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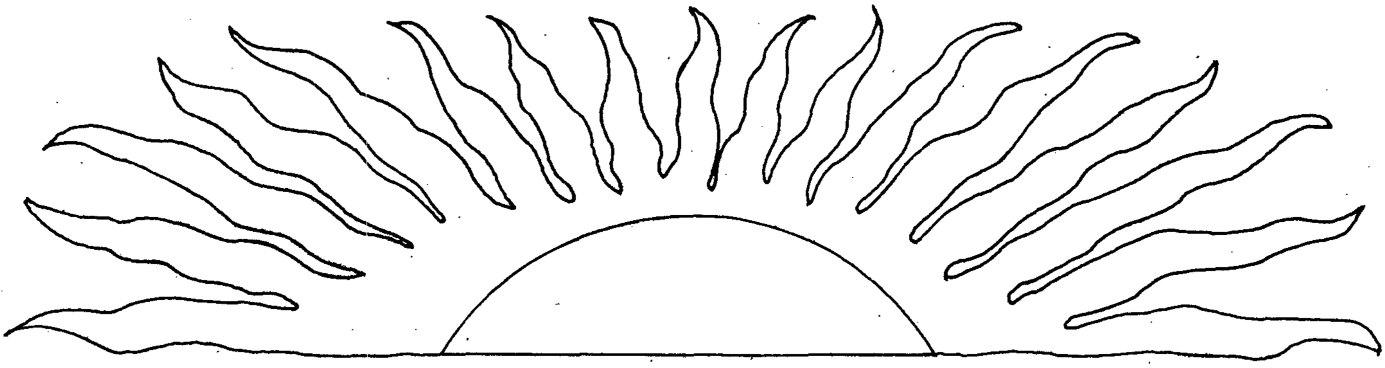

A SURVEY AND ANALYSIS OF ELECTRICAL ENGINEERING CURRICULA IN COMMUNICATIONS AND SIGNAL PROCESSING

Rodger E. Ziemer and William H. Tranter

INTRODUCTION

How does one accomplish the task of obtaining and analyzing data in order to describe current trends in a certain segment of electrical engineering education? A year ago, when asked by the Editor of the IEEE COMMUNICATIONS MAGAZINE if we thought that the results of such an endeavor dealing with communications and signal processing would be of value to electrical engineering faculty and working communications engineers alike, we struggled with this question. A year later, at the time of writing of this article, we are still struggling with it! In addition to not being sure of just how to analyze and organize the data, we are swamped with more information from a larger sample of electrical engineering departments than we ever dreamed possible.

Given this insight into the past and current state of our naiveté, then, the reader is asked to accept this article at face value—much data, some analysis, and a few inferences. The outline of the paper is simple. We first overview the general conclusions, trends, and implications gained from the survey. We next describe how we gathered the data and how the sample of electrical engineering departments that was used as a data base evolved. Finally, the data on course offerings, textbooks used, areas of research and special investigations, and numbers of students involved are presented along with some discussion of the meaning of the presentations.

II. GENERAL CONCLUSIONS, TRENDS, AND IMPLICATIONS

Before discussion of the specific results of the survey, we will attempt to present some general trends and implications drawn from the survey. First, what are students learning today in communications and/or signal processing that they were not exposed to five or ten years ago? At the *undergraduate level* there appears to be a much wider introduction to general systems analysis techniques and their applications. As a result, there appears to be a more unified approach to teaching communication systems concepts including the use of probabilistic

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techniques. There is more emphasis on what might be termed "modern communications" including digital communications, basic information and coding theory applications, and more frequent discussion of real-world systems such as television, radar, and telephone communication systems. Perhaps more significant, however, is the introduction of digital signal processing courses at the undergraduate level.

Classical areas such as probability and random processes, detection and estimation theory, information theory, and coding theory are still standard courses offered at the *graduate level.* Areas of "new" courses include digital communications, spread spectrum systems, optical communications, satellite systems, image processing, and computer communications. Digital signal processing courses have become extremely popular at the graduate level.

