



HISTORY OF THE INSTITUTE OF ACOUSTICS AND SPEECH COMMUNICATIONS OF THE TU DRESDEN

Rüdiger Hoffmann

TU Dresden, Institut für Akustik und Sprachkommunikation, 01062 Dresden, Germany

ABSTRACT

At the TU (formerly TH) Dresden, acoustics is part of the faculty of electrical engineering. Its development started in 1911 when HEINRICH BARKHAUSEN was appointed Professor for “low-current technology”, which was an umbrella for both, acoustics and communications engineering. BARKHAUSEN contributed to the field of acoustics, e. g., with the first device for loudness measurement. After the war and the retirement of BARKHAUSEN, several new institutes were established from which we mention: (1) the Institute of Electrical and Building Acoustics led by WALTER REICHARDT, contributing to many fields of technical acoustics, and (2) the Institute of Telecommunications Engineering supervised by KURT FREITAG, contributing to speech acoustics with the design of a vocoder and the measurement of speech quality. When the GDR performed a “higher education reform” in 1969, the acoustical activities were concentrated in a department for “communications and data acquisition” which included five chairs in acoustics, sensors, speech, and measurement. This step took into account the growing role of computer technology. After the political changes in 1990, the number of chairs was reduced to two which is expressed by the today’s name “Institute of Acoustics and Speech Communications”. The paper is finished by an overview on the recent activities of the institute.

Keywords: History of Acoustics, History of Speech Technology, TU Dresden

*Corresponding author: ruediger.hoffmann@tu-dresden.de.

Copyright: ©2023 Rüdiger Hoffmann. This is an open-access article distributed under the terms of the Creative Commons Attribution 3.0 Unported License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

1. EARLY DEVELOPMENT UNTIL WW II

1.1 The Beginning of Activities in Acoustics

The *Technische Bildungsanstalt* (Technical School) Dresden, the germ cell of today’s *Technische Universität* (TU), was founded in 1828. The founding director was WILHELM G. LOHRMANN (1796–1840). He cooperated in his own scientific work with FRIEDRICH W. OPELT (1794–1868) who was also interested in musical acoustics and published a book on the tone system in 1852. He invented a special version of the hole siren for his experiments [1].

It took some years before the new school reached an academic level in education. In 1842, AUGUST SEEBECK (1805–1849) was appointed director of the school and professor for physics and natural science. He was an important physicist with special interest in acoustics [2]. After his death the field of acoustics became deserted.

After the turn of the century, there were two activities in the field of room acoustics. The school had been upgraded to a *Technische Hochschule* (TH) meanwhile. RICHARD HEGER (1846–1919) was a teacher at the famous Holy Cross High School and also honorary professor at the TH Dresden. He had research activities in room acoustics since 1890 and read lectures on this topic since 1910. He was given the opportunity to establish a laboratory for experiments in room acoustics at the TH in 1912 which he used until his death [3, pp. 18 – 19].

The other early representative of the field of room acoustics with a special focus on church acoustics was JOHANNES BIEHLE (1870–1941). He was already a renowned director of church music in Bautzen when he additionally started his work in physics at the TH Dresden in 1908. He worked at the Physical Institute where he had his own laboratory, but in 1916, he changed to the TH Berlin where he was the founding director of the Institute of Room Acoustics, Church Music, Organs and Bells [4].

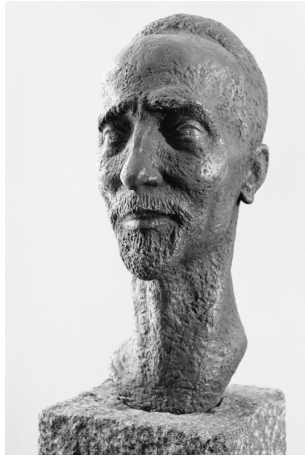


Figure 1. Bust of HEINRICH BARKHAUSEN, installed at his 100th birthday in the Barkhausen building of the TU Dresden. Artist: WALTER HOWARD (1910 – 2005). Photograph by ROLF DIETZEL.

