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From inspecteur to ingénieur: telegraphy and the genesis of electrical engineering in France, 1845-1881

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From *inspecteur* to *ingénieur*:

Telegraphy and the genesis of

electrical engineering in France, 1845-1881

by

Andrew J. Butrica

A Dissertation Submitted to the

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INTRODUCTION

The first international electrical exhibition took place in Paris in 1881.[1] Held under the auspices of the French Ministry of Posts and Telegraphs, the Paris International Electrical Exposition and Congress of Electricians, as it was called, served as an arena for competition in the electrical industry[2] and as a local starting point for electrical engineering. Although not formally founded until 1884, the French electrical engineering organization, the Société internationale des Electriciens, began as a consequence of the Exposition and Congress.[3] According to the British electrical engineer A. P. Trotter, moreover, "electrical engineering was born" at the 1881 Paris Electrical Exposition, "a lusty child of science and machinery".[4] The real "star" of the Paris show, and what Trotter likely intended as "electrical engineering," was electrical illuminating technology, although many other electrical technologies figured among the expositions stalls, including telephones, electric motors, batteries, signalling systems, and electromedical apparatus. As the noted British electrical expert William Henry Preece pointed out, while the Paris Exposition and Congress marked "an epoch in the history of the practical applications" of electricity, "it was, however, as an exhibition of electric lighting that it was principally attractive".[5] Albeit that the Exhibition and Congress may have served as its birthplace, "electrical engineering," however understood, like any historical phenomenon, did not spring, Athena-like, fully formed from the Paris Exposition, nor from electrical lighting. Some thing or things else provided Trotter's "lusty child" with a gestation period.

The chief "something" was telegraphy, as is clear from an examination of several electrical engineering societies' memberships. For example, the founding members of the British Institution of Electrical Engineers, originally called the Society of Telegraph Engineers, were people involved primarily in telegraphy.[6] Similarly, in the United States, 21 of the 25 founding members of the American Institute of Electrical Engineers were associated with telegraphy, the society's first president being also the president of Western Union.[7] A look at the founders of the French Société internationale des Electriciens also reveals the extensive part played by telegraph people in France.[8] The presence of so many individuals involved in telegraphy among the founding members of electrical engineering societies suggests, to extend Trotter's metaphor, that the "birth" of electrical engineering received considerable "obstetric" assistance from telegraphy. Given the importance of telegraph people in founding electrical engineering societies, what, then, were the "telegraphic origins" of electrical engineering?

As the country whose Ministry of Posts and Telegraphs hosted the 1881 International Electrical Exposition and Congress where, according to Trotter, electrical engineering was "born," France offers an appropriate place to begin the search. Those members of the French telegraph industry who participated in the 1881 Electrical Exhibition and who founded the Société internationale des Electriciens generally consisted of employees of the state Telegraph Administration and telegraph instrument manufacturers. An examination of the genesis of electrical engineering necessarily must begin with them and include the education and training of telegraph agents and manufacturers, telegraph technologies and techniques and their relationship with electrical theory, the development and application of telegraph theory and the means for diffusing telegraph knowledge, the adaptation and creation of institutions associated with telegraphy, and the contribution of telegraphy to the emergence of electrical industry in general.

Before telegraph people and the technologies, theories, and institutions associated with them could develop, the electric telegraph had to come to France. The introduction of the electric telegraph into France, then, is the logical starting point of a search for electrical engineering's "telegraphic origins". The construction of an extensive network of telegraph lines and stations made possible the establishment and growth of a telegraph manufacturing industry. Initially a monopoly, telegraph manufacturing developed into a competitive enterprise with the state's commitment to a large-scale telegraph network. The infiltration of telegraph manufacturers into other electrical technologies, notably lighting and telephony; the emergence of spinoff industries, such as electrical signalling and braking systems for railways and electric doorbells for domestic, government, and business use; and the establishment of a company devoted virtually exclusively to the development and manufacture of electrical apparatus necessarily form a part of any study of the electric telegraph industry. Too, the institutional relationships of the telegraph industry deserve attention, especially but not solely those relations with the Telegraph Administration, the Paris Academy of Science, and the Society of Encouragement for National Industry. The education and training of telegraph manufacturers, especially the role of "grandes écoles" like the Ecole polytechnique and the Ecole centrale, also form a part of this investigation into electrical engineering's beginnings.

