Otto Herbert Arnold Schmitt (1913–1998): Overview of his Scientific Production

Max E. Valentinuzzi, EE, PhD[1]
[1]Departamento de Bioingeniería, FACET-INSIBIO/ UNT-CONICET
CC 327, Correo Central, 4000 Tucumán, Argentina; mvalentinuzzi@herrera.unt.edu.ar

Abstract—**Otto Schmitt was a prolific intellectual creator with over 60 patents and more than 300 scientific and technical publications produced during his lifespan. Besides, he left an enormous amount of manuscripts, letters, and equipments of different kind. The objective here is to give an overview of his published production trying to separate out and group the many subjects he dealt with assessing also the impact some of them had. There is an important number of papers in physiology, which in turn subdivide in electrophysiology, neuroscience and electrocardiology. Chronobiology was a matter of concern, too. A few belong to biomedical engineering at large, including clinical engineering. Electromagnetic fields called his interest during a period of his life and, curiously enough, bioinstrumentation, which accounted for only about 3% of his whole production, was the area of highest impact, displaying his most known and still used contributions: the now called Schmitt Trigger, the Differential Amplifier and the RF Isolating Unit. He was collaborator of Nobel Class researchers and he could be considered as a member of such class. No doubt, he was a pioneer in Biomedical Engineering.**

Keywords—**History, education, physiology, bioinstrumentation, electromagnetic fields**

I. INTRODUCTION

History of science and technology is a highly educational and formative discipline because it shows the intellectual pathway followed by those who preceded us and, many times, it teaches modesty, too. Moreover, it may enlighten our knowledge of a given subject and, occasionally, it may also offer the lead to continue an old idea or concept, especially when new technologies become available. Finally, it serves to recognize the contributions of superb researchers sometimes not well-known or even forgotten.

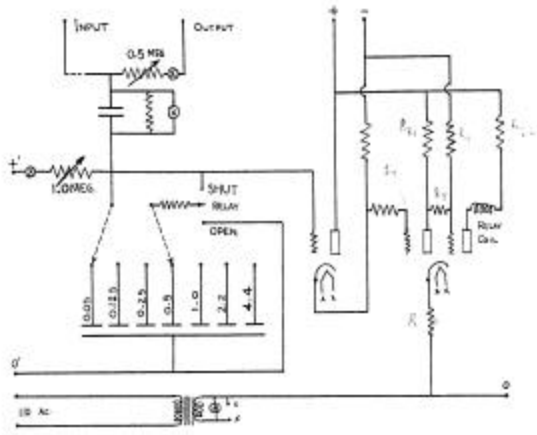


FIGURE 1. Original Schmitt Trigger circuit as it appears in his dissertation.

Otto Schmitt represents an example of early beginning, indefatigable work and great accomplishments. As a child and adolescent, he manifested a clear inclination for science and technology. Before he turned 22, he already wanted to offer a theory of nerve impulse propagation. The subject inspired his doctoral dissertation entitled *An Electrical Theory of Nerve Impulse Propagation*, presented to the Departments of Physics and Zoology, Washington University, on June 1937, Saint Louis, Missouri. Such interest marked the invention and beginning of a device that turned out to become far-reaching in applications.

II. OTTO IN BIOINSTRUMENTATION

Schmitt Trigger. This is the nowadays name of the above-mentioned device, whose first vacuum tube circuit version is shown in pages 48 and 49 of his dissertation (Fig. 1). As many researchers in those days, he designed and built his own equipments and models. The trigger intended to model the membrane behavior. During the action potential, there is a change in the membrane impedance (capacitive and conductive). We now know that the conductive component strongly predominates, represented by the sodium, potassium and calcium ionic currents. Otto aimed at a "synthetic nerve" hoping to solve the equations of such circuit in order to understand the physiological response. The capacitance would be given one value whenever the potential across the membrane exceeded a certain fraction of the resting potential, and another higher value when the potential was less than it. A quick acting relay connected an additional capacitance in shunt with the normal capacitance (hypothetical membrane). His own words stated "the circuit is rather unusual. It constitutes what might be called a thermo-ionic trigger circuit since the current in the plate which connects to the relay can take only a full or zero value as the control grid of the other triode section of the same tube takes on potentials below or above a critical voltage." Neither the explanation nor the circuit drawing is clear enough to fully understand the trigger operation. The Bakken Museum, in Minneapolis, keeps a rack with several units of this kind built by Otto himself (Fig. 2).

