Wilhelm Cauer

Wilhelm Cauer belonged to a very respected family in the German capital of Berlin. His father was a professor railway engineering at the Technical University of Berlin and several other family members were scientists or artists. Cauer's research interests were initially focused on theoretical physics, but with his contributions to the mathematical foundations of filter synthesis he became one of the founders of the new engineering discipline of network theory. Unfortunately, Cauer was killed in Berlin in the last days of World War II and therefore did not witness the later success of insertion loss filter design which is associated with his name, as well as with Edward Norton, G. Cocci, Hans Piloty and Sidney Darlington.

Wilhelm Cauer was born on June 24, 1900 in Berlin. His early high school was the Kaiserin-Augusta-Gymnasium in Cauerstrasse, founded by his great-grandfather Ludwig Cauer. From 1919 he studied electrical engineering at the TH Berlin. After his preliminary exams, he studied mathematics and physics at the universities of Bonn and Berlin and completed his diploma studies in 1924 at the TH Berlin in the subject of "Technical Physics". Cauer then moved to Mix & Genest, a Berlin-based company involved in the development of telephone and telegraph equipment, and began publishing articles in the field. However, he was probably inspired to work on the design of electrical filters, which play a key role in carrier-frequency telephone systems. Cauer realized that filter design can be treated as an inverse problem, as it was already known in mechanics, and after leaving Mix & Genest due to lack of work, he went to Georg Hamel at the Institute for Applied Mathematics and Mechanics at TH Berlin. Cauer's estate contains an exchange of letters with Ronald M. Foster from 1926, which shows that he followed up on Foster's seminal publication "A reactance theorem" from 1924, which quickly inspired Wilhelm Cauer to begin his research of network synthesis filters which put the design of filters on a firm mathematical footing. He was awarded a doctorate degree for his thesis "Die Verwirklichung von Wechselstromwiderständen vorgeschriebener Frequenzabhängigkeit" (The realization of impedances of specified frequency dependence) in July 1926 [1]. This work was later considered to be the beginning of modern network synthesis, meaning synthesis in the sense of chemistry as inverse analysis. In electrical network theory, synthesis was first used in Otto Brune's dissertation instead of realization, it being Cauer "who suggested the subject of this research" (Brune's acknowledgement). In 1927, Cauer became a research assistant at Richard Courant's Institute of Mathematics at the University of Göttingen.

In 1928, Cauer submitted his habilitation thesis "Untersuchungen über ein Problem, das drei positiv definite quadratische Formen mit Streckenkomplexen in Beziehung setzt" (On a problem where three positive definite quadratic forms are related to one-dimensional complexes) [2]. Among other things, he showed that the external behavior characterized by an impedance Z is an invariant function of this triple of quadratic forms and a set of real affine transformations which became the starting point for further group theoretical studies on electrical networks.

It quickly became clear that the realization of filter circuits involved lengthy mathematical calculations, and soon Cauer came up with the idea of constructing an electronic calculator for linear equations with 10 variables to support the filter design. He then contacted several calculator experts around 1927-28 and this put him in touch with Vannevar Bush of MIT in Boston who, along with Richard Courant, helped him get a scholarship by the Rockefeller Foundation. In September 1930 he sailed from Bremen to New York with his wife Karoline, and arrived 10 days later. Before they travelled to Boston, Cauer first visited Otto Julius Zobel and Ronald M. Foster at Bell Laboratories. At MIT, Cauer presented several lectures and met colleagues such as Norbert Wiener and Ernst Guillemin, visited Oswald Veblen, Eberhard Hopf and Jacob David Tamarkin at Harvard University, and visited also the General Electric's laboratories in Schenectady, New York. One of the most important contributions of Cauer's visit to MIT was suggesting the topic of Otto Brune for his doctoral research, which became one of the most important findings in filter design theory. In his acknowledgements of his thesis, Brune wrote that he "is also indebted to Dr. W. Cauer of the University of Göttingen, who is at present in Cambridge, Massachusetts as an International Research Fellow supported by

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the Rockefeller Foundation, and who suggested the subject of this research" [3]. During his visit he prepared an article for the Journal of Applied Physics, which he only submitted after his return to Göttingen in November 1931 [5]. Also following Brune's results, in 1932 he submitted the article "The Poisson integral for functions with positive real part" to the Bulletin of the American Mathematical Society [6]. In 1931, Cauer introduced a very important step in circuit theory by proposing the use of "approximations in the Chebyshev sense". In his memoir, Sidney Darlington described it thus: "At Bell Laboratories, a number of us first learned about some of Cauer's canonical circuits and his Chebyshev approximations at a conference on Cauer's proposed sale of some of his patents. It was an important event in my professional life" [10]. When AT&T offered Cauer $5,000 for the US and Canadian patent rights, he accepted.