The employees of the Telegraph Administration also played an important role in the "telegraphic origins" of electrical engineering. While the shift from a mechanical to an electric telegraph raised questions about "technological unemployment" and the effect of technology on the workplace, it necessarily led to the institution of a corps of electric telegraph agents who, one day, would organize the 1881 Paris International Electrical Exhibition and Congress of Electricians. Electric telegraphy demanded the existence of a corps of inspectors who would understand and manage the telegraph network. For this corps, the Telegraph Administration drew initially upon graduates of the Ecole polytechnique, thus assuring the reliance of telegraph practice upon science-educated agents. Eventually, the telegraphs drew more and more upon its own operators to fill these positions. Concomitant with these changes was the reorganization of the network that centralized traffic in a few lines. Centralization was possible, however, only with science-educated individuals in key administrative positions (the inspectors) overseeing the work of highly-skilled, highly-trained operators manipulating sophisticated, high-speed apparatus, while the great number of lines, carrying a lighter traffic load, depended upon part-time employees working simple instruments. The education and training of skilled operators and inspectors, then, forms part of the telegraph story, since their education and training were so essential for the organization and operation of the telegraph network and from the ranks of the operators came many telegraph inspectors.

Any investigation of the start of electrical engineering must include the development and application of telegraph theory as well as the means for the diffusion of telegraph knowledge. The means for the diffusion of knowledge includes such verbal modes as classroom lectures and textbooks and telegraph and other journals as well as nonverbal methods. The specific application of theory to practice, such as in the design of a particular instrument, and the investigation of theoretical questions by telegraph manufacturers and agents of the Administration deserve particular attention. The close relationship between manufacturers and scientists and the transfer of knowledge from mathematical physics to telegraph practice also demand study. Finally, the creation of a special position within the Telegraph Administration to undertake investigations into telegraph technology and the improvement of technology with theory falls into the realm of this examination of electrical engineering's genesis.

In carrying itself to the 1881 Paris International Electrical Exposition and Congress of Electricians itself, this study concludes with the organization and execution of the exhibition, which took place within the context of a battle between privately-employed civil engineers and graduates of the Ecole polytechnique working for the state, a battle that provided the framework for the organization of the Ecole supérieure de Télégraphie in 1878 and the development of French electrical engineering after 1881. The penetration of Ecole polytechnique graduates into the electrical industry, including lighting, railway signalling, and telegraph instrument manufacturing, and the hiring of telegraph inspectors by private firms provided the background to the complaints voiced by civil engineers, largely graduates of the Ecole centrale, that the polytechnicians were increasingly taking positions in business while the state continued to hire exclusively from the Ecole polytechnique. Significantly, in the midst of this battle, the telegraph and postal administrations joined. Telegraph inspectors' objections to fusion, especially their argument that telegraphy demanded "special knowledge" that only they possessed; the creation of a "*grande école*" of telegraphy; the adoption of the title "*ingénieur*", i.e., moves that made the telegraph inspectors more than ever resemble the civil engineers of the Corps des ponts et chaussées, also form part of the story. Finally, before the private engineers could execute their planned exhibition of electrical industry, the Ministry of Posts and Telegraphs, placing telegraph agents and manufacturers in charge, put together an international electrical exhibition and congress, which, according to A. P. Trotter, became the "birthplace," of electrical engineering.

FOOTNOTES

[1]As far as I have been able to determine, no complete secondary account of these expositions exists, with the exceptions of François Caron and Christine Berthet, "Réflexions à propos de l'exposition de Paris de 1881," Bulletin d'histoire de l'électricité 2 (1983): 7-18; Patrice A. Carré, "L'exposition internatinale d'électricité de 1881 à travers quelques textes," ibid., pp. 63-84; and Jane Mork Gibson, "The International Electrical Exhibition of 1884 and the National Conference of Electricians: A Study in Early Electrical History," M.A. Thesis, University of Pennsylvania, 1984. Nonetheless, it is possible to identify both international and local electrical exhibitions of the late nineteenth-century and discover useful accounts of them in such electrical journals as La Lumière électrique.

[2]François Caron and Christine Berthet, "Electrical Innovation: State Initiative or Private Initiative? Observations on the 1881 Paris Exhibition," History and Technology 1 (1984): 307-318.

