DOI: 10.61782/fa.2023.0238

forum acusticum 2023

DANISH PIONEERS AND COMPANIES IN ACOUSTICS WITH A FOCUS ON DR. BRÜEL

Claus Møller Petersen[1*]
[1] Sweco Danmark A/S, Ørestads Boulevard 41, 2300 København S, Denmark

ABSTRACT

This paper is about the early part of the history of the Acoustics in Denmark. It is based on previous anniversary writings, the author's interviews with Dr. Brüel and Brüel's own notes "Episodes and Achievements within Acoustics before 1954". Starting with the invention of the "Telegraphone" in 1898 and other early acoustical inventions (loudspeakers, sound film, radio production), the paper will concentrate on Dr. Brüel and the company he established in 1942 with Dr. Kjær (B&K). The acoustical instrument development took its early start with the world's first frequency analyzer with constant relative bandwidth (1940) - where B&K's iconic light-green front plate was seen for the first time. Some background story for Dr. Brüel's multifaceted effort in acoustics will be revealed, e.g., his work with the acoustics in the new building for the Danish Radio (1941), his work with sound absorbers and university activities in Sweden during WWII (1942) and the doctoral thesis "Use of the standing wave-method in Acoustics" (1944). The early groundbreaking instruments from B&K include: The tapping machine (around 1945), the level recorder (from 1943 and on), the pistonphone (around 1950) and the condenser microphones (1950; 1955). Finally, the Danish hearing aid companies and loudspeaker companies will be mentioned.

Keywords: *Acoustical inventions - Measurement instruments*

1. INTRODUCTION

When the Danish Acoustic Society (DAS) was to celebrate its 50th anniversary in 2005, it was only natural to involve Dr. Brüel – co-founder of Brüel & Kjær and of DAS - in the anniversary publication [1] that was being prepared. Through this work, the author had the opportunity to interview Dr. Brüel and write a summary of Brüel's own notes: "Episodes and Achievements within Acoustics before 1954" [2]. It became clear that here was an interesting and almost forgotten story which from around 1930 formed part of the foundation for the development of the acoustic field in Denmark.

But it all started long before with some important Danish discoveries and inventions in the field of low-current electricity: The fundamental discovery was the Electromagnetism (1820) by Hans Christian Ørsted[1]. Later came the "Telegraphone" – forerunner of the tape recorder (1898) by Valdemar Poulsen[2] and the "Poulsen Arc transmitter" – for wireless transmission (1902) by Valdemar Poulsen and Peder Oluf Pedersen[3].

New companies were started such as Nordic Film in 1906 and radio production at Bang & Olufsen (B&O) in 1925 – both still in action. Same year the first Danish sound film recorded indoors was shown in Copenhagen. Danish Broadcasting (now Danish Radio, DR) started in 1925 and this helped to kick-start the development of the Danish loudspeaker industry[4].

[*] ***Corresponding author***: clausmoller.petersen@sweco.dk

[1] H.C. Ørsted (1777-1851), physicist and chemist, 1817 Prof. at the *Copenhagen University,* 1829 founder of the *Polytekniske Læreanstalt (PL)* – now *Danish Technical University* (DTU).
[2] V. Poulsen (1869-1942), engineer and inventor.
[3] P.O. Pedersen (1874-1941), 1912 Prof. in low-current electro technology, 1927 Author of the internat. recognized reference-book *The Propagation of Radio Waves…,*1933 president at *PL.*
[4] Including the large companies Peerles, Vifa and Dynaudio (drivers) as well as JAMO and DALI (speaker systems) – also co-operating and with a common research project at DTU.

Although the period includes WWI, it was a time of progress and "electrotechnics was the new subject that met the challenges through applications in radio and movies; areas that were going to get great scientific, social, and economic importance. The foundation of the Acoustical Society of America already in 1929 reflects this aspect" [7].

1.1 Acoustic research activities also in Denmark

In fact, a project that went completely wrong was among the reasons why P.O. Pedersen[5] in 1935 started the first acoustic research activities at the Laboratory of Telegraphy and Telephony (LTT) at Polyteknisk Læreanstalt (now DTU) and became thereby "The source of Danish Acoustics". In the following years international scientific exchange was growing both in Europe and in the USA.
One of P.O. Pedersen's most interested students was Per Vilhelm Brüel.