1.2 The Era of Heinrich Barkhausen

A continuous development of acoustics at TH Dresden started with the appointment of HEINRICH BARKHAUSEN (1881–1956, Fig. 1) as professor for “low current engineering” (which we would call telecommunications today) in 1911. He came from Berlin where the big electric companies like Siemens & Halske had installed laboratories for research and development in telephony and (later) radio technology. They required new knowledge on speech production, hearing, and speech transmission. This is the reason why electroacoustics developed under the umbrella of telecommunications in that times.

BARKHAUSEN considered this development in his scientific work very early. In his dissertation (Göttingen 1906) on the generation of vibrations, he had already treated electrical, mechanical and acoustic vibrations from a uniform point of view. He elaborated the electromechanical analogies so far that the symbolic method of AC networks could be transferred to mechanic and acoustic systems. The symbolic method (commonly known as “ $j\omega$ calculation”) was invented by KARL STEINMETZ (1856 – 1923) in 1889.

BARKHAUSEN is mainly known for his contribution to theory and application of the electronic valve and his work as academic teacher [5]. The acoustic community values him for his numerous contributions in this field. They started with underwater acoustics while



Figure 2. Loudness meter from BARKHAUSEN, produced by *Siemens & Halske* starting 1927. Photograph of the device in the HAPS collection of TU Dresden [39, no. 15–1].

BARKHAUSEN was conscripted during WW I [6, 7]. His studies on the sensation of loudness [8] resulted in the first commercially available apparatus for loudness measurement (Fig. 2). To honor him, the “bark” unit for the critical bands remembers his name.

After several attempts, BARKHAUSEN succeeded with the expansion of the capacity by an extraordinary professorship for telecommunication systems and technical acoustics in 1938. It was given to WALTER WOLMAN (1901–2003) who also came from *Siemens & Halske*. Unfortunately, the following WW II and the switch to military research prevented the intended consolidation of the acoustics branch. Along with nearly the whole town, the TH Dresden was completely war destroyed in February 1945, and the work was suspended.

1.3 The Institute of Scientific Photography

The sound film played an important role in the application of electroacoustics since its invention in the 1920s. Dresden had a long tradition in the photographic industry, and therefore the TH Dresden included an important Institute of Scientific Photography. In the time when HELLMUT FRIESER (1901–1988) was the director, the institute conducted research on the sound film, including the development of a sound spectrograph based on an optic-photographic method [9].



Figure 3. WALTER REICHARDT in a lecture. Private photograph, approx. 1968.

2. NEW INSTITUTES AFTER WW II (1950–1968)

The difficult restart after WW II included a re-organisation of the faculties. After some intermediate steps, the TH Dresden opened a separate Faculty of Electrical Engineering in 1952. It was subdivided in a “high current” and a “low current” branch. The latter, which represented the BARKHAUSEN tradition, included finally six institutes [10]. Two of them were important for the further development of acoustics and will be treated here. The TH Dresden was upgraded to a university (TU) in 1961.

2.1 Institute of Electrical and Building Acoustics

The successor of BARKHAUSEN in the field of technical acoustics was WALTER REICHARDT (1903–1985, Fig. 3) [7, 11]. He finished his Dr.-Ing. thesis at BARKHAUSEN in 1930 and worked as senior engineer in various German broadcasting companies. After WW II, the TH Dresden tried to win REICHARDT as a university lecturer which finally resulted in his appointment as professor and director of the new *Institute of Electrical and Building Acoustics* in 1950.

REICHARDT developed the institute into an important facility in research and teaching; it was the leading institute in acoustics in the German Democratic Repub-

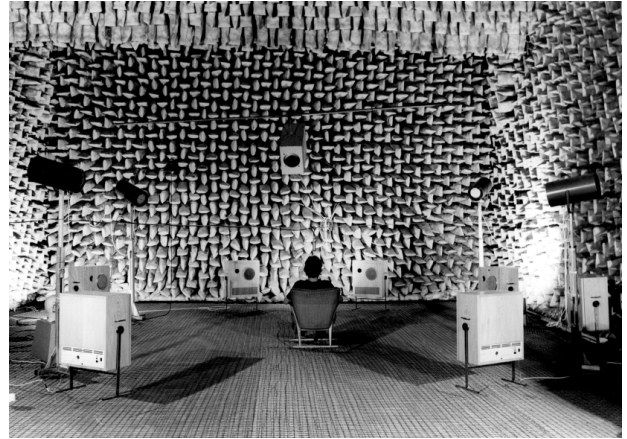


Figure 4. Synthetic sound field in the big anechoic chamber. Photograph from 1978 by ROLF DIETZEL.