The Schmitt Trigger is currently a comparator application, which switches the output negative when the input passes upward through a positive reference voltage. It then uses negative feedback to prevent switching back to the other state until the input passes through a lower threshold

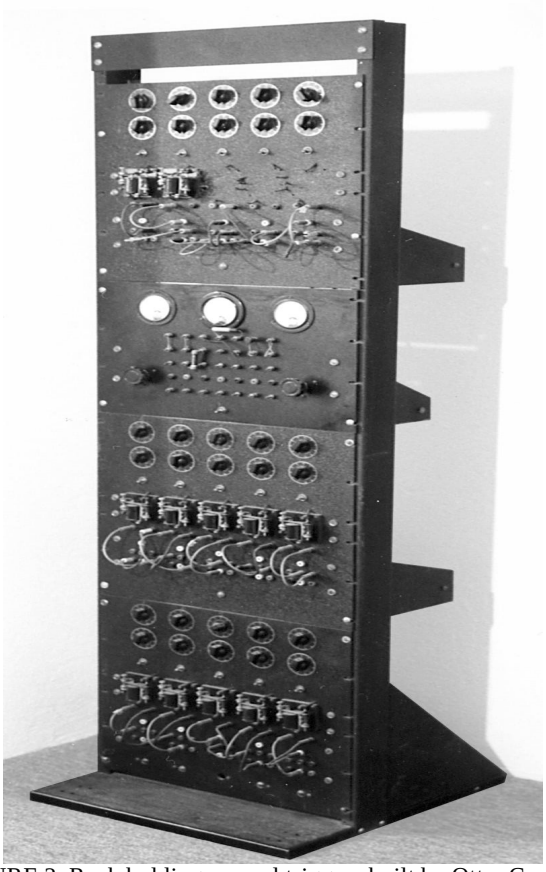


FIGURE 2. Rack holding several triggers built by Otto. Courtesy of The Bakken Museum, Minneapolis, MN.

voltage, thus stabilizing the switching against rapid triggering by noise as it passes the trigger point. In fact, it acts as a filter for low amplitude changes (Fig. 3). How this ingenious circuit became so popular in applications other than the biomedical sciences is not apparent. Its description is hidden in his doctoral dissertation and, apparently, there was no other published paper or patent.

Differential Amplifier. Four were the main contributors to the development of the differential amplifier [1]: Matthews, in 1934 and 1938, Toennies, in 1938, Offner, in 1937, and Otto, in 1937 [2]. Gain is not important in this circuit, but the rejection of in-phase signals is, together with high input impedance. Obviously, the idea was floating and technology was ripe enough so that more than one researcher came up with similar solutions.

Isolating Unit. The third important bioinstrumentation contribution by Otto was the radio frequency (RF) isolating unit to eliminate stimulus artifact in electrophysiological records, when an excitable tissue is stimulated [3, 4]; however, he started very early in his life with this subject, when he was only 18 years old, in collaboration with his elder brother Francis Otto [5]. Any commercial biological stimulator is provided now with Otto's isolation unit that, sometimes, is replaced by the more recent optic coupler.

Other contributions to bioinstrumentation included a cathode ray oscillograph for the study of nerve action potentials, pointer-galvanometer for muscle heat measurement (with A.V. Hill), and cathode ray presentation of three-dimensional data. The surprising quantitative outcome is that only 10 out of about 300 papers (3% of his production) was in bioinstrumentation, meaning that his main concern was the physiological problem; however, the impact of these three inventions has transcended the action of time because they are today widely used, even in fields other than biomedical engineering or physiology.

III. Otto and Electrophysiology

This area called his attention early in his life and, by sheer necessity, led to the bioinstrumentation ideas previously described. The propagation of the action potential and the nature of the excitatory process spurred his curiosity and ended in many publications, some of them with the Nobel Prize Bernard Katz, as for example those dealing with the adjacent conduction phenomenon, known as ephaptic conduction [6, 7, 8]. A few of his papers touched basic and hot subjects in those days, as the membrane current-voltage characteristics and the impedance variation of the nerve membrane during the action potential [9, 10]. K.S. Cole and H.J. Curtis had published in 1939 their superb demonstration of such membrane impedance change using an impedance bridge. The Second World War (1939-45) and its after-effects came about. Scientific research essentially came to a halt and it took time to pick up impulse again. The famous Nobel Prize series of experiments by Hodgkin, Huxley and Katz appeared between 1949 and 1952 leading to the first coherent and now accepted ionic theory of electrophysiology. We counted 21 out of 300 papers, that is, about 7% of Otto's production deals with electrophysiology, but subjects, journals, collaborators, all were of Nobel class and Otto was in the circle, indeed!