The next question to be considered is the variation in curriculum content and quality from one school to another. Judging from the textbooks and course content reported, content is fairly uniform. Smaller programs tend to follow the lead of the larger programs through textbook selection. Quality is much harder to evaluate. An obvious problem in smaller programs is the lack of variety in course offerings, but coverage of basic material is still present in smaller programs with less frequency, perhaps, than in the larger programs.

Several departments surveyed reported innovative features in their curricula that could be adopted by other departments to improve their teaching techniques. Examples are senior-level special projects with emphasis on laboratory work and laboratories that employ modular experimental setups or, in the case of digital signal processing, programmable digital filters. At our own institution, we have offered a communications project laboratory that emphasizes systems concepts [1]; some of the ideas developed in this elective laboratory are now included in our required undergraduate laboratory sequence. Other communications laboratories that concentrate on systems and concepts rather than devices have been reported [2].

Independent-project laboratories are excellent in terms of developing the student's initiative. They are, unfortunately, very costly in terms of faculty time. In view of the large enrollment increases in engineering at many institutions it seems imperative that innovative means be used if project experiences such as these are to be provided for all students in a department. The introduction of an advanced-level design project has been discussed within the IEEE as a possible part of the ECPD accreditation criteria. At least one school has reported prior experience in this area [3], but just how it would be introduced into a large electrical engineering program with limited teaching faculty, such as at a state-supported institution, is not clear.

Where should practicing engineers obtain additional training? From the survey results it appears that relatively new areas, such as digital signal processing, optical communications, spread sprectrum communications, and satellite communications, probably represent voids in the background of many older engineers. One problem that the engineer who has been in industry ten or more years faces is where to get this additional training. These areas are well represented in the many short courses taught through universities and private educational corporations. Another possible type of short course is the in-company after-hours course purchased as a package by the company from a local university. Videotaped lectures of courses for university credit is another mode of instruction which is catching on rapidly. What are the possibilities for recognition of course work taken by those persons who do not qualify for graduate school? IEEE has recently made a move to evaluate short courses and assign continuing education units [4]. At our institution an engineer may use such courses as partial fulfillment for a Professional Development Degree, which is a degree that recognizes an individuals post-baccalaureate study which is not at the graduate level.

III. THE EVOLUTION OF THE SAMPLE

The first two questions to be answered when one sets out to determine the current state of affairs of a given area is how one gathers the data and from whom. Naturally, when conducting a survey, one needs a survey form—simple! Unfortunately, it took the authors approximately two months of sporadic communication (not reflected in the survey) to design the survey form, shown in Fig. 1, which was used in this study. The fact that such an inordinately long gestation period was required does not reflect a lack of prodding by the editor (he did), or the superior quality of the final product (the reader can be the judge of this). It simply means that one of the coauthors (insert a name at random from the sample of two) is obstinate and cannot appreciate good ideas. In a more serious vein, we wanted the survey form broad enough so that it would not limit responses, either in number or detail, yet specific enough so that the respondent would not throw up his hands and proceed to the nearest circular file. Judging from the response of 73 Electrical Engineering Departments out of a sample of a possible 121 (60 percent), we accomplished the latter objective. Our criteria for selecting the sample of Electrical Engineering Departments to be sent the form were the following. Of the 200 plus engineering departments listed in the March 1978 issue of *Engineering Education,* we selected those departments that graduated fifty or more B.S.E.E.'s or had a graduate enrollment (masters plus doctorate) of 40 or greater. We do not differentiate between full-time or part-time students in any part of this study because of the impossibility of determining this with certainty. In addition to selecting a sample of Electrical Engineering Departments as described above, a notice was published in the November 1978 issue of the IEEE COMMUNICATIONS SOCIETY MAGAZINE inviting any

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FOLD, STAPLE AND MAIL TO
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BY JANUARY 15, 1979

COMMUNICATION AND SIGNAL PROCESSING CURRICULUM QUESTIONNAIRE
(Attach additional sheets as necessary)

I. COURSE INFORMATION (Courses that you consider "Communications" or "Signal Processing")

Course Title	Level	Avg. # of students per offering	Text*	Required/ Elective	Frequency of Offering

II. List below thesis and dissertation titles from your department in the communications area in the past two years. Indicate which are M.S. and which are Ph.D.

