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Reported are specifications for a computer-oriented first course in electrical engineering giving new direction to the development of texts and alternative courses of study. Guidelines for choice of topics, a statement of fundamental concepts, pitfalls to avoid, and some sample course outlines are given. The study of circuits through computer analysis, simulation, and signal processing is recommended at the sophomore level as a means for implementing these studies for the electrical engineer. (GR)

Some Specifications For A Computer-Oriented First Course In Electrical Engineering

September 1968

Cosine Committee Commission on Engineering Education

SOME SPECIFICATIONS FOR A COMPUTER–ORIENTED FIRST COURSE IN ELECTRICAL ENGINEERING

An Interim Report of the

COMPUTER SCIENCES IN ELECTRICAL ENGINEERING (COSINE) COMMITTEE

of the

COMMISSION ON ENGINEERING EDUCATION
Washington, D. C.

September, 1968

TASK FORCE ON THE FIRST COURSE
COSINE Committee
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SOME SPECIFICATIONS FOR A COMPUTER-ORIENTED FIRST COURSE IN ELECTRICAL ENGINEERING

I. INTRODUCTION

It is evident that most electrical engineering courses are becoming significantly influenced by the convenient availability of digital computers and the introduction of programming courses at elementary levels. To redirect the orientation needed for all courses to take full advantage of these changes is a task which will ultimately require the expenditure of considerable time and energy. A natural starting point in this task is the first course. The updating of this course can initiate a trend in which other courses will change as we gain experience and insight.

It is the judgment of many working in this field that the concepts involved in computerizing electrical engineering course material are not difficult, and the first course is therefore a logical place to begin. We cannot follow the traditional pattern of moving material originally in graduate courses down through the curriculum, but rather we must rearrange the means by which the order in which topics are presented.

To explore the possible contents of such a first course, a group of educators met at Princeton University for two days of discussion in December, 1967. Under the sponsorship of the COSINE Committee of the Commission on Engineering Education, the group was designated the Task Force on the First Course. The contents of this report are the outgrowth of these discussions, refined by considerable correspondence and discussion since the original meeting date.

A major objective in issuing this report is to stimulate educators to experiment in the classroom and to write textbooks suitable for the first course in electrical engineering. The writing of such a textbook is by no means a trivial task, for a new organization of knowledge and a new blending of fundamental topics in electrical engineering with appropriate topics relating to the computer will be required. Most textbooks we now have, have an order of presentation fixed by tradition and are difficult to change. Each book contains a canonical set of problems, usually problems that can be solved with a slide rule in 30 minutes or less. There is a coupling between these problems and the topics treated in our classes: we treat only topics that can associate with easily solved problems — avoiding difficult subjects, even those that have obvious relationship to important technological developments. With the ready availability of the computer, we should re-examine the list of topics we teach and the way in which we teach them. For example, if nonlinear effects are dominant in a given electronic device, then there is no need to retain the linear or piecewise linear model exclusively in classroom study.

Even though many people may understand clearly the situation we have attempted to describe, unless their ideas are formalized in the written form so that it may be read and understood by others, we may have a bottleneck to progress. Our efforts to modernize our courses to incorporate the digital computer can advance no more rapidly than textbooks (or preliminary versions of them in note form) become available:

II. OBSERVATIONS ON THE FIRST COURSE

In discussing the first course, we shall make a number of assumptions concerning the level and background of the students. At most schools, the first course is given in the sophomore year, and is taken by all electrical engineering students. The typical student taking this course will have completed most of his calculus, he may be taking differential equations (although there is a trend to incorporate the topics of this subject in engineering courses), he may have had a course in linear algebra, and he will have taken an introductory course in computer programming, probably using FORTRAN.

At the sophomore level, the best vehicle for teaching the use of the computer, and at the same time covering material that will be used in later courses, is a course in circuits.[1*] This choice leaves us with a large list of important topics that might be covered depending on the interests and talents of the faculty at each school.

In the final choice of topics, we suggest the following guidelines:

(1) The theme of the course should be computer analysis, device simulation and signal processing with the circuit as the vehicle. These choices will provide interest and motivation to engineering students.

(2) The subjects taught must lead naturally to the use of the digital computer. It must be clear that the computer provides an advantage, or we will lose the confidence of the students:

(3) The student must be introduced to elementary numerical analysis (sometimes called numerical methods or numerical calculus). This is a difficult task, for we must cover enough topics for him to understand the problem of using the computer without becoming immersed in the infinite "art" of numerical techniques.

(4) The subject material must remain relevent to the real world, and we must provide an ample supply of well chosen and physically motivated examples and problems to convey to the student the generality and power of the computer approach to problem solution. We must admit to the wide variety of jobs for which electrical engineers are being educated.

(5) Motivation is an important factor in deciding what to teach and how to teach it: the student must be convinced that he is involved in meaningful studies leading to real-world application of the computer to engineering. In this connection, we should consider introducing **design concepts.**[2*] into the course as well as the associated laboratory.

*Footnotes appear at end of Summary.

