Origins of Carrier Multiplexing-
Major George Owen Squier and AT&T

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Abstract

This paper discusses the connection between the invention of carrier telephone multiplexing by Major George O. Squier of the United States Signal Corps in 1910 and the AT&T commercial system developed during the period 1914-1918. Dr. Frank Jewett, a Western Electric executive at the time, initially concluded that Squier's system was not commercially viable. This view was not shared by others in the engineering community, including John Stone Stone, a distinguished independent telephone engineer. After much prodding by Stone, Jewett in 1913 requested a new analysis of the feasibility of the Squier system. By the end of that year, a complete study of the Squier system was underway in the Bell System, with Jewett questioning, in a note to an associate, whether he had been wrong in his original appraisal of the Squier system. AT&T development of its commercial system began shortly after, in 1914. By 1918, however, at the time its commercial system went into service, AT&T was claiming that Squier's work had only been "suggestive" and that its system was based on inventions of its own engineers. The conclusion of this paper, based on the points outlined above, is that there does exist a strong connection between Squier's inventions and the system put into service by AT&T, and that his work was not just "suggestive".

1. Introduction

The possibility of transmitting multiple signals over a common wire using a different frequency of transmission for each is an old idea. It was first considered by many investigators working in the then relatively-new area of telegraphy in the 1870s. It is, in fact, considered as one of the principal reasons Alexander Graham Bell first got involved with telecommunications: he began working on the possibility of transmitting multiple telegraph signals simultaneously over a single pair of wires using mechanical resonance to distinguish and separate the different signals.

Each frequency of transmission is defined as the *carrier* of the transmission, hence the term *carrier multiplexing* or combining of signals. (This term has come down to the current day when we talk of AM or FM carriers as being the frequencies at which these signals are transmitted.) But Bell was not alone in considering different frequencies or carriers to be used for transmitting multiple telegraph signals simultaneously. As noted, others had the same or similar ideas. This early work, both in the United States and Europe, is discussed in detail in a comprehensive 1921

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journal article on carrier multiplexing by Colpitts and Blackwell, members at the time of the technical staff, respectively, of Western Electric and AT&T [1].

It was then natural, once multiplexing for telegraphy was being investigated, to follow with proposals for carrier multiplexing of telephone signals. Reference is also made in [1] to a variety of proposals made for combining multiple telephone, as well as telegraph signals, on the same pair of wires using carrier multiplexing techniques. A number of patents were, in fact, issued in the early years of the 19th century on carrier telephone multiplexing, both in the United States and abroad. Four U.S. patents numbered 980,356-980,359 issued to the then-Major George Owen Squier of the U.S. Army Signal Corps on Jan. 3, 1911 and titled Multiplex Telephony and Telegraphy were probably the most prominent of these. (Squier later became Chief Signal Officer with the rank of Major-General.) Major Squier's patents followed his investigations on the possibility of using wireless (radio) techniques for transmitting voice signals over telephone wires beginning in 1909. By September 18, 1910 he had succeeded in transmitting two simultaneous voice signals over a single seven-mile-long private telephone circuit connecting a Signal Corps laboratory located within the Bureau of Standards with another Signal Corps laboratory at 1700 Pennsylvania Avenue [2]. 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/sec). Since the high-frequency signal used wireless techniques, Squier coined the term "wired wireless" to represent his method of carrier multiplexing [2].

This work of Major Squier was presented publicly as a paper read at the 28th Annual Convention of the American Institute of Electrical Engineers (AIEE), Chicago. Ill. June 28, 1911, and subsequently published as a paper in the Transactions of the AIEE [3]. (Squier was away on Signal Corps business at the time of the convention and the paper was read for him by another engineer.) Among the discussants of the paper 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 [4]. Although noting that the work was "beautiful…from a physical standpoint", Jewett went on to state that "as yet I have not been able to determine that the research…possess [sic] any great commercial value of possibilities." He then went on to quote some calculated attenuation figures for high-frequency transmission of signals over commercial telephone circuits indicating such high projected attenuation that the power required to transmit these signals would be enormous. "These figures show, I think, that the problem of applying a high-frequency method of transmission to an existing wire plant would be an exceedingly difficult one…" He further stated "I have not as yet been able to see how this difficulty can be overcome in a way that will admit this kind of system to the complicated requirements of a commercial telephone plant." Jewett, in his remarks, raised other issues as well negating the commercial applicability of this work, including possible problems of interference, the signaling required, problems with transmitting high-frequency signals in the presence of loading coils, etc.

