CARRIER-WAVE TELEPHONY OVER POWER LINES: EARLY HISTORY

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ABSTRACT

In this column we discuss the early history of power line voice communication, beginning in 1918 and continuing until the early 1930s. We note that these developments were based on the 1910 demonstration by Major George Squier of the United States Army Signal Corps of his "wired wireless" technique for transmitting multiple telephone channels over one pair of wires. Power companies world-wide picked up on this carrier-wave telephony technique for use over power lines, with electrical manufacturing companies such as GE and Westinghouse in the United States and Telefunken in Germany, among others, then developing a variety of systems for this purpose. By 1930, the technique had reached a period of maturity, with 1000 systems installed throughout Europe and the United States.

INTRODUCTION: "WIRED WIRELESS" OVER POWER LINES

The field of power line communications has recently seen a revival of interest, with increased research activities taking place, as well as new standards and products being introduced. It is thus timely and appropriate to look back and delve into the early history of the field. Among the first communication applications using power lines were those for reading meters at remote locations [1, 2].[1] (Remote reading of electrical meters using telegraph lines was carried out even earlier.) In this column, however, we focus on the early history of using power lines for voice communications, beginning in 1918 and carrying the story forward to the early 1930s, when telephony using power lines had essentially established itself as a mature technology worldwide.

Why use power lines for telephonic communications? Power companies had, for years in the early part of the 20th century, used normal telephone circuits for operational support, often running telephone lines parallel to their power transmission lines. Experience had shown, however, that there were often severe problems developing with the use of telephone lines for their necessary communications. Telephone circuits were often unreliable. They were also expensive. Telephone lines were found to be fragile, particularly in mountainous terrain, even prone to collapsing under conditions of bad weather, with storms and snow encountered frequently in the winter season. In addition, electrical interference between parallel telephone and power lines was a fairly common occurrence. Power lines themselves, however, were much more robust and sturdy. Since they were already there, why not use them?

This idea of using power lines themselves for transmitting voice messages appears to have occurred to a number of people and organizations in a number of countries just after Major George Squier, of the United States Army Signal Corps, demonstrated in 1910–1911 the transmission of multiple telephone channels over a single telephone circuit using a carrier-frequency technique. (This early work of Major Squier was previously discussed in the May 2008 History of Communications column of this magazine [3]). In this technique, similar to that of amplitude modulation (AM) transmission, each channel uses its own frequency (called a "carrier frequency") for transmission. AT&T began development of such a system in 1914, inaugurating commercial carrier frequency transmission over telephone lines in 1918 [3]. Major Squier termed his carrier technique "wired wireless," and that term began to be used in power line communications, as well as other applications proposed for the technique.[2, 3]

The first test and commercial operation of carrier telephony over power lines, as reported in the technical literature, took place in 1918 in Japan [4]. In May of that year, the Imperial Japanese Electro-Technical Laboratory of Tokyo successfully tested "wave telephony" over the Kinogawa Hydro-Electric Co. 144 km (90 mi) long power line. Commercial operation followed, beginning in December 1918, over the Fuji Hydro-Electric Co. 22-kV 3-phase power line. Although the paper [4] describing this work contains no specific reference to Squier's pioneering work, reference is made on page 206 to "wired wireless."

The first experiment with telephone communications over power lines in the United States was carried out by the American Gas & Electric Co. (later the American Electric Power Co.) on July 7 and 8, 1920. The results of this experiment were reported as follows some 10 days later in *Electrical World* [5]:[4]

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[1] *A French paper claims otherwise: M. Marius LaTour,* Communications Telephoniques Entre Centrales, Bulletin de la Societe Francoise des Electriciens*, vol. 2, March 1922, 137–148. This paper notes "the idea of modulating a high-frequency current on* any type of transmission line *to handle high-frequency telephony or telegraphy had been described by M.LeBlanc (Lumiere Electrique 1886; French patents 215, 901 of 1891 and 234, 785 of 1893) and M. Turpain (Revue de Physique, Aug. 1900)." [Emphasis added].*

[2] *The German literature cites the work of Ernst Ruhmer as an influence on power line telephony as well. His articles and a book on multiplex telephony appeared 1908–1911. His U.S. patent in the field was issued after that of Squier. But, as noted, the phrase "wired wireless" used in the early days of power line telephony was coined by Squier in reference to his work.*