2. PER VILHELM BRÜEL

Per Vilhelm Brüel (1915-2015) was born in a forester family, but his interests were in the technical field [3]. Already as a young boy Brüel built a crystal radio and later, aged 14, he read with interest an article about radio and electromagnetic waves [2]. The author was Professor P.O. Pedersen, who many years later would become Brüel's mentor. At LTT Brüel met Viggo Kjær and they became friends. Soon they decided that they wanted to start something together. In 1939 they both got their MSc degrees studying several extra months including the summer holidays. Brüel's technical skills quickly showed themselves when he as part of his MSc assignment constructed a "photocell amplitude meter" when he should measure the oscillation amplitude of a wall. This apparatus is described in the publication by P.O. Pedersen [4], see Figure 1. The first part of this publication is written by Brüel, but his name was not on the cover, which somewhat disappointed the ambitious Brüel. Even though it was a natural consequence of P.O. Pedersen being the leader of the laboratory it bothered Brüel for many years. Nevertheless, it has not diminished Brüel's respect for his professor. As Brüel tells "I owe him a lot".

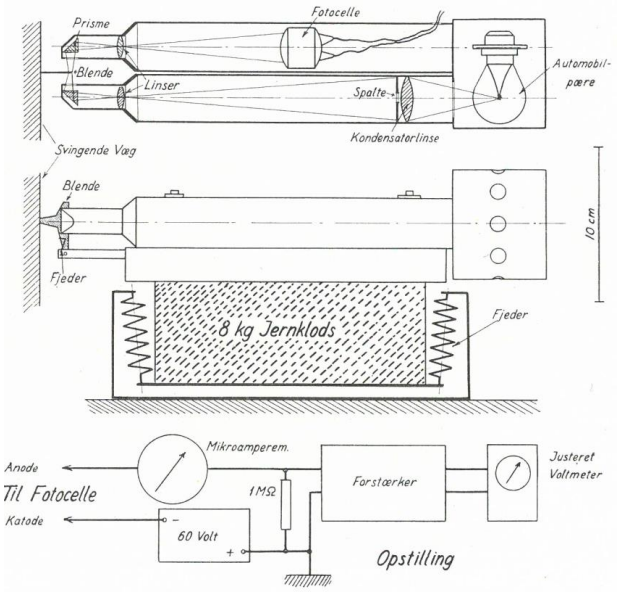


Figure 1. Brüel's photocell amplitude meter [4]

Brüel became P.O. Pedersen's assistant, and he suggested that Brüel should work on writing a doctoral thesis – a suggestion he liked very much. The thesis was supposed to be about using the Standing Wave Tube (SWT) to measure the complex acoustic impedance (and sound absorption). P.O. Pedersen would seek funding for 1½ years employment at LTT to carry out this work.
In the autumn of 1939 Brüel was drafted to the Danish army and started serving as dispatch rider driving motorbike all around Denmark. Later he was transferred to the Army's radio workshop at the headquarters in Ryvangen, Copenhagen. Here the work was about radio transmitters – and then Brüel was back on track as scientist and engineer.

2.1 Brüel's story up to 1943

In 1939 the last issue of JASA, the Journal of Acoustical Society of America, came to Denmark before the WWII closed the connection with the outside world. In this both Brüel and Kjær read about a selective amplifier in which the selective part was an amplifier with a double T-joint in a feedback loop. This principle had to be useable in an acoustics analyzer where the bandwidth would be proportional with the frequency. In his spare time at the Army's radio workshop in Ryvangen, Brüel started experimenting with what was to become a brand-new invention: The world's first acoustics analyzer with constant relative bandwidth. It was finished in February 1940 and is shown at Figure 2

[5] See more information in the FA2023-paper *"Origin and early activities in acoustics at the Technical University of Denmark"* by J.H. Rindel and C.M. Petersen.

with typical military instrumental look and a characteristic light green color at the front plate – a color which later became a distinctive feature of a whole production of high standard acoustic measuring instruments.

