



DEVELOPMENT OF ELECTROACOUSTICS AT THE UNIVERSITY OF ZAGREB IN THE SECOND HALF OF THE 20TH CENTURY

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ABSTRACT

This paper presents the development of the scientific field of acoustics and electroacoustics at the University of Zagreb in the period that started with the establishment of the Department of Electroacoustics in 1954. Initially, the department was a part of the Faculty of Engineering, and from 1963 to the present it has been associated with the Faculty of Electrical Engineering. To this day, the department has been a unique and central institution on the territory of Croatia that covers research and teaching in many fields of acoustics. Over the years, scientific and professional activities undertaken by the members of the department influenced the development of certain branches of technology and industrial products, particularly in the fields of electroacoustic transducer technology and audiometry, but also in the design and evaluation procedures implemented in room acoustics, building acoustics and noise control. Many engineers, experts and scientists have received their education in this field through the great effort invested into the teaching activities by the department staff. In turn, this led to the launch of several companies that tackle everyday acoustic-related issues, but also to the development of both specialized and multidisciplinary research teams needed in various scientific projects that involve acoustics.

Keywords: *electroacoustics, audiometry, University of Zagreb*

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1. INTRODUCTION

It is not easy to concisely present the development of an entire research area during the 20th century within the University of Zagreb and Croatia in one paper. Many people have contributed to the development of this field. From the very beginning, it has been strongly linked to the development of the Department of Electroacoustics of the Faculty of Electrical Engineering and Computing, FER (formerly the Faculty of Electrical Engineering ETF) of the University of Zagreb. Credits must be given to Prof. Dr. Tihomil Jelaković as the founder of the department, and to his co-workers for their pioneering spirit, commitment to the field and productivity in terms of authorship and teaching. The aim of this paper is to present important moments and achievements that stem from the effort of the department staff invested in its development. The authors of this paper apologize in advance to all who will not be mentioned in this review, but who contributed significantly to the development of electroacoustics at the University of Zagreb.

2. HISTORICAL DEVELOPMENT OF THE DEPARTMENT OF ELECTROACOUSTICS

The Department of Electroacoustics was founded on October 1, 1954, as one of nine departments of what was then the Technical Faculty of the University of Zagreb. With the relocation of the Technical Faculty in 1959 to a new building, the Department expanded to a total of five rooms. This facilitated higher quality of scientific and teaching activities. Finally, in 1963, the Department of Electroacoustics moved to its present location, i.e. to the 10th floor of the then newly built building C of the Faculty of Electrical Engineering shown in Fig. 1. Thus, the department gained new laboratories, classrooms, and office spaces, occupying around 700 m² in total. The founder and the life-time head of the Department was Prof. Tihomil Jelaković. After his death in 1978, his



colleagues Prof. Miroslav Gregurić, Prof. Ivan Jelenčić, and Prof. Branko Somek continued working as teachers in the department, with the latter two alternating as heads of the department until their retirement at the turn of the 21st century.



Figure 1. Building B (the low-rise building) and building C (the skyscraper) of the Faculty of Electrical Engineering. The 10th floor of the skyscraper was given to the Department of Electroacoustics.

2.1 Prof. Tihomil Jelaković

University professor and engineer Prof. Dr. Tihomil Jelaković (1914-1978) is the most important person in the history of research in acoustics at the University of Zagreb. A fan of not only audible sound, but also ultrasound and infrasound, he dealt with the problems of recording, reproduction, processing, and transmission of sound, as well as the design of electronic devices.

He graduated in 1939 from the Technical Faculty in Zagreb. He worked as an engineer (1940-1952) in the studio equipment workshop at Radio Station Zagreb. Under his leadership, the workshop increased in space and staff, and in 1943 it had about 40 qualified workers. After World War II, in 1945, he founded the Laboratory for audio-frequency technology at Radio Station Zagreb and expanded the workshop shown in Fig. 2. Under his leadership it developed into the largest radio-engineering industry in Croatia at the time, i.e. the company called Radio Industry Zagreb (RIZ), with its experts and inventory as the core of the new company.

