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"He was the father of us all." Ernie Guillemin and the teaching of modern network theory.

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Abstract—**Historians of electrical technology deal routinely with inventions, inventors, theoreticians, large-scale socio-technological systems, and corporate and institutional history. Yet one category of major contributor to the development of the discipline is rarely considered in detail: the engineering educator. This paper presents the contribution of one of the outstanding teachers of electronics of the twentieth century – in particular, a teacher of the communications networks, circuit theory and filter design so important to modern telecommunication systems – Ernst (Ernie) Guillemin. Guillemin studied electrical engineering at Wisconsin and MIT. He was granted a Saltonstall Traveling Fellowship which allowed him to study under Arnold Sommerfeld in Munich, gaining a PhD there in 1926. He returned to MIT and spent the majority of his career there, working first with Vannevar Bush, and then contributing to various wartime projects in the MIT Radiation Laboratory. Guillemin became full professor in 1944, concentrated increasingly on network theory in his teaching and research, and was awarded various medals and honours over the next two decades. He died on 6 April 1970. Guillemin's major pedagogical legacy is a magisterial series of six sole-authored books together with substantial contributions to two of MIT's renowned "blue books" – the text books authored by MIT staff as the EE curriculum was modernised in the late 1930s and 1940s. This paper aims to demonstrate why his name became a by-word for excellence in electronics engineering education, and why a several generations of former students and colleagues revere him and his legacy.**

Index Terms **— telecommunications, history, engineering education, Ernst Guillemin**

I. INTRODUCTION

Ernst Adolph Guillemin, known informally as Ernie, was born on May 8, 1898 in Milwaukee, Wisconsin. He received a BS in electrical engineering from Wisconsin in 1922 and moved to do postgraduate work at MIT the same year. Indeed, he was immediately appointed as a teaching assistant, which guaranteed him financial support for his own researches. In spring 1924, Arnold Sommerfeld contacted MIT from Munich, suggesting an exchange program for graduate assistants, and Guillemin was offered a place, supported by a Saltonstall Traveling Fellowship. He gained a PhD from Munich University's *Institut für Theoretische Physik* in 1926.

Guillemin seems to have been greatly influenced by Sommerfeld, and his relationship with the great physicist (a highly gifted teacher as well as a major contributor to the development of early twentieth-century physics) was to influence the remainder of his career, particularly in the way he approached teaching and supervising research students.

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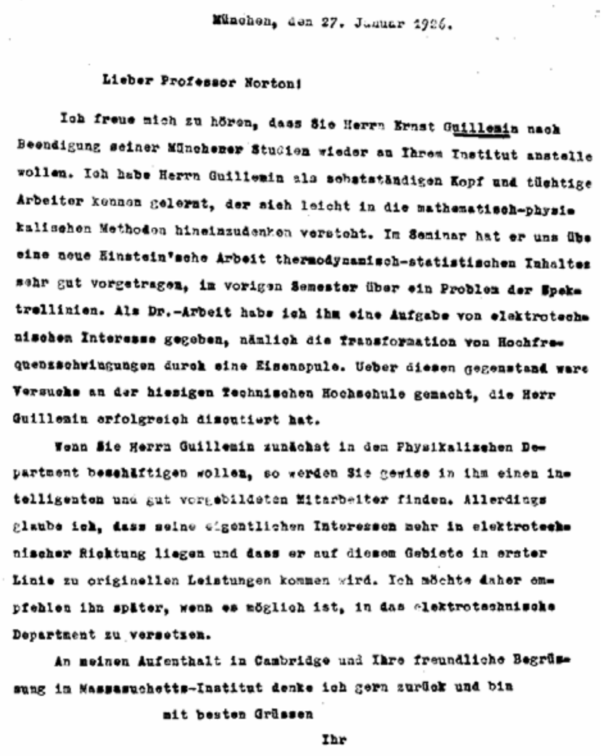
München, den 27. Januar 1926.

Lieber Professor Norton!