Figure 5. Model of the congress hall of the “House of Teachers”, constructed for acoustical planning at TU Dresden. Original building erected at the Alexanderplatz in Berlin 1961–1964. Photograph by ROLF DIETZEL.

lic (GDR). Until his retirement, 419 Dipl.-Ing., 41 Dr.-Ing., and 3 habilitation degrees were acquired at the institute [7]. The institute was installed in a new building, today known as the Barkhausen building, and was equipped with a reverberation room as well as two anechoic rooms (Fig. 4).

REICHARDT made an important contribution to theory and application of the electromechanical analogies. He published a textbook [13] on electroacoustics which gained the status of a standard work.



Figure 6. KURT FREITAG (left), director of the Institute of Telecommunications, and WALTER TSCHESCHNER. Private photograph from the 1960s.

In the first years, speech analysis was one of the research topics of the institute [12]. Soon, this field was moved to the Institute of Telecommunications Engineering (see 2.2).

REICHARDT and his institute became famous for the development of acoustic model measurement technology and its application to numerous cultural buildings (Fig. 5), including the acoustic design of the rebuilt Semper opera house in Dresden.

The development of an adequate terminology and a correct usage of physical units was another focus of REICHARDT. He was a very active member of German and international boards for standardization.

Before REICHARDT retired in 1968, two of his scholars were appointed professors: WOLFGANG KRAAK (1923–2015) for Technical Acoustics in 1966 and ARNO LENK (1930–2017) for Electromechanical Measurement Technology in 1967. Considering the modified profile, the institute was renamed *Institute of Technical Acoustics* in 1967. The title of the REICHARDT’s renowned textbook was changed accordingly [14].

2.2 Institute of Telecommunications Engineering

The *Institute of Telecommunications Engineering* of TH Dresden was founded as one of the last new institutes in 1954. It was directed by the physicist KURT FREITAG (1901–1977, Fig. 6). He had an excellent background in research and industrial development in the field of wire-bound communications technology [15]. The tasks of the institute included speech transmission and speech quality



Figure 7. W. TSCHESCHNER in front of the Dresden vocoder in 1962. Newspaper photograph [19], reproduced from [20].

measurement.

In the post-war times, the vocoder raised strong interest. There was an obvious question whether this innovation was really able to transfer speech economically with reasonable quality. The best way to find an answer was the investigation of a prototype, which was designed in the framework of the Dr.-Ing. thesis of EBERHARD KROCKER (1927–2022) in the years 1954–1957.

This was the starting point for speech technology research at TH/TU Dresden. When KROCKER finished his thesis, the field of work was transferred to WALTER TSCHESCHNER (1927–2004, Fig. 7), thus initializing his scientific carrier as a pioneer of electronic speech signal processing. As a first task, he investigated the objective evaluation of speech comprehensibility, which resulted in an analysis of the German sounds, summarized in his Dr.-Ing. thesis from 1961 [17].

The continuation of this research was mainly thanks to the linguist GEORG F. MEIER (1919–1992), director of the Institute of Phonetics and Communications Sciences of the Humboldt University Berlin since 1961. He organized a network in speech communications research in the GDR which included the activities of TSCHESCHNER. Therefore it was possible to install a project “physics of speech” which resulted in his habilitation in 1967. It shifted the focus from speech analysis to speech synthesis, which was still serving as an experimental method to clarify the acoustic structure of speech sounds. The production of synthetic speech for communication purposes was at that time at most a question for the future [18].

3. LABORATORY FOR COMMUNICATIONS AND DATA ACQUISITION (1968–1990)

3.1 The Higher Education Reform of 1968/69

The so-called 3rd higher education reform of the GDR in 1968/69 was intended to respond to new demands of the 1960s in society, science, and technology. The reform is seen controversially today, because it increased the influence of the state and party organs at the universities. But the engineering faculties benefited from the new structures, because they reflected the challenges of the upcoming electronic age. The Faculty of Electrical Engineering was re-organized in scientific units called “Wissenschaftsbereiche”, which we translate here as laboratories.