Therefore, Prof. Jelaković can be considered one of the founders of the electronic industry in Croatia.

Together with engineer Roman Galić, he translated the first books on the topic, written in German by W. Daudt: Radio Technique 1 and Radio Technique 2. The third book of this series, Radio Technique 3, focused on the field of electroacoustics and was translated solely by Prof. Jelaković. These translations of approximately one thousand pages in length represent the first literature in the field of electronics and electroacoustics available in Croatia. Prof. Jelaković was also one of the founders and editors of the magazine "Radio", first published in the fall of 1945. He was a contributor to the magazines Radio Technique, Electrotechnician and Electrotechnics. On his initiative, a school for technicians was founded at Radio Station Zagreb in 1947. Prof. Jelaković worked at that school as a teacher for five years and provided initial training for personnel of the Broadcasting Service of Croatia.



Figure 2. Prof. Jelaković (far right) and his co-workers design an audio amplifier in his workshop in 1948.

In 1951, Prof. Jelaković was elected assistant professor at the Technical Faculty in Zagreb, which developed into the Faculty of Electrical Engineering, where he became a full professor in 1962. At first, he taught a course called Electroacoustics to students majoring in the study program called Weak current, and a course called Weak current to students majoring in the Strong current study program. He recognized the need for continuous training of engineers due to the rapid development of electrical engineering. On his initiative, the Technical Faculty established the Department of Electroacoustics in 1954. He actively and significantly participated in the process of establishing an independent Faculty of Electrical Engineering in 1956.

He was the president of the Acoustical Society of Yugoslavia, and designed the first anechoic chamber in Yugoslavia, which was built in the Department of Electroacoustics.

As an associate of the Department of Phonetics of the Faculty of Philosophy in Zagreb, he designed and constructed several types of devices for the rehabilitation of people with hearing loss. This work is the result of his comprehensive knowledge of auditory acoustics and the experience gained in construction of sound studio devices.

Prof. Jelaković devoted his entire professional life to studying, teaching, and writing literature in the field of radio engineering and acoustics. As an author, he wrote seven books which were sold in more than 50,000 copies in thirteen editions in the period from 1952 to 1977. Almost all of them were pioneering works written for the first time in Croatian. These books are:

1. Transformers and Ballasts (1952)
2. Negative Reaction in Audio-Frequency Technology (1957)
3. Magnetic Sound Recording (1959)
4. Architectural Acoustics (first edition 1962; second edition, published under the title Sound, Hearing, Architectural Acoustics in 1978)
5. Introduction to Electrical Engineering and Electronics (1967)
6. Microphones (1969)
7. Transistor audio amplifiers (1973)

All these books have a monographic character, since they were written according to his original concept based on his own theoretical and practical experience. The covers of his books are shown in Fig. 3.

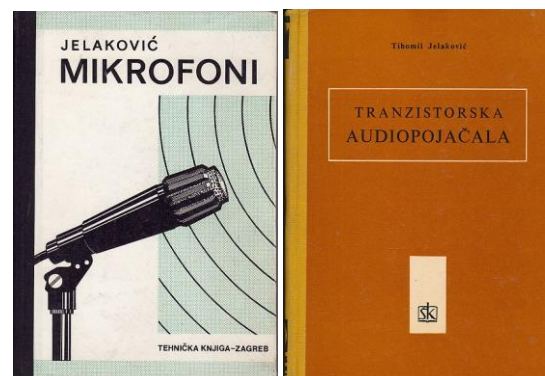
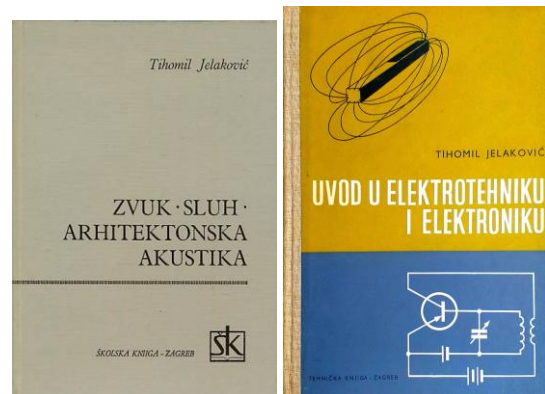