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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. This work led to the introduction of commercial service in 1918. AT&T was particularly proud of this system, with the-then AT&T President, Theodore N. Vail, noting in a Dec. 11, 1918 letter to the Postmaster General, Albert S. Burleson, announcing this system that "it is possible to increase manyfold the message carrying capacity of long telephone and telegraph wires, especially of the open wire type." [5]. This letter was released to the press by the Post Office Department Office of Information the following day. The letter lauds the work of the technical staff of the Bell System in this endeavor, stating, just prior to the quotation above, that "after several years of intense effort, they have *invented* and developed a practical system of multiplex telephony and telegraphy" (emphasis added). 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? This is the question we address in this paper. 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 despite 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 will be made clear in the rest of this paper.

Before continuing with our analysis of the connection between Squier's earlier "wired wireless" work and the development of carrier multiplexing at the Bell System, it is worth looking further into Vail's letter to the Postmaster General. Note that, later in this letter, Vail does mention Squier's contribution, but indicates that Squier's earlier work was "suggestive", and one among many earlier attempts to develop multiplexing schemes: "From the earliest days of both the telephone and the telegraph, there have been almost numberless attempts by inventors, scientists, and engineers to develop methods for the multiplex transmission of messages...While heretofore no substantial practical results had been obtained not withstanding the efforts which have been directed to this problem, some proposals made by the earlier workers have naturally proved suggestive in the successful solution to this problem. I have in mind particularly a suggestion made by Major-General George O. Squier, Chief Signal Officer of the United States Army, about ten years ago and which at the time attracted very general attention." [5]. Paul Wilson Clark, in his doctoral thesis studying Squier's accomplishments throughout a long distinguished career as a military scientist/engineer [6], notes that there was a reason Vail wrote his letter when he did: Squier's four patents of 1911 had been "dedicated to the public". This dedication was, in part, due to an interpretation of the phrase "any other person in the United States" in an 1883 act relating to patents involving inventions by officers of the government. Squier's dedication, based on this Act, meant that any company could presumably engage in carrier multiplexing development without seeking the inventor's permission or paying royalties. The many patents issued during World War I to civilian scientists and engineers temporarily assigned to government work resulted in a reassessment of the 1883 Act. The Acting Judge Advocate General of

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the Army issued a ruling November 30, 1918 that the phrase above referred to any "like person in the United States", meaning a person working for the government [6]. (This ruling was subsequently confirmed by the Attorney General of the United States.) In particular, the Bell System's carrier multiplexing activities might then have fallen under the purview of Squier's patents. As Clark states, Vail, in his letter, "began laying the groundwork for a defense for any possible claim from Squier that the public dedication of 1910 [sic] patents did not apply to corporations or private individuals."[6] (Note that Squier's patents were issued in 1911. They were transmitted to the Patent Office in 1910.) We are concerned in this paper, however, principally with the years before these rulings interpreting the 1883 Act were made. In an Epilogue, we do discuss briefly the events leading up to a patent suit by Squier against AT&T in the early 1920s.

2. Evidence for strong connection between Squier's work and ATT system

As noted above, the then-Major George O. Squier of the US Army Signal Corps had successfully completed his experiments on carrier telephony multiplexing during September of 1910. As indicated, he was able to transmit two telephone calls simultaneously over a single seven-mile private telephone circuit, one a normal "baseband" call, the other transmitted by modulating a high-frequency carrier. The issuance of Squier's four patents covering his "wired wireless" system in January of 1911, including the statement that they were dedicated to the public, was announced to the press and was "attended by great fanfare and acclaim."[6] Dr. Jewett of Western Electric, in his lengthy comment at the AIEE Convention in June 1911 on Squier's paper, to which reference was made earlier, noted that "it was …with more than usual interest that *I commenced an investigation* of Major Squier's work in the early part of this year *at the time the newspapers first announced the issuance of his patents* and described in a general way the character of his discoveries. My investigation had for its object the determination of whether any of Major Squier's reported discoveries contained the germ of a speech transmission system that could be made commercially applicable in a general, universal telephone system" (emphasis added).[4, p.1666] We note that this is the first indication publicly that anyone at the Bell System had become aware of Squier's work, and had, as a result, begun looking into carrier multiplexing, following Squier's concepts, as a viable commercial possibility.

