Critical issues and current views on teaching basic circuits and systems in electrical engineering education

Joos Vandewalle
Department of Electrical Engineering (ESAT)
Katholieke Universiteit Leuven B-3001 Leuven, Belgium
Joos.Vandewalle@esat.kuleuven.be

***Abstract*—This paper discusses a number of critical issues that occur in the teaching process of basic circuit and systems concepts and methods to electrical engineering students. Different role models are introduced and some views on alternative choices are made. It is felt that extensive discussion and debate is desirable in order to enhance the efficacy of the teaching, its impact in the electrical engineering education and in order to increase the intrinsic interest of the students.**

I. INTRODUCTION

The paper is organized as follows. First we discuss the current state of affairs of CAS education in Section II. On the one hand CAS education is quite established for more than 50 years, but some erosion and lack of visibility and motivation is happening. In Section III we discuss a number of critical issues related to CAS education. As a particular point of attention for CAS education we discuss in Section IV a number of examples where CAS education can bring in necessary mathematical rigor and precision in the EE program. We present a number of valuable action points in Section V and give conclusions in Section VI.

II. STATE OF AFFAIRS FOR BASIC CAS EDUCATION

A. High school education evolutions

The CAS education and in general the whole EE education builds strongly on the mathematical skills and insight of the students. Hence the buildup of this knowledge already in high school with algebra, geometry and trigonometry is very valuable. In many countries one can perceive less interest in these subjects in high school, even though our society needs more mathematics nowadays. Some of the reasons for the reduced interest are that the mathematical skills are often reduced by the use of advanced calculators, and computers. Moreover the mathematics used in these calculators and computers is hidden inside, and the users have a nice interface that hides the mathematics. It is important to digest out of this state of affairs the need for common action to stress the role of mathematics in our society and the need for high school students to invest time and effort in it. In fact mathematical language and skills are the basic way of expressing concepts and designs in engineering. Some common outreach action is needed for making mathematics attractive to high school students. This perception may also have a major influence on the choice of Science, Technology, Engineering, and Mathematics (STEM) studies after the high school. Here we can learn from good examples like Finland and Ireland that typically have 30% of STEM students in higher education, while many European countries only have around 20%.

B. Bachelor master system

In most European countries by now the bachelor master system has been implemented in engineering according to the Bologna process. It implies a 3 year bachelor (Ba) and 2 year master (Ma) program. This brings the education in many countries of Europe more in line with the Anglo-Saxon world. But most countries do consider engineering degrees to require a buildup of knowledge and skills of 5 year education. Hence the bachelor degree brings the EE students only to a transfer level which they can continue with a master study program at their own institute or at another university or country. Hence the bachelor degree is not directly intended for a job in industry. Among some political leaders and education decision makers it is not always understood that a smooth and efficient 5 year BaMa engineering programme does not allow for a professional output on the job market after the bachelor.

C. Evolution of student populations in bachelor program

Not only in the US but also in several European countries one can perceive that the students are impatient, and expect instant gratification. In fact by using computers and internet extensively they are used to receive instant satisfaction to their requests or actions. This implies also that their attention span in lectures and educational processes is shorter [15], [23], and

978-1-4244-3896-9/09/$25.00 ©2009 IEEE

[24]. Hence the bachelor students need more argumentation and motivation for studying abstract but useful mathematics like linear algebra, and differential equations during the basic EE bachelor program. This certainly affects the way that CAS topics should be introduced to students, and it imposes extra effort from the side of the teacher to link the basic concepts to reality and realistic issues.