Figure 3. The covers of books written by Prof. Jelaković.

Prof. Jelaković was the leader of several scientific projects, and wrote many scientific papers, studies, and reports. As an excellent teacher who taught in a comprehensive, but easy-to-understand way with the emphasis on practical problems, he was very popular and loved by students.

2.2 Prof. Miroslav Gregurić

Prof. Dr. Miroslav Gregurić (1924-1990) worked at Radio Station Zagreb since 1948, and as a designer at RIZ since 1949. From 1952 he worked as a teacher at the Secondary Technical School in Zagreb. In 1962, he completed his habilitation and became an assistant professor at the Faculty of Electrical Engineering in Zagreb. He received his doctorate in 1972 and was elected associate professor in the same year.

At the undergraduate level, he taught the following courses: High-quality Technology Sound Reproduction, Receivers, Audiotechnics, Magnetic Sound Recording and Special Receivers. He taught Underwater Acoustics at the Faculty of Electrical and Mechanical Engineering in the city of Split, Croatia. He also taught some classes on audiometry at the Medical Faculty in Zagreb. His scientific work is largely associated with the field of hearing acoustics. He wrote the script Basic Electronics, and the textbook Radio Receiver Technique (two editions), shown in Fig. 4.

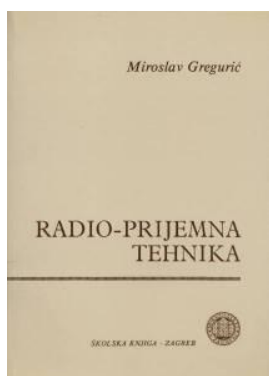


Figure 4. The cover of the book written by Prof. Gregurić.

As a research assistant, he designed various electroacoustic and other measuring instruments for application in laboratories. He designed devices for studio equipment. He worked in the field of measurements and protection against noise and vibrations, and tackled room acoustics problems. His principal field of interest was auditory acoustics and audiometry, where he was one of the leading experts in the country. The knowledge he gained contributed to the construction of several audiometers produced in the Department of Electroacoustics, as shown in Fig. 5. He created several electronic devices for medical diagnostics and rehabilitation. He designed and constructed several types of hearing rehabilitation devices. He collaborated with

domestic and foreign companies in this area of research (Ghetaldus, Wienaton, RIZ, Siemens).



Figure 5. An audiometry device designed and constructed at the Department of Electroacoustics.

2.3 Prof. Ivan Jelenčić

Prof. Dr. Ivan Jelenčić (1932-2016) completed all his education in Zagreb, graduating in 1959. He received his master's degree in 1971 and doctoral degree in 1976 at the Faculty of Electrical Engineering. From 1956 to 1966 he worked in RIZ, and in 1967 in the company Brown-Boveri as a construction engineer on the design of transmitters and receivers. From 1962 until his retirement in 2002, he worked as a teacher at the Department of Electroacoustics. Prof. Jelenčić is shown in a photograph in Fig. 6.

