THE ORIGINS OF CARRIER MULTIPLEXING: MAJOR GEORGE OWEN SQUIER AND AT&T

MISCHA SCHWARTZ, CHARLES BATCHELOR PROFESSOR EMERITUS OF ELECTRICAL ENGINEERING, COLUMBIA UNIVERSITY

EDITOR'S NOTE

In November 2007, ComSoc's Board of Governors approved the creation of the History Committee under the VP of Technical Activities and appointed Mischa Schwartz, our former President, to serve as the committee's first chair. IEEE Communications Magazine *launches the History Column this month to provide a forum for discussion among interested readers (see also http://www.comsoc.org/history). The History Column features articles authored by committee members and the technical community at large. This is the first article of a series that will appear in this column.*

ABSTRACT

George O. Squier, the inventor of the Muzak system, was the inventor as well, in 1910, of telephone carrier multiplexing, the forerunner of microwave frequency multiplexing after World War II, and its current incarnation as optical wavelength multiplexing. Squier was a Major in the United States Army Signal Corps at the time, later becoming Major General and Chief Signal Officer. His invention was initially rejected by AT&T engineers as not being commercially viable. This view was not shared by others in the engineering community, including John Stone Stone, a distinguished independent telephone engineer. After prodding by Stone, AT&T officials began a reappraisal of the "wired wireless" system, as Squier chose to call it, and by 1914 development of a commercial system, was underway. By 1918, however, when the AT&T system went into service, AT&T was claiming that Squier's's work had only been "suggestive" and that its system was based on inventions of its own engineers. We describe the sequence of events, beginning with Squier's invention, that led to the AT&T commercial rollout of carrier multiplexing. We also offer some possible reasons, based on archival documents, as to why AT&T downplayed Squier's invention.

INTRODUCTION

In this article we discuss the origin of telephone carrier multiplexing, the process of transmitting multiple signals over a common wire using a different frequency of transmission for each. Carrier multiplexing as such is an old idea. It was first considered by many investigators, including Alexander Graham Bell, working in the then relatively-new area of *telegraphy* in the 1870s. It wasn't until 1918, however, that the first commercial implementation of carrier multiplexing for *telephony* was introduced by AT&T in the United States. This system enabled five simultaneous conversations to be carried over a single pair of wires, thus improving telephone communications capability significantly. It was the forerunner of many more systems introduced over the years, including microwave frequency multiplexing systems developed after World War II and, in more recent years, optical communication systems capable of carrying literally thousands of "wavelength multiplexed" signals simultaneously over a single optical fiber.

Although AT&T introduced the first commercial carrier multiplexed telephone system in 1918, the first demonstration of a carrier multiplexed system was carried out by then Major George Owen Squier of the U. S. Army Signal Corps on September 18, 1910 in Washington, DC. This demonstration followed his investigations beginning in 1909 of the possibility of using wireless (radio) techniques for transmitting voice signals over telephone wires. We provide a summary in this article of the sequence of events transpiring between Squier's 1910 demonstration of carrier multiplexing and the beginning of commercially operated carrier multiplexed systems by AT&T in 1918. (It is of interest to note that Major Squier, with an electrical engineering Ph.D. degree from Johns Hopkins, went on to become a Major General and Chief Signal Officer of the U. S. Army. He is particularly known for his later invention of the Muzak system, major contributions to the aircraft industry, and other engineering activities and inventions, in addition to his invention of telephone carrier multiplexing.)

In his 1910 demonstration Squier transmitted two simultaneous analog voice signals over a single seven-mile-long private telephone circuit connecting a Signal Corps laboratory located within the U. S. Bureau of Standards with another Signal Corps laboratory at 1700 Pennsylvania Avenue. One signal was that of a normal telephone circuit conversation, commonly referred to today as being sent at baseband. The other signal was a modulated high-frequency signal, with the high-frequency carrier used in the experiments varying in frequency from 20 kHz to 100 kHz (then called kilocycles per second). Since the high-frequency signal used wireless techniques, Squier coined the term "wired wireless" to represent his method of carrier multiplexing . Four patents titled Multiplex Telephony and Telegraphy were issued to Squier on January 3, 1911, with the work being presented publicly as a paper read at the 28th Annual Convention of the American Institute of Electrical Engineers (AIEE) in Chicago, Illinois, June 28, 1911 [1]. Among the discussants of the article following its presentation was Dr. Frank B. Jewett, then an official with Western Electric and, years later, the first President of the Bell Telephone Laboratory. Jewett's assessment of the work was essentially negative. Although noting that the work was quite interesting, Jewett indicated he saw no great commercial value in it since the high-frequency attenuation of signals over telephone lines would be so great as to require enormous power for transmission. In addition, he noted there would be a number of other problems with introducing such a system into the commercial telephone plant.