Back in Germany he was able to hire a personal research assistant, Ernst Glowatzki, who helped him with the filter calculations until 1935. At the end of his visit, he worked for Wired Radio, Inc. for three months before returning to Germany by ship in August 1931.

Cauer's first book "Siebschaltungen" was completed during his visit to MIT and published after his return to Germany in 1931 [4]. Then, he tried to find a university position where he hoped for a change to obtain one of the free professor positions of Jewish mathematicians. Although Cauer published other well-regarded papers with mathematical and electrotechnical contributions to filter design, it became clear by 1934 at the latest that he would probably not be able to get a professorship because of his Jewish origins. So, he applied for positions in electrical engineering companies such as Telefunken, Siemens and Philips and aircraft manufacturers such as Henschel, Donnier, and Junkers. Finally, in July 1935, Cauer was employed by the Fieseler aircraft company in Kassel, but in 1936 he moved again to Mix & Genest Berlin, where he became head of the laboratory. In order to be able to give lectures there, Cauer had to pass the habilitation requirement at TH Berlin. The common method to get a professorship at a German university is the habilitation (teaching thesis). It consists of a postdoctoral thesis, the habilitation treatise, and a public lecture. From 1938 to 1942 he gave lectures about "Mathematical foundations of the theory of elasticity", "Theory of transient processes", and "Theory of linear AC circuits". In 1939, he was appointed extraordinary professor at the TH Berlin.

Even before he left Göttingen, he published some results about his analog computer, but soon he presented the first publications in the technical journal of Mix & Genest. In 1939, based on the pioneering work of Edward Norton, Cauer developed a new type of filter design method, which is now called insertion loss theory, simultaneously and independently with Hans Piloty and Sidney Darlington. However, since 1934 Cauer wanted to write a book about analysis and design of AC circuits and finally in 1940 before he signed a contract by a book publisher. In 1941 the first volume of his famous monograph "Theorie der linearen Wechselstromschaltungen" was published [7]. It was the last publication during his lifetime, because Cauer was not able to publish any results in the last two years of the war. For although he collected the material for the second volume, the manuscript was twice destroyed. A first version of Cauer's second volume was destroyed in March 1943 during an Allied bombing attack on Mix & Genest. Cauer prepared another version of this book that was lost when he died shortly before the end of World War II in April 22, 1945, when Soviet troops took his Berlin district of Marienfelde. He had only recently left his family, who were in relative safety in Witzenhausen near Göttingen. He had only received temporary permission to leave Berlin and therefore wanted to return to Berlin out of a sense of duty.

Thanks to the energy of Cauer's wife, Karoline Cauer, and the kind editorial help of E. Glowatzki, G. E. Knausenberger, W. Klein, and F. Pelz, some papers were published posthumously. A revised and expanded version of Volume 1 of Cauer's book appeared in 1954, and using Cauer's estate and parts of Cauer's second volume that had remained with colleagues, Glowatzki collected material for a second volume, which appeared in 1960 [9]. Already in 1958 these both volumes together with a lot of further material were collected to a volume "Synthesis of Linear Communication Networks" by W. Klein, and F. Pelz as well as G. E. Knausenberger and J. N. Warfield [8]. In the closing remarks of this book, Karoline Cauer wrote: "Cauer's work was then internationally recognized as pioneering. He had opened an important discipline of electrical engineering to exact mathematical treatment". One may envisage from these words some of the difficulties he had to meet. For the electrical engineers he used too much mathematics; for the mathematicians he used too much electrical engineering. "Faced by such criticisms, Cauer once laughingly pointed at the efforts as he was burdened with because of his work in two such specialized fields" [8].

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Submitted by Professor Wolfgang Mathis, Professor Emeritus, Leibniz Universität Hannover, Hannover, Germany (Email: mathis@tet.uni-hannover.de).

YPW 2021 *(continued from page 67)*

Section III: The testimonials from 12 industry professionals reporting which soft skills they think most contributed to their career.

The series of YPW has been very successful and the 2021 edition had record attendance, getting 272 participants from 35 countries around the world. It is expected to have a face-to-face edition on November 3-4 of this year at Porto Alegre, Brazil.

General Chairs: Alexandra Zimpeck (UCPEL, Brazil) and Guilherme Paim (INESC-ID, Portugal).

YPW Program Chairs: Calebe Conceição (IFSUL, Brazil) and Israel Lopes (SERMA, France).

CAS Society Liaison: Ricardo Reis (UFRGS, Brazil).

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