In this way, the *Laboratory for Communications and Data Acquisition* was installed at TU Dresden. It integrated the Institute of Technical Acoustics and parts of two other institutes with the aim to address the future requirements, which were expected to occur at the interfaces of the computer with its environments as well as with the human user. This decision was a very early one, compared to other German universities, and we count it as the founding act of the recent institute. The laboratory included four working groups, which are described very briefly in the following [10, 11, 21]. The name was changed to *Laboratory for Acoustics and Measuring Technology* in 1977. A specialist colloquium was organized by the laboratory every fourth year (Fig. 8).

3.2 Working Group on Technical Acoustics

The field of technical acoustics was considered so important that two professorships were established. The aforementioned W. KRAAK was in effect the successor of W. REICHARDT. Additionally, WALTER WÖHLE (1928–2020) was appointed professor for Technical Acoustics in 1970.

From the numerous activities of W. KRAAK, hearing acoustics, measurement of noise and its impact on human beings should be mentioned. The latter is known as “Dresden hearing damage model” [22]. He was one of the editors of a highly valued handbook on acoustics [23].

W. WÖHLE worked among other on sound propagation in buildings and applied and improved the method of statistical energy analysis.

W. KRAAK introduced the first lectures on digital signal analysis at the faculty. He retired in 1988. His successor was DETLEF HAMANN for the short time of only three years.



Figure 8. Representatives of the Dresden acoustics at the 8th “Fachkolloquium Informationstechnik” in January 1975. Left (2nd row) A. LENK; first row W. REICHARDT, W. WÖHLE, and W. KRAAK (standing). Photograph by ROLF DIETZEL.

3.3 Working Group on Electromechanical Measurement Technology

A. LENK continued in his new group the work on electromechanical systems and transducers. He developed the corresponding theory to a high level and summarized it in a textbook of three volumes [24]. One of the most important applications was the development of piezoresistive transducers for medical and other purposes.

3.4 Working Group on Speech Communications

W. TSCHESCHNER started as a lecturer in the new laboratory and was appointed professor for Speech Communications in 1972. Until his retirement in 1992, he supervised 37 Dr.-Ing. and Habilitation theses in the field of speech synthesis and recognition. The scientific results were applied in numerous projects of the *Kombinat Robotron* as well as the *Kombinat Musikinstrumente*. He developed new teaching activities in speech communications.

3.5 Working Group on Electronic Measurement Technology

The field of theory and application of electronic measurement was represented by UWE FRÜHAUF as lecturer since 1969, professor for Electronic Measurement Technology since 1975 [25]. The group was transferred to another institute in 1992.

4. INSTITUTE OF ACOUSTICS AND SPEECH COMMUNICATIONS

4.1 Reorganization in the Political Turn of 1990

In the framework of the political changes of 1989/90, the “laboratories” were re-organized to institutes. The Laboratory of Acoustics and Measuring Technology regained the historical name *Institute of Technical Acoustics*. The number of chairs was reduced to three in the following years, namely Technical Acoustics (WÖHLE), Electromechanical Systems (LENK), and Speech Communications (TSCHESCHNER). The annual German Acoustics Conference (DAGA) was organized for the first time in Dresden in 1994 to demonstrate the integration after the German re-unification.

When A. LENK retired in 1996, no successor was appointed. His working field was continued by his collaborator GÜNTHER PFEIFER who held the status of an adjunct professor since 1992 [26].

This means that two chairs with their corresponding working groups remained in the end. Their development will be explained subsequently. Details can be found in the annual reports from 1991 to 2013. Considering the designations of the two remaining groups, the name of the institute was changed in *Institute of Acoustics and Speech Communications* in 1999.

4.2 Working Group on Acoustics

When W. WÖHLE retired in 1993, the successor at the chair of Technical Acoustics was PETER KÖLTZSCH. He came from the *TU Bergakademie Freiberg* where he acted as professor for Fluid Mechanics. He supervised numerous research projects in the traditional fields of the institute, but also in new areas like sound generation, structure-borne noise, and flow acoustics [27]. Following an own design, the institute received an aeroacoustic wind tunnel with extremely quiet jet flow in 1996.