III. Do you have any areas, perhaps innovative, not covered by the above listings? How many students involved? What is their level (Undergraduate, M.S., Ph.D.)?

IV. DEPARTMENTAL INFORMATION: Your School ____________ Your Name (Optional) ____________

☐ Semester Basis — EE Undergraduate Enrollment ____________

☐ Quarter Basis — EE Graduate Enrollment ____________

No. of Graduate Students Identified as communication or signal processing majors ____________ { M.S. ________ Ph.D. ________

*If possible, please send a course outline for each course. If outlines are unavailable, indicate chapter coverage.

Fig. 1. Survey form used to obtain data.

Electrical Engineering Department to respond if it desired. A few additional ones did. The sample of departments that responded with a filled-out questionaire by the time the data were compiled (plus other information in many cases) is shown in Table I in alphabetical order.

IV. CHARACTERISTICS OF THE SAMPLE

In order to gain insight into the characteristics of the sample of Electrical Engineering Departments used in this study, the data in Figs. 2-5 are presented. These figures show percentiles for various student and degree categories in electrical engineering for the academic years 1969-1970, 1973-1974, and 1977-1978. Except for the data on communications/signal processing enrollments given in Fig. 2, which were obtained from survey results, these percentiles were constructed from data given in the issues of *Engineering Education* referenced in the figures. The data show that the sample of departments responding to the survey included both small and large programs at the undergraduate and graduate levels. Because of the criteria used to establish the sample very few responding departments have small programs at both the undergraduate and graduate levels.

One characteristic of the programs surveyed, which can be inferred from Fig. 2, is that the fraction of electrical engineering graduate students pursuing programs of study in communications and/or signal processing is roughly 15-20 percent of the total. Other characteristics of the sample are that M.S. degrees granted in electrical engineering or related fields (such as computer, information, or control engineering) are about 40 percent of the B.S. degrees granted. These statistics are indicative that the sample is not atypical; for example, roughly half of the new B.S. degree holders today will acquire at least one advanced degree [5].

By comparing the percentiles given in Figs. 2-5, other interesting trends of the electrical engineering programs included in the sample may be inferred. First, the trend for the large graduate programs in electrical engineering included in the survey is down; the upper tenth percentile for graduate students in electrical engineering per department declined from 316 in 1970 to 216 in 1978. The trend for the medium-sized graduate programs appears

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TABLE I
Electrical Engineering Departments Responding to Survey

Air Force Institute of Technology
The University of Alberta
The University of Arizona
University of Arkansas
Auburn University
California State University, Los Angeles
University of California, Berkeley
University of California, Davis
University of California, Los Angeles
University of California, Santa Barbara
Clarkson College of Technology
Colorado State University
Columbia University in the City of New York
Cornell University
Drexel University
Fairleigh Dickinson University
Florida Institute of Technology
University of Florida
George Washington University
Georgia Institute of Technology
Illinois Institute of Technology
University of Illinois at Urbana-Champaign
University of Iowa
Kansas State University
The University of Kansas
University of Kentucky
Laval University
Louisiana State University and A & M College
University of Louisville
Loyola Marymount University
University of Maryland
Michigan State University
Michigan Technological University
The University of Michigan
University of Minnesota
Mississippi State University
University of Missouri-Rolla
Naval Postgraduate School
New Jersey Institute of Technology (formerly Newark College of Engineering)
Northwestern University
University of Notre Dame
The Ohio State University
Oklahoma State University of Agriculture and Applied Science
University of Oklahoma
Old Dominion University
Oregon State University
University of Ottawa
University of the Pacific
University of Pennsylvania
Purdue University
University of Rhode Island
Rutgers, the State University of New Jersey
The University of Santa Clara
Seattle University
University of South Alabama
South Dakota School of Mines and Technology
Southeastern Massachusetts University
University of Southern California
Syracuse University
Tennessee Technological University
Texas A&I University in Kingsville
Texas A&M University
University of Toronto
United States Coast Guard Academy
United States Naval Academy
University of Utah
Valparaiso University
Virginia Military Institute
University of Waterloo
Wayne State University
West Virginia University
University of Wisconsin—Madison
Worcester Polytechnic Institute