[3] *One application proposed for wired wireles was that of wired radio broadcasting. A brief note appearing in* Electrical World*, vol. 81, no. 2, Jan. 12, 1923, p. 117, describes tests conducted in New York City and Washington, D.C for several months in August 1922. This application had in fact been proposed by George Squier, and the tests were carried out by R. D. Duncan, Jr., one of Squier's associates. Another application proposed for the wired wireless technique was for communication over trolley lines. As reported in an article in the* New York Times*, March 27, 1923, p. 23, under the heading "Trolley Cars Try Radio Telephones," "A carrier telephone, operated by radio guided by trolley wires, was demonstrated yesterday on trolley lines of the Third Avenue Railway in the Bronx [New York] by engineers of the General Electric Company and the Third Avenue line. By the use of this… 'wired wireless' telephone apparatus a conversation was carried on between a trolley in motion… and a sub-station three miles distant."*

[4] *The article was presumably taken verbatim from an AG&E press release since essentially the same article appeared a few months later in* Telephony*, Sept. 11, 1920, p.22.*

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"At last successful telephone communications has been conducted over live high-tension lines by the AG&E, which has been convinced thereby that the method employed will solve one of its most important problems, namely, insuring a reliable and less expensive mode of communication between its load dispatchers and interconnected stations. The test which proved the practicality of the method was conducted July 7 and 8 between the company's Atlantic City and Ocean City stations, over a live 11,000 [kV], 60-cycle [Hz] line 12 miles (19.2 km) long. [Adding transformers and an underground cable, the] equivalent length [was] 22 miles (33 km)… The system employed works on the principle of the wired wireless or directed radio… The carrier current for the communications had a frequency in excess of 5000 cycles [Hz]… Among the chief advantages… the investment and maintenance expense connected with private lines are eliminated… high rental charges for leased telephone lines avoided, no interference from power circuits or static is experienced… the system can be used with any voltage transmission, the possibility of the power circuits breaking is remote, and, even if they all fall to the ground, communication can still be maintained… The investment for apparatus will be about $500 station,… more economical than an ordinary wired telephone system… audibility is higher than with ordinary telephones. [AG&E] is planning to apply the communication scheme to all of its properties for system load dispatching ."[5]

Other power companies in the United States, noting the success of this first experiment, were quick to follow with their own installations. Among the first such carrier-current telephone systems was that of the Great Western Power Co. According to an oral interview with Dr. Leonard Fuller, a well-known engineer in the field of radio communications, he was approached in the "early 1920s" [1921–1922] by John Koontz, chief engineer, Great Western, to improve communications between the dispatcher's office in Oakland, California, and hydroelectric plants on Feather River [6]. These were the "longest and highest-voltage lines in the world." These lines ran at 100 and 165 kV, consisted of multiple circuits and branch lines, and interconnected nine substations. Normal telephony was unreliable with winter storms. Fuller, after "looking into the matter," proposed carrier-current operation on the power lines. His design and subsequent installation in fall 1922 were found to be quite successful. A subsequent report by Koontz in 1923 noted that the system had been operating for one year, providing good service, with no interruptions "last winter [of 1922]" [7].

Fuller followed this installation with one designed for the Pacific Gas & Electric system, with PG&E specifically engaging him to "install carrier-current transmission on their new 220-kV Pitt River lines," 202 mi in length [6], with the system completed and placed in operation April 11, 1923 [8]. This system at the time of its installation was the longest carrier-current system in the United States, the power line itself operating at a voltage higher than that of Great Western [9]. (As we shall see below, carrier-current systems began to proliferate by this time, many designed by General Electric Corp. [GE], followed soon thereafter by Westinghouse Corp.) Both the Great Western and PG&E systems utilized *simplex* transmission; that is, one frequency only is used for all telephone communications, whether to or from the central control station. This meant such a system had to incorporate a means for someone at either the central station or a substation on the power line to gain control of the transmission when wishing to speak. The Great Western system used a carrier frequency of 55 kHz; the PG&E system used a frequency of 50 kHz. Both systems used "antenna [wire] coupling" to connect the telephone receivers and transmitters to the power lines. In this method, as distinguished from capacitor coupling, which was adopted by many later systems as we shall see below, a long wire paralleling the power line and carrying the high-frequency carrier telephone signals is used to induce these high-frequency currents in the power line on the transmission end, with the reverse process used on reception. The power required of the telephone transmitters was normally 250 W, although a transmitting power of 50 W was found sufficient for smaller sections of power line. PG&E's appraisal of carrier-current performance was very positive, with a number of advantages cited over the use of telephone wire lines [8]. Its operation, because it obviated the need to install a parallel telephone wire system, was better than wire phone "due to absence of inductive interference." The choice of 50 kHz frequency resulted in a system "free from all outside interference [resulting in the] best combination of signal strength and voice modulation" [8].

