solid-state devices, optoelectronics, LabVIEW, and more specialized topics that faculty may wish to cover in advanced courses.

23. **Optimizing Op Amp Performance**, J. G. Graeme and J. E. Graeme (McGraw–Hill, New York, 1997). As the title suggests, this design-oriented book aids the nonrookie user of op-amp circuits in adjusting circuit and layout variables to achieve optimal performance in such areas as stability, noise, distortion, and the like. Not overly theoretical, but still quite technical. (A)
24. **Microelectronic Circuit Design**, R. C. Jaeger (McGraw–Hill, New York, 1997). This is a text for a comprehensive two- or three-semester analog and digital circuit design course. SPICE and MATLAB are used in the problem sets, and design problems abound. (I, A)
25. **Learning with LabVIEW 6i, Second Edition**, R. H. Bishop (Prentice–Hall, Upper Saddle River, 2001). This is the official textbook for use with LabVIEW Student Edition 6i, produced by National Instruments. The Prentice–Hall student edition comes with a CD-ROM with the student edition of LabVIEW. The book employs tutorials and other pedagogical techniques for learning graphical programming of virtual instruments. (E, I)
26. **Advanced LabVIEW Labs**, J. Essick (Prentice–Hall, Upper Saddle River, 1998). Written by Reed College physics professor John Essick, this book has received praise for its clarity and effectiveness. Reviewed by E. D. Jones in Phys. Today **52** (12), 60 (1999). (I, A)
27. **LabVIEW Graphical Programming, Third Edition**, G. W. Johnson and R. Jennings (McGraw–Hill, New York, 2001). This latest edition in the series is updated for LabVIEW version 6.0, and comes with a CD-ROM, for both PC and MacIntosh platforms. Publication announcement was received just as this Letter was finalized. (E, I)
28. **Advanced Superconductor Digital Electronics**, K. Likharev (Department of Physics and Astronomy, State University of New York at Stony Brook, 1999). This is the final report on stage two of the Department of Defense-sponsored research project "Advanced Superconductor Digital Electronics" [Contract No. FF49620-95-1-0415]. The topic is well off the path for undergraduate courses, but may be of interest as a benchmark, with close connections to device physics. (A)
29. **Optical Electronics in Modern Communications, Fifth Edition**, A. Yariv (Oxford U. P., New York, 1997). This book is a leading engi-

neering text in laser physics and optical communication. As such, its overlap with physics electronics courses is very small, but advanced students and faculty whose projects include electro-optics will find it a good reference. (A)

C. Additional references

30. **McGraw–Hill Electronics Dictionary, Sixth Edition**, N. Sclater and J. Markus (McGraw–Hill, New York, 1997). This is an illustrated dictionary for laypersons, not an engineers' handbook. It includes acronyms, abbreviations, and technical terms from related areas of science and technology. (E)

31. **The New IEEE Standard Dictionary of Electrical and Electronic Terms** (IEEE, Piscataway, 1993). This dictionary, which was unfortunately out of print at this writing, is designed for technical users and can be found in many university libraries. (I, A)

32. **Electronic Dictionary**, H. M. Berlin (Prentice–Hall, Englewood Cliffs, NJ, 1990). As with many of the other books by this author, this dictionary, now somewhat dated, is primarily written for the hobbyist and technician. (E)

33. **Electronic Formulas, Symbols and Circuits**, F. M. Mims (Radio Shack, Fort Worth, 2000). Inexpensive and aimed at the hobbyist. (E)

34. **Semiconductor Cross Reference Book, Fifth Edition** (Sams Technical Publishing, Indianapolis, 2000). Cross-reference books find their greatest utility in maintenance and repair situations, but can be useful when projects call for unavailable devices. No specifications. Covers ECG, NTE, TCE, and Radio Shack brands. Also available on CD-ROM. (E)

35. **The Encyclopedia of Electronic Circuits**, Vol. 7, R. F. Graf (McGraw–Hill, New York, 1998). Circuit collections must be used with a considerable wariness, since a great many published circuits contain errors. Students should probably be kept ignorant of their existence until a late stage. (E)

36. **Principles of Electronics: Analog and Digital**, L. R. Fortney (Harcourt–Brace–Jovanovich, San Diego, 1987). Now out of print, this text provides a particularly thorough analysis of passive and active analog circuits, using complex algebra freely. Other standard topics are handled at a somewhat lower level. The reader is cautioned about numerous typos and errors. (I)

37. **A Practical Introduction to Electronic Circuits, Third Edition**, M. H. Jones (Cambridge U. P., New York, 1996). A well-regarded entry-level book for self-study and the hobbyist. (E)

38. **Practical Electronics for Inventors**, P. Scherz (McGraw–Hill, London, 2000). Comprehensive in coverage and directed at the hobbyist and self-study market, with minimal mathematics, but also with its share of typographical errors. (E)

39. **Digital Circuits (Study Guide/Laboratory Manual)**, W. J. Streib and M. R. Berren (Goodheart–Willcox, Tinley Park, IL, 1997). This inexpensive paperback fits most naturally into the two-year vocational-technical market. (E)

40. **Schaum's Outline of Theory and Problems of Digital Principles, Third Edition**, R. L. Tokheim (McGraw–Hill, New York, 1994). As with the other Schaum Outlines, this book is most popular as a study tool for students in courses that use other books. Faculty have been known to pull exam problems from them, too. (E, I)

41. **Experimental Physics: Modern Methods**, R. A. Dunlap (Oxford U. P., New York, 1988). A number of electronics devices and techniques are covered in the broader context of modern experimental physics methods. Reviewed by D. G. Haase, Am. J. Phys. **58**, 1216 (1990). (I)

42. **McGraw–Hill Electronic Testing Handbook: Procedures and Techniques**, J. D. Lenk (McGraw–Hill, New York, 1994). Currently out of print. Focus is the use of electronic test equipment for measurement purposes. (I)