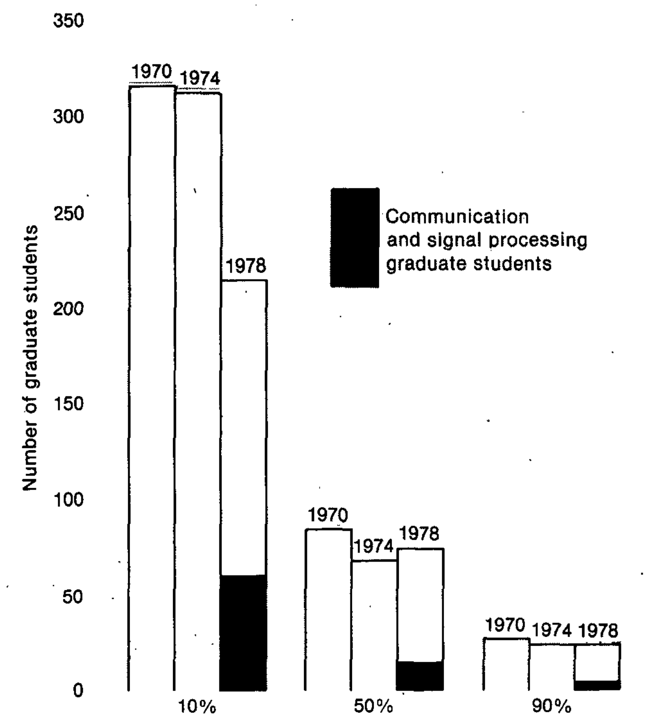

Fig. 2. Percent of departments with graduate enrollments at least as large as the ordinate. (Data from *Engineering Education*, March 1971, 1975, and 1979—schools responding to survey only. Data on communications/signal processing from survey.)

to be up after a decline in the mid-1970's; the 50th percentile went from 84 in 1970, to 69 in 1974, and back up to 75 in 1978. The smaller graduate programs have stayed at roughly the same size over the eight year period under consideration.

Those of us involved in graduate student recruitment are painfully aware of the reasons for these trends which include the recession of the mid-1970's and the intense recruitment of B.S.-level engineers by industry at the end of the 1970's. Unfortunately, the outlook for the first half of the 1980's does not appear any brighter with the prediction for the number of B.S. engineering graduates declining after a peak in about 1981 [6].

The trend for graduate degrees granted per Electrical Engineering Department is also downward, particularly in the larger programs and at the Ph.D. level. Those of us involved in graduate education are again painfully aware of this trend. The decrease in the number of M.S. degrees appears to be leveling off, perhaps reflecting either the willingness on the part of more students to sacrifice 1-2 years of salary, but not 3-5, or an increase in the number of working engineers pursuing after-hours M.S. degrees.

As those of us in academia are well aware, the downward trend in the number of Ph.D. degrees granted has serious implications for the future training of engineers, particularly in high-technology areas such as communications and signal processing. In the late 1980's and the 1990's, when many of the electrical engineering faculty presently engaged in research and teaching in these areas move into more heavily administrative positions or retire, it appears that there will be a severe shortage of mid-career, mature faculty members to replace us. If the authors have one sermon to preach to today's B.S.-level engineering students who have thought of teaching as a possible career, it is that now is the time to begin pursuing that doctorate, which may appear at this point to be a far-off "maybe." We believe that teaching careers in

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engineering, and in particular in electrical engineering, will become increasingly attractive and rewarding as the end of this century approaches, partly because of this downward trend in Ph.D. graduates as well as the fast pace of new developments within the discipline.