Despite this negative assessment of Squier's work by a leading engineer at Western Electric, the manufacturing arm of AT&T, the Bell System did begin development of a carrier multiplexing system in 1914, with the work, as noted, leading to the introduction of commercial service in 1918. AT&T was particularly proud of this system, with then AT&T President Theodore N. Vail noting in a December 11, 1918 letter to U. S. Postmaster General Albert S. Burleson announcing the system that it would substantially increase the capacity of the telephone plant. In this letter, released to the press, Vail

(Continued on page 22)

Presented, IEEE 2004 History Conference. Bletchley Park, United Kingdom, August 2004. A more detailed version of this article, with full documentation, is available from the author.

0163-6804/08/$25.00 © 2008 IEEE

(Continued from page 20)

specifically lauded the technical staff of the Bell System for its "invention" and practical development of this work. Vail did mention Squier's contribution in this letter, but indicated that this earlier work was "suggestive" and one among many earlier attempts to develop multiplexing schemes.

The question arises, *did* the engineers of the Bell System *invent* this system of carrier multiplexing, or was it based on the earlier work of Squier? In providing a summary of the events transpiring between Squier's 1910 demonstration and the inauguration of the AT&T system in 1918, we address this question as well. Our conclusion, as we shall see, is that the work of engineers at the Bell System was strongly motivated by Squier's earlier work, despite Jewett's negative comments, noted above, and Vail's assessment that the Bell System carrier multiplexing activity was invented by Bell System engineers. The full degree of connection between Squier's work and the subsequent Bell System commercial service is difficult to assess based on documents currently available and studied, but a strong connection is there, as is made clear in the rest of this article.[1]

FROM THE SQUIER DEMONSTRATION TO THE AT&T IMPLEMENTATION

Dr. Jewett of Western Electric, who questioned the commercial value of Squier's work at the June 1911 AIEE convention, was already familiar with Squier's wired wireless invention, having the previous March attended a demonstration of the Squier system in Washington, DC. At that time Squier gave him a manuscript copy of a paper he had written on carrier multiplexing, essentially the same paper presented at the AIEE Convention. Jewett noted, in a follow-up thank you letter to Squier, that he would be investigating the commercial potential of superimposing carrier signals over telephone wires. His negative comments at the convention came as a result of this investigation. As indicated above, this negative assessment was due in part to the determination that extremely high attenuation would be encountered during transmission. It turns out that Jewett's assessment was unduly pessimistic, however, because he had, in his calculations, assumed very long telephone lines, hundreds of miles long, with the carrier frequencies chosen (50 kHz and 100 kHz) also relatively high at the time. Had he reduced the line lengths and incorporated lower frequencies in his calculations, as was subsequently done in the AT&T commercial system, the calculated power attenuation would have been reduced considerably. The use of repeaters was, in fact, being studied at the time, and Jewett himself had, in 1910, begun a search for an individual to carry out research into the repeater problem. H. D. Arnold was soon thereafter recruited for this purpose and was ultimately successful in developing an electronic repeater for telephone use [3]. It is thus surprising that Jewett, in investigating the commercial potential of carrier multiplexing, did not consider the use of repeaters for this application.

Jewett's negative comments about possible commercial use of the Squier "wired wireless" system were not shared by individuals outside the Bell System. A committee of distinguished engineers appointed by the Franklin Institute reported back favorably about Squier's experiments. This committee included, among others, John Stone Stone, an eminent engineer and inventor who had worked for the Bell System early in his career, had left that position to work independently on wireless systems, and, at the time of Squier's invention, was an AT&T consultant. It was Stone who succeeded in getting the Bell System to change its mind on the commercial prospects of Squier's invention of carrier telephone multiplexing and, through his prodding, got that organization to begin development of a multiplexing system.