COMMERCIALIZATION OF POWER LINE COMMUNICATION SYSTEMS

As noted above, GE was the first company in the United States to commercialize the use of carrier-current telephony over power lines. Engineers in its Radio Department, based in Schenectady, New York, designed a 50 W simplex carrier-current system, using antenna coupling, with the first test of this system carried out December 7, 1921 over lines of the Adirondack Power & Light Company. The first commercial installation followed a year later over the lines of the Utica Gas & Electric Company, with tests being conducted in November 1922 over a 44-kV 12.5-mi-long line and regular service begun shortly thereafter on December 8, 1922 [10–12]. The appraisal of the GE installation by E. P. Peek, the general superintendent of Utica Gas & Electric, was very positive [12]. He noted the quality of transmission was as good as commercial telephony, with the system itself better than one with telephone lines using the same power line towers. He commented that there was a "very noticeable absence of hum and extraneous noise." Based on these results, Utica G&E ordered an additional higher-power set of 250 W to provide communication between Utica G&E and the Northern NY Utilities system, covering 60 mi at 66 kV and a lower voltage for 30 mi [12]. A later note from Peek indicated that the carrier-current system was more reliable than "space radiophone" (i.e., radio telephone transmission), with a comment made that the expense of purchasing and installing a carrier-current system, quoted at $2000-$3000 per transmitting-receiving set, was "small" if outages using the system occurred only a few times a year, with service restored quickly [13].

It is apparent that GE engineers had made the decision to design relatively low-power simplex systems. Their design called for 50 W transmitters for lines up to 85 mi in length, 250 W for longer lines. Antenna coupling was adopted for these first installations, as being at this time the "best method… determined by operating conditions and cost," although they were aware of capacitor coupling as another method of coupling [10]. (GE, in fact, did adopt the capacitor

[5] *Philip Sporn, then Chief Electrical Engineer of AG&E, later (1947–1961) President of AEP, commented as follows seven years later at a September 1927 AIEE convention: "We have 22 carrier installations on our 132-kV system." Almost all of these used condenser (capacitor) coupling, the more common method of coupling telephone signals to the power lines, as will be seen later in this column.*

coupling technique later as capacitors capable of handling the high voltages used were developed.) GE, focusing on designing simplex systems, expressed skepticism about providing duplex transmission, since this technique, allowing two-way telephone communication to go on simultaneously, required the use of two frequencies, one for each direction of transmission [10]. Westinghouse, coming on the scene soon after GE, differed in its approach. The designs of its Radio Engineering Department specified duplex transmission and called for higher-power transmitters. Tests of its first system were carried out in January 1923 over 66 kV 30-mi-long lines of the Duquesne Light Company. Duplex transmission was used, as noted above, transmitters operated at 250 W, and antenna coupling was used [14, 15]. A joint evaluation of the tests by Westinghouse and Duquesne indicated the cost and maintenance expense was much less than using normal telephony, while the reliability was much higher since power lines were much more rugged than telephone lines. However, there were limitations found, with disturbances occurring due to "spitting" insulators, problems occurring during switching operations, and problems encountered with the stringing of antenna wires at stations and substations [15].