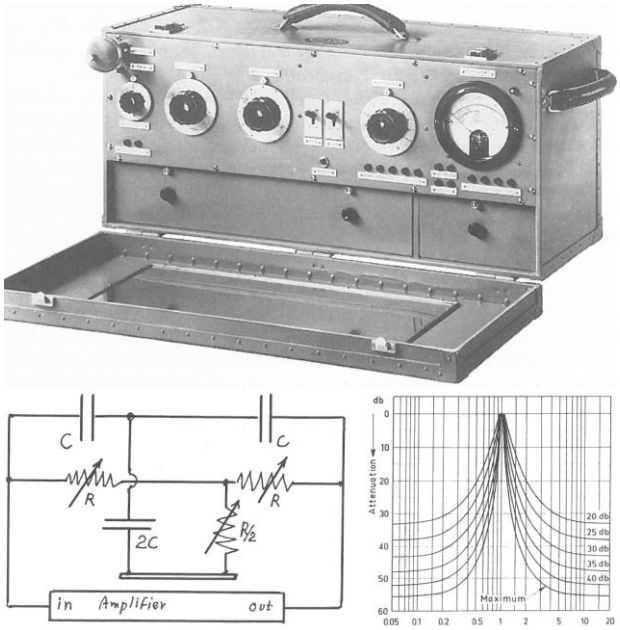


Figure 2. The world's first acoustics analyzer with constant relative bandwidth [3]

Due to the German occupation, it was decided to demobilize all drafted personnel in the Danish Army and therefore Brüel had plenty of spare time to make plans together with Kjær for their future company. They added line powering instead of battery powering at the frequency analyzer.
Both Brüel and Kjær got new jobs in the following year, 1941. Kjær at radio manufacturers. Brüel who worked on his doctoral thesis was – again thanks to P.O. Pedersen – engaged as assistant to Prof. Nøkkentved[6] who was responsible for the building engineering at the new Radio house under construction for the Danish Broadcasting (now Danish Radio). The work consisted, among other things, of tuning the reverberation times in the studios which went incredibly well with Brüel's competences from the work at LTT and his doctoral thesis. The engagement at the Radio house ended in late 1942, but before that a director from a Swedish glass-wool factory, Höganäs, had visited the new Radio house and he and Brüel had a good meeting about acoustic absorbers with glass-wool. This was the start of Brüel's work in Sweden[7] developing different types of absorbers among others resonance panels with holes. In 1943 he was offered a job as a part time associate Prof. at Chalmers University of Technology in Gothenburg – bound until 1947. Here Brüel became head of the acoustical laboratory which i.a. had 12 academic refugees employed.

2.2 Brüel's doctoral thesis, 1944

Brüel's work with his doctoral thesis included results from the new Radio house and was finished at the end of 1944. One of Brüel's graphs showing the translation of normal incidence absorption (from SWT measurements) to random incidence (from a reverberation room) is shown in Figure 3. When Brüel should defend his doctoral dissertation[8] at PL in Copenhagen it almost went wrong. Brüel came from Sweden and at the Danish border the German soldiers were in an evil temper and ripped through all his papers and tossed them into the air without finding anything – and then they tore off the heels of his shoes. So Brüel defended his doctoral dissertation wearing shoes with glued-on heels. He got his scientific degree Dr. Techn. – and hereafter he mostly was addressed as "Dr. Brüel".

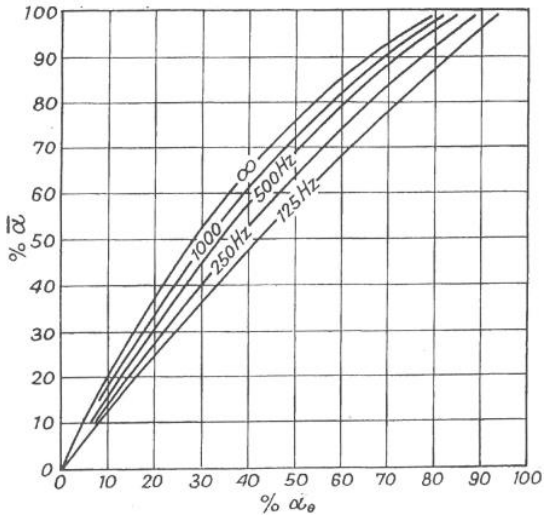


Figure 3. Normal incidence absorption (x-axis) versus random incidence (y-axis) [2]

[6] Christian Nøkkentved (1892-1945), 1932 Prof. in building statics at *Polyteknisk Læreanstalt* (now DTU).

[7] The problem of crossing the country border in wartime Brüel solved using a previous job relationship with the Danish water treatment specialist Kryger A/S to obtain a visa.