III. THE FOUNDATION CONCEPTS

The first course should introduce some combination of five important aspects of the use of the computer by electrical engineers. These are:

(1) It should introduce the algorithmic approach to problem formulation.

In most of the student's previous training, he will have been introduced to analytical techniques, so that his first contact with an algorithmic approach may strike him as clumsy and indirect. This prejudice must be overcome through numerous examples and problems, implemented as computer programs.

(2) It should introduce material which will serve as a vehicle for the student to learn numerical computer techniques.

Numerical problems in the use of the computer should be introduced in terms of problems with an engineering motivation. For example, the study of simple nonlinear memoryless systems will probide a vehicle through which important concepts can be introduced.

(3) It should introduce the computer as a simulator.

The simulation of simple dynamic systems (with memory in contrast to those of section 2) will introduce topics that should be understood by the students.

(4) It should introduce the computer as a processor of information presented in discrete rather than continuous form.

Signal processing, such as the smoothing or filtering of a discrete signal waveform, offers a significant vehicle to introduce the student to the computer as a processor of information.

(5) It should introduce the important subject of the circuit model of the physical device.

Since computer results must ultimately relate to physical measurements, we must stress the importance of the choice of a circuit model used in computation on the accuracy of the computations. The computer provides us with a means for making this important conclusion very evident, since the effect of more complete models can readily be seen through computation of results for each case.

It is clear that it may not be possible to treat all five subjects adequately in the first course, even though it may extend over an academic year. We advocate experimentation with various mixtures of these topics, the choice stemming from the interests of the faculty members involved.[3*]

We should also note that in many schools economic factors may dictate one course which will be taken as the first course by students from several branches of engineering, as well as non-engineering disciplines. This can be accomplished, perhaps at the cost of motivation, by substituting (1) general memoryless systems (mechanical, electromechanical, hydraulic, etc.) for electrical systems made up of resistors, diodes, etc., (2) general dynamic systems for RLG networks, and (3) general information processing with various engineering applications in place of electrical signal processing. We regard such an approach as being within the general recommendation for educational experimentation.

IV. ANALOG CIRCUITS

For the first course, we must select a combination of models more complicated than simple resistive networks, yet not as complex as the completely general RLC network. The best choice appears to be the **memoryless nonlinear resistive circuit.** In making this choice, we postpone consideration of networks containing capacitors and inductors, but include as network elements linear and nonlinear resistors, diodes, and transistors. These models permit us to represent many typical electronic circuits such as clippers, regulators, mixers, wave shapers, etc. Thus we have adequate material for motivation and for an introduction to the elementary aspects of modeling.

The first topic for study is the writing of the Kirchhoff equations that describe the network. If the equations are written for a computer program such as ECAP, the mastery of technique becomes a matter to be resolved between the student and the machine which has low tolerance for error! The machine should be a most effective teacher when it comes to writing node equations. Once the equations are properly written, we will turn to the techniques for the numerical solution of these equations.

Some numerical techniques that should be covered are:

1. Solution of simultaneous linear algebraic equations.
2. Iterative solution of nonlinear algebraic equations
3. Numerical integration
4. Interpolation and least squares methods

If the course includes reference to the design of circuits (or there is an associated laboratory covering such topics), then the course should include techniques of optimization (or minimization) accomplished through computer methods. A related topic is tolerance analysis which will require the introduction of elementary statistical methods into the course.

A possible outline of one order in which these topics might be covered is given in Appendix I, Course I.

The addition of a linear or perhaps a nonlinear capacitor to the class of networks previously considered is one way in which the subject of simple dynamic circuits can be introduced at the beginning level. The manner in which such a course in dynamic circuits might be approached is indicated in Appendix I, Course II.

V. DIGITAL PROCESSORS

The models mentioned under the heading of analog circuits are those that are useful in representing physical systems such as electronic systems, power systems, and the like. In the transmission of information, information processors are substituted for the analog circuits. When the signals being transmitted are continuous, analog circuits of the type discussed in Section IV are used, filters and distortion-correcting networks being well-known examples. There is every indication that in the near future almost all information transmission will be by digital or discrete signals, and that different systems from analog circuits will be used to process this information. It becomes important to the electrical engineer to understand digital information processors (digital filters being an example) if he is to understand modern techniques employed in the transmission of information.

In the past, such topics have been covered in communications courses and in courses in automatic control. There is no reason that these topics cannot be treated at the sophomore level since the concepts underlying digital processors (and signals) are no more complex than those used for analog circuits (and signals). Most of the discussion can be in terms of algebraic equations, with little mention of matrices or differential equations!

A possible first course on this subject may have the following general outline:

1. The generation of digital signals; properties
2. The manipulation of signals
3. Reconstruction of signals

The first topics would be largely motivational with discussions of sampling rate, magnitude and time quantization.

The second topic will require the bulk of the time available and would cover smoothing through a study of a simple example such as $y_n = x_n + x_{n-1}$. Polynomial approximation, drawn from the standard numerical methods treatment, would lead to an understanding of the manipulations needed to yield the appropriate information from a digital signal. Frequency-domain analysis of discrete signals would lead to an understanding of digital filters of various kinds through a consideration of the amplitude and phase characteristics of discrete signals.