V. ANALYSIS OF DATA ON COURSES AND CURRICULA

Subject areas corresponding to course data for the 73 schools responding to the survey are summarized in Table II. In order for a subject area to be included in Table II, at least four departments had to report courses offered in a given subject area. Many other course subject areas were reported, however. Examples are classical noise calculations, microprocessor applications to communications, radio communication systems, switching theory, spread spectrum systems, phase-lock

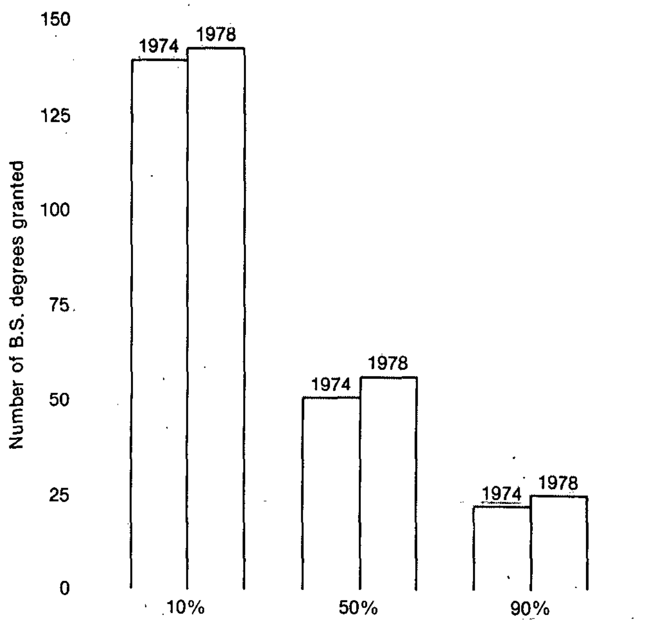

Fig. 3. Percent of departments with B.S. degrees granted at least as large as the ordinate. (Data from *Engineering Education*, March 1975 and 1979—schools responding to survey only.)

and frequency-lock systems, remote sensing systems, and television. The 73 schools reported a total of 164 undergraduate courses, 215 graduate courses, and 55 courses which were available to both graduate and undergraduate students.

A number of subjective judgments had to be made in developing Table II. For example, a number of courses covered more than one of the topics included in Table II. For the most part, courses were placed in the area receiving major emphasis. Where a course outline or other supporting evidence was not available, an educated guess, based on our own experience, was used. Courses entitled "Information Theory and Coding" were classified as information theory courses.

The most popular course was the survey course. For the undergraduates, this course tended to cover linear

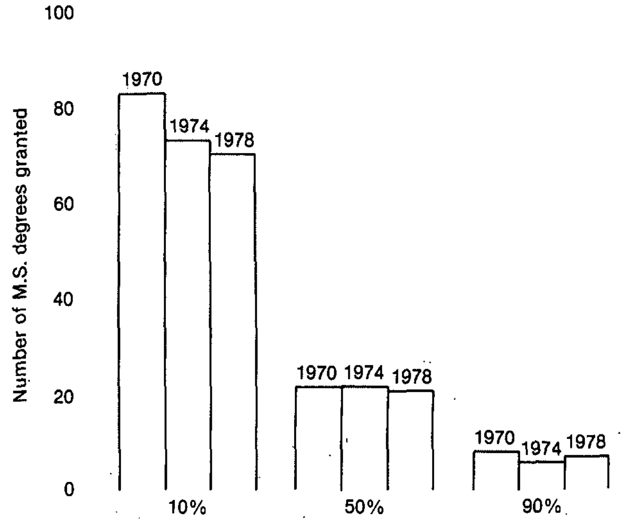

Fig. 4. Percent of departments with M.S. degrees granted at least as large as the ordinate. (Data from *Engineering Education*, March 1971, 1975, and 1979—schools responding to survey only.)

system theory including noiseless modulation theory and an introduction to probability and random processes. The graduate survey courses tended to cover noise effects in analog modulation systems and digital communication systems. Of the 65 undergraduate survey courses reported, 19 were required and 46 were elective.