The name of the chair was changed to Communications Acoustics when it was posted for succession. It was passed to UTE JEKOSCH in 2005. She came from the *Rensselaer Polytechnic Institute*, Troy, N. Y., and was especially known for her work in sound design and sound quality [28]. She initiated the construction of a laboratory for multimodal measurement. In 2008 she brought the DAGA conference to Dresden for the second time. Additionally, the capacity of the institute was extended by the appointment of WOLFGANG KLIPPEL as honorary professor for electroacoustics in 2007.

The chair of Communications Acoustics was deputized by ERCAN ALTINSOY, a specialist in auditory-tactile interaction, since 2009. He was appointed professor for Acoustics and Haptics in 2016. His research group is investigating the relationship between physics (sound/vibration) and perception (auditory/haptic) [30] [31]. Furthermore the interaction of these two modalities is a topic of interest. The investigations are conducted in the fields of e.g. vehicle acoustics, household appliance acoustics, audio reproduction systems, psychoacoustics, vibroacoustics and VR. The aim is to create models which can predict (product-) perception of the acoustic and haptic properties [32]. He is one of the core team members of the cluster of excellence CeTI (Centre for Tactile Internet with Human-in-the-Loop) at TU Dresden (www.ceti.one/).

4.3 Working Group on Speech Communications

When TSCHESCHNER was retired in 1992, he was succeeded by RÜDIGER HOFFMANN who was already present as lecturer in Human-Machine Communications since 1986. He guided the Dresden sub-project of the German Verbomobil, which offered a tremendous chance under the new political conditions in the 1990s. He supervised 36 Dr.-Ing. and habilitation theses as well as numerous cooperation projects. He expanded the educational activities of the chair to the theory of signals and systems [29]. This resulted in the re-naming of the chair to System Theory and Speech Technology in 2007 and in the expansion of the scientific focus to cognitive systems.

PETER BIRKHOLZ started as Junior Professor for Cognitive Systems with tenure track as successor of HOFFMANN in 2014 and was appointed full professor for Speech Technology and Cognitive Systems in 2020. His group researches at the confluence of speech technology, phonetics, and machine learning. It follows a major interdisciplinary course and encompasses speech technology, instrumental and acoustic phonetics and medical technology. The research group develops and maintains one of the most advanced systems for articulatory speech synthesis [33] [34] (www.vocaltractlab.de) and techniques to recognize silently produced speech [35] [36] [37]. One of the silent speech techniques has led to the spin-off of *Altavo GmbH* in Dresden, which aims to give laryngectomies a new voice.

Two international conferences in speech communications were hosted in Dresden: the 3rd Int. Conf. on Speech Prosody in 2006 and the Interspeech in 2015.

5. THE HISTORIC ACOUSTIC-PHONETIC COLLECTION (HAPS)

The historic acoustic-phonetic collection (HAPS) has its roots in the rather long history of acoustics and speech communications at TU Dresden. A variety of old devices from half a century of research and development formed the base of the collection. It could be considerably expanded by devices from two old and renowned phonetics institutes in Berlin and Hamburg, thus extending the time span far into the pre-electronic era.

The HAPS is supervised by the author since his retirement in 2014. The objects are made available in two catalogue volumes [38] [39]. The collection is a place for historic research in communications sciences and media technology, which is summarized in a recent paper [40].

6. ACKNOWLEDGMENT

The author likes to express his cordial thanks to Dr.-Ing. ROLF DIETZEL for many inspiring dialogues and for contributing four photographs from his archive.