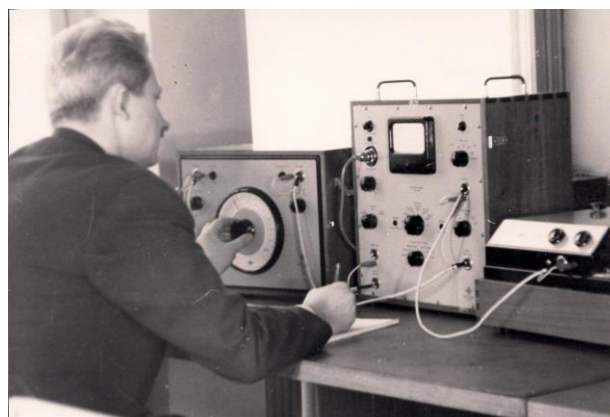


Figure 6. Prof. Jelenčić conducting measurements on electroacoustic devices at the department.

As a teacher, he taught the following courses: Acoustics and Electroacoustics, Audio-Frequency Techniques, Receivers, Digital Broadcasting and Multimedia Transmission, and Speakers and Sound Systems. Within the postgraduate study program, he taught Acoustic Design, Reception Technique in Digital Transmission and Electro-Mechanical-Acoustic Analogies.

He supervised many bachelor and master theses, as well as doctoral dissertations and worked in several research and professional projects at the department. He wrote many teaching materials, as well as his author book Loudspeakers shown in Fig. 7.

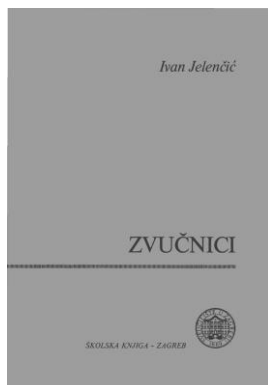


Figure 7. The cover of the book written by Prof. Jelenčić.

2.4 Prof. Branko Somek

Prof. Dr. Branko Somek (1931-) started his professional career in the RIZ company as an independent constructor of radio receivers in the electroacoustics department. After being elected as a permanent assistant at Faculty of Electrical Engineering at the Department of Electroacoustics in 1960, he continued working as an external associate, designer, and constructor in RIZ-IETA Institute, and later as a consultant at the RIZ-ELAK Factory. He received his doctorate in 1972 on the topic of infrasound. In 1974 he was elected full-time assistant professor and worked as a teacher at the department until his retirement in 2002.

In addition to studying electrical engineering, he was engaged in music, attending the music school (double bass), played in bands and orchestras, and recorded sound in radio and television production, as well as for record labels. He was also the leader of the music section at his faculty, as shown in Fig. 8.



Figure 8. The music section of the Faculty of Electrical Engineering under the leadership of prof. Branko Somek.

Prof. Somek was also a teacher of the course Musical Acoustics at the Academy of Music in Zagreb. He wrote the script Electroacoustics. He also worked on numerous professional projects in electroacoustics, room acoustics and acoustic measurements.

2.5 Prof. Momir Vujnović

Prof. Dr. Momir Vujnović (1931-2020) graduated from the Department of Electroacoustics in 1958. At first he worked at RIZ, and later in the Institute for Electrical Engineering Zagreb from 1959 to 1967, where he also worked in the field of audiometry and electroencephalography. He was also a part-time, and later full-time assistant at the Department of Electroacoustics from 1967 to 1982. He received his doctorate in 1977. In 1982, he was elected associate professor and worked at the department until his retirement in 1996.

He taught the courses Magnetic Registration, Music and Speech Acoustics, Noise and Vibrations in the master study program, and Auditory Acoustics in the postgraduate study program. He wrote several scripts in the field of electronics, acoustics, electroacoustics and tone frequency technology, as well as the books titled Oscillators, and Magnetic Recording of Signals, shown in Fig. 9.

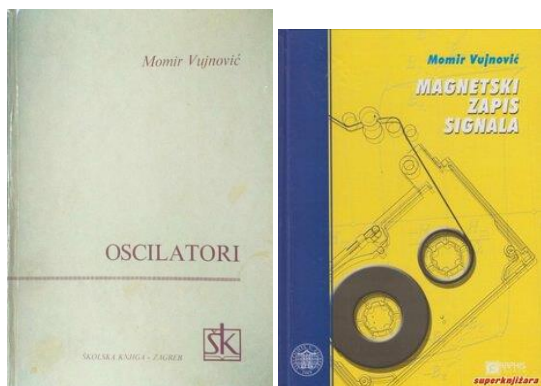


Figure 9. The covers of books written by Prof. Vujnović.