The results of the survey indicate that digital signal processing has become a major new curriculum area. Of the 73 schools responding to the survey, there were 79 separate courses in this area. Only 18 schools reported no courses, 36 schools reported one course and 19 schools reported two or more courses, with two schools having four. Four schools reported required undergraduate courses in this area.

Statistics on course offerings and average course enrollment are summarized in Table III. Not all courses

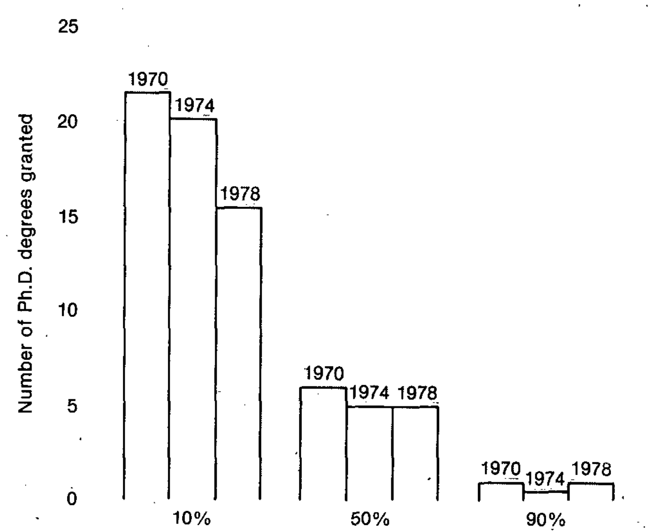

Fig. 5. Percent of departments with Ph.D. degrees granted at least as large as the ordinate. (Data from *Engineering Education*, March 1971, 1975, and 1979—schools responding to survey only.)

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which were reported are included in Table III since complete data were not obtained for each course mentioned.

Several comments are in order. First, there are very few required courses in the communications and/or signal processing areas even at the undergraduate level. Most of the required undergraduate courses were either communications survey, probability and random processes, or digital signal processing courses. The required graduate courses result from graduate core curricula. Most courses are offered on an annual basis, with the more basic courses offered more frequently. The large average enrollment in the undergraduate courses was dominated by a relatively small number of large schools which offer multiple sections of survey courses.

TABLE II
Summary of Course Offerings in Communications/Signal Processing

Course Subject Area	Total Number of Courses	Level: Undergraduate	Level: Mixed	Level: Graduate
Communications Survey Course	88	65	10	13
Probability and Random Processes	64	16	6	42
Digital Communications	61	18	6	37
Noise Effects in Analog Modulation	19	6	4	9
Detection/Estimation Theory	42	2	2	38
Digital Signal Processing	81	23	12	46
Information Theory	40	5	2	33
Coding Theory	26	1	3	22
Optical Communication Systems	19	1	3	15
Satellite Systems	11	0	1	10
Image Processing	9	1	1	7
Pattern Recognition	12	0	0	12
Radar/Sonar Systems	13	0	2	11
Communication Laboratory	6	4	2	0
Communication Electronics	10	7	2	1
Computer Communication Systems	16	3	2	11
Optimal Filtering Theory	4	0	0	4
Speech Processing	4	0	3	1

TABLE III
Statistics on Course Offerings

	Undergraduate	Mixed	Graduate
Total number of courses	95	46	254
Number of required courses	18	1	8
Number of elective courses	77	45	246
Courses offered more frequently than annually	16	8	15
Courses offered annually	75	28	172
Courses offered less frequently than annually	4	10	67
Average enrollment per course	37	21	12

TABLE IV
Frequently Cited Textbooks

Survey Course

A. B. Carlson, *Communication Systems: An Introduction to Signals and Noise in Electrical Communication*, Second ed. New York: McGraw-Hill, 1975.