43. **The Circuits and Filters Handbook**, edited by W. K. Chen (CRC Press, Boca Raton, FL, 1995). Nearly 2900 pages divided into about 100 sections with as many authors, covering almost anything one could want to know about filter theory, design, and characteristics. (I, A)

44. **CMOS Cookbook, Second Revised Edition**, D. Lancaster and H. M. Berlin (Newnes, Boston, 1997). A descendent of the long-running Lancaster cookbooks, later revised by Berlin. Lots of data on devices, and working circuits, although many are quite dated. The static sensitivity of CMOS makes teaching lab use of this family somewhat tricky in some environments. (E)

45. **Lancaster's Active Filter Cookbook, Second Edition**, D. Lancaster (Butterworth–Heinemann, Woburn, MA, 1996). The first version of this useful book was published in 1975, and there have been few changes in succeeding printings. (E, I)

46. **Experiments in Instrumentation and Measurement, Facsimile Edition**, H. M. Berlin and F. C. Getz (Merrill, Columbus, OH, 1990). Given the evolution of modern electronic test equipment, this title may be more useful for instructor inspiration. (E)

47. **Electronics the Easy Way, Third Edition**, R. Miller and M. R. Miller (Barron's, Hauppage, NY, 1995). An inexpensive introductory book in electronics, suitable for pre-college courses, with a knowledgeable instructor. (E)

D. Historical references

48. **Electrons and Holes in Semiconductors, with Applications to Transistor Electronics**, W. Shockley (Van Nostrand, New York, 1950). From The Bell Telephone Laboratories series. An historic and influential monograph. (I, A)

49. **A History of Engineering and Science in the Bell System**. Vol. 4. Physical Sciences (1925–1980), M. D. Fagen, A. E. Joel, and G. E. Schindler (The Laboratories, New York, 1975). Includes photocopies of Brattain's notebook pages for the discovery of amplification in the point-contact transistor. Out of print now for more than a decade, these volumes were originally distributed at no cost to some academic departments. Very high quality. (E)

50. **A History of Engineering and Science in the Bell System**. Vol. 6. Electronics Technology (1925–1975), M. D. Fagen, A. E. Joel, and G. E. Schindler (The Laboratories, New York, 1975). The late Bell Laboratories were key to much of the evolution of the vacuum tube and the entire field of electronics. Hard to put down if you have an historic bent. (E)

51. **A History of Computing Research at Bell Laboratories (1937–1975)**, B. D. Holbrook and S. W. Brown (Bell Telephone Laboratories, Murray Hill, 1982). Harry Nyquist (''Nyquist frequency'') and Claude Shannon (''Father of information theory'') are but two of the pioneers who worked at Bell Laboratories. Their work is interestingly described. (E)

E. General

52. **How Things Work: The Physics of Everyday Life**, L. A. Bloomfield (Wiley, New York, 1997). Chapters 13 and 14 discuss the physics of audio amplifiers, computers, radio, television, and microwave ovens in this text for nonscience audiences. (E)

IV. ARTICLES

A. Pedagogy and methods

53. ''An investigation of CAI teaching methods in an electronics course,'' K. W. Wood, Am. J. Phys. **50**, 683–693 (1982). (E)

54. ''A quantitative analysis of the effectiveness of simulated electronics laboratory experiments,'' T. M. Hall, Jr., J. Eng. Tech. **16**, 60–66 (Fall, 2000). (E)

55. ''The oscilloscope as a measuring instrument,'' B. A. Cooke, T. J. Harris, and H. S. Derbyshire, Am. J. Phys. **58**, 933–935 (1990). (E)

56. ''The first course on electronics and ABET criteria 2000,'' M. H. Rashid, Proc. IEEE Frontiers Educ. Conf. **1**, 11a4–1113 (1999). (E)

57. ''Nonionizing radiation: Appropriate topic in a physics curriculum,'' A. J. Adams, Am. J. Phys. **51**, 807–810 (1983). (E)

58. ''A collaborative multimedia, web-based electronics course,'' S. Villareal and B. Zoghi, Proc. IEEE-Frontiers Educ. Conf. 1, 39 (1996). (E)

B. Passive circuits and circuit theorems

59. ''Thevenin's theorem in linear circuits with controlled sources,'' P. A. Valberg, Am. J. Phys. **44**, 577–580 (1976). (I)

60. ''Variational alternatives to Kirchhoff's loop theorem in dc circuits,'' D. A. Van Baak, Am. J. Phys. **67**, 36–44 (1999). (A)

61. ''Equivalent resistors of polyhedral resistive structures,'' F. J. van Steenwijk, Am. J. Phys. **66**, 90–91 (1998). (I)

62. ''The random walk method for dc circuit analysis,'' R. A. Sorensen, Am. J. Phys. **58**, 1056–1059 (1990). (I)
63. ''Piecewise linear anharmonic *LRC* circuit for demonstrating soft and hard spring nonlinear resonant behavior,'' E. L. M. Flerackers, H. J. Janssen, and L. Beerden, Am. J. Phys. **53**, 574–577 (1985). (I)
64. ''Electronic device of didactic and electrometric interest for the study of RLC circuits,'' A. L. Pérez Rodríguez, J. J. Peña Bernal, and B. Mahedero Balsera, Am. J. Phys. **47**, 178–181 (1979). (E)
65. ''Why are resonant frequencies sometimes defined in terms of zero reactance?,'' J. D. Dudley and W. J. Strong, Am. J. Phys. **55**, 610–613 (1987). (I)
66. ''The significance of zero reactance frequency,'' J. A. Stuller, Am. J. Phys. **56**, 296 (1988). (E)