[8] The official title was "*Rørmetodens anvendelse i akustikken*" (Application of the tube method in acoustics).

2.3 Brüel's further carrier

Brüel was very committed to the professional acoustical environment and in 1944 he co-founded the Swedish Acoustical Society (SAS) – 10 years before he co-founded the Danish Acoustical Society (DAS). In addition, he was a highly respected international knowledge-based salesman who also had a seat in numerous standardization committees and led the way in new technologies. In [3] Brüel is described as charismatic, adventuresome, full of ideas, expert craftsman, clever negotiator and able to express complex subjects verbally and on paper in an understandable way. Besides, Brüel had a flight certificate[9] for both propeller planes and turboprop planes, and B&K itself had such planes in the "B&K Airline" (1963-1992), where he was the chief pilot. Brüel was personal friend with the famous American acoustician Dr. Leo L. Beranek (1914-2016) since 1950 and the Chinese professor Maa Daa You (1915-2012). The latter he met in 1953, when Maa acted as interpreter for Brüel who during two weeks held 10 lectures on acoustics for 300-500 listeners at the university in Beijing. Both Beranek and Maa did their doctoral thesis's at Massachusetts Institute of Technology (MIT), Boston. The three often met and because they were almost the same age, every 10 years they celebrated their round birthdays together at festive gatherings. Brüel and Beranek lived to be 100 years old.
As Beranek writes in [3]: "A major reason for the success of B&K was the unusual marketing efforts of Brüel, who seemed to be everywhere at once – in the USSR, Europe, North America, China".

3. THE COMPANY BRÜEL & KJÆR

In 1942 the company Brüel & Kjær obtained an official license to operate. Even though they started with a small production and a few employees from the Army's radio workshop the first year, they sold to the Nordic countries and got some good connections to the acousticians there.

3.1 The first years

During the first five years when Brüel was busy in Sweden and Kjær worked at different Danish radio manufactures, the activity level of the company was rather low. Not least because of WWII which made it difficult to get materials and components. After just a few years, the level recorder (1949, see section 4.2) really opened the world market and several other instruments also contributed, especially the measurement microphones (1955, see section 4.4). B&K's instruments were known as second to none and in the following years, the company was the world leader in acoustic instruments.

3.2 A successful company

Among the many well-known later instruments are accelerometers, sound level meters, digital frequency analyzers (1/1- and 1/3-octave bandwidth as well as narrowband) sound intensity and one of Brüel's favorites, the RASTI-system measuring Rapid Speech Transmission Index. The company had many highly skilled experts in each of their fields of expertise and attracted many talented electro-acousticians from all over the world. B&K grew steadily and peaked in 1990 with approx. 4000 employees worldwide and annual sales from Danish companies of Euro 124 million [3]. The complete story is that after the peak came hard times and in 1992 the company was sold at the same time as the founders left. The company was split into several separate companies and Brüel & Kjær Sound & Vibration ended up in HBK, Hottinger Brüel & Kjær in 2020 as the continuing company for the core sound and vibration market (2021: 425 employees, revenue Euro 90 million).

3.3 Viggo Kjær

Viggo Kjær[10] (1914–2013) was Brüel's companion and co-founder of B&K. In [3] Kjær is described as shy, soft spoken, brilliant engineer and designer, meticulous attention to detail, cost-conscious to an extreme, encyclopedic knowledge of everything he considered important and always highly respected. Even though Kjær received an honorary doctorate he always was addressed as "Mr. Kjær".

4. GROUNDBREAKING B&K INSTRUMENTS

In the following, only a few of the early B&K instruments will be described in detail based on [1], [2] and [3].

4.1 The tapping machine (around 1945)

At Chalmers University of Technology in Gothenburg they worked intensively with noise problems in wooden houses and many measurements of footsteps from floor separations were performed. It was therefore necessary to have a structural sound source which, with a sufficient

[9] For 43 years – until he was 85 Brüel flew approx. 18.000 hours and had 7.000 landings mainly in Europe.