M. Schwartz, *Information Transmission, Modulation, and Noise*, Second ed. New York: McGraw-Hill, 1970.

F. G. Stremler, *Introduction to Communication Systems*, Reading, MA: Addison-Wesley, 1977.

H. Taub and D. L. Schilling, *Principles of Communications*. New York: McGraw-Hill, 1971.

R. E. Ziemer and W. H. Tranter, *Principles of Communications: Systems, Modulation, and Noise*. Boston, MA: Houghton Mifflin, 1976.

Probability and Random Processes

A. Papoulis, *Probability, Random Variables and Stochastic Processes*. New York: McGraw-Hill, 1965.

Detection/Estimation

H. L. Van Trees, *Detection, Estimation and Modulation Theory*, vol. I. New York: Wiley, 1968.

Digital Signal Processing

A. V. Oppenheim and R. W. Schafer, *Digital Signal Processing*. Englewood Cliffs, NJ: Prentice-Hall, 1975.

Information Theory

R. G. Gallagher, *Information Theory and Reliable Communication*. New York: Wiley, 1968.

Coding

S. Lin, *An Introduction to Error Correcting Codes*. Englewood Cliffs, NJ: Prentice-Hall, 1970.

W. W. Peterson, *Error Correcting Codes*. Cambridge, MA: MIT Press, 1961.

W. W. Peterson and E. J. Weldon, Jr., *Error Correcting Codes*, Second ed. Cambridge MA: MIT Press, 1972.

(Note: A. J. Viterbi and J. K. Omura, *Principles of Digital Communication and Coding*. New York: McGraw-Hill, had not appeared at the time the survey was completed.)

Optical Communications

R. M. Gagliardi and S. Karp, *Optical Communications*. New York: Wiley-Interscience, 1976.

J. W. Goodman, *Introduction to Fourier Optics*. New York: McGraw-Hill, 1968.

Image Processing

H. C. Andrews and B. R. Hunt, *Digital Image Restoration*. Englewood Cliffs, NJ: Prentice-Hall, 1977.

Pattern Recognition

R. O. Duda and P. E. Hart, *Pattern Classification and Scene Analysis*. New York: Wiley-Interscience, 1973.

J. T. Tou and R. C. Gonzalez, *Pattern Recognition Principles: Applied Mathematics and Computation Series*, Second ed. Reading, MA: Addison-Wesley, 1975.

Communication Electronics

K. K. Clarke and D. T. Hess, *Communication Circuits: Analysis and Design*. Reading, MA: Addison-Wesley, 1971.

Computer Communication Systems

M. Schwartz, *Computer Communication Network Design and Analysis*. Englewood Cliffs, NJ: Prentice-Hall, 1977.

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TABLE V
M.S. and Ph.D. Areas of Research: 1976-1978