C. Devices, analog circuits, amplification, and filters

67. ''Exercises in the synthesis of electrical impedances,'' R. L. Collier, Am. J. Phys. **57**, 362–365 (1989). (I)
68. ''An inexpensive variable voltage regulated power supply for the introductory lab,'' B. Holton, Am. J. Phys. **53**, 1116 (1985). (E)
69. ''Computer simulation of $p-n$ junction devices,'' N. S. Rebello, C. Ravipati, D. A. Zollman, and L. T. Escalada, Am. J. Phys. **65**, 765–773 (1997). (I)
70. ''A hands-on approach to op-amp basics,'' F. Nachbaur, Pop. Electron. 15, 31 (February 1998). Introduction and three projects. (E)
71. ''The considerations when choosing an audio op amp,'' T. Murphy, Electron. News **44** (2208), 34 (March 2, 1998). (E)
72. ''Using the NE602,'' J. J. Carr, Electron. Now **68** (2), 47 (February 1997). An introduction to an rf analog of the popular 555 timer. (I)
73. ''Phototransistor basics,'' I. Pool, Pop. Electron. 16, 83 (September 1999). (E)
74. ''Understanding analog optoisolator/couplers,'' D. Eichenberg, Pop. Electron. 14, 44 (December 1997). Introduction with lab/project examples. (E)
75. ''Phase-locked loops,'' R. Marston, Electron. Now 65, 69 (October 1994). First of three feature articles on the theory and applications of PLL. (I)
76. ''Closed-loop control systems,'' D. Eichenberg, Electron. Now 66, 69 (February 1995). Feature article on the fundamentals of closed-loop control systems. (I)

D. Digital circuits, logic, waveshaping

77. ''A low-cost timer for free-fall experiments,'' A. Edgar, Am. J. Phys. **59**, 568–569 (1991). (E)
78. ''Simple universal logic state checker,'' J. W. Rudmin, Am. J. Phys. **50**, 283–284 (1982). (E)
79. ''A fringe-counting circuit for use with the Michelson interferometer,'' B. Aghdaie, Am. J. Phys. **56**, 664–665 (1988). (I)
80. ''Electronic integrator for physics experiments,'' M. K. Albert and H. C. Hayden, Am. J. Phys. **54**, 720–722 (1986). (I)
81. ''Generator Circuits,'' C. D. Rakes, Pop. Electron. 15, 58 (December 1998). Seven examples of rectangular waveform generator circuits using common ICs. (E)
82. ''Timing is everything,'' C. D. Rakes, Pop. Electron. 15, 57 (September 1996). Five timing applications with common ICs. (E)

V. LABORATORY EXPERIMENTS, MANUALS, AND PROJECTS

The lecture–laboratory combination for electronics remains popular where courses are offered in physics departments. However, perhaps more the case here than in other parts of the physics curriculum, commercially available laboratory manuals and experiment collections represent only a small fraction of materials followed by students and required by instructors. Locally produced laboratory manuals, with experiments drawn from a variety of sources, are the norm. Topical articles in academic journals and leisure or hobby magazines, including those cited above, are useful sources of both exercises and inspiration. I offer below additional examples at different levels, as well as a number of laboratory manuals and references that include experiments.

The project component of the electronics laboratory or junior–senior laboratory course can be an enriching capstone experience. Student enthusiasm to build challenging, dramatic, and sometimes ''Rube Goldberg'' contraptions is typically high, but runs headlong into the usual constraints imposed by limited equipment, course time, and practicality. Physics experimentalists with ongoing research may have a ready source of smaller tasks that work well as projects. The modification of published experiments, or the enhancement and testing of a commercial piece of electronic equipment or kit can also contribute to the pool of project ideas. As is true of project work in any course, feasibility, faculty support, and fallback plans are all-important elements.

A. Laboratory experiments for introductory courses

83. ''Harmonic or Fourier synthesis in the teaching laboratory,'' G. Whaite and J. Wolfe, Am. J. Phys. **58**, 481–483 (1990). (I)
84. ''Transmission line exercises for the introductory physics laboratory,'' G. H. Watson, Am. J. Phys. **63**, 423–425 (1995). (I)
85. ''Phasemeters and their use in the undergraduate physics laboratory,'' J. P. van der Merwe, Am. J. Phys. **53**, 1089–1092 (1985). (E)
86. ''Use of a voltage-to-frequency converter to measure the integral $E\,dt$,'' L. N. Beard, Am. J. Phys **57**, 475–476 (1989). (E)
87. ''Measuring magnetic fields with an IC chip in the introductory lab,'' P. A. Bender, Am. J. Phys. **54**, 89–90 (1986). (E)
88. ''A pulser circuit for measuring the speed of light,'' M. E. Ciholas and P. M. Wilt, Am. J. Phys. **55**, 853–854 (1987). (E)

B. Laboratory experiments for advanced courses

89. ''Coupled oscillators: A laboratory experiment,'' G. Hansen, O. Harang, and R. J. Armstrong, Am. J. Phys. **64**, 656–660 (1996). (I)
90. ''Experiment on the physics of the *PN* junction,'' A. Sconza, G. Torzo, and G. Viola, Am. J. Phys. **62**, 66–70 (1994). (I)
91. ''Shot-noise measurements of the electron charge: An undergraduate experiment,'' D. R. Spiegel and R. J. Helmer, Am. J. Phys. **63**, 554–560 (1995). (I)
92. ''Modern optical signal processing experiments demonstrating intensity and pulse-width modulation using an acousto-optic modulator,'' T.-C. Poon, M. D. McNeill, and D. J. Moore, Am. J. Phys. **65**, 917–925 (1997). (I)
93. ''The lock-in amplifier: A student experiment,'' R. Wolfson, Am. J. Phys. **59**, 569–572 (1991). (I)
94. ''A simple integrated circuit model of propagation along an excitable axon,'' P. H. Bunton, W. P. Henry, and J. P. Wikswo, Am. J. Phys. **64**, 602–606 (1996). (E)
95. ''Experimental measurements on a simulated lumped transmission line,'' H. J. T. Smith and J. A. Blackburn, Am. J. Phys. **65**, 716–725 (1997). (A)
96. ''A capable voltage logger for the PCI bus,'' C. D. Spencera, Am. J. Phys. **68**, 966–968 (2000). (A)
97. ''A computer-based data acquisition laboratory for undergraduates,'' J. Maps, Am. J. Phys. **61**, 651–655 (1993). (I)
98. ''A laboratory course in computer interfacing and instrumentation,'' C. A. Kocher, Am. J. Phys. **60**, 246–251 (1992). (I)