D. Position and role of CAS topics in bachelor EE program

Referring to figure 1, the circuits and systems education has in most programs of EE a rather central role between the basic sciences like mathematics and physics and subsequent courses of signal processing, control, electrical energy, biomedical circuits and systems, microwave and telecommunication systems. This position in EE has already been established since 1930 [1], [2] and has since not dramatically changed, but has been incrementally adapted to more complex systems and circuits and better computing and simulation facilities [1-6]. The CAS education involves often more lab oriented courses where students learn to analyse basic circuits and build these and measure these. This is often followed by a more mathematically oriented course on circuit and system analysis. Often department chairs or deans feel in difficult times, like with the present economic crisis, that this central role of such CAS courses implies that every professor of EE should be able to teach basic circuit and systems. This role of "joker" or "wild card" is however not suitable for improving the quality or the attractivity. Indeed it is experienced that the circuits and systems field has a number of dedicated expertises that are vibrant and necessary. First of all there is an intrinsic motivation for basic circuits that can appeal to students in the first year already. The ideas and methodologies of Yannis Tsividis [13], [23] at Columbia University are quite convincing to expose the students at an early stage in their EE education to real circuits and their capabilities. It has also triggered a renewed interest in EE. Also methods of direct teaching of systems as advocated by Babak Ayazifar [22] at U.C.Berkeley have lead to strong motivation of students. Second, circuits and system theory courses can bring some interesting link between the mathematics and the study and design of circuits. In [15] a collection of topics is described that typically occur in a sequence of such courses. It should be mentioned that several mathematical intricacies are important in a deep academic study of this subject. We discuss a number of these in Section IV.

E. Views, experiences and needs from industry

Of course the EE education is primarily intended for industry and hence the views of industrial recruitment officers and recent graduates of the last decade (GOLD) in industry are important. In [21] it is stressed that both groups consider the basic and broad knowledge to be of very great value and more important than the direct operational skills. Moreover the international cooperation, teamwork, communication and group dynamics are vital skills in our global arena. Certainly

This research has been supported by the Research Council K.U. Leuven: GOA AMBioRICS, CoE EF/05/006, and the Belgian Federal Science Policy Office: IUAP P5/22, IUAP DYSCO.

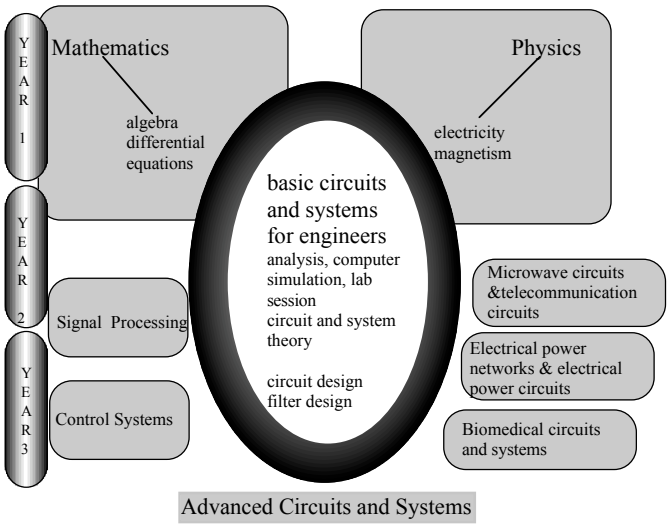


Figure 1. Positioning of the Circuits and Systems education in the bachelor program in EE.

also laboratory skills and fluency with computers and simulation tools are also recommended. Hence it is valuable to bring these elements into the CAS education as several nice examples illustrate [23], [24].

III. CRITICAL ISSUES

We discuss a number of critical issues related to the CAS education as they occur in our current circumstances.

A. Role of simulation versus analysis

In some universities there is very little attention to the mathematical analysis of circuits and systems, because EE students do not like these mathematical aspects. Of course more and more simulation tools are handy and efficient to use, and can avoid extensive analysis. Then the students are very quickly seduced to work with these simulation tools rather than being introduced to real basic circuit and systems concepts and methods like Helmholtz/Thévenin and Mayer/Norton equivalent, two port parameters, Bode diagrams, transfer functions, Tellegen's theorem, state space models, impulse responses… This is however a shallow approach to circuits and systems, and limits the insight to a level of technician. On the other hand a deep understanding of the phenomena in basic linear circuits and systems is a solid basis for further design courses in electrical engineering. Moreover strong circuit and systems insights, that the students gain in the process, generalize very well to many other domains and strengthen their academic depth.