2.6 Other staff at the department

Over the course of almost 70 years since the founding of the Department of Electroacoustics, many colleagues were employed at the department as university teachers, research or teaching assistants, laboratory, and administrative staff. Due to space restrictions, only university teachers will be mentioned here, although all employed staff contributed a lot to the development of various branches of acoustics. The list includes all teachers (assistant, associate, and full professors) that were actively employed during the 20th century, as well as those who continue the legacy of the department in the 21st century until the present day. The years in the parenthesis indicate the period of employment:

- Tihomil Jelaković (1952 - 1978)
- Miroslav Gregurić (1955 - 1990)
- Branko Somek (1960 - 2002)
- Ivan Jelenčić (1962 - 2002)
- Momir Vujnović (1967 - 1996)
- Mladen Maletić (1970 - 2009)
- Bojan Ivančević (1980 - 2016)
- Hrvoje Domitrović (1991 - 2018)
- Siniša Fajt (1992 -)
- Ivan Đurek (1997 -)
- Kristian Jambrošić (1997 -)
- Antonio Petošić (2002 -)
- Marko Horvat (2002 -)
- Mía Suhanek (2007 -)

There are also other written and electronic teaching materials developed by department staff, such as the book Introduction to Hi-Fi Technique (1987) by prof. Ivančević, shown in Fig. 10.

The Department staff cooperated with other institutions at the University of Zagreb and beyond, almost since its

foundation. These are the Institute of Phonetics of the Faculty of Philosophy, Faculty of Mining, Geology and Petroleum, Faculty of Medicine, Academy of Music, all in Zagreb, and the Faculty of Mechanical Engineering and Shipbuilding in Split. Until 1991, the teachers from the department also taught at the Faculty of Electrical Engineering in Banja Luka, Bosnia and Herzegovina.



Figure 10. The cover of the book written by Prof. Ivančević.

3. TEACHING

The number of courses taught by the department staff has changed and increased over the years.

In the academic year 1959/60, the course Weak Current is taught to students majoring in the Strong current studies, and the courses Electroacoustics and Audio Engineering to students majoring in the Weak current studies.

In the academic year 1967/68, the courses Electroacoustics, Receivers, Audio Engineering, Spatial Acoustics and High-Quality Sound Reproduction Techniques are taught within the Electronics - Electrocommunication major. The department also participated in the postgraduate study, with the following courses taught at the postgraduate level: Electroacoustic Transducers, Magnetic Registration, Auditory Acoustics and Reception Technology.

By adopting the ETF-4 curriculum in the academic year 1978/79, the Department of Electroacoustics and the Department of High-Frequency Technology became the holders of the Radiocommunications and Professional Electronics major. The department staff teaches courses in two large groups: Acoustics and Electroacoustics, and Audio-Frequency and Receiver Electronics. Obligatory courses are Electroacoustics, Audio-Frequency Technique, Receivers and Magnetic Recording. Elective courses are Quality of Electroacoustic Systems, Professional Audio-

Frequency Devices, Special Receivers, Loudspeakers and Speaker Systems, Digital Audio Technology, Music and Speech Acoustics, Noise and Vibrations, Ultrasonic and Infrasound technology, Electroacoustics and Audiometry. Fig. 11 shows the middle generation of professors of the department.



Figure 11. (from left to right) Profs. Domitrović, Maletić, Ivančević and Fajt, correcting student written exams.

At the postgraduate level, the following courses were taught: Electroacoustic Transducers, Auditory Acoustics, Reception Technique, Electroacoustic - Mechanical Analogies, Theoretical Hydroacoustics, Hydroacoustic Transducers and Systems, Noise and Vibration Measurement.