On March 2, 1911, a few months after the Squier patents were issued and announced to the press, Jewett attended a demonstration of the "wired wireless" system in Washington, DC [7]. Squier, at that time, gave him a manuscript copy of a paper on carrier multiplexing he had written that was later published as a Signal Corps report under the title Multiplex Telephony and Telegraphy, and was essentially the same as the paper read later in June at the AIEE Convention. Jewett returned the manuscript to Squier March 14 with an accompanying letter stating, in part, "…I have enjoyed the paper very much indeed and I am sure that the facts contained therein will be of great assistance to me in prosecuting our investigation of the commercial possibilities of super-imposing high frequency telephone and telegraph circuits on the ordinary telephone plant… I have not yet had time to fully digest all of the paper, and in view of your permission to make free use of the paper for anything connected with

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our work,… I (have had) portions of it transcribed for my own personal use." [7] Jewett's (negative) comments at the June Convention clearly represented the results of the investigation alluded to in this letter..

We note, as stated earlier, that a major reason for these negative findings on the possibility of commercial application of the Squier system was due to the calculation that extremely-high attenuation would be encountered with the transmission of high-frequency signals over telephone wires. Two later writers indicate that Jewett's calculations were incorrect [6], [8]. These writers are themselves wrong. Re-calculations by this author show Jewett's numbers were correct. Jewett's assessment was unduly pessimistic, however, because he had assumed, in his calculations, the use of extremely-long telephone lines. He focused on long-distance telephony, using, as examples of his calculations, no. 8 copper wire lines 1000 miles long, no. 12 copper circuits 450 miles, and no. 13 cable circuits 61 miles long. His calculations were carried out as well at the relatively high-frequencies of 50,000 and 100,000 Hz (cycles/sec at the time). It is true that power losses at these relatively-long distances and very high (for the time) carrier frequencies are inordinately large. But, for some unexplainable reason, he had neglected the possibility of using repeaters to reduce the length of the lines required. We note that signal attenuation increases exponentially with distance and roughly exponentially as the square root of the frequency used. Power attenuation, which goes as the square of the signal attenuation, is even much more critically dependent on distance and frequency of carrier transmission. Reducing the lengths of the circuits analyzed and incorporating much lower carrier frequencies in the calculations, as was subsequently done in the AT&T commercial system, would have reduced the power attenuation calculated tremendously.

The use of repeaters incorporating mechanical amplifiers was, in fact, being studied at the time within the Bell System for use with long-distance circuits [9]. Such amplifiers would not be appropriate for use at high frequencies, but Jewett himself, aware of the deficiencies of mechanical amplifiers, had initiated a search for a well-trained individual to begin studying the possibility of developing an electronic amplifier. In 1910, the year Squier applied for his patents and a year before the patents were issued, Jewett "told his friend Dr. Robert A. Millikan at the University of Chicago about the repeater problem and asked him to recommend a man…who could conduct research in the area." [10]. Millikan recommended H.D. Arnold, who was ultimately successful in developing an electronic amplifier for telephone use. It is thus inexplicable why Jewett did not consider, at the time of his investigation into the commercial potential of carrier multiplexing, the possibility of using repeaters for that application as well. (As we shall see shortly, this focus on long-distance circuits had changed by 1913, two years later.)

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, stating " These quantitative experimental results characterize Major Squier's work as a distinct contribution in the field…proving for the first time the practicability of the invention on a commercial scale…" [11] This committee included, among others, John Stone Stone, an eminent

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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. Stone counted among his earlier inventions a number pertaining to carrier telegraph multiplexing. The documents to be quoted in the material following show that 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 who, through his prodding, got that organization to begin development of a multiplexing system.