Ich freue mich zu hören, dass Sie Herrn Ernst Guillemin nach Beendigung seiner Münchener Studien wieder an Ihrem Institut anstellen wollen. Ich habe Herrn Guillemin als selbständigen Kopf und tüchtigen Arbeiter kennen gelernt, der sich leicht in die mathematisch-physikalischen Methoden hineinzudenken versteht. Im Seminar hat er uns über eine neue Einstein'sche Arbeit thermodynamisch-statistischen Inhaltes sehr gut vorgetragen, im vorigen Semester über ein Problem der Spektrallinien. Als Dr.-Arbeit habe ich ihm eine Aufgabe von elektrotechnischem Interesse gegeben, nämlich die Transformation von Hochfrequenzschwingungen durch eine Eisenspule. Ueber diesen Gegenstand waren Versuche an der hiesigen Technischen Hochschule gemacht, die Herr Guillemin erfolgreich discutiert hat.

Wenn Sie Herrn Guillemin zunächst in dem Physikalischen Department beschäftigen wollen, so werden Sie gewiss in ihm einen intelligenten und gut vorgebildeten Mitarbeiter finden. Allerdings glaube ich, dass seine eigentlichen Interessen mehr in elektrotechnischer Richtung liegen und dass er auf diesem Gebiete in erster Linie zu originellen Leistungen kommen wird. Ich möchte daher empfehlen ihn später, wenn es möglich ist, in das elektrotechnische Department zu versetzen.

An meinen Aufenthalt in Cambridge und Ihre freundliche Begrüssung im Massachusetts-Institut denke ich gern zurück und bin

mit besten Grüssen

Ihr

Fig. 1. Letter from Arnold Sommerfeld to Professor Norton at MIT dated 27 January 1926, in which he recommends Guillemin for a position in electrical engineering, following the completion of his doctoral thesis.

Guillemin worked from 1926 to 1928 mostly under Vannevar Bush, but soon after his promotion to Assistant Professor moved to the Electrical Communication Division under Professor Edward Bowles, where he was charged with the design of a new graduate course in Electrical Network Theory [1]. This position was to colour his entire MIT career.

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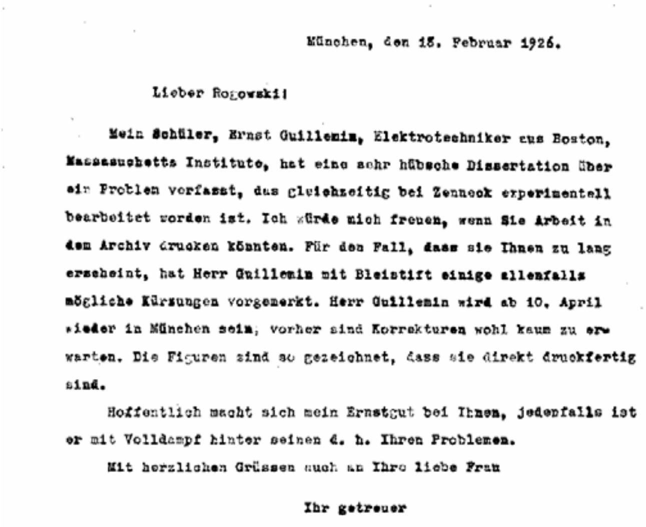
II. GUILLEMIN THE RESEARCHER

Guillemin's doctoral thesis was soon published (see Fig. 2) and he went on to have a distinguished research career, even if it was eclipsed by his even more superb teaching. Indeed, he was one of those university academics for whom the distinction between the two was irrelevant: much of his educational writings were greatly influenced by research carried out by him and his postgraduate students; and many aspects of his textbooks were so novel they deserve to be characterised more as research.



München, den 15. Februar 1926.

Lieber Rogowski!

Mein Schüler, Ernst Guillemin, Elektrotechniker aus Boston, Massasuchetts Institute, hat eine sehr hübsche Dissertation über ein Problem verfasst, das gleichzeitig bei Zenneck experimentell bearbeitet worden ist. Ich würde mich freuen, wenn Sie Arbeit in dem Archiv drucken könnten. Für den Fall, dass sie Ihnen zu lang erscheint, hat Herr Guillemin mit Bleistift einige allenfalls mögliche Kürzungen vorgemerkt. Herr Guillemin wird ab 10. April wieder in München sein, vorher sind Korrekturen wohl kaum zu erwarten. Die Figuren sind so gezeichnet, dass sie direkt druckfertig sind.

