Session 3547

A New Paradigm for Teaching Circuit Analysis

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Abstract

Traditionally, circuit analysis has been taught as a two-term sequence with DC circuit analysis in the first term and AC circuit analysis in the second. The normal two-term sequence may be shortened to a single term if DC and AC analysis are taught concurrently rather than consecutively. In the modified sequence, DC circuit analysis is considered as a special case of AC analysis in which the frequency of the sinusoid approaches zero. This results in a unified view of circuit analysis without the artificial separation of AC and DC analysis topics. In addition, the new unified approach results in a considerable savings of valuable curriculum time and, more importantly, an increase in comprehension. The new unified approach has been used at TCI where it has been taught for several years with great success. A textbook that uses this approach has been written by the authors of this paper and published by Prentice Hall.

I. Introduction

The rapid growth of new topics in electronics and computers has placed a stress on the Electrical Engineering Technology curriculum. A requirement to introduce important new subject material and concepts is forcing educators to either choose to eliminate older fundamental concepts or to limit the introduction of new concepts. In an effort to create space for new topics the old curriculum was examined to see how it might be recast to save time for new topics. Circuit analysis, with its normal two-term curriculum, contains many topics that are repeated twice-once for DC and once for AC. In an effort to teach this fundamental course in less time we devised an approach that allows us to teach AC and DC circuit analysis concurrently in a single course. The result has been a one-term six hours per week course that replaces the original two-term curriculum. Valuable time saved by this approach has been used for the introduction of new material.

II. The Program

Figure 1 below shows the typical structure of a two-term curriculum that may be used for teaching circuit analysis. It is derived from the 8th edition of Boylestad's "Introductory Circuit Analysis" published by Prentice-Hall. The development of this book is along classical lines where first DC and then AC topics are discussed. When we look at the list of topics we see that almost half of the second term's material is a repeat of the first term's material recast in the AC format. While repetition is a useful teaching tool, we wondered if there was a way to restructure the curriculum that would eliminate some, if not all, of the repetition. With this notion in mind we examined the structure to see how this desired result could be accomplished. The resultant combined curriculum is shown below in figure 2.

Typical Two-Term Circuit Analysis Curriculum

First Term	Second Term
1. Units and the MKS System	1. Capacitor Properties
2. Current and Voltage	2. Magnetic Fields and Inductors
3. Resistance	3. Sinusoidal Waveforms
4. Ohm's Law, Power and Energy	4. Phasors / Complex Numbers
5. Series DC Circuits	5. Series and Parallel AC Circuits
6. Parallel DC Circuits	6. Series/Parallel AC Circuits
7. Series/Parallel DC Circuits	7. Mesh and Nodal AC Analysis
8. Mesh and Nodal DC Analysis	8. Network Theorems
9. Network Theorems	9. AC Power
10. Transients in RC and RL Circuits	10. Resonance and Tuned Circuits

Figure 1

A Revised Curriculum for Circuit Analysis

One Term

1. Units and the MKS System – The Nature of Voltage and Current
2. Voltage and Current Sources – Concepts of Phase Relationships
3. Complex Numbers – The Calculator as Friend and Converter
4. Behavior of Resistors, Inductors, and Capacitors in AC and DC Circuits
5. Generalized Ohm's Law
6. Simple Series and Parallel Circuits
7. Series/Parallel Circuits
8. Mesh and Nodal Analysis
9. Network Theorems
10. Power and Energy Considerations
11. Resonance and Tuned Circuits
12. RL and RC Transients

Figure 2

The revised curriculum begins with the study of atomic theory, conductors, insulators and units of measurement. This approach is historical as well as physical with an emphasis on the physical processes that are taking place inside the conductor as the free electrons move through it. The concept of the insulator as a material with few free electrons explains the difference between insulators and conductors. We stress that ***<u>all free electrons must move</u>*** in response to the applied voltage and that their motion is extremely slow in comparison to the speed with which their applied force (voltage) propagates (speed of light). This picture of all of the free electrons moving is an important precursor to Kirchoff's Current Law, i.e., if all free electrons feel the effect of the voltage force then none can collect at any point of the circuit. Current is thus seen as a consequence of voltage applied, with greater voltage producing greater current. We point out that free electron flow represents the motion of large numbers of charged particles even for the smallest measurable currents.

Armed with an understanding of the concepts of voltage and current, the student is ready to grasp the idea that sources of voltage exist and that these sources can indeed vary in time without changing the nature of their effect on any circuit. We point out that DC sources (batteries) as well as AC sources (outlets in their home) exist and other than their time varying property these sources both have the ability to push electrons through a circuit and thereby produce a current. We introduce the concept of time-varying periodic waveforms and cite examples of these waveforms that vary in amplitude, frequency and phase. Square waves, triangular waves and sine waves are discussed with reference to their appearance and properties. Period, frequency, peak amplitude and the concept of time and/or phase angle differences as well as the concept of RMS value are introduced. As a result, the student develops a good understanding of the fundamental properties of waveforms in general and sinusoidal waveforms in particular.

The fundamental understanding of the properties of waveforms is cemented with the introduction of the use of an oscilloscope and a digital voltmeter in a concurrent lab course. Concepts of frequency, amplitude and phase discussed in the classroom are reinforced by what students observe and measure in the laboratory. Modern function generators with their DC offset capabilities are used to demonstrate that AC and DC voltages can be added to each other with the resultant waveform being the algebraic sum of the applied voltages. Even before understanding what a circuit is, the student develops a sense of what a voltage waveform, (or a current waveform), is and how it varies as a function of time.