Specifically, in paper by Stone on carrier multiplexing, published October 1912 in the Journal of the Franklin Institute, some 15 months after the AIEE conference at which Squier's paper on carrier telephone multiplexing was presented, Stone wrote very favorably about Squier's work [12]. The paper begins with the paragraph "A new art has been born to us. The infant art of high-frequency multiplex telephony and telegraphy is the latest addition to our brood of young electric arts. It is certainly a most promising youngster and should, after the manner of its kind, call lustily for its share of attention and sustenance." Stone then went on to extol Squier's work, stating "The results of his [Squier's] labors are to demonstrate beyond a peradventure that not only Morse signals but speech may be transmitted over the ordinary telephone cable and pole line circuits and to very considerable distances by means of high-frequency electric currents or waves, and that a large number of telegraphic or telephonic messages may thus be transmitted simultaneously over a given telephone or telegraph circuit without interfering with each other through the use of electrically tuned or electrically resonant receivers." [12, p.354] Stone further went into detail on circuitry that might be utilized in practical implementations of carrier telephony systems, and suggested means of enhancing the commercial adoption of such systems. He indicated no special fear of attenuation to be encountered in such systems, the critical problem raised by Jewett at the AIEE conference the previous year, stating "In the new high-frequency system of telephony, *attenuation, though greater than in the older system* [i.e., ordinary "baseband"telephony], *brings with it no distortion whatsoever*" (emphasis in the original paper). [12, pp. 372, 373] Stone's only concern was that Squier's dedication of his patents to the public might retard progress, with companies not willing to enter a new field involving unrestricted competition [12, pp. 354, 355]. Commenting on this paper 10 years later in a letter to William R. Ballard, written in connection with the patent infringement suit brought by Squier against AT&T, Stone noted that he had, with the publication of this paper, "introduced into the new art all the fundamental features necessary to make it [wired wireless] a practical working system….It was this that made my paper something of a stumbling block in the path to patents of some of those who later undertook the commercial development of the art."[13]

It is in this same letter to Ballard that Stone describes his efforts in 1912 to get the Bell System to initiate work on commercial development of wired wireless. He notes, "I was awarded the Edward Longstreth medal for this paper, but what was much more to the purpose, *I succeeded, as I had hoped, through the publication of this paper in interesting Mr. Carty* [John J. Carty, Chief Engineer, AT&T] *in the carrier current system of multiplex telephony over wires…"* (emphasis added). [13]

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Stone then goes on in this letter to indicate that Carty invited him to his office "to discuss the possibility of this system with his engineers." He further notes that, at this meeting, he urged the use of the audion amplifier, "which I had but recently brought to Mr. Carty's attention, [removing] the last objection to the practicality of the carrier system of multiplex telephony over wires by overcoming the effect of enhanced attenuation."[13] (It is to be noted that Major Squier, in his wired wireless patents, stressed the use of the audion as a detector of the speech signals, although he did not mention the possibility of its use as an amplifier.)

Stone presumably had two meetings with Carty, the one mentioned above in the letter and an earlier one alluded to in the letter with Stone's comment quoted above on having "but recently brought to Mr. Carty's attention" the use of the audion amplifier. The earlier meeting is independently corroborated by the Bell Labs volume, "History of Engineering and Science in the Bell System (1875-1925)". [14] One finds there the statement "John Stone Stone…learned of experiments, made by de Forest in 1912, aimed at using the audion as an audio amplifier. Stone appreciated its amplifying abilities and, because of his background, had recognized its potential value in telephony. He and de Forest demonstrated the device as an amplifier to Bell officials on October 30 and 31, 1912…the telephone people were impressed with its possibilities and organized a project under H. D. Arnold to study its possibilities…"[14]. (This is the same Arnold referred to earlier as having been recruited by Jewett to develop an electronic amplifier. As noted earlier, he was successful in this endeavor. Vacuum tubes were successfully demonstrated over commercial telephone circuits less than one year later [14].)

Stone's meeting with Carty and his engineers thus presumably took place in November of 1912, following the earlier meeting the end of October at which de Forest was present. Either at this November meeting, or at a subsequent one later in November, Stone conferred with Jewett as well on carrier multiplexing. For, again quoting from the letter to Ballard, we note Stone writing "My conference with Mr. Jewett in November 1912 did not result in Mr. Carty's staff immediately accepting the practicability of the carrier system, though it did accept my estimate of the importance and utility of the audion amplifier which I was also urging upon his attention. My Franklin Institute paper, however, and the conference I had with the Telephone engineers in connection with its subject matter [carrier multiplexing], set the ball rolling. That was my ulterior motive in writing the paper, and particularly for including in it so much of a new and practical character." [13]