C. Laboratory manuals

99. **Laboratory Manual to Accompany Principles of Electronic Instrumentation, Third Edition**, A. J. Diefenderfer and B. Holton (Saunders, Philadelphia, 1994). Written by Brian Holton, this manual includes 18 experiments, of which 15 cover passive and active linear circuits. The remaining three introduce digital gates, flip-flops, and A/D conversion. (E)
100. **Experiments in Electronic Devices: To accompany Floyd's Electronic devices, Fifth Edition**, H. M. Berlin and T. L. Floyd (Prentice–Hall, Upper Saddle River, NJ, 1999). Apparently available in two versions, to match the current convention of the related texts. (E)

101. **Introductory Electronic Devices and Circuits (LAB MANUAL), Fifth Edition**, R. T. Paynter, S. C. Harsany, and H. M. Smith (Prentice–Hall, Englewood Cliffs, NJ, 2000). Available in two versions, to match the current convention of the related texts. (E)

102. **Experiments for Electronic Principles: A Laboratory Manual for use with Electronic Principles, Sixth Edition**, A. P. Malvino (McGraw–Hill, New York, 1999). (E)

103. **Experiments in Digital Principles, Fourth Edition**, D. P. Leach (McGraw–Hill, New York, 1998). (E)

104. **Introduction to Electronic Devices Laboratory Manual**, S. Briggs, D. Quatrine, R. St. John, and R. Topolewski (Kendall/Hunt, Dubuque, 1994). This manual and those published by Kendall/Hunt and listed elsewhere are primarily developed for courses at the authors' institutions, but are available for use elsewhere. (E)

105. **Experiments in Modern Electronics**, W. Leach, Jr. and T. E. Brewer (Kendall/Hunt, Dubuque, 2000). Laboratory Manual for introductory course in electrical and computer engineering. (E)

106. **Analog Electronic Circuits and Systems: Laboratory Manual, Second Edition**, M. A. Soderstrand and G. E. Ford (Kendall/Hunt, Dubuque, 2000). (E)

107. **Laboratory Explorations for Microelectronic Circuits, Fourth Edition**, K. C. Smith and S. Smith (Oxford U. P., New York, 1998). Designed to be used with the authors' text **Microelectronic Circuits, Fourth Edition**, for the EE market. (I)

108. **Lab Manual, a Design Approach: To Accompany Digital Systems: Principles and Applications, Eighth Edition**, G. L. Moss and R. J. Tocci (Prentice–Hall, Upper Saddle River, NJ, 2001). (I)

109. **Laboratory Manual for Digital Electronics Through Project Analysis**, R. A. Reis (Merrill, New York, 1991). (I)

110. **Laboratory Manual for Electronics via Waveform Analysis**, E. C. Craig (Springer-Verlag, New York, 1994). Somewhat nontraditional, as is the text. (I)

111. **Digital Electronics Laboratory Experiments Using the Xilinx Xc95108 CPLD with Xilinx Foundation Design & Simulation Software**, J. W. Stewart and C.-Y. Wang (Prentice–Hall, Paramus, NJ, 2001). Text for a lower-division EE course in digital design, using the Xilinx Xc95108 Complex Programmable Logic Device. This platform is becoming common in engineering courses, but appears to be rare in physics electronics courses. Three TTL and 20 CPLD experiments, all with familiar titles and objectives, are augmented by six appendices. (I)

112. **Experiments with Integrated Circuits: The IC Electronics Toolbox**, R. J. Higgins (Prentice–Hall, Englewood Cliffs, NJ, 1983). Long out of print, as is the companion text, but contains some good experiments. Text takes the unusual approach of introducing digital topics before analog. (E)

113. **Digital Systems Laboratory Manual**, M. A. Michelen (Simon & Schuster Custom Publishing, Needham Heights, MA, 1998). Includes four computer disks. (I)

114. **Applied Electricity & Electronics Laboratory Manual**, C. Bayne (Goodheart–Willcox, Tinley Park, IL, 2000). Aimed primarily at the vocational-technical course. (E)

D. Project resources

115. **The Forrest Mims Circuit Scrapbook**, F. M. Mims (L1h Technology, Eagle Rock, VA, 2000). (E)

116. **Electronic Components: A Complete Reference for Project Builders**, D. T. Horn (TAB Books, Blue Ridge Summit, PA, 1992). (E)

117. **Electronic Sensor Circuits & Projects**, F. M. Mims III (Radio Shack, Fort Worth, 2000). (E)

118. **Beginning Digital Electronics Through Projects**, A. Singmin (Newnes, Boston, 2001). (E)

119. **Advanced Electronic Projects, Second Edition**, S. Kamichik (PROMPT, Indianapolis, 1998). Contains a variety of audio and other projects at an intermediate level. (I)

120. "Freeze motion with the laser scope," S. Campisi, Electron. Now 16, 33 (December 1999). (I)

VI. SOURCES OF EQUIPMENT AND PARTS

I include manufacturers and suppliers of electronic test equipment, components, and other supplies used in teaching circuits and electronics. Many firms operate globally, and increasingly offer e-commerce options in addition to their often indispensable printed catalogs. Sales representatives of larger firms may be found in most regions of the United States, and educational discounts may sometimes be negotiated. Lab instructors, particularly those on tight budgets, should not overlook local electronics distributors and surplus shops. Ebay often carriers used equipment of value.

A. Measurement and test equipment vendors

121. (www.fluke.com) Fluke Instruments.

122. (www.agilent.com/tm/indelec/English/) Formerly Hewlett–Packard.

123. (www.bkprecision.com) B&K Precision. Medium price range.

124. (www.tek.com) Tektronix.

125. (www.tucker.com) Tucker Electronics. New and reconditioned equipment.