4. DEPARTMENT EQUIPMENT

The successful development of the department and its teaching and research activities highly depended on the quality of specialized laboratory spaces and equipment procured by the department since its formation.

One of the most important rooms was the anechoic chamber built in 1963, shown in Fig. 12. Although quite small (net volume area of $2 \times 3 \times 2 \text{ m}^3$), it was the first one ever built in Croatia. As such, it was key to a lot of measurements performed on various electroacoustic devices.

Another important room used for many laboratory exercises, listening tests on loudspeakers, listening tests in general, etc. was the listening room that was acoustically treated and equipped with the necessary electroacoustic devices, as shown in Fig. 13.



Figure 12. The anechoic chamber in the department.



Figure 13. The listening room in the department.

The process of equipping the department with the necessary instruments began with self-construction of measurement systems: electronic voltmeters, oscilloscopes, phase meters, oscillators, voltage stabilizers, amplifiers, speaker systems, audiometers, sound meters, etc. In the beginning, instruments were borrowed from RIZ, radio and TV stations, and Jugoton record label. Generations of students were educated on these devices. The procurement of industry-manufactured instruments increased gradually, with instruments procured from companies such as Iskra, Siemens, Grundig, Philips, Hewlett & Packard, Tektronix, Rhode & Schwartz, etc. The first major step was the procurement of acoustic measurement equipment from Bruel & Kjaer. In this process, sound meters, analyzers, printers, microphone calibrators, measuring microphones, accelerometers, artificial heads, artificial ears, etc. were acquired, some of which are shown in Fig. 14.

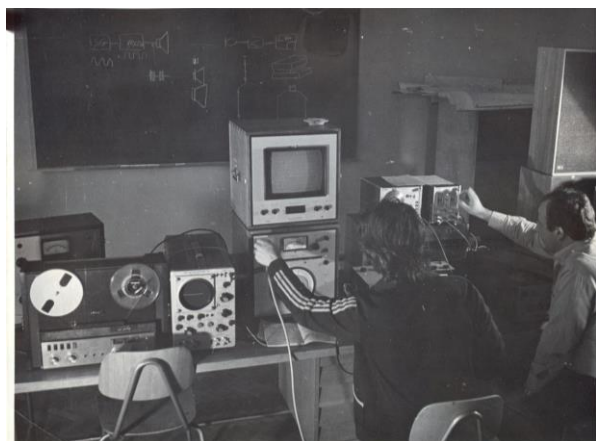


Figure 14. Measurements of the quality of electroacoustic equipment performed in the department.

The next major equipment procurement was in 1991, when the department received the first personal computers and modern acoustic equipment, such as digital sound level meter from Bruel & Kjaer, and other measurement devices from Techron TEF, Nagra-Kudelsky, AKG, AudioPrecision, etc.

The main sources of funding have always been the scientific and industry projects led by members of the department. In this way, the measuring equipment is constantly kept up to date, which makes it possible to carry out all kinds of acoustic and audio measurements according to international standards.

5. CONCLUSIONS

The Department of Electroacoustics has always served as a beacon of acoustics and the source of knowledge in this diverse field on the territory of Croatia and beyond, ever since it was founded almost seventy years ago. During this time, four generations of teachers have worked in the department and helped make it what it is today, starting with its founders as the “great-grandfathers” to us all. The senior teachers, now retired or deceased, have been the driving force of the development of the department all through the 20th century. The younger generations have taken over in the 21st century and have actively worked ever since to carry on the legacy of their elders, for many more successful years to come.

6. ACKNOWLEDGMENTS

The authors feel deeply thankful and would like to express their sincere gratitude not only to the founders of the Department of Electroacoustics, but also to all those who have contributed to the continuous development of the department and the field of acoustics in Croatia over the past seventy years.

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