John Stone Stone was ultimately successful in getting the Bell System interested in pursuing Squier's work on carrier multiplexing. A detailed memo from E. H. Colpitts to Jewett, then Assistant Chief Engineer at Western Electric, dated September 30, 1913, and entitled Multiplex Telephony- Squier Method, describes the results of a detailed analysis of the Squier method [15]. (Colpitts was the Western Electric engineer who, some years later, co-authored the journal paper on carrier telephony mentioned earlier.) The memo was prepared in reply to an earlier memorandum from Jewett, written September 17, asking Colpitts to carry out a study of Squier's scheme for multiplex telephony over a non-loaded 150-mile circuit using #12 gauge wire [15]. Note that the Squier scheme was specifically referred to as such in this memo. Jewett had thus, by this time, 10 months after the discussions with

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Stone, presumably reconsidered his original objections to Squier's work, and asked for new calculations of attenuation and power requirements of a carrier-multiplexed telephone circuit. As noted, these calculations were to be carried out for a #12 gauge circuit 150 miles long, not one 1000 miles long, one of the examples used by Jewett at the 1911 AIEE conference in concluding that Squier's scheme, although interesting from a research point-of-view, was not commercially feasible. As noted earlier, the difference between assuming a 1000 mile-long circuit and a much shorter-one 150 miles in length leads to dramatically-different attenuations and consequent power requirements for the system. Colpitts' memo goes on to provide detailed tables and curves of the attenuation and power requirements for a 150 mile-long circuit at carrier frequencies ranging up to 145 kHz (periods per second in Colpitts' terminology). The memo includes as well cost estimates for a system carrying 20 two-way transmissions. This proposed system would incorporate filters just recently designed at the time by George Campbell of the Bell System. (Campbell's filters were ultimately incorporated in the AT&T carrier multiplexing system noted earlier that was introduced commercially in 1918. They provided much better discrimination between multiplexed signals than did Squier's method which relied on simple resonance phenomena at different carrier frequencies, allowing more carriers to be sent simultaneously over one circuit. Colpitts, in his cost calculations, did, however, project the use of arc generators, much less effective, albeit considerably less costly, than the high-frequency alternator used by Squier in his experiments. The 1918 commercial system used vacuum-tube transmitters.)

By mid-December of 1913, 2 1/2 months after Colpitts' September 30 memo had been sent to Jewett, the latter finally admitted he might have been wrong in his original negative comments about the commercial viability of Squier's system. Lloyd Espenschied, a distinguished Bell Labs engineer, writing many years later to a Mr. W. Fuller, notes that on December 10, 1913 Jewett wrote a letter to Ghirardi [a Bell System executive] in which he specifically raised the question as to whether they had been wrong in assuming the Squier system was not one with commercial possibilities. In that same letter, quoted by Espenschied, Jewett proposed seeking John Stone Stone's advice on the matter. Espenschied continues by further noting that, on December 22, two weeks after sending the Ghirardi letter, Jewett did tell Stone that a complete study was being made of the Squier system (again mentioned by name). Espenschied's conclusion, in this memo to Fuller, was that Stone had been very influential in getting the Bell System to actively begin work on high-frequency-telephony [16, p.5]. (It is to be noted that Espenschied had been with the Bell System for many years at the time of his writing, having joined the company in 1910, and had personally participated in the AT&T development of carrier multiplexing beginning in 1914. He was among the Bell engineers singled out by T. N. Vail for their contributions to the success of the AT&T carrier multiplexing system in the 1918 letter to the Postmaster-General A. S. Burleson cited earlier in this paper.)

Espenschied, in the same memo to Fuller, provides further evidence of the decisive influence of Stone on the decision by AT&T to begin development of a carrier multiplexing system. He notes that Stone had begun as early as 1892, while working at the Bell engineering laboratory in Boston, to carry out experiments on the possibility of applying high-frequency transmission to telephony, using both wire and

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radio. He indicates that Stone maintained an interest in high frequency transmission all his life, and that, in 1912, Stone, now working independently, brought the de Forest audion to the attention of Bell personnel, as well as converting them into belief in high-frequency telephony using wires [16, pp1, 2]. Later in this memo, Espenschied refers to a November 5, 1913 IRE (Institute of Radio Engineers) meeting at which de Forest demonstrated the use of the audion as a detector and amplifier. In the discussion following, the use of an audion as an oscillator was also proposed. Espenschied further says that it was at this meeting that Stone noted that any problems with the telephone repeater and "wired wireless" (by name) would be solved using the audion. Espenschied comments that it was probably Stone's remarks at this meeting, as well as subsequent confirmation of them to Jewett, "more than any one other factor", that resulted in AT&T's decision in 1914 to begin development of vacuum-tube-based carrier current telephony [16, p.5]

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-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. [16, pp.5, 6] By the Fall of 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. [16, p.6], [17]. Work on a version of this system suitable for trials over the telephone plant was begun in the Fall of 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.[17] This is the system described in the Vail letter referenced earlier.