Other power companies in the United States were quick to order and have installed carrier-current systems over their power lines. By early 1923 there were 10 such installations, the number rising to 43 by the start of 1924 [16]. European systems were initially installed at an even more rapid rate than in the United States. By late 1922 there were at least a dozen systems operating in Europe, most of them in Germany, with systems as well in Switzerland, Norway, and Sweden [17].[6] The power line lengths over which these systems operated were generally shorter than those in the US, running from 30 to 90 miles in length, and tended to be of lower voltages as well, varying from 50 kV to 110 kV. These systems were the first to use "condensers" (capacitors) for coupling the telephone signals to the power lines, at this time only for voltages less than or equal to 75 kV. (The cost of using coupling condensers for higher line voltages from 80 to 110 kV was "prohibitive," in addition to possible danger with their use at this time at the higher voltages [17].) Carrier-current operating experience in Europe was similar to that in the United States: systems tended to have a "marked advantage over ordinary line telephony" and were little affected by large disturbances on the lines. "Even when one or two conductors… are broken or grounded," intelligible conversation was possible [17]. By 1924, at least five companies in Germany alone were developing such systems for the power industry [21]. These included Telefunken, Deutsche Telephonwerke, C. Lorenz, E. Huth, and Gesleschaft Funkentelegraphie. Telefunken had 20 systems in operation with 67 stations covering 3400 connected kilometers [21]. (Credit is given in this paper being referenced to both Squier and E. Ruhmer in discussing the history of carrier-current telephony.)

Trade journals in the United States were quick to note the emergence of carrier telephony over power lines as a viable and often superior alternative to telephony over normal telephone lines. The *Editorial World*, for example, editorialized about this new means of providing power line voice communications in two successive weeks in May 1923. In its May 12 issue, which carried an article on the experiences of the Pennsylvania Water and Power Company with a GE-installed system, an editorial preceding the article noted that communications in the power field had always posed problems, but commented "recently, a good deal of interest has been excited in radio communication, particularly… 'wired wireless,' [as this new technology is] loosely known." The editorial went on to say that much was still to be learned of this technology, "as might be expected," particularly the effect on communications of power surges, short circuits, switching, and "spitting insulators." But "wired wireless [is promising]" [22]. The editorial published a week later, May 19, 1923 [23], commenting on the Westinghouse experience with its Duquesne installation described earlier in [15], itemizes some of the potential problems with carrier-wave telephony: getting the telephone-line coupling right, choosing the right carrier frequency, handling the cutting in/out of branch lines ("each tap adds 15–20 [equivalent] miles to the line length"), effect of charging of lightning arrestors, arcing grounds, switching circuits on and off, and so on. But the editorial then notes that, despite these "difficulties, progress is being made" and the "manufacturers are to be congratulated on their broad viewpoint." (As an aside, was *Editorial World* providing equal time to GE and Westinghouse in its editorials?) Comparing these two editorials published a week apart, one could say there is cautious optimism about the use of this new technology for communicating over power lines. This cautious optimism was reflected in an appraisal made shortly thereafter, in June 1923, by the power industry itself. In a report by the Subcommittee on Communications of the Pacific Coast Electrical Association comparing ordinary telephony, space radio, and carrier-current radio, presented at the Association meeting June 19–23, 1923, the Subcommittee concluded "Carrier-current radio functions well but… its efficiency should not be over-estimated."[24] The report noted, as well, that duplex communication, although presumably desirable, was, at the present time, complicated and expensive. It noted that more work on these systems was needed to reduce interference, as well as handling the problem of large numbers of branching taps. (As noted above in [23], each tap adds from 15–20 equivalent miles of power line length.)

CARRIER-WAVE TELEPHONY OVER POWER LINES COMES OF AGE

This "cautious optimism" in 1923 about the use of carrier-current telephony over power lines clearly turned to unfettered optimism beginning a year later. The technology had now come of age. Focusing on the United States, it was noted

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[6] *This author has been unable to determine the date and place of the first "wired wireless" or common carrier power line system installation in Europe. The presumption is that it occurred in Germany, but one would expect that the problems arising from World War I resulted in a delay in the introduction of such systems. A 1920 German paper [18] asserts the need for* drahtlose *(wireless) telephony and references Telefunken patent D.R.P. 291604 by A. Meisner. Figures in the paper show a diagram and photo of antenna coupling to a power line, but with no date or place given. Another figure shows a wireless telephone station, but it is not clear whether this is designed for telephone lines or power line use. The author does note a "new epoch" has arrived, but, again, it is not clear whether "wired wireless" (carrier frequency) telephony over telephone lines or power lines is meant. A somewhat later German paper by Erich Habann [19] refers in its title to telephony on power lines. But the specific experiments described as beginning in 1918 relate to carrier-current technology over telephone lines. The paper then deals at length with issues arising specifically with carrier telephony over power lines, but examples of specific installations are not given. A third paper appearing in 1923 [20] describes a new high-frequency telephone system for power lines called the "Habann system," commenting specifically that it uses a simplex technique, which is preferred to duplex technology when interconnecting multiple stations.*