Hoffentlich macht sich mein Ernstgut bei Ihnen, jedenfalls ist er mit Volldampf hinter seinen d. h. Ihren Problemen.

Mit herzlichen Grüssen auch an Ihre liebe Frau

Ihr getreuer

Fig. 2. Letter from Sommerfeld recommending that Guillemin's doctoral thesis, or an abbreviated version of it, should be published in the prestigious *Archiv für Elektronik*.

From the mid 1930s Guillemin devoted himself almost entirely to aspects of circuit theory. During the Second World War he acted as a consultant to various groups in the MIT Radiation Laboratory, where he invented the Guillemin line, of crucial importance for generating the rectangular pulses required for radar systems. (He was granted a patent in 1949.) A full list of his publications can be found in [1], pp. xiii– xv.

III. GUILLEMIN THE TEACHER: THE FIRST TEXTBOOKS

Having developed a new course at MIT in communication networks, Guillemin wrote up his approach in his first textbook, the two-volume *Communication Networks* that appeared in 1931 and 1935. Volume 1 was considered by many at the time to be rather 'advanced' for a supposedly introductory text, introducing transient and steady-state response; network theory; the Heaviside approach; and Fourier analysis. In his preface he is unapologetic: "Methods are frequently designated as advanced merely because they are not in current use. To the student the entire field is new; the advanced methods are no exception. If they afford better understanding of the situation involved, then it is good pedagogy to introduce them into an elementary discussion. It is well for the teacher to bear in mind that the methods which are very familiar to him are not necessarily the easiest for the student to grasp. [...] I am chiefly indebted to Professor Arnold Sommerfeld, through whose teaching I gained my first real insight into the philosophy of oscillatory systems, and particularly in the use of complex methods ..." [4].

Volume 2 is even more novel, and in many ways established the general approach to linear systems in both electronics and elsewhere. Guillemin stresses the generality of the techniques: "Specifically, the present volume is intended to present a thorough treatment of the transmission line as a communication facility, leading quite naturally into the field of filter theory and its related problems. More generally, however, the discussions pertain to the field of network theory as a whole, and apply to the power as well as the communications aspect. [...] Then, too, the problem of synthesis, which has been an important motivating influence in the enlargement of our view and process with regard to network theory, not only had its inception in the field of communications but owes its development almost wholly to workers in that field. Nevertheless, these ideas and principles are too general in nature to remain confined to one field of application ..." [5].

As is often the case in Guillemin's pedagogical writings, he begins with a lengthy, discursive, almost musing introduction: there is only one equation in the first twelve pages – and that is simply $v = f\,\lambda$! A treatment of waves on transmission lines is followed by an introduction to filter theory, and (probably as a result of his German connection) Guillemin is just as familiar with German work (Wagner, Cauer, etc) as he is with the Americans (Campbell, Foster, Zobel, etc). These chapters lead to a discussion of filter synthesis, and the general behavior of linear systems, including the work of Karl Küpfmüller, one of the German founders of a generalized approach to linear system theory.