Interestingly, Heising was, in a December 10, 1914, report on his laboratory work on carrier telephony, still referring to Squier's system by name. Heising's report has not been found in the AT&T archives, but it is referenced in a one-page note prepared in 1944 by Espenschied as part of his historical study of Bell System work in radio and carrier telephony [18]. The Filing Subject of Heising's report, as reported in Espenschied's note, is given as "Squire's [sic] System of Telephony (crossed out and made) High Frequency Telephony". A summary of the report follows the Filing Subject in this one-page note and describes the work being carried out in the laboratory as designed to investigate certain issues arising in determining the practicality of Squier's high-frequency "wired wireless" system. (This summary has, within it, the phrase "the practicability of (the Squire [sic] system of high frequency telephony, crossed out) high frequency telephony 'wired wireless' …". It is thus apparent that someone had, after the fact, attempted to expurgate reference to Squier in both the Filing Subject listing and the report summary, although Squier's name for carrier telephone multiplexing, "wired wireless", was left unchanged! Who did this is not known. It clearly wasn't Espenschied. He was simply copying the references as he saw them. It was noted earlier that Squier did later sue AT&T for patent infringement. More will be said about this later, but these efforts to eliminate any

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reference to Squier and his system may have occurred during the patent litigation in the early 1920s,or even earlier, at the time of the Vail letter.) These 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 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 some of the documents appearing in Lloyd Espenschied's files available in the AT&T archives [16], [19]. One conjecture is the relatively common one of a company being reluctant to make use of devices or systems invented or developed by others. For example, reference [19] includes a document from July 6, 1944 labeled "An Early Touch of Multiplexing, and Introduction to the Mercury-Vapor Tube, in 1905-07 (As shown by Correspondence in Boston Black File 139, Entitled Multiplex Telephony)". This document summarizes GE's attempt, beginning in 1905, to interest AT&T in mercury arc rectifier tubes for use with telephone repeaters. The telephone engineers had difficulty using them. GE personnel offered to help. The experiments did not work out. A letter sent May 11, 1907 from the AT&T Chief Engineer to the GE inventor of the tube concluded that the system would not prove of commercial value, at least in its form at that time. Espenschied notes that the letter bore the initials FBJ of the drafter of the letter, i.e. Jewett. The same document by Espenschied continues by describing the attempt at that time by Peter Cooper Hewitt to interest the Telephone Company in the mercury vapor tube as an amplifier. Espenschied comments that here were two cases in which the use of vacuum tube devices for solving the telephone repeater problem had, by 1907, been called to the attention of telephone engineers [19]. Two handwritten letters by Espenschied accompany this document. One to a Thomas Shaw, written December 11, 1944 comments, in a seemingly ironic way, at how many new "gadgets and systems" had been "thrown at us and… successfully… resisted." He notes this was particularly true of F.B.J. [Jewett]. The second letter, to R.W. King and dated December 18, 1944 (but with a filing date of Dec. 11!) indicated that in 1906 GE had told Bell personnel of the need for the Bell System to hire a scientist experienced in mercury vapor tubes. Espenschied then notes that it wasn't until 1911 that action was taken. What accounted for this delay in such a "formative period"? Espenschied comments that it looked as if the retrenchment and the move to New York during that period (see below) caused disruptions more than was recognized [19].

The reference to retrenchment and move to New York in the letter to King provides a second conjecture as to why Jewett was overly conservative in dismissing Squier's invention as not of commercial interest. Espenschied in reference [16] refers at some length to the Bell System retrenchment and reorganization of 1907 during the Financial Panic of 1907. These changes clearly disrupted the technical operations and played a significant role in slowing down Bell innovations at the time. Technical leadership moved from Boston to New York. The New York leadership was, for a

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time, more conservative in its outlook on new developments. Espenschied notes how the American Bell Company based in Boston over-expanded and found itself in need of refinancing just as the Panic of 1907 set in. The Morgan interests in New York took over the operation of the Bell System. Vail was appointed President of AT&T, and headquarters moved 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 moved to New York. Espenschied goes on to laud the accomplishments of the Boston laboratory before the move to New York. He states that the experiments there on spark and arc discharges, as well as mercury vapor tubes, might well have led them to the vacuum tube and to the potentialities of deForest's tube. He writes that the new organization in New York group became "obsessed with loading." He notes that it wasn't until 1911, four years later, that serious work 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 [16, pp.2,3]. (Note that the latter part of this period is precisely the time one during which Squier carried out, and reported on, his "wired wireless" activities.)

