

Radoslav Horvat and Mirko Milić, Founders of Circuit Theory in Former Yugoslavia

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Abstract—Professors Radoslav Horvat and Mirko Milić taught theory of electrical circuits in the Faculty of Electrical Engineering at the University of Belgrade during the second half of the 20th century. They introduced the most up-to-date topics in their courses and for decades educated thousands of engineers and scientists. They established a well-known “School in Theory of Electrical Circuits” that was recognized worldwide. As prominent educators and scientists, they left a profound trace in broad spectrum of topics in the area of circuit theory and were considered to be founders of circuit theory in former Yugoslavia. This paper is a brief overview of their fruitful and long-lasting contributions.

Keywords—circuit theory, network analysis, network synthesis, education

I. INTRODUCTION

The beginning of circuit theory at the University of Belgrade is considered to be the year of 1956 when Professor Radoslav Horvat established the undergraduate course on “Theory of Electrical Circuits” in the Faculty of Electrical Engineering. The same year, a brilliant graduate engineer Mirko Milić, became a teaching assistant for the subject of circuit theory. During decades that followed, the advanced topics in circuit theory for graduate students have been introduced: *Synthesis of Electrical Networks*, *Special Electrical Circuits*, *Elements of Analysis of Electrical Circuits*, *Elements of Graph Theory*, and *Electrical Modeling of Physical Processes*.

Professor Horvat always surrounded himself with extremely capable collaborators. Mirko Milić, who became an outstanding and well recognized scientist, greatly contributed to the reputation and influence of the Belgrade’s circuit theory school. The team formed around Professors Radoslav Horvat and Mirko Milić was able to adopt, develop, and create new topics in the field of electric circuit theory. Lectures offered in various undergraduate and graduate courses were up-to-date and well organized. Many students were attracted to continue their education in circuit theory and many of them consequently built respectable university careers.

This paper is dedicated to the memory of late professors Radoslav Horvat and Mirko Milić. Material presented in this

contribution is based on published [1]–[7] and an unpublished [8] manuscripts.

II. RADOSLAV HORVAT (1920–2004)



Fig. 1. Professor Radoslav Horvat, photo taken in 2002.

Radoslav Horvat served in the Faculty of Electrical Engineering at the University of Belgrade since 1950 and has been responsible for the education in circuit theory and network analysis and synthesis of thousands of his country’s engineers. He is the author of five books and numerous research articles. Radoslav Horvat joined the Faculty of Electrical Engineering at the University of Belgrade in 1950 and taught the course on *Theoretical Principles of Electrical Engineering*, which emanated from a course on *Fundamentals of Electrical Engineering*.

Professor Horvat, who was also a mathematician, realized early the importance of circuit theory. He noticed the importance of analyzing electrical circuits using a complex mathematical apparatus, which enabled obtaining precise models of realistic circuits and systems as well as the simulation of the behavior of these circuits. In 1956, shortly after returning from a sabbatical spent in United Kingdom, he established a course on *Theory of Electrical Circuits*, a title that has remained on the curriculum until today. Professor Horvat introduced the most up-to-date topics at that time dealing with circuit analysis. He systematically organized the material used

in the course offered to electrical engineering students and in 1959 published the well-known textbook *Theory of Electrical Circuits* published by Građevinska Knjiga. The book is known to thousands of electrical engineers not only in the Faculty of Electrical Engineering in Belgrade but throughout former Yugoslavia. It served as an example to younger faculty members who later authored their own textbooks. Shortly afterwards, Professor Horvat published another well-known textbook entitled *Special Electrical Circuits* that contained coupled circuits (transformers), two-port elements, and filters.

In early 60s, Professor Horvat established the program on the Synthesis of Electrical Networks taught to graduate students. In 1970, his textbook *Synthesis of Electrical Networks* was published by Naučna Knjiga. The book consists of three main sections: Synthesis of Two-Terminal Networks, Synthesis of Two-Port Networks, and Approximations in the Synthesis of Electrical Networks. The essence of the book has been underlined by the author himself: "The choice of topics as well as the way of presentation were guided by the goal that not only do students learn how to implement the network, but also gain a deeper insight into the subject".¹ Professor Horvat followed the same principles in all his work. He finalized the series of textbooks with the book entitled *Elements of Analysis of Electrical Circuits* where he used a modern approach to describe principles of analyzing circuits in the time domain.