[10] V. Kjær, 1939 MSc, 1974 honorary doctorate from the Danish Technical University *(For significant efforts to promote electronic research as a basis for industrial production of measuring instruments).*

signal-to-noise ratio, could simulate walking/trampling people. Brüel reports [2] that they had heard of experiments in Germany, where they tapped repeatedly with a 500 g hammer on the floor separation and measured the noise level below with a correction for room absorption. Actually, there was already in 1936-1937 [9] a German proposal for a tapping machine, which has technical specifications that were later adopted in the standard ISO 140. Brüel's contribution was to improve the mechanical construction of the tapping machine when he and his team constructed the hammer mechanism, in which five hammers of 500 g sat close together, and each hammer fell 40 mm twice a second. The machine was manufactured in five copies so that colleagues in Norway and Finland could also test it, see Figure 4.

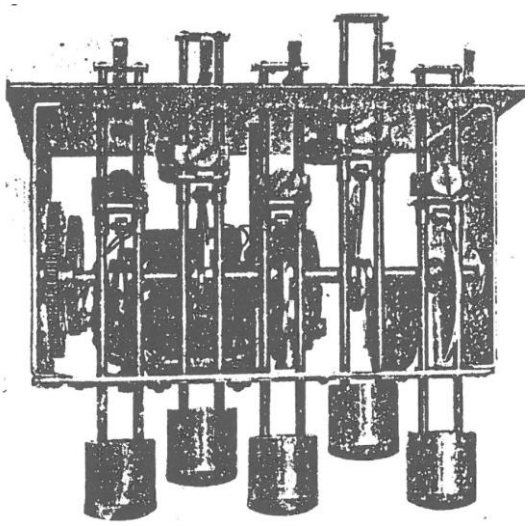


Figure 4. Prototype tapping machine [2]

Shortly after the war approx. 1945, the IEC (International Electrotechnical Commission) wanted to standardize such a machine. Brüel heard about it, and on his own initiative he forwarded drawings and descriptions and went to a meeting at IEC in Switzerland with the machine under his arm. The plan for the machine was to be produced in Denmark. The machine was approved with the minor adjustment that the distance between the hammers had to be increased. The final version of the tapping machine is shown in Figure 5.

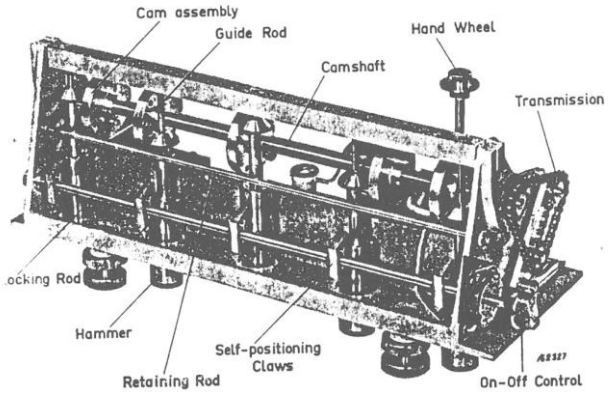


Figure 5. Tapping machines (B&K's model) [2]

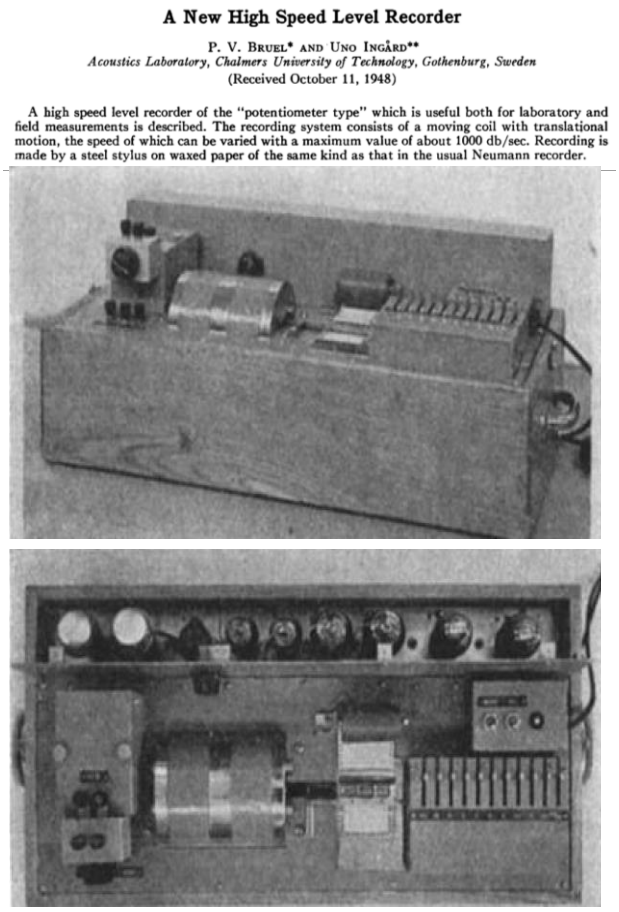
It is with tapping machines according to this principle that in most of the world right up until 2015[11] standardized impact sound measurements exclusively were carried out (cf. ISO 140-7). In this way, Brüel came to play a decisive role in the standardization of the tapping machine.