above that there were 43 installations in early 1924, up from 10 in 1923. By the start of 1925, the number had risen to 108 installations, 11 of which now used capacitor, instead of antenna, coupling [16]. The beginning of 1926 saw the number increase to 150 systems, 25 using capacitor coupling, while by the start of 1928 there were 280 such systems in the United States, 130 of which used capacitor coupling [16]. In fact, beginning in early 1927, all new installations used capacitor coupling. Why this switch to capacitor coupling? Companies had overcome the problem of using capacitors at high transmission voltages. For power lines operating at 66 kV and below, mica and porcelain capacitors proved satisfactory. Higher voltage lines such as those operating at 110, 120, and 220 kV used specially developed oil-filled cable or oil-filled tank capacitors. Southern California Edison, for example, in its carrier-current system installed October 1, 1926 over its 220-kV 270-mi-long power line, used oil-filled tank capacitors and found their use "thoroughly satisfactory" [25]. Mica coupling capacitors had been developed some years earlier and standardized in units of 22 kV; they could then be connected in series for higher-voltage use. They had, in fact, first been adopted and used earlier in Europe [25].

AT&T, which was presumably concerned about competition with its own telephone lines, possibly holding back for this reason on installation of carrier-current systems over power lines, joined the fray in 1924 [26, 27]. Its system design used capacitor coupling, incorporated two-frequency duplex communications, and worked with the relatively low power of 50 W. Tests and measurements made on the Tallulah Falls–Gainesville 110 kV line of the Georgia Railway and Power Company showed the power line telephone system was highly reliable, with low initial cost, and required small maintenance charge. It was found to provide increased safety for operating personnel, as well as transmission quality and freedom from noise comparable to high-grade commercial telephone toll lines [27].

By 1927, as noted above, power line telephony had come of age and been widely adopted by power companies throughout the United States and Europe. It began to be used over longer, higher-voltage, and more complex systems, with multiple branch connections requiring multiple sets of communication gear. It began to be used for communication over larger interconnected systems as well. For example, the S. E. Power and Light system included Alabama Power, Georgia Power, Mississippi Power, and South Carolina Power, interconnecting 1000 mi of power line, with its power line communications system described as "one of the most extensive installations of power-line carrier equipment in the world" [28, 29]. New technology was introduced on some systems as well. GE, sticking to a single frequency for each channel of two-way transmission, adopted a system of "single-frequency duplex," in which speakers at each end of a connection were automatically switched on and off as required [11, 30]. In 1928 AT&T incorporated single-sideband (SSB) AM transmission into its power line carrier systems [31, 32]. In the SSB transmission scheme, only one of the two sidebands normally used in AM transmission is transmitted, halving the bandwidth required for transmission. The AM carrier-frequency signal is not transmitted as well, effectively reducing the power required by a factor of four. In addition, with the reduced bandwidth, less noise and interference were found to be introduced. The resulting system was more complex, however, since means had to be incorporated for re-introducing the carrier frequency at each receiving station. Pacific Gas & Electric, which had originally adopted a Fuller-designed carrier -frequency system [6, 8], was the first to adopt this newer type of system [32].

Throughout these years of introduction of carrier-frequency systems over power lines in the United States, GE and Westinghouse, the dominant manufacturers of these systems, competed head on, but, interestingly, with very different design solutions. We have already noted that GE, beginning with single-frequency simplex transmission systems, moved to "single-frequency duplex," but still with a bias toward a single frequency per channel of communication. Westinghouse consistently kept to duplex transmission, requiring two frequencies per channel. GE, in its various installations, tended to use lower powers than did Westinghouse, 50 W for the former as compared to 250 W for the latter. GE moved quickly to adopt capacitor coupling of its own design [16] once the problems of high voltage were conquered, while Westinghouse used both antenna and capacitor coupling, indicating that, for high voltage lines, "antenna coupling is in general to be preferred… [it is much safer and less expensive, while] for low-power lines, condenser [capacitor] coupling is cheaper." [33][7]