Three methods for the reconstruction of signals might be studied. These are (1) the zero-order hold, (2) energy storage devices (e.g., capacitor with switches or computer memory) and (3) linear point connector as implemented with ideal integrators.

These studies will provide the motivation for the study of accumulation and roundoff error (or "simulation error"), the various error measures, and the engineering importance of these errors.

VI. SOME PITFALLS TO AVOID

We have frequently mentioned motivation and its importance in the first course. The incorporation of the computer into our engineering courses offers us the possibility of increasing the motivation. We should remember that the engineering student is interested in involvement in real-world problems, especially the opportunity to design. The writer of textbooks should keep this orientation in mind, remembering that subjects taught in the abstract usually do not appeal to engineering students!

It was mentioned earlier that a significant problem is to decide what not to teach; we should not underrate this problem. In general, the student's chances for learning are improved if we cover relatively few topics and cover them well. An obsession with rigor and completeness should be avoided, but every effort should be made to stimulate the student to see beyond what is presented.

The course must be a concept course more than a techniques course. We must avoid having the student spend an unreasonable amount of time learning programming tricks (as well as the teacher using valuable class time explaining details of solution). To do this is fun, like chess or crossword puzzles, but it is not **education.**

We should not avoid requiring students to write computer programs, say in FORTRAN, nor should we avoid using existing computer programs such as ECAP. We must remember the importance of preparing suitable manuals, and providing consultation to the students during laboratory periods and outside of class hours.

VII. SUMMARY

Because of the widespread availability of digital computers, the education of the electrical engineer must change rapidly to incorporate such concepts as that of the algorithm and the analysis of numerical procedures. There is also the associated requirement of precision in explanation; the necessity of knowing and describing clearly what every procedure does and what it does not, when it applies and when it does not. Instruction of the type required can begin early in college (if not in high school). The study of circuits through computer analysis, simulation, and signal processing is recommended at the sophomore level as a means for implementing these studies for the electrical engineer.

We hope that this report will call the attention of electrical engineering educators to the need for experimentation in the teaching of a new first course. It is our hope that a number of different courses will be stimulated and that the successful ones will result in textbooks becoming available for the use of all students.

[1] At least this is the course most often found at the beginning of the electrical engineering curriculum.

[2] Most design is done by repeated analysis coupled with experience. Students do not seem to mind this approach to design.

[3] Two possible course outlines are given in Appendix I. The bare outline of another course is suggested in Section V.

APPENDIX I – SAMPLE COURSE OUTLINES

Course I. Resistive Circuits

A. Modeling
1. Forms of representation – tabular, functional interpolation, approximation
2. Linearization, piecewise linearization
3. Physical model of a resistor and a junction diode

B. Equation Formulation
1. Conservation of charge and energy – KVL and KCL
2. Nodal analysis and cutsets, brief mention of duality (little graph theory)
3. Matrix representation for linear case
4. Matrix addition, multiplication

C. Equation Solution for Linear Circuits
1. Gaussian reduction as a way to find the inverse
2. Physical interpretation of row operations
3. First order iteration for solving linear case

D. Use of Iteration in Circuit Design
1. First order iteration for nonlinear circuits
2. Newton-Raphson iteration for one-dimensional nonlinear case (or search-in-one-direction-at-a-time methods)
3. Optimization by iteration

E. Amplification
1. Voltage and current amplification
2. Circuit models and characteristic curves for a transistor
3. Linear models, y parameters, and reciprocity

F. Tolerance Analysis (optional)
1. Random numbers and their generation by a computer
2. Uniform distribution and application to resistive circuit tolerance analysis
3. Normal distribution

Course II. Dynamic Circuits

A. First-Order Circuits
1. Physical modeling of a capacitor
2. Zero-input response for linear circuit
3. Example of calculation of e^x
4. Zero-state response
5. Superposition and complete response

B. First-Order Nonlinear Circuit
1. Modeling of a nonlinear abrupt junction diode capacitance
2. Equation formulation and numerical integration using trapezoidal rule or Euler's method
3. Linearization
4. Comparison of trapezoidal rule for linear case with e^x
5. Relation between numerical integration and difference equations
6. Parasitic solutions and comparison of circuit stability with numerical stability

C. Second-Order Linear Active RC Circuits

1. Zero-input response (over, under, and critical damped)
2. State space formulation
3. Phase plane trajectories

D. Second-Order Nonlinear Networks

1. Formulation and solution using Runge-Kutta methods (optional)
2. Phase-plane and stability
3. Limit cycles and initial conditions

The course would be desired to include a number of the conventional topics which are not as easily related to the computer. In the study of the sinusoidal steady-state, for example, conventional topics would certainly cover complex numbers and phasors, impedance and admittance, poles and zeros, Q and resonance, etc.

APPENDIX II: SOME TEXTBOOK REFERENCES

Circuits and Computers

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