4.2 The level recorder (after 1943; 1949)

Already in 1942-43 there was a great need for level recorders with logarithmic recording of the decay of the sound pressure level to determine the reverberation time in a room. It was supposed to replace Neumann's recorder, which Siemens stopped production of at the start of WWII. Brüel and his staff developed an entirely new type of level recorder based on an electrodynamic system with magnet, coil, relief arm and recorder pin as well as some stretched wires. At first there was doubt as to whether there was a sufficient market for these level recorders; Kjær believed that only 50 could be sold, which was too few. Brüel therefore had to produce the first examples in Sweden. Later, B&K in Denmark started the production – and the level recorder turned out to be extremely successful. During 30 years, 25.000 units were produced – according to Brüel especially because the acoustic world had a great need to be able to make reverberation curves and because this level recorder did not have the faults of its predecessors (wear and inertia). After 1949, Kjær improved the level recorder with an extra coil outside the drive coil, which made the printer very fast and precise. The B&K level recorder created a sensation among acoustical professionals – never before had sound pressure level in decibels been measured as

[11] From 2015, impact sound measurements with a heavy rubber ball were also standardized (cf. ISO 16283-2).

a function of time. Better yet it included a pen system for recording. But perhaps the most important success parameter was that the company's management knew the product's use and could discuss it with the customers, which included all important institutions and people in the area. Brüel himself says in [2] that "there is no doubt that this level recorder, in addition to being a good business, has also greatly increased Denmark's position as the country where people know something about acoustics". It was also the level recorder which, in a ½-page article authored by Brüel and Uno Ingård in JASA 1949, opened the market for B&K in both the USA and Japan. Also, the communist countries were interested. See Figure 6 for the headline of the JASA article and the 1949-version of the level recorder.



A New High Speed Level Recorder

P. V. Bruel* and Uno Ingård**
Acoustics Laboratory, Chalmers University of Technology, Gothenburg, Sweden
(Received October 11, 1948)

A high speed level recorder of the "potentiometer type" which is useful both for laboratory and field measurements is described. The recording system consists of a moving coil with translational motion, the speed of which can be varied with a maximum value of about 1000 db/sec. Recording is made by a steel stylus on waxed paper of the same kind as that in the usual Neumann recorder.

Figure 6. From the JASA article, vol. 2, no. 2, 1949

From the USA Dr. Leo L. Beranek and from Japan Prof. Sato came to visit B&K in Denmark and with their own eyes see the level recorder and the company. Beranek's visit was the beginning of a lifelong friendship.

4.3 The pistonphone (around 1950)

After the war, there was difficulty with the long-term stability of measuring microphones and therefore a simple and easily transportable calibration method was needed. Best it would be if it produced sound in the same way as the sound sources to be measured, i.e. typically vibrating surfaces. It is significantly easier to make a stable sound source than a stable microphone with associated electronics. The pistonphone from approx. 1950, based on two pistons, is ideal for the purpose and provides a stable and portable calibration option for condenser microphones. Brüel emphasizes that the pistonphone is extremely stable – and mentions, for example, that after 43 years of use the accuracy still remained within +/- 0,03 dB [2]. By calibrating before and after measurements, you could compensate for minor changes in microphone sensitivity – which was a real risk at the time.