Professor Horvat always surrounded himself with extremely capable collaborators including the late Professor Marija Šušnjar who began as an Assistant Professor teaching *Fundamentals of Electrical Engineering* and then continued to teach *Theory of Electrical Circuits* as Associate Professor, the late Professor Mirko Milić, member of the Serbian Academy of Sciences and Arts, and outstanding scientist with an international reputation, and Professor Branimir Reljin, member of the Academy of Engineering Sciences of Serbia, who started as Professor Horvat's Teaching Assistant in 1973. In addition to courses on circuit theory and network synthesis, Professor Reljin extended the curriculum with new disciplines such as *Signals and Systems*, *Image Processing*, *Telemedicine*, *Neural Networks*, authored several textbooks and numerous scientific papers, and organized series of *International Symposia on Artificial Neural Networks (NEUREL)* held biannually since 1990.

During his career between 1950 and 1985, Professor Horvat established programs in *Theory of Analysis and Synthesis of Electrical Circuits*, first at the University of Belgrade and then, in cooperation with his former students, at other University centers in former Yugoslavia: Niš, Novi Sad, Podgorica, Čačak, Banja Luka, Sarajevo, Skopje, and Priština. He also directly contributed to the programs in centers established in Split, Zagreb, Ljubljana, and Maribor. In those centers, students of Professor Horvat continued to work in the area of circuit theory. They include Professors Momčilo Bogdanov (Skopje), Milić Đekić (Čačak), Petar Hinić (Banja Luka), Gordana Jovanović-Doleček (Sarajevo, Mexico), Dragan Kandić (Belgrade), Ljiljana Milić (Belgrade), Slobodan Milojković (Sarajevo, Priština), Ladislav Novak (Novi Sad),

¹Preface in *Synthesis of Electrical Networks*, Naučna Knjiga, Beograd, 1973, in Serbian.

Radoje Ostojić (Podgorica), Branislava Peruničić (Sarajevo), Radmila Petković (Niš), Branimir Reljin (Belgrade), Dušan Starčević (Belgrade), Ljiljana Trajković (Canada), and eminent researchers Dr. Aleksandar Koturović (Belgrade) and Dr. Borivoje Stamenković (Bern).

The School in Theory of Electrical Circuits of Professor Horvat was known and recognized worldwide, as noted in the article by Van Valkenburg in 1984 that appeared in the issue of the *IEEE Transactions on Circuit Theory* published on the occasion of the IEEE Centennial [1].

Besides teaching, in 1968 Professor Horvat had already established a series of international symposia on theory of electrical networks, *International Symposium on Network Theory (ISYNT)* that were organized by the *Yugoslav Committee for Electronics, Telecommunications, Automation, and Nuclear Sciences (ETAN)* and held in Yugoslavia. The first *ISYNT* was held in 1968 in Belgrade and was subsequently held in Herceg-Novi (1972), Split (1975), Ljubljana (1979), Sarajevo (1984), and Zagreb (1989). They were attended by the best-known scientists in this field including J. Aggarwal, T. Bickart, H. Carlin, L. Chua, P. Civalieri, A. Davies, T. Deliyannis, C. Desoer, S. Dutta Roy, J. Fidler, A. Fettweis, M. Ghausi, E. Kuh, E. Laker, E. Lindberg, G. Martinelli, S. Mitra, G. Moschytz, J. Neirynek, R. Newcomb, A. Petrenko, T. Roska, R. Saal, J. Scanlan, G. Temes, Y. Tokad, M. Van Valkenburg, A. N. Willson, Jr., V. Zima, among others. Note that the *European Conferences on Circuit Theory and Design (ECCTD)* started in 1974, six years after the *ISYNT*.

Professor Horvat served as a Program Committee member of the *European Conference on Circuit Theory and Design (ECCTD)* and served as one of the Editors of the *Int. Journal on Circuit Theory and Applications*. He was Honorary Chair of the *IEEE Conference of Artificial Neural Networks (NEUREL 2000)* and reviewer for the *IEEE Trans. Circuits and Systems* and *Int. Journal on Circuit Theory and Applications*. He was a founder and active member of ETRAN Society and its Honorary President.

Over several years, he collaborated with National Committee for Standardization and edited *The International Electrotechnical IEC Dictionary with Terms in Serbian: Electroenergetics, Electronics, and Telecommunications*, published in 1996 and 1997.

Professor Horvat possessed an extraordinary memory and capability of profound understanding of theoretical problems in engineering sciences. He had a clear and precise writing style and his lectures in crowded classrooms were perfect. Reading his textbooks, many decades after they have been written, seems like reading classics.

Professor Horvat was respected and admired by his colleagues, his students, and his associates. On the occasion of his 80th birthday and 50 years of service, a special session entitled *Modern Methods in Electrical Engineering Education* was organized during the 44th ETRAN Conference held in Soko Banja in June 2000. Lectures were given by Professor Horvat's former students.