3. Epilogue

We noted earlier that Theodore Vail's 1918 letter to the Postmaster-General announcing AT&T's successful introduction of commercial carrier multiplexing was presumably designed to position AT&T as the inventor of such a system following the Advocate-General's ruling on the 1883 Act. The implication was that, under this ruling, Squier's "public dedication" of his 1911 patents did not apply to private individuals or corporations such as AT&T. It is not clear exactly when, but some time afterwards, Squier did decide to assert his rights as the inventor of carrier telephone multiplexing: In a January 22, 1919 letter to his New York attorney, R. Randolph Hicks, concerning sale of his Canadian multiplexing patent, Squier was still stating that in the United States he had given his patents to the public [20]. But several months later, in March of 1919, we have Hicks, in a letter to Squier, commenting that it seemed peculiar that AT&T was claiming its carrier multiplexing system was different from Squier's invention, while Western Electric, a part of AT&T, was buying rights to Squier's multiplexing patent taken out in England [21]. (It is to be noted that Squier obtained patents on his invention in England, Mexico, Canada, Sweden, Italy, and France. Western Electric was among the companies licensed to sell his multiplexing equipment in England. From 1912-1914, Squier carried on protracted negotiations with AT&T to purchase some of his foreign patents. AT&T finally decided negatively [22].)

Whether the AT&T claim to which reference is made in the March 1919 letter from Hicks is based on the Vail letter, or to discussions with AT&T, is not clear. But an October 15, 1919 letter from Hicks to Squier makes clear that by that time Squier was insisting AT&T was infringing his patents [23]. In that letter Hicks indicates he had met with an AT&T attorney with respect to Squier's patent (which one is not indicated), that the talk was unsatisfactory, and AT&T was only willing to settle on a

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"nuisance basis", offering $15,000. Hicks noted he had turned that offer down, but had indicated a willingness to meet to come to some kind of compromise. Hicks further noted that the AT&T lawyer had stated Squier was not the originator of the AT&T system and that there were patents antedating those of Squier. Hicks then went on to suggest to Squier the desirability of bringing suit as soon as possible, which would, in turn bring further negotiations. Squier's response to Hicks was to go ahead with a suit. He also noted that GE might be interested in purchasing the rights to "wired wireless". In a letter two weeks later from Squier to Hicks, Squier indicated that Carty, now a Vice-President of AT&T, would take personal charge of negotiations. There then followed a period of on again-off again negotiations, with Squier and his attorney expressing concern about the delays [16]. Finally, in November, 1921, AT&T & Squier came to an agreement that Squier would initiate suit against AT&T on the basis of infringement of his patents. This would decide, in court, the validity of Squier's claims. AT&T, in this Memorandum of Agreement, agreed to pay Squier $100,000 to initiate the suit, plus an additional $750,000 if it lost in court [16]. The validity of Squier's claims was, however, never decided by the court. The court, instead, ruled that, by dedicating his patents to the public, he had given up all rights to them. This decision was upheld on appeal [24].

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.

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[1] E. H. Colpitts and O.B.Blackwell, Carrier Current Telephony and Telegraphy, Journal AIEE , vol. 40, no. 4, April 1921, 301-315; no. 5, May 1921, 410-421; no. 6, June 1921, 519-526.

[2] The Invention of "Wired Wireless" Telephony and Telegraphy, Sept. 30, 1910, Extract from Laboratory Note Book of Major George O. Squier, Signal Corps, Washington, D.C., period November 18, 1909 to September 15, 1911, George Owen Squier Collection, Bentley Historical Library, University of Michigan. *Note:* All subsequent references to this collection will be labeled Bentley Library Collection.

[3] George O. Squier, Multiplex Telephony and Telegraphy by Means of Electric Waves Guided by Wires, Transactions AIEE, vol. XXX, pt. II, April 25-June 30, 1911, 1617-1665; discussion, 1666-1680.

[4] ibid., 1666-1672.