B. Discrete time systems first and afterwards continuous time systems or the other way round

Many textbooks start by introducing for linear continous time systems the concepts like impulse response, transfer function, poles zeros, Bode diagram,.. The reason for this choice is first of all historical, because these concepts have first been derived for continuous time systems, before they

were established for discrete time systems. However students encounter intrinsically more difficulties in these concepts, since they require the understanding of unnatural continuous time signals like the Dirac impulse, and the solution of differential equations with Dirac impulses.

It is advocated here and many recent textbooks also take the simpler approach of first introducing all these concepts like impulse response, transfer function, poles zeros, Bode diagram,.. for discrete time systems and later generalize it for continuous time systems. Indeed for discrete time systems the notion of an impulse does not require a limit of a block wave of unit area with duration going to zero, but just a very simple and easy to generate discrete time signal that is 1 at t=0 and 0 elsewhere. Moreover discrete time systems tie in very nicely with the digital systems and computer systems and the simulation tools on digital computers.

C. *Can the education of circuits and systems be made more attractive by closer links with reality ?*

-The role of CAS education has drastically changed with the advent of computers and the Internet. New challenges such as environmental issues, energy shortages, and globalization offer new opportunities for CAS. Hence, when students learn about circuits as networks containing components and exhibiting dynamical behavior, they build a conceptual and a practical insight into such systems. This can serve as an ideal basis for understanding various issues related to complex systems in other fields of technology, such as biology, world economy, climate, and environment systems. This link may be used to motivate students and to broaden their views. A nice example that illustrates this is a recent book [25].

-CAS topics should also be used for teaching students to understand the impact of engineering on society and the ethical issues related to the use of technology in society.

-There is a serious shortage of engineers. Hence, attracting students to engineering should begin early. CAS should provide examples that are fun for twelve-year old kids, stimulate their creativity, and motivate them to later begin engineering studies.

-Typically the interest of female students can be enhanced with subjects that are closer to biological systems. It is hence recommended to use some biomedical systems and circuits as examples, in order to increase the number of female students in EE, that is in most countries very low (less than 20%).

IV. CAS Courses are crucial for bringing Mathematical Precision in EE education

We illustrate the importance of mathematical rigor and precision in many EE issues with an illustrative collection of insights that students should acquire in the CAS courses.

A. *Links between Fourier and Laplace transforms*

Implicitly most publications assume that the one sided Laplace transform is used in order to be able to handle initial conditions of differential equation models of circuits or systems with the Laplace transform. Quite often students learn in a course on circuits and systems that one can convert a Laplace transform into a Fourier tansform by mechanically substituting the Laplace variable "s" by "jω" with j the imaginary square root of -1. And indeed this is correct if the jω-axis is within the region of absolute convergence of the Laplace transform and if the signal that is transformed is zero for negative times. For signals like sinus functions or unit step function these conditions are not satisfied, so a serious study of these Fourier transforms cannot be done based on the Laplace transform, but needs more specific understanding of distributions like Dirac functions. Hence a separate derivation of Fourier transforms of signals that do not satisfy these criteria is needed. We refer to solid textbooks like [7], [10] for a correct treatment.

B. *Distributions*

In many studies of systems signals and circuits it makes sense and it is intellectually efficient to make use of distributions (Dirac impulses, shifted versions and any derivatives of such functions) [10], [14], both in the time and frequency domain. Then Dirac functions are often introduced as limits of a block of area 1 with duration going to zero. Often students have problems with this limit and they fail to see the benefits. Then it is important to stress that there are many limiting processes of obtaining the same distribution (called Dirac function, but the value at the origin is not defined, and hence it is not a regular, but a generalized function). But the important issue is that the processing of the Dirac impulse in a linear system e. g. an integration of such a function is rather simple and does not depend on the choice of the generating function (block function in the case of a Dirac function). For the integration of a Dirac impulse for example we obtain a step function whatever the choice of block and limiting process.