Research Area	Number of M.S.'s	Number of Ph.D.'s
Acoustic imaging, holography, and tomography; propagation	3	6
Acoustic wave device applications to communications and radar;		
Surface and bulk	2	1
Aids for the deaf	2	
Antennas and antenna arrays	7	3
Coding and decoding:		
Channel	3	7
Source (including picture)	2	7
Communications; Systems:		
Computer Communications	2	5
Echo suppression	5	1
Digital transmission	4	3
Electronics	12	3
Channel characterization and performance	2	3
Correlation and correlator applications	2	
Data:		
Storage, retrieval, and updating	3	
Compression and classification		2
Quantization	2	
Detection/estimation and applications	1	16
Delta modulation	4	1
Digital filters:		
Frequency Sampled		1
Recursive	1	3
Two dimensional	3	
Quantization effects		1
Special topic areas	3	3
Digital sequence generation and applications	3	1
Digital signal processing and applications		3
Distributed computer systems and data base networks	2	
Fading/dispersive channels—communication in (diversity, equalization)	5	2
Filtering—stochastic	2	1
Frequency and phase lock systems	2	
Image analysis encoding, processing, and reconstruction	9	12
Interferometer systems	2	
Information theory and applications	2	
Infrared scanners and receivers	2	1
Jamming techniques	2	
Laser communication and ranging systems	7	
Matched filters—digital	1	4
Mircoprocessors:		
Data acquisition applications	2	
Data transmission applications	6	
Distributed processing	3	2
Miscellaneous topics	4	
Modems—modeling, survey, performance characterization	4	
Modeling and simulation	3	1
Modulation techniques and systems	6	1
Multiple access techniques and systems	4	5
Noise Modeling	3	
Nonlinear system analysis	3	2
Optical communication links, trackers, and processing	9	2
Pattern recognition and classification	8	7
Propagation—electromagnetic	2	
Radar systems, position location, and target classification	8	2
Rate distortion theory and applications		3
Reliability	1	
Remote sensing	3	
Sampling and sampled data communication systems	2	1
Satellite communication systems	2	1
Spectral estimation	6	4
Speech analysis, recognition, and synthesis	3	3
Spread spectrum systems	5	
System evaluation	2	
System identification and characterization	4	6
Synthesizers—frequency	4	1
Unclassified	15	7
Walsh functions and applications		2

Table IV gives a few of the trends in textbook selection for several of the subject areas. It is very difficult to identify the most popular textbooks since a large number of books is available and most of the highly specialized books have relatively small adoption lists. For example, 108 textbooks were identified as being used in courses reported on the survey. Of these books, 75 were cited fewer than four times and 42 of the books were cited only once. The groups of books in Table IV account for 70 percent of the citations in a given subject area. Where only one book is listed for a given area, that one book had more than twice as many citations as the next most frequently cited book. Where more than one book appears in a given area, the books are placed in alphabetical order by author. Some books that would otherwise have made the list were deleted because they are not clearly referenced or are out of print. Several course areas are not included since, for these areas, no single book received a significant number of citations.

VI. DATA ON RESEARCH AND AREAS OF INNOVATION

The data on M.S. and Ph.D. theses are categorized by subject area and presented in Table V. The thesis titles reported are limited to the time period 1976-1978. As with the data on courses and curricula, many subjective judgments had to be made. Note that an "Unclassified" category is included, which consists of thesis titles that did not fit well into any of the other categories listed. A significant percentage of those theses categorized as unclassified were concerned with biomedical topics, and several others involved combinations of two or more of

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the other categories listed. Other than noting the broad range of topics included, we will simply let the data speak for itself, with apologies offered to anyone whose favorite research area is omitted.

The survey form also asked for possible responses on areas, perhaps innovative, not covered in other questions on the form. We will simply list a few of the responses that appeared to be innovative to us. At the undergraduate level, several departments mentioned special projects involving laboratory work or hardware implementation of theoretical concepts. At one school, students devote one-third of the senior year to such endeavors. Several departments reported laboratories for digital signal processing experimentation. At the M.S. level, one department responding to the survey reported a degree program on professional practice in the communication and signal processing industry. Several research areas were listed in response to this question. Those not listed in Table V include adaptive operation of large array antennas, which involved a large experimental facility, computer communication networks, nonlinear analysis of two terminal active microwave circuits, and artificial intelligence. One interdisciplinary program in biomedical engineering was reported.

VII. CONCLUSION

As a final note, we simply wish to thank all those persons who took the time to respond to the survey. We hope that the readership of this MAGAZINE finds the results of the survey interesting as well as useful. Our apologies are extended for any unintentional misrepresentations of the data supplied to us. We now feel that we know how to go about taking a survey, and we welcome any comments and criticisms, if done kindly, to this article. Perhaps we can share them in a future article, provided the Editor is willing and we recover from the birthpains of this paper.

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