4.4 The condenser microphones (1950; 1955)

Already at the end of the 1930s, it had become clear that the Rochelle salt used at the time was bad for normal microphones, because the sensitivity varies with the moisture content. In the USA, they standardized e.g. a 1" condenser microphone developed at Bell Lab and produced by Western Electric (type no. WE 640AA), which was however smaller than 1". Unfortunately, the WE 640AA became more sensitive over the years (0.5-1.5 dB/year) – which was not optimal for a microphone designated as an American laboratory standard. In addition, it was a disadvantage that the WE 640AA had problems in free field, as the membrane was placed in a cavity/recess in the microphone housing under a ring and the front grill. From 1950, B&K sold condenser microphones, developed and produced by the Fono Film company who continued A. Poulsen and A. Petersen's[5] activities for sound recording instruments. These microphones had a diameter of 36 mm, but both this and other condenser microphones also became more sensitive over the years. The phenomenon of the unstable sensitivity was quite inexplicable. Brüel recounts in [2]: "One evening in 1954, I sat and played with a piece of paper, which I held firmly to the surface of the table with strong pressure with my hand. When the hand that pressed the paper was still, the paper also remained completely firm, even if it was pulled hard. But if you moved your hand just a little, the paper could slip out. Here was the solution to the problem. If the microphone's ring and housing occasionally had dif-

ferent temperatures, even enough bolts could not prevent a minimal slippage between the ring and housing, with the result that the membrane could move a millionth of a millimeter. The result was that the microphone became more sensitive. If a microphone were to be more stable, it was therefore necessary that the diaphragm had a crystalline connection to the housing by either welding, hard soldering, or galvanic deposition". The detailed development of B&K's condenser microphones and pre-amplifiers was due to Gunnar Rasmussen's[12] great efforts as an extraordinary developer over a large number of years.

From 1957 B&K was on the market with 1" measurement microphones (type 4131-4132) with far fewer parts than existing microphones which resulted in superior mechanical stability, improved temperature coefficient and long-term acoustic stability.

Later B&K's condenser microphone type 4160 became the new WE640-equivalent and thereby *the* American laboratory standard microphone. According to [5] Gunnar Rasmussen tells that "Then I felt that we had helped put B&K on the world map, at least within acoustics". In 1958 the ½" microphone was launched, and this type is today the dominant type of measurement microphones, see Figure 7.

Brüel tells in [2]: "For 25 years, B&K condenser microphones had the privilege of being the world leader and earned then between Euro 4 and 6,5 million annually".

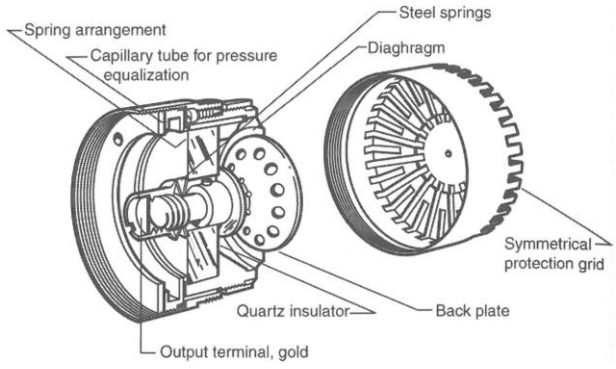


Figure 7. B&K's ½" measurement microphone [3]

[12] Gunnar Rasmussen (1925 -), 1950 BSc E., employed at B&K same year. 1994 founder of the company G.R.A.S. Sound & Vibration which i.a. manufactures microphones.

4.5 The Artificial ear (1965)

Around 1965, there was disagreement about how an artificial ear should be designed. There was a need for a measurement system that ensured uniform and calibrated results for measurement of e.g. telephones and hearing aids. Together with Gunnar Rasmussen, Brüel had to develop a method to carry out some of the first measurements of the impedance of the ear canal as a function of frequency. They used two 3 mm condenser microphones that were inserted into the ear in parallel and in a form that completely closes off to the outside world except for a ventilation channel. One microphone act as a transmitter and emits a frequency-independent volume velocity. The second microphone measures the sound pressure, which is proportional to the impedance, because the volume flow is constant. With this basis, they could construct an artificial ear with an impedance corresponding to their measurements, see Figure **8**.