Specifically, Stone first published a paper on carrier multiplexing in the October 1912 issue of the *Journal of the Franklin Institute*, some 15 months after Squier's conference presentation, in which he wrote very favorably about Squier's work [4]. He followed this paper by interesting John J. Carty, chief engineer of AT&T, in the possibility of carrier-current telephony, meeting with Carty and his engineers in November 1912. (At an earlier meeting with Carty in October, Lee de Forest had joined Stone in bringing to Carty's attention the possible use of de Forest's audion amplifier in telephony [3].) Stone conferred with Jewett as well on carrier telephony. As Stone noted some years later, "My Franklin Institute paper … and the conference I had with the telephone engineers … set the ball rolling. That was my ulterior motive in writing the paper…" [5] Some months later, in September 1913, E. H. Colpitts, a Western Electric engineer reporting to Jewett, carried out a study at Jewett's request on the Squier scheme (specifically named as such in Jewett's request memo) for multiplex telephony over a 150-mi circuit rather than the 500- and 1000-mi circuits originally studied by Jewett, and found the scheme at this much -shorter distance worth pursuing [6]. (Cost estimates were included, in addition to attenuation and power requirements.) By mid-December 1913, two and a half months after receiving Colpitts' study results, Jewett finally admitted he might have been wrong in his original negative comments on the commercial viability of Squier's system. He did this in a letter to a Bell System executive, following up by notifying John Stone Stone that a complete study of the Squier system was being carried out [7].

It is thus clear that Stone, pushing Squier's invention of "wired wireless" and the use of the audion in the commercialization of that system, got the Bell organization to finally begin development of a commercial carrier multiplexing system. Progress was rapid once Bell executives had become convinced of the viability of such a system: from January to March 1914, combined attacks were carried out by Bell engineers on the development of vacuum-tube-based modulators, receivers, and oscillators for both radio telephony and carrier multiplexing [7].

By fall 1914 an experimental vacuum-tube-based carrier-multiplexed telephone system carrying two simultaneous signals over a single circuit had been set up in the laboratory of R. A. Heising [7, 8]. Work on a version of this system suitable for trials over the telephone plant was begun in fall 1915. Laboratory testing was carried out first until early 1917, at which time field testing was begun. Commercial service between Pittsburgh and Baltimore began in 1918 using an expanded five-carrier system. Interestingly, Heising was, in a December 10, 1914, report on his laboratory work on carrier telephony, still referring to Squier's system by name. This and other references by Heising to "Squier's system" make it clear that the Bell engineers at the time of the initial development of carrier telephony at AT&T considered their work to have been based on Squier's earlier inventions.

The evidence thus seems to indicate that, despite Vail's assertion in his 1918 letter announcing the inauguration of commercial carrier-current service that the system was based on an AT&T invention, there was a strong tie between

(Continued on page 24)

[1] *It has been suggested that patent considerations played a strong role in the preparation of the Vail letter [2]. Squier had originally dedicated his patents to the public. He subsequently changed his mind after a ruling in November 1918 by the U. S. Army Advocate-General reassessing an 1883 act relating to inventions by officers of the government.*

(Continued from page 22)

Squier's "wired wireless" experiments and AT&T's subsequent move to develop a commercial system. Squier's work was not just "suggestive," as indicated in Vail's letter.

The obvious question now arises as to why Dr. Jewett was initially so negative about possible commercialization of Squier's "wired wireless" system, and why it took prodding from Stone to get Jewett and Carty interested to the point where they finally got engineers to first seriously study the parameters and cost of such a system, and then initiate a development project. The documents examined provide no definitive answer. Some plausible conjectures can, however, be made, based on a reading of documents appearing in the files of Lloyd Espenschied, a distinguished engineer working at AT&T during this period [7, 9]. One conjecture is the relatively common one of a company being reluctant to make use of devices or systems invented or developed by others. Another possibility is that the Bell System retrenchment and reorganization of 1907 during the Financial Panic of 1907 in the United States disrupted the technical operations and slowed down Bell innovations at the time. Technical leadership moved from Boston to New York, and the New York leadership was, for a time, more conservative in its outlook on new developments. This was the time when the J. P. Morgan interests in New York took over the operation of the Bell System. Vail was appointed President of AT&T, and headquarters moved as well from Boston to New York. Carey, chief engineer of the New York Telephone Company, was promoted to Chief Engineer of AT&T, and the technical departments in Boston were consolidated with those in New York. Espenschied lauds the accomplishments of the Boston laboratory before the move to New York. He states that ongoing experiments there might well have led them to the vacuum tube and the potentialities of deForest's tube. He writes that the new organization in New York became "obsessed with loading." He notes that it was not until 1911, four years later, that the work noted at the beginning of this section began in the New York laboratories on the vacuum tube repeater problem. His conclusion: the move to New York had disrupted the Boston activities, resulting in a late start on vacuum tube development. (Note that the latter part of this period is precisely the time during which Squier carried out, and reported on, his "wired wireless" activities.)