126. (www.globalspecialties.com) Global Specialties, formerly CSC. Relatively inexpensive.

127. (www.leaderusa.com) Leader Instruments.

128. (www.alfaelectronics.com) Alfa Electronics. Some national brands of test equipment, but mostly imports at competitive prices.

129. (www.sencore.com) Sencore. Primarily directed toward repair technicians.

130. (www.ni.com) National Instruments. LabVIEW products and support.

B. Semiconductor components and small parts

131. (www.digikey.com) Digi-Key Corp. Extensive inventory.

132. (www.arrow.com) Arrow Electronics. Strong industrial focus.

133. (www.jdr.com) JDR Computer and Electronic Products.

134. (www.nteinc.com) NTE Electronics Inc. Carriers ECG line of semiconductors.

135. (www.partsexpress.com) Parts Express. Primarily repair parts for consumer and A/V electronics.

136. (www.insight-electronics.com) Insight Electronics.

137. (www.Xilinx.com) Xilinx programmable logic devices (PLD) and support.

C. Multiple categories

138. (www.mouser.com) Mouser Electronics.

139. (www.mcmelectronics.com) MCM Electronics.

140. (www.newark.com) Newark Electronics.

141. (www.alliedelec.com) Allied Electronics.

142. (www.jameco.com) Jameco.

143. (www.mpja.com) Marlin P. Jones & Assoc., Inc.

144. (www.radioshack.com) Radio Shack. Annual catalog and web site list many items not available in retail stores.

145. (www.jensentools.com) Jensen Tools. Primarily tools, with some test equipment and supplies.

D. Used and surplus

146. (www.herbach.com) Herbach & Rademan. Strong on electromagnetic devices, power supplies, unusual items.

147. (www.allcorp.com) All Electronics.

148. (www.73.com/a/index1.shtml) Surplus Traders.net

149. (www.eio.com) Electronics and Computer Surplus City.

E. Kits

150. (www.paia.com) PAIA Electronics. Mostly audio and special effects.

151. (www.goldmine-elec.com) Electronics Goldmine. Numerous kits.

152. (www.ccnet.com/~lnstech/) Kits from LNS Technologies.

153. (www.ramseyelectronics.com) Ramsey Electronics.

154. (www.heathkit.com) Heathkit Educational Systems. Products are now entirely directed toward training courses at the secondary and vocational level. However, their line of analog and digital trainers is still available for separate purchase. Follow links to instructional materials-hardware. Numerous private web sites keep alive the memory of the historic lines of audio, ham radio, and other Heathkits.

VII. INSTRUCTIONAL AND DESIGN SOFTWARE

The use of commercial software for simulation and design of electronic circuits, devices, PC boards, integrated circuits, and systems is now well established in electrical engineering practice. The *de facto* standard is the PSpice family of programs, formerly offered by MicroSim and, after 1998, as Orcad PSpice by Cadence Design Systems, Inc. Various nonproprietary modules and elements continue in circulation from the Spice development days at U.C. Berkeley and elsewhere. The DOS platform has been supplanted by Windows, but UNIX systems are the norm in industry. Electrical engineering and technology courses, and a variety of texts and trade books are the principal educational vehicles. Single copies and educational site licenses are relatively expensive, and the learning curve to reach proficiency is steep.

Still, some physics instructors and departments may wish to incorporate an introduction to circuit simulation software, for pedagogical and other reasons. Two other packages have achieved a level of acceptance, accessibility, and economy that merit their consideration. Electronics Workbench from Interactive Image Technologies is used in a wide range of educational settings, and is frequently included in published designs and simulations. CircuitMaker from Microcode similarly emphasizes the educational entry path, while providing sophistication and growing interoperabililty. All three vendors offer free demonstration software, and usually a free student version for home use. Instructor and user support are also included for licensees. As might be expected, new versions, releases, and updates preclude the establishment of low-maintenance curricula.

A. Books and articles

155. **Electric Circuits**, J. W. Nilsson (Prentice–Hall, Paramus, 1999). This is the sixth edition in a series that provides a relatively easy entry into PSpice for analog circuits. (E)

156. **Simulations for Electronic Devices Using PSpice**, J. L. Antonakos (Prentice–Hall, Paramus, 2000). (I)

157. **Simulations for Transistors Using PSpice**, J. L. Antonakos (Prentice–Hall, Paramus, 2000). (I)

158. **Simulations for Digital Electronics Using Electronics Workbench**, J. L. Antonakos (Prentice–Hall, Upper Saddle River, NJ, 1999). (I)

159. **Microelectronics Laboratory Using Electronics Workbench Self Study Course**, M. Rashid (IEEE, Piscataway, 2000). (I)

160. **Mastering Electronics Workbench**, J. J. Adams (McGraw–Hill, New York, 2001). (I)

161. **Using MultiSIM 6.1: Troubleshooting DC/AC circuits**, J. Reeder (Delmar, Albany, 2000). (E)

162. **Troubleshooting Analog Circuits (The Edn series for design engineers)**, R. A. Pease (Butterworth–Heinemann, Woburn, MA, 1993). Includes disk with approximately 60 pre-built Electronics Workbench circuits (Electronics Workbench software required). (I, A)

163. **OrCAD PSpice for Windows DC & AC Circuits**, R. W. Goody (Prentice–Hall, Paramus, 2000). (E)

164. **OrCAD PSpice for Windows Devices, Circuits & Operational Amplifiers** (Prentice–Hall, Paramus, 2000). (I)

165. **OrCAD PSpice & Circuit Analysis**, J. Keown (Prentice–Hall, Paramus, 2000). (I)

166. **OrCAD PSpice with Circuit Analysis**, F. J. Monssen (Prentice–Hall, Paramus, 2000). (I)

167. **OrCAD PSpice for Windows Digital & Data Communications**, R. W. Goody (Prentice–Hall, Paramus, 2000). (I)