C. *Initial conditions and Laplace transforms*

The single sided Laplace transform takes an integral from zero to infinity, but some confusion can arise if the signal has in the time domain a Dirac function for t=0. It is then not clear where the integration should start, either just before zero, which we call 0-, or just after t=0, called 0+. In the first case the Laplace transform of a Dirac impulse is 1 and in the latter case it is 0. So it is a matter of choice which one to use, and afterwards to be consistent with that choice for later derivations like initial value properties or Laplace transform of the derivative of a function [10], [14]. Typically one has to solve a differential equation with initial conditions at the start of the system, that we assume to be at t=0-. If the input contains a Dirac impulse at t=0 several authors [10],[14] rightfully advocate the use of the Laplace transform starting at t-. In doing so, one can use the Laplace transform to take into account all the intricacies that happen at t=0 between 0- and 0+.

D. *Steady state solutions and effects of initial conditions*

As the faster and faster circuits and systems and circuits with lower power consumption are being designed, designers are more and more intereste in transient behavior, compared to steady state behavior. So, the effects of initial conditions and transients is getting more important and need to be calculated accurately.

E. *Intensive use of linear algebra and systems concepts*

Linear algebra and linear dynamical systems concepts require some abstraction from the side of the students but can give very powerful and comprehensive insights and views. The understanding of the Helmholtz/Thévenin and Mayer/Norton equivalent as alternative representations of a straight line in a plane is but a simple example. More involved examples are the use of multiport representations, or coupling between twoports. Also state space representations are powerful.

V. CONCLUSIONS AND RECOMMENDATIONS

Recommended actions:

-Within the IEEE CAS Society a new Technical Committee has been established on Education and Outreach last year : the CASEO Technical Committee (see http://www.ieee-cas.org/), that is an open for participation.

-Prepare Special Issues of journals or magazines reporting experiences and adopted teaching models.

-Generate a position paper by CASEO TC.

-Develop a dedicated website to collect material related to the education issues.

-Establish collaborations on CAS Education.

-Advertise initiatives in CAS Magazine, CASS e-newsletter, and the IEEE Transactions on Education and other fora.

-Work closely with regional initiatives in various continents.

-Develop a series of video recordings of lectures and related educational material.

-Stress the role of mathematics in our society and the need for high school students to invest time and effort. Many concepts in CAS need geometric thinking on top of some basic algebra.

-Develop a list of objectives and tools with the goal to motivate EE students.

-Develop the CAS concepts inventory.

-Promote group-based design projects for active learning.

-Promote projects that "rattle things apart" and build systems for the first-year engineering students.

-Develop career trajectories in CAS.

-Promote ethics and professional conduct.

-Teaching CAS should be done by CAS specialists and should be attractive and should stimulate the thinking process

-CAS teachers should have good practices like designing "structure" in developing geometric interpretations of the various concepts, providing examples from applications and including historical facts to help students reflect about the origin of the field and to introduce open problems

ACKNOWLEDGMENT

The various stimulating discussions in IEEE CAS Society EXCOM, BOG , Technical Committee on CAS Education and Outreach and at the workshop on CAS Education in May 2008 in Seattle are gratefully acknowledged.

REFERENCES

[1] F. Terman, "A brief history of electrical engineering education," Proceedings of the IEEE, vol. 64, no. 9, Sept. 1976, pp. 1399–1406, reprinted in Proceedings of the IEEE, vol. 86, no. 8, Aug. 1998, pp. 1792–1800.

[2] W. L. Everitt, "Engineering education-circa 2012 A.D.," Proceedings of the IEEE, vol. 87, no. 8, Aug. 1999, pp. 1397–1398.

[3] T. N. Trick, "Update on engineering education-circa 2012 A.D.," Proceedings of the IRE, vol. 50, no. 5, May. 1962, pp. 571–572, reprinted in Proceedings of the IEEE, vol. 87, no. 8, Aug. 1999, pp. 1399–1403.