Professor Radoslav Horvat passed away in December 2004 at the age of 84.

III. MIRKO MILIĆ (1932-1993)



Fig. 2. Professor Mirko Milić, photo taken in 1993.

Professor Mirko Milić was born in Galace, Romania, on April 21st, 1932 as the only child of a respectable middle-class family. His father, originally from Dubrovnik (Croatia), worked as a professional ship-pilot in Galace, a small town in the Danube-river delta. His mother was a fine lady of Italian and Austrian origins. She influenced her son Mirko to be interested in the fine arts, music, and mathematics. From early years, Mirko Milić exhibited a strong and deep interest for art, music, languages, and philosophy. He graduated in 1950 from a high school in Belgrade with the highest honors. He continued his studies in the Faculty of Electrical Engineering at the University of Belgrade and in 1956 graduated from the Department of Telecommunications with excellent grades (grade point average 9.43 out of 10.00). As an undergraduate student, he worked part-time in the Research Institute for Nuclear Sciences Vinča in Belgrade.

In the Faculty of Electrical Engineering, he was especially attracted by the theory of electric circuits, a new subject that was just introduced by Professor Radoslav Horvat. Already in 1956, he accepted the academic position of Teaching Assistant for the electric circuit theory in the Faculty of Electrical Engineering. In 1963, he received the M.Sc. degree in Electrical Engineering with a diploma work entitled “*The Application of Graph Theory to the Analysis of Electrical Networks with Multi-Terminal Elements.*” In 1968, he received the Ph.D. degree in Electrical Engineering for his dissertation entitled “*Topological Dynamic Properties of State-Space Model of Non-Reciprocal Networks.*”

He was promoted to Assistant Professor (1963), Associate Professor (1973), and Full Professor (1980). His main research subject was circuit theory. From 1961 to 1965, he was a research consultant at the Institute “*Nikola Tesla*” and the Mathematical Institute, both in Belgrade.

Professor Milić was primarily teaching *Circuit Theory*, a fundamental subject connecting all areas of electrical engineering, and also a number of other subjects offered to undergraduate and graduate students, such as: *Topology-Based Methods for Network Analysis and Synthesis*, *Selected Topics for Circuit Analysis*, *Nonlinear Circuits*, *Digital Signal*

Processing, *Application of Computer System ECAP*, *Computer-Aided Circuit Design*, and *Dynamics of Measuring Systems*. He introduced the course entitled *Electrical Modeling of Physical Processes*, where he used well-known methods from circuit theory to solve various non-electrical problems. He wrote several textbooks and solution manuals covering subjects in circuit theory as well as textbooks *Graph Theory and Applications* (co-authored with Academician Dragoš Cvetković) and *Electrical Modeling of Physical Systems*. Mirko Milić also played an active role in teaching and research activities in the area of electrical engineering at the University of Niš and in the Military Technical Academy in Belgrade.

From 1965 to 1967, he was at the Imperial College of Science and Technology in London (UK) on a British Council Scholarship. In 1977, he was invited as a visiting professor-researcher to the University of California, Berkeley (USA). During 1990, he held a series of lectures at the Technical University of Istanbul (Turkey).

As a scientist, Professor Mirko Milić was interested in a wide range of fundamental problems of the theory of electric circuits and systems. He highly appreciated and applied complex mathematical methods and algorithms in the analysis and study of electric circuits and systems where he achieved new and remarkable results. His comments, discussions, and reviews were profound, clear, and extremely valuable to his colleagues. He contributed to several areas of fundamental circuit and system theory. The main characteristic of his research was “to be at least one step before others.” He was one of the pioneers in the foundation of spectral graph theory, having also published a textbook (with Prof. D. Cvetković) in this field. His papers cover a variety of areas, including topological dynamic properties of passive and active networks, state-space descriptions of linear and nonlinear networks, qualitative analysis and bounds of the solutions of semi-state models, Lagrangian descriptions of nonlinear networks, numerical analysis, modeling, and signal processing. He introduced a new model based on anti-Lagrangian equations for describing nonlinear networks with topological degeneracies. Especially important are papers that introduce semi-state models with the use of Liapunov functions that enable efficient solution of large linear and non-linear stationary and non-stationary systems. During the last years of his life, he was interested in neural networks, particularly cellular neural networks (CNN) where he suggested a novel CNN cell having only one active element.