168. ''Electronics lab bench in a laptop: Using Electronics Workbench to enhance learning in an introductory circuits course,'' E. Doering, Proc. IEEE-Frontiers Educ. Conf. **1**, 18 (1997). (I)

B. Instructional, circuit simulation, and design software

169. (www.orcad.com/Product/simulation/PSpice/) Orcad PSpice from Cadence Design Systems, Inc. (I, A)

170. (www.interactiv.com) Interactive Image Technologies, producer of Electronics Workbench, now called Multisim. (E, I)

171. (www.microcode.com) CircuitMaker software and support from Microcode Corp. (E, I)

C. Websites

172. (www.ee.mtu.edu/faculty/rzulinsk/pspice.htm) Professor Bob Zulinski at Michigan Technological University offers a very helpful faculty site summarizing the recent commercial evolution of the versions of PSpice, with support for the Microsim DesignLab Release 8. (I)

173. (www.coe.uncc.edu/project_mosaic/PC/pspice/) PSpice help page from the University of North Carolina at Charlotte. (E)

174. (http://et.nmsu.edu/~etti/spring97/electronics/ceamp/ceamp.html) Link to Huffine's article on the CE amplifier in using Electronics Workbench, published in ET the Technology Interface online magazine. (E)

175. (www.pspice.com) PSpice community site. (I, A)

VIII. VIDEOS

Film and video tape are used in a number of ways within the scope of this Resource Letter. These media probably find their most comprehensive instructional use in the electronics curriculum in vocational and technical schools, and at the secondary school level. A somewhat smaller category is represented by lecture series for electrical engineers at later stages of their educations, and during their careers. Only a few examples from these two categories are cited because of their limited interest and accessibility to physics faculty teaching electronics at the college level. However, in those departments where small staff or enrollments cannot support traditional courses, self-paced instructional materials and accompanying video tapes can offer a workable alternative to the absence of any electronics in the curriculum. The distance-learning mode is encouraging the production of new materials as well.

A limited number of tape productions are available that cover specific applications, technologies, and historical developments. Examples that do so with a combination of depth and breadth that may make them of interest to instructors of electronics courses for college audiences are cited below. Instructors of courses with a Liberal Arts or communications focus will find some of the historical productions particularly relevant and well done.

A. Instruction

176. **Electronics Series**, Heathkit Educational Systems (www.heathkit-.com). Fifteen video tapes on introductory topics are available separately, or with the firm's educational packages for individual or classroom instruction. (E, I)

177. **Fundamental Electronic Design Experiments**, P. R. Mukund (Rochester Institute of Technology, Educational Technology Center, Rochester, NY, 1994). Twelve videocassettes in lecture format covering topics in analog electronics. (I)

178. **Basic Electronics Series; Digital Electronics Series** (UCANDO VCR Video Educational Products Co., Greenville, OH, 1991). Both series cover standard topics, and are available at (www.wordbench.com/video/ucan.html), and other vendors. (E, I)

179. **Professional Engineers (P.E.) Review: Electronics**, S. Soclof and M. S. Roden (IEEE Educational Activities Department, Piscataway, NJ, 1999). (I, A)

180. **IEEE Individual Learning Program on Transducers and Sensors**, J. G. Webster and J. W. Tompkins (IEEE, Piscataway, NJ, 1989). Three videocassettes, study guide, examinations. (I)

181. **A/D and D/A Converters**, D. Wade and J. Bergwall (Bergwall Video Productions, Garden City, NY, 1992). A set of four short tapes, part of a large offering in electronics aimed at the vocational-technical market. (E)

B. Semiconductors and integrated circuits

182. **Silicon Run Lite**, R. A. Carranza (Ruth Carranza Productions, Mountain View, CA, 1997). An overview of the production of microchips and their assembly into computers. Combines key sequences and images from both *Silicon Run I and II*, which present more in-depth technical coverage. (I)

183. **The Chip That Changed the World**, C. Stanley (Educational Video Network, Huntsville, TX, 1998). (E)

184. **Analog vs. Digital? Or Do We Really Mean Analog and Digital?**, T. Redfern (MIT Microsystems Technology Laboratories, Cambridge, MA, 1998). (A)

185. **GaAs HBT and HEMT Technologies for Agilent Instruments**, D. D'Avanzo (MIT Microsystems Technology Laboratories, Cambridge, MA, 2000). (A)

C. Instrumentation and applications

186. **Applications of Electronic Engineering**, Conscient, Inc., CSM Productions, France (Films for the Humanities & Sciences, Princeton, 1994). (E)

187. **Biasing Circuits for Analog ICs**, R. Dobkin (MIT Microsystems Technology Laboratories, Cambridge, MA, 1999). (A)

188. **DSP: How Did We Get to Where We're Going**, A. V. Oppenheim (MIT Center for Advanced Education Services, Cambridge, MA, 1999). (A)

189. **Error-Correcting Codes for Digital Signal Processing**, R. E. Blahut (University Video Communications, Stanford, CA, 1988). (A)

190. **Integrated Circuits and Op Amps** (Instrument Society of America, Research Triangle Park, NC, 1991). (I)

191. **Organic Transistors, Circuits, and Injection Lasers**, A. Dodabalapur (MIT Microsystems Technology Laboratories, Cambridge, MA, 2000). (A)

192. **RF Circuit Fundamentals II**, L. Besser (Besser Associates, Los Altos, CA, 1990). Six tapes. (A)

193. **Microwave Opto-Electronics**, A. Seeds (IEEE, Piscataway, NJ, 1992). (A)

194. **Silicon Vision**, M. Mahowald and J. A. DeVinney (WGBH Educational Foundation, Boston, 1995). Available from Films for the Humanities and Sciences. (E)

195. **Spread Spectrum Communications Fundamentals and Applications**, G. E. Prescott (IEEE, Piscataway, NJ, 1989). (A)

D. Historical

196. **Transistorized!**, I. Flatow, E. Augenbraum, G. D. Guercio, and R. Hudson (Twin Cities Public Television, Inc. and ScienCentral, Inc., St. Paul, 1999). A recounting of the development of the transistor, with interviews with the principals. (E) [Coordinated website for teachers at www.pbs.org/transistor/]