Having introduced the students to voltage and current concepts as a function of time, we next turn our attention to the complex numbers that form the arithmetic of circuit analysis. For students to properly understand circuit analysis they must have a strong background in complex number arithmetic.

Complex numbers are introduced as arising from the square root of negative numbers. We introduce the concept of points in a complex plane spanned by a rectangular coordinate system. Each point in the plane is identified by the value of its real (x-axis) and its imaginary (y-axis) coordinates. Two- dimensional addition and subtraction are easily explained using this complex plane image. Students rapidly grasp the concepts of addition and subtraction as an extension of the usual operations of addition and subtraction. Polar coordinates are introduced as an alternative way to represent the location of a point in two-dimensional space. Addition and subtraction of two-dimensional arithmetic is more complex using the polar coordinates. A graphical picture shown in figure 3 below helps to explain the concept of polar addition. At the same time the figure shows the relationship between polar and rectangular coordinates. Students are thoroughly drilled in this concept of the duality of representation.

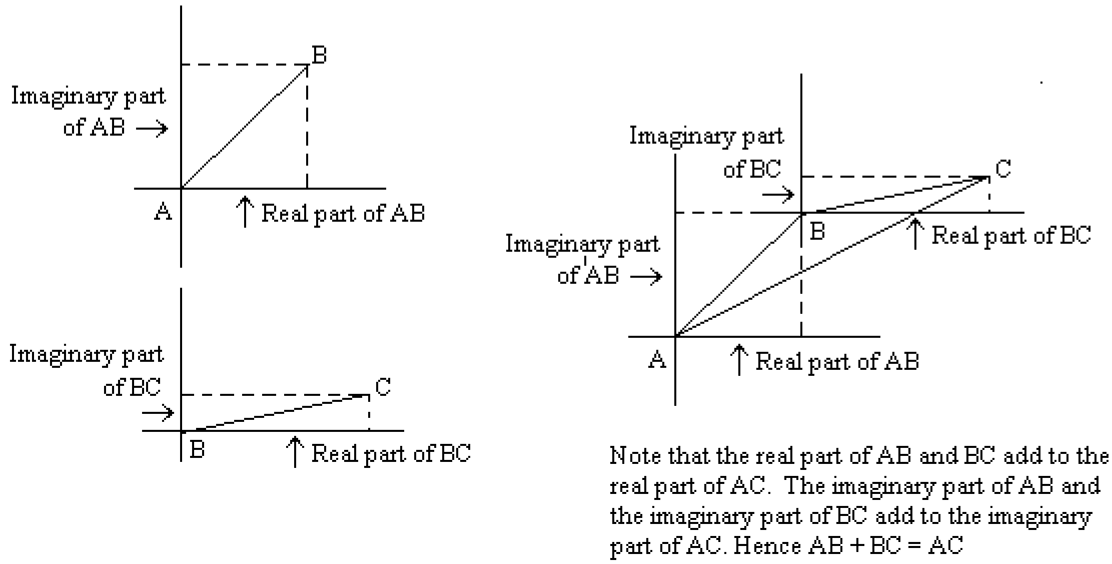

Figure 3

Having established both rectangular and polar coordinates we next introduce the concepts of multiplication, division and complex conjugates. Multiplication and division are carefully explained as an extension of the properties of algebra and completely covered and drilled until students are comfortable with handling all forms of complex number manipulations as represented in rectangular coordinates as well as polar coordinates. This final piece of the complex number arithmetic completes the study of complex numbers.

An important aid in the process of education in complex number manipulation is the modern scientific calculator as typified by the Sharp model EL-506R. This inexpensive calculator allows for rapid and simple complex number manipulation of both polar and rectangular quantities at the same time. With the aid of the calculator the students quickly learn to carry out all of the operations required for complex number manipulation. The calculator performs addition, subtraction, multiplication, and division as well as conversion between polar and rectangular coordinates so simply that students learn to perform the calculations long before they fully appreciate the process. As they continue their studies in their concurrent mathematics course their complex number manipulative skills are augmented with the theoretical understanding of why they work. This approach builds a solid understanding of complex numbers very quickly.

A final piece of the mathematics required is the explanation of the relationship between sinusoidal voltages and phasors. It is demonstrated that the addition of sinusoids through the addition of phasors produces the proper results for all instants of time. This result, easily proven with trigonometry, completes the mathematics tools needed for circuit analysis.

Having mastered the mathematics necessary the formal study of circuit analysis begins. The physical laws governing the properties of resistors, capacitors and inductors are discussed. These laws are shown to lead to voltage- current relationships for each circuit element that are unique.

Differences in behavior among these elements are discussed. This leads to the generalized form of Ohm's Law (V = I Z). Finally, the behavior as frequency goes to zero is discussed which introduces DC properties. From this point on, students are able to solve problems in AC and DC and are encouraged to do both through the use of many problems that combine AC as well as DC sources simultaneously.

III. Summary

This approach to circuit analysis has been taught very successfully for more than five years at TCI. Its adoption has allowed us to introduce new courses with the time saved. More importantly, the retention rate has increased and students seem to understand the unified approach without the difficulties often associated with the standard approach to circuit analysis as taught in the past at TCI.

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