Among others, his result concerning unique solvability of linear time-invariant generalized RLC circuits has proved to be one of the deepest results in circuit theory [9], [10]. Two textbooks, two solution manuals with solved problems in circuit theory, and numerous scientific papers published in international journals and conference proceedings have marked the productive period of Professor Milić’s life.

Many people knew Professor Milić as a pure and precise theoretician. It is, hence, interesting that he had a patent submission entitled “Analog n^{th} Order Filter Suitable for Integrated Technology.” Furthermore, although he preferred exact solutions in closed form over the numerical solutions, he recognized an importance of computer applications and in

1970s took a course in computer-aided program ECAP and a course in computer-aided design of electronic circuits.

Professor Milić was an active member of several international and Yugoslav scientific societies and committees as well as chair and member of a number of conference committees (*ISCAS*, *ISTET*, *ECCTD*). He was scientific secretary, program committee member, active participant, and lecturer of international symposia *ISINT* (*International Symposium on Network Theory*) established by Professor Radoslav Horvat and held in Yugoslavia from 1968 to 1989 (about) every four years. He was a corresponding member of the Serbian Academy of Sciences and Arts, a permanent member of the Scientific Committee of the *International Symposia of Theoretical Electrical Engineering* (*ISTET*) and the Information Committee of SEFI (*Société Européenne pour la Formation des Ingénieurs*), a senior member of the IEEE (Institute of Electrical and Electronics Engineers), and a member of the Yugoslav Society for Electronics, Telecommunications, Computers, Automation, and Nuclear Engineering (*ETAN*). He was a member of scientific committees for numerous conferences and participated as invited lecturer at a number of well-respected conferences. He was a reviewer for technical journals such as: *IEEE Transactions on Circuits and Systems*; *International Journal on Circuit Theory and Applications*; and *Circuits, Systems, and Signal Processing*.

With several colleagues from the Faculty of Electrical Engineering at the University of Belgrade, he initiated the first Seminar on Neuro-Computing, held from December 20–21, 1990 in Belgrade. During the Winter of 1992–93, at the time of enormous inflation in Serbia and Montenegro, he organized the second *Seminar on Neural Networks* as a series of lectures held on Saturdays from November 1992 to May 1993. The seminars now continue as the biennial *Symposium on Neural Networks and Applications* (*NEUREL*). In co-operation with the IEEE Signal Processing Society, *NEUREL* is organized by the IEEE YU Section and the Circuits and Systems Society and Signal Processing Society Chapters. It hosts authors from all over the world.

For his work, Mirko Milić obtained many awards and acknowledgements from universities and societies. Among others, in 1984 he received the *Special Certificate* from IEEE on the occasion of centenary of the IEEE Society, and *Silver Medallion* of the Technical University of Istanbul (Turkey).

Professor Milić loved to work with students and introduce them to research. With both graduate and undergraduate students, he analyzed and studied the latest and top-ranked papers in the field of circuit theory. To popularize the circuit theory and motivate students for this subject, in 1990 he decided to establish a foundation for awarding talented students in the Faculty of Electrical Engineering at the University of Belgrade. The funding was to be provided from his own income. Unfortunately, his early death in 1993 stopped these plans. In 2004, his wife, Professor Miroslava Olujić, established the *Foundation of Professor Mirko Milić*. Each December during the celebration of the School Day, the best senior student having the highest grade in *Circuit Theory* and a

student having the best published paper in the field of circuit theory are recognized and awarded.

An extraordinary scientist, researcher, professor, and art aficionado, Professor Mirko Milić had two main passions in his life: passion for science and passion to travel. He passed last days of his life enjoying his two passions: he was at the *European Conference on Circuit Theory and Design* (*ECCTD*) in Davos (Switzerland), far from his home in Belgrade, sharing experiences and ideas with his colleagues and scientists. After the conference, he spent some time in Switzerland and suddenly passed away in Bern on September 9th, 1993.

Professor Milić was an academic who left an exceptional mark on engineering science. His sudden death prevented him from completing many of his projects and ideas. His collaborators continued the research and published four papers in 1993 and 1994. Colleagues and former students, the admirers of Professor Milić, prepared for publication two books: *Electrical Modeling of Physical Processes*, second edition (2004), and *Lectures from Circuit Theory* (2006). *NEUREL* 2014, held in Belgrade, was devoted to Mirko Milić while at *ECCTD* 2009 held in Istanbul, Turkey, Professor Cem Gökner organized a special session devoted to Mirko Milić. The recently published textbook “*A Short History of Circuits and Systems*” contains contributions devoted to late Professors Radoslav Horvat [4] and Mirko Milić [5].

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