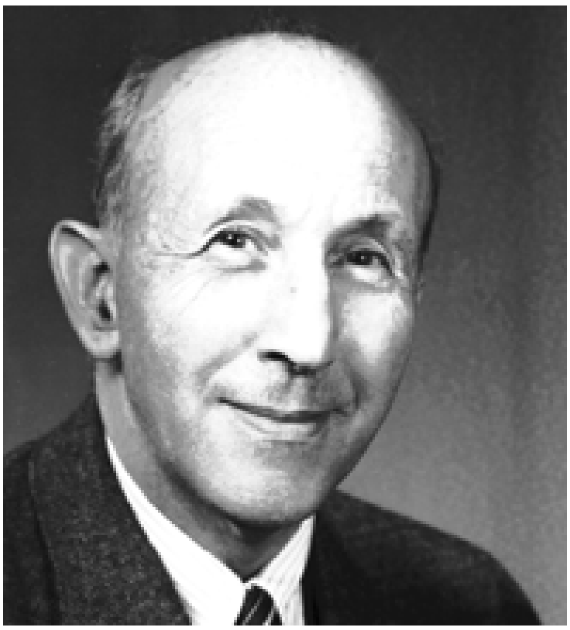


Fig. 3. Ernie Guillemin

IV. Post -war books

Guillemin had made a major contribution to two in-house MIT texts of the 1940s (*Electric Circuits* and *Applied Electronics*) during and after the war, but it was the period 1949 to 1963 that saw an outpouring of the results of his teaching and research, with the publication of another four, sole-authored volumes, each consisting of several hundred pages. In 1944 he had become full professor, and his continuing work on course revision and development led him to take a particular interest in engineering mathematics. The 1949 publication *Mathematics of Circuit Analysis*, with its subtitle "extensions to the mathematical training of engineers" is extraordinary for its time. Covering the now classic areas of determinants, matrices, vectors (including vector calculus), functions of a complex variable, Fourier and Laplace transformations, conformal mapping, and so on, it broke genuinely new ground in the mathematical education of what we might now call information engineers. All these topics still lie at the heart of control engineering, telecommunications, filter design, network analysis, and form the basis of advanced mathematics courses even today. The only serious omission by modern standards is perhaps discrete techniques – which, of course, were in their infancy in the late 1940s.

Guillemin's personal approach – some at the time saw it as quite radical – to the teaching of his subject extended into the next text: *Introductory Circuit Theory* of 1953 [7]. Remarkably, the book begins with the concepts of graphs, networks and trees, cut-sets, duality and so on before even mentioning Kirchhoff, loops and nodes. As always, Guillemin is interested in the power and generality of essentially quite simple ideas (if "advanced" to many of his colleagues at the time). Of the concept of duality he writes: "The object in discussing the subject of duality is twofold. First, duality is a means of recognizing the analytical significance of pairs of physically dissimilar networks; so far as mappable networks are concerned, it essentially reduces by a factor of two the totality of distinct network configurations that can occur. Second, and no less useful, is the result that the principle of duality gives us two geometrically different ways of interpreting a given situation; if one of these proves difficult to comprehend, the other frequently turns out far simpler ..." and he goes on to give a number of interesting examples, with recourse to virtually no formal mathematics [7], pp. 51-57.

Later in the text, of course, we have the less surprising topics of Thévenin and Norton theorems, impulse and step response, sinusoidal steady-state response, and so on – but all remarkably fresh over half a century later.

The final two of this magisterial set of books are *The Synthesis of Passive Networks* (1957) [8] and *The Theory of Linear Physical Systems* (1963) [9]. The first of these represents in many ways the first coherent presentation of the comparatively new discipline of network synthesis. Much of the book is concerned with realization theory and methods, with particular attention paid to the non-uniqueness of realization. The book concludes with a presentation of Butterworth, Chebyshev and elliptic approximation techniques for filter design. But from the pedagogical point of view, the preface again offers us insights into Guillemin's teaching style. His are some of the most self-aware textbooks I have come across. For example, he remarks: "In engineering teaching we cannot overemphasize the importance of having our students grasp the significance and the thrill of acquiring some depth of understanding in at least a few topics […] The educational value lies in the experience of following a line of reasoning to its logical conclusion; and in the thrill of suddenly realizing that our topic has thereby gained a much wider significance than initially seemed possible …".

Guillemin's final book is rather different: more the product of an older man (he retired the year it was published) reflecting on a beloved discipline than the much more teaching-oriented texts of the earlier year. It partly fills in some of the gaps not covered by the earlier books, and partly offers alternative approaches and theoretical consolidation. But it is still highly original, dealing in more detail than earlier works with Fourier techniques and including chapters on convolution, sampling, numerical methods and the Hilbert transform.

V. Honors

Guillemin received many honors during his academic life, including:

1948 President's Certificate of Merit for outstanding wartime contributions
1960 First permanent holder of Edwin Sibley Webster Chair
1961 IRE Medal of Honor
1962 AIEE Medal in Electrical Engineering Education
1963 Professor Emeritus

VI. Conclusions

I have included a number of citations above to try to indicate my general conclusions about Guillemin's unique approach to teaching, and what we might learn from it today.