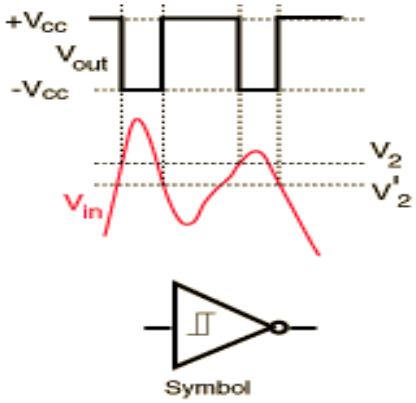


FIGURE 3. When the signal crosses upwards the V2 level, the circuit switches. When it crosses downwards the V'2 threshold, it switches back. Changes kept always above V2 or below V'2 are not "seen" by the circuit. There is also a standardized symbol for the trigger.

IV. Otto and Chronobiology

This area of strong current interest also attracted Otto's concerns and, as before, joined forces with high caliber scientists, as Frank Halberg. One of the papers described adaptive analog models for biologic rhythms, quite advanced concept at the time [11]. Less than 3% of his overall production accounts for this area.

V. Otto and Electrocardiology

No doubt, this specialty strongly called his attention for he lists over 93 contributions, which means in the order of 30% of the total production. Subjects like leads, concept of transfer impedance, cardiac vectors and spatial representation are treated in several papers [12]. It is beyond the scope of this brief account to list them all or even partially. Several equipments and physical models are still available in a Minneapolis warehouse. A model torso, built after his wife Viola and similar to torsos made by the Burger brothers (one physicist, the other physician), in The Netherlands, is on display with The Bakken Museum (Fig. 4). The Burgers made important findings in this area, some of them quite similar to Otto's.

VI. Otto and Biomedical Engineering

There are at least 74 contributions (about 25% of his production) that can be clearly classified as interdisciplinary and, thus, within the biomedical engineering discipline.



FIGURE 4. Torso built by Otto modeled over his wife and collaborator of all his life, Viola. Courtesy of The Bakken Museum.

Several belong to the now called clinical engineering area. Criteria for classification may differ and a more detailed analysis of his production is mandatory.

VII. Otto and Electromagnetics

Electromagnetic fields and their possible actions on biological tissues were also a matter of his research. In one article [13] we read: "I vividly remember accidentally demonstrating the visual magneto phosphenes on myself many years ago by accidentally exciting a Helmholtz coil in which I had stuck my head to examine a vacuum system with full line voltage on a coil wound for excitation at 1.5 volts." This interesting and not harmful phenomenon, which occasionally may cause momentary dizziness or headache, was well explained by Max Valentinuzzi Senior, this author's father [14]. In about 24 papers (8% of Otto's production), several deal with magnetic and electromagnetic subjects.

VIII. Discussion

"Let me know who you work or hang out with and I will tell you who you are" is a popular motto that parents often tell their children to call attention for possible bad guys. The beneficial and potentiating influence from the good guy is also valid. Otto Schmitt related and worked with other prominent people in science: A.V. Hill, R. B. Levine, Herman Schwan, Peter A. Stewart, Bernard Katz (Nobel Prize of Physiology), V.K. Zworykin (pioneer of Biomedical Engineering and inventor of the television image vidicon), his brother Francis O. Schmitt, Alan Burton (renown cardiovascular physiologist), John J. Almasi, Cesar A. Caceres (coiner and promoter of Clinical Engineering), David B. Geselowitz, Eugene Lepeschkin (great contributor in electrocardiology), W.S. McCulloch, Franz Halberg, and the list has other names, all impressive for the scientific and academic level. To intermix and interact, as Otto did, is not an easy enterprise for the candidate must keep intellectual and physical pace with people of such rank. When baby Otto joined the Schmitt's (April 6, 1913), his brother Francis was almost ten, his sister Viola was nearly eleven, his mother was 35, and his father was 37 (Fig. 5). Young Otto was a precocious child, and his natural talents were nurtured by the combination of counsel and generous support.