7. REFERENCES

- [1] M. Fürstenau. Friedrich Wilhelm Opelt. In *Allgemeine Deutsche Biographie* 24 (1887), p. 366.
- [2] P. Költzsch. August Seebeck – der erste Akustiker der Dresdner “Universität”. In: D. Mehnert et al. (eds.), *Systemtheorie, Signalverarbeitung, Sprachtechnologie*. Dresden: TUDpress 2013 (Studentexte zur Sprachkommunikation, vol. 68), pp. 295 – 302.
- [3] W. Voss. Dresdens große Mathematiker. *Dresdner Universitätsjournal*, special issue no. 2001-1.
- [4] R. Laue. *Johannes Biehle zum 150. Geburtstag gewidmet*. Stadtverwaltung Bautzen, Kulturbüro 2020.
- [5] K. Lunze (ed.). *Barkhausen-Ehrung der Akademie der Wissenschaften der DDR und der Technischen Universität Dresden*. Festschrift, Dezember 1981 (Wissenschaftliche Zeitschrift der TU Dresden, Separatdruck: Reihe 4, Elektrotechnik-Elektronik, Nr. 6/7).
- [6] R. Dietzel. Technische Akustik an der Technischen Hochschule Dresden von 1911 bis 1950. In: *Sprachsynthese. Herrn Prof. Dr.-Ing. habil. Walter Tscheschner zum 70. Geburtstag*. Edited as CD-ROM, TU Dresden 1997.
- [7] P. Költzsch. *Erwin Meyer – Akustik in Göttingen; Heinrich Barkhausen und Walter Reichardt – Akustik in Dresden*. Berlin: Pro BUSINESS 2019 (Schriftenreihe zur Geschichte der Akustik; 11).
- [8] H. Barkhausen and G. Lewicki. Die Empfindlichkeit des Ohres für nicht sinusförmige Töne. *Physikalische Zeitschrift* 25 (1924) 21, pp. 537 – 541.
- [9] R. Hoffmann. Der historische Beitrag der TH/TU Dresden zur Entwicklung von Sprachsichtgeräten. In: *Fortschritte der Akustik, DAGA 2021, 46. Jahrestagung für Akustik, Wien, 15. – 18. 8. 2021*, pp. 629–632.
- [10] K. Lunze. Die Herausbildung der Elektrotechnik als wissenschaftliche Disziplin an der Technischen Universität Dresden. *Wissenschaftliche Zeitschrift der TU Dresden* 42 (1993) 2, pp. 3–16.
- [11] P. Költzsch (ed.). *Ehrenkolloquium Reichardt – Kraak – Wöhle*. Festschrift, TU Dresden, 2. ergänzte Aufl. 2003.
- [12] S. Steinbach. Ein schnell arbeitender Suchton-Spektrograf für den Sprachfrequenzbereich. *Nachrichtentechnik* 6 (1956) 8, pp. 365–368, and 9, pp. 396–400.
- [13] W. Reichardt. *Grundlagen der Elektroakustik*. Leipzig: Geest & Portig 1952, 2nd ed. 1954, 3rd ed. 1960.
- [14] W. Reichardt. *Grundlagen der Technischen Akustik*. Leipzig: Geest & Portig 1968.
- [15] W. Bärwald. Kurt Freitag. In: *125 Jahre VDE Bezirksverein Dresden e. V. – Entwicklung der Elektrotechnik, Elektronik und Informationstechnik*. Dresden: VDE 2017, pp. 153–162.
- [16] E. Krockner. Aufbau und Untersuchung eines Übertragungssystems für synthetische Sprache. *Wissenschaftl. Ztschr. der TH Dresden* (1956/57) 4, pp. 757–776.
- [17] W. Tscheschner. Verfahren und Ergebnisse der Analyse deutscher Vokale und Konsonanten. *Proc. 4th International Congress of Phonetic Sciences, Helsinki, September 4-9, 1961*. The Hague: Mouton 1962, pp. 280–298.