[4] R. Rohrer, "Taking circuits seriously," IEEE Circuits and Devices Magazine, vol. 6, no. 4, pp. 27–31, July 1990.

[5] E. Guillemin, Introductory Circuit Theory. New York: Wiley, 1953.

[6] M. Van Valkenburg, "Teaching circuit theory: 1934–1984," IEEE Transactions on Circuits and Systems, vol. 31, no. 1, Jan. 1984 pp.133–138.

[7] C. A. Desoer and E. S. Kuh, Basic Circuit Theory. New York, NY: McGraw-Hill, 1969.

[8] L. O. Chua, C. A. Desoer, and E. S. Kuh, Linear and Nonlinear Circuits. McGraw-Hill Series in Electrical Engineering: Circuits and Systems, New York: McGraw-Hill, 1987.

[9] W.-K. Chen (Ed.), The Circuits and Filters Handbook. CRC Press, 2nd edition, 2008.

[10] T. Kailath, Linear Systems. Upper Saddle River, NJ: Prentice Hall, 1979.

[11] J. Fouke (Ed.), T. Bell, and D. Dooling, Engineering tomorrow, Today's technology experts envision the next century. IEEE Press, 2000.

[12] Y. Tsividis, "Some thoughts on introducing today's students to electrical engineering," IEEE CAS Newsletter, vol. 9, no. 1, p. 1, 6–7, Mar. 1998.

[13] Y. Tsividis, "Teaching circuits and electronics to first-year students," Proc. IEEE Int. Symp. Circuits and Systems, Monterey, CA, May/June 1998, pp. 424-427.

[14] K.H. Lundberg, H.R. Miller, and D. Trumper, "Initial conditions, generalized functions, and the Laplace transform; Troubles at the origin," IEEE Control Magazine, Feb.2007, pp. 22-35.

[15] J. Vandewalle, L. Trajkovic and S. Theodoridis, " Introduction and outline of the special issue on Circuits and Systems education : Experiences, Challenges and Views," IEEE CAS Magazine, Vol. 9. No 1, First Quarter 2009, pp. 27-33.

[16] L. Trajkovic, "Regional views and experiences on circuits and systems education, " IEEE CAS Magazine, Vol. 9. No 1, First Quarter 2009, pp. 33-35.

[17] R. Geiger, "Regions 1-7: Circuits and electronics-the past , present, and future, " IEEE CAS Magazine, Vol. 9. No 1, First Quarter 2009, pp. 35-37.

[18] J. Nossek, "Region 8: Importance of basic principles, " IEEE CAS Magazine, Vol. 9. No 1, First Quarter 2009, pp. 37-38.

[19] P. Diniz, "Region 9: Generating motivation among students and faculty, " IEEE CAS Magazine, Vol. 9. No 1, First Quarter 2009, pp. 38-39.

[20] Y. Lian, "Region 10: Designing circuits curriculum and following good practices, " IEEE CAS Magazine, Vol. 9. No 1, First Quarter 2009, pp. 39-41.

[21] T. Tarim, M. Di Frederico, Pui-In Mak, "Circuits and systems education: viewpoint of GOLD and industry, " IEEE CAS Magazine, Vol. 9. No 1, First Quarter 2009, pp. 42-48.

[22] B. Ayazifar, "Can we make signals and systems intelligible, interesting and relevant?", IEEE CAS Magazine, Vol. 9. No 1, First Quarter 2009, pp. 48-58.

[23] Y. Tsividis, "Turning students on to circuits", IEEE CAS Magazine, Vol. 9. No 1, First Quarter 2009, pp. 58-63.

[24] C. Trullemans, L. De Vroey, S. Sobieski, and F. Labrique, "From KCL to class D amplifier", IEEE CAS Magazine, Vol. 9. No 1, First Quarter 2009, pp. 63-74.

[25] F. Ulaby, and M. Maharbiz, "Circuits", NTS Press, 2009.