197. **Invention of the Transistor: Report from Bell Laboratories** (Bell Telephone Laboratories, Inc., Murray Hill, NJ, 1982). Interviews with the inventors of the transistor: Walter Brattain, John Bardeen, and William Shockley. (E)

198. **The Transistor**, T. Amman, S. Pach, and H. W. Franke (Films for the Humanities & Sciences, Princeton, NJ, 1994). (E)

199. **Marconi and Wireless Telegraphy**, D. Sirthos, S. Pach, and H. W. Franke (Films for the Humanities & Sciences, Princeton, NJ, 1994). (E)

200. **Empire of the Air: The Men Who Made Radio**, Ken Burns (Florentine Films/WETA, Alexandria, VA, 1991). Available from PBS Video. (E)

201. **Television: Window to the World**, J. Hanig, C. Hayes, E. Boen, W. Haugse, and G. Clausen (Gregg, New York, 1996). A&E Home Video. (E)

202. **The Development of Television**, J. Schroder (Films for the Humanities & Sciences, Princeton, NJ, 1994). (E)

203. **Radar**, H. Schuler (Films for the Humanities & Sciences, Princeton, NJ, 1994). (E)

204. **The History of Digital Computing**, J. Burke, G. Vignola, and Gervais (Films for the Humanities and Sciences, Princeton, NJ, 1998). (E)

205. **Silicon Valley: Center of a Modern Renaissance**, J. R. McLaughlin and W. Cronkite (Films for the Humanities and Sciences, Princeton, NJ, 1999). Includes interviews with the founders of Intel, Netscape, Atari, Hewlett–Packard, Intuit, Apple, Sun, and others. (E)

206. **Tesla: Master of Lightning**, R. Uth, P. Geller, S. Keach, E. Noone, and M. Cheney (New Voyage Communications, Alexandria, VA, 2000). Distributed by PBS Home Video. (E)

IX. WEBSITES

The standard disclaimer about the tenuousness of URLs is particularly valid in the case of noncommercial, individually created and maintained websites. With that caveat, I offer examples in categories that have not otherwise been represented, but which provide useful curricular development and support.

A. Courses, syllabi, and on-line books

207. (www.physics.udel.edu/wwwusers/watson/phys345/) Electricity and Electronics for Engineers, University of Delaware. (I)

208. (http://physics.gac.edu/~huber/classes/phy270/) Electronics I, Gustavus Adolphus College. (I)

209. (http://pneuma.phys.ualberta.ca/~gingrich/phys395/) Instrumentation and Electronics, University of Alberta. (I)

210. (http://campus.northpark.edu/physics//phys2510/) Electronics for scientists, North Park University. (I)

211. (http://hep1.physics.wayne.edu/harr/teaching/5620/W99/) Electronics, Wayne State University. (I)

212. (http://keller.physics.oberlin.edu/courses/p242syll.htm) Electronics, Oberlin College. (I)

213. (www.nku.edu/~physics/courses/syllabi/phy34001.html) Digital Electronics, Northern Kentucky University. (A)

214. (www.phy.duke.edu/Courses/171/) Electronics, Duke University. (I)

215. (www.lehigh.edu/~mcm6/pchemlab/) Physical Chemistry Laboratory-Electronics, Lehigh University. (I)

216. (http://courses.csusm.edu/phys301go/) Digital Electronics, California State University, San Marcos. (I)

217. (http://physics.angelo.edu/~vparker/phys3444/) Digital Electronics, Angelo State University. (I)

218. (http://nimbus.ocis.temple.edu/~cmartoff/teaching/ph221/) Electronics, Temple University. (I)

219. (http://psheldon.rmwc.edu/Class_Archive/p331fa99/) Electronics Laboratory, Randolph-Macon Woman's College. (I)

220. (http://www.ee.pdx.edu/~vanhalen/courses/ece321/syllabus.html) Electronics I, Electrical and Computer Engineering, Portland State University. (E)

B. Publishers

221. (http://ieeexplore.ieee.org/lpdocs/epic03/) IEEE publications search site

222. (www.gernsback.com) Publisher of Poptronics and holder of predecessors *Popular Electronics* and *Electronics Now* titles. *Radio Electronics* became *Electronics Now* in January 1993.

223. (www.epemag.wimborne.co.uk) Home page for *Practical Electronics*, a leading hobby electronics magazine in the United Kingdom.

224. (www.electronicproducts.com) Home page for *Electronics Products*, a free-subscription magazine for the electronics designer and industry.

225. (www.shopping-today.com/HWSams/) Selling site for all Howard W. Sams technical books in print.

C. Organizations and institutions

226. (http://rleweb.mit.edu/) M I T Research Laboratory of Electronics

227. (http://webdiee.cem.itesm.mx/wwwvlee/) Virtual Library for E.E. educational programs, publications, vendors, and standards.

D. Tutorials and other resources

228. (www.epanorama.net) Extraordinarily comprehensive collection of links on electronics and its applications.

229. (www.williamson-labs.com/home.htm) Wide variety of tutorials, circuits (some animated), reference data.

230. (http://www.electronics-tutorials.com/) Over 120 tutorials, other technical information.

231. (http://teacher.shop.pbs.org/) Video tapes and auxiliary materials.

E. Technical specifications

232. (www.national.com/catalog/) National Semiconductor Corp.

233. (http://e-www.motorola.com/webapp/sps/library/docu_lib.jsp) Motorola Corp.

234. (www.ti.com) Texas Instrument.

235. (www.panasonic.com) Panasonic.

236. (http://icmaster.com/) **IC Master**.

X. ELECTROMAGNETIC INTERFERENCE AND COMPATIBILITY RESOURCES

Electronic equipment and circuits must operate in an electromagnetic environment that ranges ''from dc to light.'' Every piece of equipment and circuit is potentially both susceptible and an emitter. The coupling mechanisms are conduction and radiation. The sources may be an adjacent circuit or component, or an intended or unintended transmitter near or far away. To the extent that the cutting edge of experimental physics deals with signals at the intrinsic noise limit, the problems of interference must already have been addressed successfully.