- [18] R. Hoffmann and D. Mehnert. Roots of Electronic Speech Communication in Linguistics and Engineering: the Genesis of the Chair of Speech Communication of the TU Dresden as a Case Study. In: *HSCR 2021. Proc. of the 4th Int. Workshop on the History of Speech Communication Research, Prague, August 27-28, 2021* (Studientexte zur Sprachkommunikation, vol. 101), pp. 83–92.
- [19] H. K. Die Geisterstimme aus Dresden. *Wochenpost* 1962, no. 36, p. 11.
- [20] P. Plassmeyer, H. Schönrich and I. Jentzen (eds.). *Der Schlüssel zum Leben. 500 Jahre mechanische Figurenautomaten*. Dresden: Sandstein Verlag 2022.
- [21] R. Hoffmann. 50 years Institute of Acoustics and Speech Communications; 30 years Conference Electronic Speech Signal Processing; 20 years Historic Acoustic-Phonetic Collection. In: *Elektronische Sprachsignalverarbeitung 2019. Tagungsband der 30. Konferenz, Dresden, 6. – 8. 3. 2019* (Studientexte zur Sprachkommunikation, vol. 93), pp. 1–8.
- [22] W. Kraak. Investigations on criteria for the risk of hearing loss due to noise. In: J. V. Tobias (ed.), *Hearing Research and Theory, vol. 1*. New York: Academic Press 1981, pp. 187–303.
- [23] W. Fasold, W. Kraak, W. Schirmer (eds.). *Taschenbuch Akustik*. 2 Bände. Berlin: VEB Verlag Technik 1984.
- [24] A. Lenk. *Elektromechanische Systeme*. 3 Bände. Berlin: VEB Verlag Technik 1971, 1974, 1975.
- [25] U. Frühauf. *Grundlagen der elektronischen Messtechnik*. Leipzig: Geest & Portig 1977.
- [26] A. Lenk, R. G. Ballas, R. Werthschützky and G. Pfeifer. *Electromechanical Systems in Microtechnology and Mechatronics. Electrical, Mechanical and Acoustic Networks, their Interactions and Applications*. Berlin etc.: Springer 2011.
- [27] P. Költzsch. Akustische und strömungsakustische Forschungen. Ein Beitrag zur Verminderung der Schallemission technischer Aggregate. In: *Berichte und Abhandlungen / Berlin-Brandenburgische Akademie der Wissenschaften* 2 (1996), pp. 37–88.
- [28] U. Jekosch. *Voice and Speech Quality Perception. Assessment and Evaluation*. Berlin etc.: Springer 2005.
- [29] R. Hoffmann. *Signalanalyse und -erkennung. Eine Einführung für Informationstechniker*. Berlin etc.: Springer 1998.
- [30] M. E. Altinsoy. *Auditory tactile interaction in virtual environments*. Shaker 2006.
- [31] M. E. Altinsoy. The quality of auditory-tactile virtual environments. *Journal of the Audio Engineering Society*. 60 (2012) 1/2, pp. 38–46.
- [32] Website TU Dresden, Chair of Acoustics and Haptics. URL (10. 4. 2023): <https://tu-dresden.de/ing/elektrotechnik/ias/aha/forschung>
- [33] P. Birkholz. *3D-artikulatorische Sprachsynthese*. Berlin: Logos 2005.
- [34] P. Birkholz. Modeling consonant-vowel coarticulation for articulatory speech synthesis. *PLoS ONE* 8 (2013) 4: e60603. doi:10.1371/journal.pone.0060603
- [35] C. Wagner, P. Schaffer, P. Amini Digehsara, M. Bärhold, D. Plettemeier, P. Birkholz. Silent speech command word recognition using stepped frequency continuous wave radar. *Scientific Reports* 12 (2022), 4192.
- [36] S. Stone, P. Birkholz. Cross-speaker silent-speech command word recognition using electro-optical stomatography. *Proc. of the 45th International Conference on Acoustics, Speech, and Signal Processing (ICASSP 2020)*, Barcelona 2020, pp. 7849–7853.
- [37] Website TU Dresden, Chair of Speech Technology and Cognitive Systems. URL (10. 4. 2023): <https://tu-dresden.de/ing/elektrotechnik/ias/stks/forschung>
- [38] D. Mehnert. *Historische phonetische Geräte. Katalog der historischen akustisch-phonetischen Sammlung (HAPS) der Technischen Universität Dresden, erster Teil*. Dresden: TUDpress 2012 (Studientexte zur Sprachkommunikation, vol. 62).
- [39] R. Hoffmann. *Historische Objekte der Sprachakustik. Katalog der historischen akustisch-phonetischen Sammlung (HAPS) der Technischen Universität Dresden, zweiter Teil*. Dresden: TUDpress 2021 (Studientexte zur Sprachkommunikation, vol. 100).
- [40] R. Hoffmann. The Historic Acoustic-Phonetic Collection of TU Dresden after Finishing the Catalogue. *Proc. IEEE HISTELCON, Florence, Sep. 7–9, 2023*, 4 pp., in press.