Jacob Siler (an old family friend) played a vital part in Otto's childhood development although he dealt with him only a few years as a child. Otto was only twelve when Siler died in 1925. But Siler's will directed that Otto be given the first choice and be allowed to select one hundred books from Siler's library. Otto kept some of these books all his life as well as many photo plates and other memorabilia and artifacts.

Thus, we should underline the importance of adequate guidance and support to the intellectual activities of children, teenagers and young people.



FIGURE 5. Brothers and sister: Francis Otto, Viola (coincidentally, with the same name as Ottos's wife) and Otto as a teenager. Courtesy of the Young family.

IX. CONCLUSIONS

We must concur with Jon M. Harness (2001, biographical report to The Bakken) when he says: "Throughout his long and full life, Schmitt would employ his talents in electrical engineering — and similar affinities for biology, physics, and mathematics — to push the frontiers of knowledge. He helped to forge the new disciplines of biophysics and bioengineering". And now let me add with conviction: Otto was a pioneer in bioengineering, no doubt, of Nobel class

ACKNOWLEDGMENTS

This communication is based on the Otto Schmitt Annual Memorial Lecture held at The Bakken Museum, on October 9, 2002, by Max E. Valentinuzzi. Help and support is recognized to The Bakken Museum and Library and to the Otto Schmitt Foundation. Besides, to Dr. David Rhees (Director of The Bakken) and Dr. Robert Patterson (member of the Foundation Board of Directors), to Mr. Tom Young (member and representative of the Schmitt family), to Ms. Elizabeth Ihrig (librarian), to Dr. Ellen Kuhfeld and Mr. Riley Hendrickson (curators) and to the Spinelli-Valentinuzzi family in Saint Paul, MN.

REFERENCES

[1] L. A. Geddes, "Who invented the differential amplifier?" *IEEE EMB Mag*, May-June 1996, pp 116-7.
[2] O.H.A. Schmitt, "A Simple Differential Amplifier." *Rev. Sci. Instr*., vol. 8, no. 4, April, 1937.
[3] O. H. A. Schmitt, "A Radio Frequency Coupled Tissue Stimulator." *Science*, vol. 107, No. 2782, p. 432, April 23, 1948.
[4] O. H. A. Schmitt and D. R. Dubbert, "Tissue Stimulators Utilizing Radiofrequency Coupling." *Rev. Sci. Instr*., vol. 20, No. 3, p. 170, March, 1949.
[5] F. O. Schmitt and O. H. A. Schmitt, "A universal precision stimulator." *Science*, vol. 76, No. 1971, Oct. 7, 1932.
[6] O. H. A. Schmitt and Bernard Katz, "Excitability changes in a nerve fiber during the passage of an impulse in an adjacent fiber." *Jour. Physiol.*, vol. 96, June 1939.
[7] O. H. A. Schmitt and Bernard Katz, "Electric interaction between two adjacent nerve fibres." *Jour. Physiol.*, vol. 97, no. 4, 1940.
[8] O. H. A. Schmitt and Bernard Katz, "A note on interaction between nerve fibres." *Jour. Physiol.*, vol. 100, No. 4, p. 369. 1942.
[9] O. H. A. Schmitt, "Analysis of the nerve membrane current-voltage characteristic as a non-linear impedance." *Amer. Jour. Physiol.*, vol. 155, No. 3, p. 467. Dec., 1948.
[10] O. H. A. Schmitt, "Impedance variation in the nerve membrane during passage of the natural action potential." *Proc. Amer. Physiol. Soc*., vol. 8, no. 1, p. 140, March, 1949.
[11] O. H. A. Schmitt, "Adaptive analog models for biologic rhythms." Annals of the N.Y. Academy Sciences, vol. 98, article 4, pp. 846-850, Oct. 30, 1962. [12]O. H. A. Schmitt, "Lead vectors and transfer impedance." The Electrophysiology of the Heart, *Annals of the N.Y. Academy of Science*, vol. 65, art. 6, pp. 1092-1109. August 9, 1957.
[13] O. H. A. Schmitt, "Living in magnetic fields", *Archaeus* (discontinued and at the Bakken Library), vol. 2, no. 1, pp. 77-80, 1984.
[14] M. Valentinuzzi Sr, *Theory of Magnetophosphenes*, North American Aviation, Inc., Jan 1961, Downey, CA, 27 pp.



FIGURE 6. Otto and wife Viola on their wedding day. Courtesy of the Young family.