POWER LINE TELEPHONY REACHES MATURITY

By the end of the 1920s, power line telephony (or carrier frequency telephony over power lines or "wired wireless" over power lines, whichever term one wants to use) was essentially widespread throughout Europe and the United States. One estimate appearing in a 1929 Austrian journal indicates that 1000 systems had by then been installed throughout Europe and the United States, with most of the European systems installed in Germany [35]. The field had clearly reached a

[7] *Judged by today's standards, it is not clear how the paper of [33], published in the* Proceedings of the Institute of Radio Engineers *(IRE), got through the review process. It is a very lengthy paper, written by a key Westinghouse radio engineer and author or co-author of many of the papers and articles in both technical and trade journals of the period describing Westinghouse carrier-current over power line designs and installations. There are no references in the paper whatsoever, and it is clearly biased toward Westinghouse solutions without mentioning Westinghouse by name. In summarizing the state of the art, he notes there are three manufacturers of this type of system (presumably GE, Westinghouse, and AT&T, only in the United States), but with no names mentioned. He notes these three have different designs as to 1) power level, 2) number of frequencies per channel, 3) methods of providing duplex communication, 4) method of calling, 5) type of selector, 6) protective equipment, and 7) method of coupling. He notes two of the three manufacturers provide lower-power systems, but suggests high power (the Westinghouse approach) is to be preferred to provide for switching uncertainties and answer the noise problem. He notes the "two-frequency system [the Westinghouse approach] is the pioneer and still safest and best method of producing duplex communication." Continuing, he states "The superiority of the two-frequency duplex system soon drove out the [GE?] manually-operated single-frequency simplex system." "One company [GE?] still manufactures single-frequency simplex equipment, but [it] is [now] automatic simplex… [which is] not as flexible as the two-frequency systems nor as stable." Finally, "It is believed the two-frequency system will be finally adopted due to its superior stability and flexibility" On the other hand, GE could be considered guilty of biased marketing as well. In a much later (1934) article in a journal of the American Institute of Electrical Engineers (AIEE), a GE radio engineer argues that single-frequency systems are much more advantageous than two-frequency ones, and then states "for a large part of this communication field the use of a single carrier frequency per communication channel* has been conceded quite generally *[emphasis added] to have a number of inherent advantages over methods employing two frequencies per channel [i.e., the Westinghouse system]" [34].*

period of maturity. A comprehensive 1933 French paper provided details of the types of systems installed, focusing on differences in the European and U.S. designs [36]. It noted that capacitor coupling was now the preferred method of line coupling used in both areas of the world, although the types of capacitor and methods of installation adopted differed because of differing power line voltages, as well as lengths and configurations of lines in the two regions. (American systems tended to be of higher voltage, longer, and more complex.) The principal manufacturers of coupling capacitors in the United States were the Ohio Brass Company and GE; in Europe, they were Hermsdorf in Germany, and Electro-Ceramique and Porcelainerie de Lasquuin in France. The frequency bands adopted for communication ranged from 50 to 150 kHz in the United States, double that range in Europe. The American carrier frequency systems, designed and installed by the three manufacturers (GE, Westinghouse, and Western Electric for the AT&T systems), used two of the three power-line wires to carry the carrier communications signals. The European systems used, most often, a single wire plus ground return. (Of the four leading European manufacturers, three, Telefunken in Germany, Perego in Italy, and "la Haute Frequence" in France, built single-wire systems; the fourth, Deutsche Telefonwerke [DTW] in Germany, chose to build two-wire systems.) Why this distinction in design? The use of the two-wire system resulted in much lower attenuation of power, and hence was preferred for the generally longer power lines in the United States. The single-wire system was, however, cheaper to install and maintain, and resulted in less distortion of the signal as well. This 1933 paper noted, however, that two-wire systems might overtake single-wire systems in Europe, following the American path, as power line coverage and subsequent carrier frequency activities became more complex. In France, for example, two companies began to install two-wire systems, Thomson-Houston using GE equipment and Etablissements Kraemer using equipment under license from DTW. In addition, as the author of the 1933 paper noted, "last year (1932) American systems began to appear in Europe" [36].

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