We are thus left with making our own judgment as to whether AT&T used Squier's inventions in developing its carrier multiplexing system for telephony. The evidence presented here indicates that there was, in fact, a strong tie between Squier's "wired wireless" experiments and AT&T's subsequent move to develop a commercial carrier multiplexing system. Squier's work was not just "suggestive," as indicated in the 1918 letter by Vail.

Interestingly, Squier's "wired wireless" invention was subsequently picked up by the power industry all over the world as the basis for power line telephony, the use of power lines instead of telephone wires to transmit telephone signals between power line stations [10]. The first installations of such a system took place in Japan in 1919 and in the United States in 1920. By the early 1930s, such systems for power line communications were widespread, with over 1000 systems installed worldwide.

REFERENCES

[1] G. O. Squier, "Multiplex Telephony and Telegraphy by Means of Electric Waves Guided by Wires," *Transactions AIEE*, vol. XXX, pt. II, Apr. 25–June 30, 1911, pp. 1617–65; discussion, pp. 1666–80.
[2] P. W. Clark, "Major George Owen Squier: Military Scientist," Ph. D. dissertation, Case Western Reserve Univ., Jan. 23, 1974.
[3] "A History of Engineering and Science in the Bell System, The Early Years, (1875–1925)," M. D. Fagen, Ed., Bell Telephone Labs., 1975, pp. 253–58.
[4] J. S. Stone, "The Practical Aspects of the Propagation of High-Frequency Waves Along Wires," *J. Franklin Inst.*, vol. CLXXIV, no. 4, Oct. 1912, pp. 353–84.
[5] Letter from J. S. Stone to W. R. Ballard, quoted in G. H. Clark, *The Life of John Stone Stone, Mathematician, Physicist, Electrical Engineer and Great Inventor*, Frye & Smith Ltd., 1946, pp. 42–43.
[6] "Multiplex Telephony — Squier Method," Correspondence from E. H. Colpitts to F. B. Jewett, Sept. 30, 1913, AT&T archives.
[7] L. Espenschied, *Vacuum Tubes as Telephone Repeaters: Correspondence, Memos, Articles, 1913–1952*, AT&T Archives.
[8] B. W. Kendall, "Carrier-Current Telephone Systems," *Bell Labs Record*, Dec. 1925, pp. 154–59.
[9] L. Espenschied, *Radio History, Audion: Correspondence, Memos*, 1913–1947, AT&T Archives.
[10] M. Schwartz, "Carrier-Wave Telephony over Power Lines, Early History," *IEEE 2007 History Conf.*, Newark, NJ, Aug. 2007.

BIOGRAPHY

MISCHA SCHWARTZ [LF] (schwartz@ee.columbia.edu) is Charles Batchelor Professor Emeritus of Electrical Engineering, Columbia University, where he was the founding director, in 1985, of the NSF-sponsored Center for Telecommunications Research. He is a member of the National Academy of Engineering, a Fellow of the AAAS, and a Fellow of the International Engineering Consortium. He is a Past President of the IEEE Communications Society as well as a former Director of the IEEE. His publications include 10 books and over 170 papers in communication theory and systems, signal processing, wireless systems, computer communication networks, and the history of communications. The awards he has received include the 1984 IEEE Education Medal, the Cooper Union Gano Dunn Medal for contributions to technology, the IEEE Edwin Armstrong Award for contributions to communication technology, the NYC Mayor's Award for excellence in technology, the Eta Kappa Nu Eminent Member award, and the 2003 Okawa Prize for contributions to telecommunications and engineering education.