As I hope is clear from the quotations, Guillemin engaged fully with his subject, and was driven to enable his students to achieve a deep understanding. He was unafraid to introduce them to topics like Fourier analysis and pole-zero plots at an early stage, and to spend whatever time necessary discussing problems and 'talking round the subject. His books are remarkable for the general discussion, inclusion of examples and analogies, and so on. Yet at the same time he was deeply committed to the importance of a full grasp of the theoretical basis of network analysis and synthesis, and a firm believer that an understanding of this would enable his students to successfully deal with novel problems in their future careers.

Let me conclude with two final quotations, from two of his former students, famous in their own right in the engineering world.

Bob Fano recalls: "Ernie was a master of thoughtful approximations that highlighted the important characteristics of expressions by eliminating inconsequential details. While well versed in the mathematics employed and very skilful in its use, he was happily oblivious of the mathematical fine points that were irrelevant to the concepts that he was trying to convey or to the network properties that he was describing. It was clear at all times that he was teaching network theory, not mathematics. Sommerfeld's influence on Ernie was very obvious in that respect. I recall asking him about something that he had said in class that did not seem to be correct in some unusual situations. He replied: *you are correct, of course; I did not point that out in class because most students would not have understood and the others would have asked me later as you did.* Lesson from Ernie: do not feed to students details that they are not ready to digest" [3].

And according to S. J. Mason: "When I entered graduate school after World War II radar work in the MIT Radiation Laboratory, one of my early graduate subjects of instruction was Guillemin 'Advanced Network Theory'. It was here that I first saw the elegant esoterica of network synthesis inveiled in all their simplicity and generality. Guillemin's hypnotic enthusiasm made it look easy, but of course the details were tricky and the work was hard, just as in any other job of learning. Guillemin gave us 'heuristic arguments' for network theorems. 'Heuristic' means 'serving to guide, discover, or reveal'. An heuristic argument is an attractive swindle intended to make some hypothesis or theoretical result seem like the most reasonable thing in the world. A good heuristic argument is (a) a thing to enjoy, (b) not a proof, (c) not easy to invent or construct, and (d) worth the effort. Guillemin's eyes twinkled as we, the class, after some struggle, arrived at revelations (a), (b), (c), and (d). He was teaching us about linear, lumped, finite, passive, bilateral networks – but the subject matter was mere vehicle to the evangelical call for ever better interpretations of theory in modern engineering." [10].

And the title of this paper? ... *Ernst A. Guillemin is dead*. So begins the eulogy written by Prof. Louis Weinberg, one of his many students. *He died on Monday, April 6. Though grown men are not supposed to cry, many will. "After all," I was told emotionally by a circuit theorist who was born and educated in Europe and who had never met Professor Guillemin "he was the father of us all."* [3].

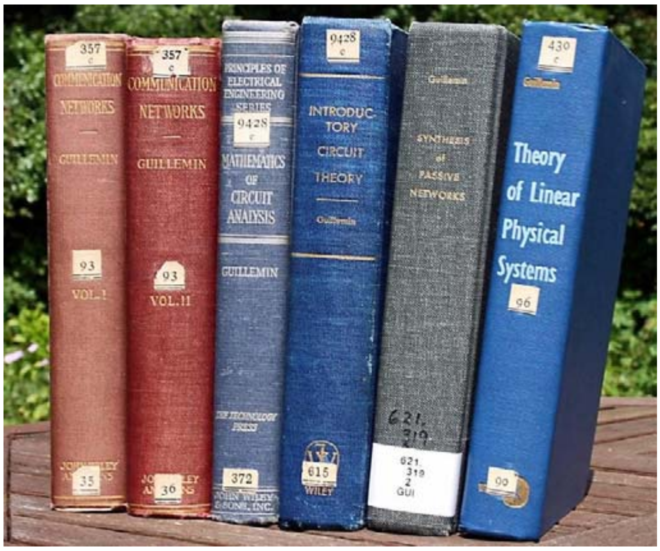


Fig. 4. Self-explanatory!

ACKNOWLEDGMENT

I wish to thank the Deutsches Museum, Munich, for permission to reproduce Sommerfeld's letters in Figures 1 and 2, and the IEEE for the photograph of Guillemin. Figure 4 was kindly supplied by Michael Barker.

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