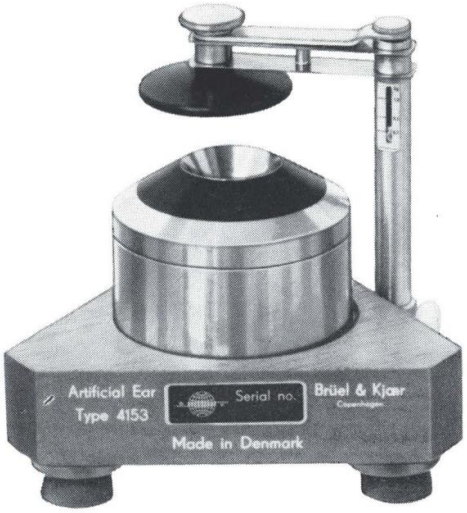


Figure 8. B&K's artificial ear [2]

In this way, "Brüel's and Gunnar Rasmussen's ears share the honor of being the basis for all current telephone measurements and measurements on mobile phones and hearing aids worldwide" [2]. Especially the Danish hearing aid industry has had a fascinating development, which is linked to the high level of knowledge in acoustics at the universities and in the industry, not least in the company B&K, which has attracted many skilled acousticians from all over the world.

5. THE DANISH HEARING AID COMPANIES

Hearing aid has a long history in Denmark. The hearing aid company Oticon[13] was established in 1904 selling imported American hearing aids based on Alexander Graham Bell's telephone principle [1], [6]. Due to WWII, it became very difficult to get the hearing aids from the USA and Oticon started its own production and in 1945 the first Danish hearing aid was ready. Another company Danavox[14] produced their first hearing aid in 1947. In 1950, a law was passed on public hearing care with free hearing aids for the Danish population. This created a very large need for hearing aids but also for technical specifications and quality control. In 1953 IEC's WG 6 "Hearing Aids", whose chairman Fritz Ingerslev[15] was a central person in Danish Acoustics, prepared IEC recommendation 118 "Measurements of Electroacoustic Characteristics of Hearing Aids". Hearing aids were subjected to input control using artificial ears, which B&K also produced in the late 1960's. The 3rd Danish hearing aid company, Widex[16] was established in 1956. These three companies were in 1986 part of a joint research collaboration with the Danish Technical University, the ODIN-project[5], with the purpose to investigate the possibilities of using digital signal processing in hearing aids. The results were extremely useful. Today all hearing aids are digital.

High technical quality and far-sighted commercial and scientific collaborations – supported by a strong university environment – have led to a thriving industry which has led to that every second hearing aid in the world is said to be "Danish".

[13] Approx. 19.000 employees (2022).

[14] Now GN Hearing, part of the GN Group, approx. 7.500 employees (2023).

[15] Fritz Ingerslev (1912-1994), 1936 MSc, 1953 Dr.Techn., 1946-1981 Head of the Acoustical Laboratory, 1954-1975/1975-1982 Prof. in low-current electronics/building acoustics, 1955 co-founder of DAS, 1968-1987 chairman of ISO TC43 "Acoustics" and its SC1 "Noise".

[16] From 2019 Widex became a part of WS Audiology (W for Widex, S for Silvantos). Approx 12.000 employees (2022).

6. REFERENCES

[1] O.J. Pedersen (editor), *Dansk Akustik 1955-2005.* Dansk Akustisk Selskab, Kgs. Lyngby, 2005.

[2] "P.V. Brüel: *Episoder og resultater inden for Akustikken før 1954.* Dansk Akustisk Selskab, Kgs. Lyngby, 2005.

[3] J. Mowry and G. Borring: *Journey to Greatness. The story of Brüel & Kjær.* Acoustical Publications, Inc., Ohio, 2012.

[4] P.O. Pedersen: *Lydtekniske Undersøgelser i Aarene 1935-40 i Den polytekniske Læreanstalts Laboratorium for Telegrafi og Telefoni*, The Academy of Technical Sciences, Copenhagen, 1940.

[5] G. Rasmussen: *Udvikling af målemikrofoner. Præcisionsmikrofoner – fra Nærum til NASA,* p.25-30 in [1].

[6] J. Voetmann et al (editors), *Dansk Lydteknologi en global styrkeposition.* Delta og Kultur & Kommunikation, Roskilde Universitets Center, 2006.

[7] T.E. Vigran: *Some highlights from the history of building acoustics and noise control in Norway,* p. 68 in [8].

[8] J.H. Rindel (editor): *Nordic Acoustic Association 1954-2014.* Proc. of BNAM 2014, Tallinn.

[9] A. Schoch: *Die Physicalischen und Technischen Grundlagen der Schalldämming in Bauwesen.* Verlag von S. Hirzel in Leipzig, 1937.