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[5] Letter from T.N. Vail to A.S. Burleson, Dec. 11, 1918, in Signal Corps Collection, National Archives and Records Administration, College Park, MD, Federal Records RG 111.2.4, "Miscellaneous Records: papers relating to the lawsuit of Gen. George O. Squier against the American Telephone and Telegraph Company, 1903-1923".

[6] Paul Wilson Clark, Major George Owen Squier: Military Scientist, Ph. D. dissertation, Case Western Reserve University, January 23, 1974. (Made available to this author by the Academy Library, USAF Academy, Colorado.)

[7] Reference appears in trial brief: United States District Court, Southern District of New York, In Equity 23-211, George Owen Squier, Plaintiff, vs. American Telephone and Telegraph Company, Defendant, Defendant's Brief on the issues of Dedication, etc., Jan. 3, 1924. Obtained from AT&T archives.

[8] C.A. Culver, Guided-Wire Telephony, Journal of the Franklin Inst., Vol. 191, No. 3, March 1921, 301- 328.

[9] "A History of Engineering and Science in the Bell System, The Early Years (1875-1925)", M. D. Fagen ed., Bell Telephone Laboratories, 1975, 253-256.

[10] ibid., 256, 258.

[11] Paul Wilson Clark, op.cit., 189. Squier, himself, in a September 17, 1914 letter to John Waterbury, an AT&T Director, refers to this committee report, and dates it as June 5, 1912. (Bentley Library Collection)

[12] John Stone Stone, The Practical Aspects of the Propagation of High-Frequency Waves Along Wires, Journal of the Franklin Inst., Vol. CLXXIV, No. 4, Oct. 1912, 353- 384.

[13] Letter from John Stone Stone to William R. Ballard, quoted in George H. Clark, "The Life of John Stone Stone, Mathematician, Physicist, Electrical Engineer and Great Inventor", Frye & Smith Ltd., 1946, pp. 42, 43.

[14] "A History of Engineering and Science in the Bell System", op.cit., 260, 261.

[15] Multiplex Telephony- Squier Method, Correspondence from E. H. Colpitts to F. B. Jewett, September 30, 1913, from File Case 200670-2, Vol A, AT&T archives.

[16] Lloyd Espenschied, Criticism of the draft Aladdin, Inc., by Milton Silverman, Case 37014, memo to Mr. W. Fuller, 27 November 1946-1400-LE-JD. In Lloyd Espenschied, Vacuum Tubes as Telephone Repeaters, Correspondence, memos, articles, 1913-1952, Box 60-09 03 07, AT&T Archives. *Note:* It has not been possible to locate Jewett's letter to Ghirardi, referred to as being in File 20067-B.

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[17] Burton W. Kendall, Carrier-Current Telephone Systems, Bell Labs Record, Dec. 1925, 154-159.

[18] Lloyd Espenschied, Initiation of Bell Systems Work in Vacuum Tube Radio and Carrier Telephony, 18 November 1944, Heisings' Reports of 1914 filed in D-200670, "Wireless Telegraph and Telephone Matters", 2. Case Subject: Wireless Telephony, Report No. 12751, Case D-1097, Filing Subjects: Squire's [sic] System of Telephony (crossed out and made) High Frequency Carrier Telephony. In Lloyd Espenschied, Radio History, Audion, Correspondence, Memos, 1913-1947, Box 60 09 03 05, AT&T Archives.

[19] Lloyd Espenschied, Radio History, Audion, Correspondence, Memos, 1913- 1947, Box 60 09 03 05, AT&T Archives.

[20] Letter from George. O. Squier to R. Randolph Hicks, January 23, 1919, Bentley Library Collection. See also reference [6] above.

[21] Letter from R. Randolph Hicks to George O. Squier, March 26, 1919, Bentley Library Collection. See also reference [6].

[22] See letters August 28, 1914 and Sept. 17, 1914 from Squier to John J. Waterbury, an AT&T director, and from Waterbury to Squier, Dec. 29, 1914, Bentley Library Collection. In the Sept. 17 letter, Squier notes that negotiations with AT&T began in 1912.

[23] Letter from R. Randolph Hicks to George O. Squier, October 15, 1919, Bentley Library Collection.

[24] Opinion, George Owen Squier, Plaintiff-Appellent vs. American Telephone & Telegraph Company, Defendant-Appellee, United States Circuit Court of Appeals, May 18, 1925.

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