The practice of ensuring electromagnetic compatibility has evolved into a specialty of electrical engineering, with on the order of 10,000 persons involved full-time world-wide. A significant fraction of these have one or more degrees in physics. In terms of graduate programs and other measures of certification and accreditation, the field is growing, but is both younger and a great deal smaller than computer engineering, for example. The study and control of electrostatic discharge are now sometimes considered a specialty of EMC. Some of the following resources will be familiar to faculty who have had to solve difficult interference problems in research environments. The treatment of interference problems in physics electronics texts can be significantly and readily enhanced by consulting some of the selected references and resources listed here.

A. Text and reference books

237. **Noise Reduction Techniques in Electronic Systems, Second Edition**, H. W. Ott (Wiley, New York, 1988). A good introduction to the subject and usable as both a text and reference. Particularly strong in analog electronics. Physics faculty tempted to teach a special topics course in EMC will find chapters and sections that articulate well with backgrounds of beginning juniors. (I)

238. **Introduction to Electromagnetic Compatibility**, C. R. Paul (Wiley, New York, 1992). Written for upper-level electrical engineering courses in the subject, and quite analytical. Assumes a background equivalent to junior-year E&M theory. (A)

239. **Principles of Electromagnetic Compatibility, Third Edition**, B. E. Keiser (Artech House, Norwood, 1987). Now in its third edition, this book covers all the standard topics with a good mix of analysis and practical solutions. (I)

240. **Grounding and Shielding Techniques in Instrumentation, Fourth Edition**, R. Morrison (Wiley, New York, 1998). The fourth edition continues a series that emphasizes fixes for EMI in instrumentation that handles low-level analog signals. (I)

241. **Principles and Techniques of Electromagnetic Compatibility**, C. Christopoulos (CRC Press, Boca Raton, FL, 1995). Begins with fundamental electromagnetic interactions, and adopts analytical and numerical techniques as necessary. Emphasizes good design techniques to ensure electromagnetic compatibility in systems, with a strong engineering orientation. (I, A)

242. **Electromagnetic Compatibility: Principles and Applications, Second Edition**, D. A. Weston (Marcel Dekker, New York, 2001). This text and reference book is aimed primarily at the electrical engineer who designs equipment to meet international standards for emissions and susceptibility. (A)

243. **EMI Suppression Handbook: Communications from the Trenches**, edited by W. D. Kimmel, D. D. Gerke, and E. T. Chesworth (Seven Mountains, Boalsburg, PA, 1999). Two highly experienced EMC engineers weave 51 case studies into mini-tutorials about noise and interference situations common to electronic and instrumentation practice. An excellent way in which to become familiar with the scope of problems and solutions of EMC. (E, I)

244. **EMI Troubleshooting Techniques**, M. Mardiguian (McGraw–Hill, New York, 1999). A collection of practical solutions for existing EMI problems from another experienced consultant and workshop lecturer. (E, I)

245. **Interference Handbook**, W. R. Nelson (Watson–Guptill, New York, 1991). Written by an electrical utility engineer and ham radio operator, this book illustrates and suggests solutions to a wide range of RFI problems in home and commercial electronic equipment caused by power lines, radio transmitters, and obscure rf sources. (E)

246. **The Technician's EMI Handbook: Clues and Solutions**, J. J. Carr (Newnes, London, 2000). One of the late J. J. Carr's many books on electronics technology, this is a nonmathematical handbook for technicians working with communications and electronic systems. (E)

247. **The EMC Desk Reference Encyclopedia**, D. J. White (emf-emi Control, Inc., Gainesville, VA, 1998). A mixed collection of definitions, formulas, tables and ads in this specialty. (E)

B. Organizations and websites

248. (www.ewh.ieee.org/soc/emcs/) The Electromagnetic Compatibility Society is a member organization of the Institute of Electrical and Electronic Engineers, and is the principal international professional society for this specialty. In addition to sponsoring symposia at various levels, the EMCS publishes the quarterly *Transactions on Electromagnetic Compatibility* (www.ieee.org/organizations/pubs/transactions/tec3.htm). Papers in the Transactions are usually highly analytical. The EMCS Education Committee publishes its *Education Manual* (www.ewh.ieee.org/soc/emcs/pdf/EMCman.pdf), originally developed by Clayton R. Paul, which outlines suggested EMC course content, and includes a section on experiments and demonstrations.

249. (www.rbitem.com) The principal annual directories of electromagnetic compatibility products and services are the *ITEM* (Interference Technology Engineers' Master) series, published by ROBAR Industries. The annual *ITEM International Journal of EMC* includes numerous articles and tutorials, most written by engineers from companies represented in the advertising sections. Subscriptions are free to qualified subscribers, which in practice means anyone involved in an employed capacity with EMI who completes an application.

250. (www.emc-journal.co.uk) Norwood UK Ltd. publishes *EMC +Compliance Journal*, with a European focus and somewhat more emphasis on regulatory and product compliance issues than the *ITEM* publications.

251. (http://emicatalog.com/) Canon Communications LLC maintains the online *emicatalog*, which offers a searchable directory of vendor catalogs for components, equipment, software, shielding materials, and services used by those solving EMI problems.

252. (www.emiguru.com) William Kimmel and Daryl Gerke (Kimmel Gerke Associates Ltd.) include a strong outreach commitment in their EMI/EMC consulting practice. While faculty are seldom in a position to engage consultants, they may find helpful the ''KGB'' and ''UBI'' (Kimmel–Gerke Bulletins and Useful Bits of Information).

253. (www.emf-emi.com) Don White Consultants, Inc. is one of the pioneering firms that helped establish the practice and study of electronic interference mitigation, primarily through commercial courses and self-published manuals and books, such as the Encyclopedia cited above.