[3]See the speech to this effect by the Society's president, Georges Berger, upon the first formal meeting of the Society Bulletin de la Société internationale des Electriciens 1 (1884): 24-27.

[4]Thomas P. Hughes, Networks of Power: Electrification in Western Society, 1880-1930 (Baltimore: The Johns Hopkins University Press, 1983), p. 50. Also cited in Caron and Berthet, p. 308. For biographical information on Trotter, see Stanley Steward, "The Astonishing Career of A. P. Trotter," Electrical Review 215 (1984): 27.

[5]William Henry Preece, "Electrical Lighting at the Paris Exhibition," Van Nostrand's Engineering Magazine 26 (1882): 151.

[6]For a history of the I.E.E., see Rollo Appleyard, History of the Institution of Electrical Engineers, 1871-1931 (London: Institution of Electrical Engineers, 1939) and Percy Dunsheath, A History of Electrical Power Engineering (Cambridge, Mass.: M.I.T. Press, 1962), pp. 319-332.

[7]Donald McNicol, "Telegraph Men Founders of A.I.E.E." Electrical Engineering 53 (1934): 675 and A. Michael McMahon, "Corporate Technology: The Social Origins of the American Institute of Electrical Engineers," I.E.E.E. Proceedings 64

(1976): 1385.

[8]The Société internationale des Electriciens had a rather eclectic composition, both from the point of view of nationalities (such as the United States and Japan) and occupations (like military pharmacist and retired naval officer) represented. Nonetheless, many of the members were French and, of the French members, most were associated with either telegraph manufacturing or service as discussed in Chapter 8. The Maison Breguet, in particular, provided some of the most prominent members: Georges Berger, _administrateur délégué_ of the Maison Breguet and president of the Société and Gaston Sciama, _directeur_ of the Maison Breguet and one of the Société's six secretaries. See "Comité d'administration" and "Liste des membres fondateurs" _Bulletin de la Société internationale des Electriciens_ 1 (1884): 22-24 and 33-63.

CHAPTER ONE

The Mixed Network, 1845-1855

Before electrical engineering could emerge from telegraphy, there had to be telegraph lines, technology, and people. Complicating the development of telegraphy in France was an extensive semaphore network that crisscrossed the French countryside and that dated from the eighteenth century. Out of a desire to keep the semaphore operators, a "mixed system" of semaphores and electric telegraphs existed between 1845 and 1855. The technology adopted on the electrical lines imitated the semaphores in order to avoid retraining the semaphorists and to facilitate the transfer of personnel from the semaphore to the electric telegraph lines. Nonetheless, the electric telegraph necessarily altered the duties and responsibilities of those charged with sending signals and, for the most part, semaphore operators either found other jobs or retired rather than transfer to the electrical service. In contrast, the hiring of inspectors reflected the need for change from the beginning. The science-trained graduates of the Ecole polytechnique became inspectors on the electrical lines in large numbers between 1845 and 1854 and formed the foundation of the French electric telegraph corps for decades to come.

The erection of the first electrical telegraph line came as an experimental solution to the problems of the semaphore. The French semaphore was that invented by Claude Chappe (1763-1805).[1] Completed in 1794, the first line connected Paris with Lille. By 1845, four other routes stretched from Paris, linking the capital with 29 cities through a network of 534 semaphore stations.[2] The semaphores served the country well until 1841, when the network began to show signs of strain. User demand had grown beyond the system's capacity, which weather and night severely restrained. As one member of the Chamber of Deputies pointed out, the telegraph had grown too important to rest inactive half the time.[3]

The dark of night and meteorological conditions such as fog and wind often prevented operation of the semaphores and, compared to twelve years earlier, traffic had increased sixfold by 1842.[4] In 1838 and 1841, the Chamber of Deputies funded revisions of the signal code in an attempt to transmit messages in less time by using fewer signals per message.[5] Starting in 1841, the Telegraph Administration entertained suggestions for ways of adapting the Chappe telegraph to nighttime communications. Of the numerous and various projects submitted, however, the Telegraph Administration asked for and received funding to test only two.[6] In the course of the Chamber of Deputies' debates on nighttime telegraphs, only two deputies suggested experimenting with an electrical telegraph, arguing that it was immune to the nocturnal and weather problems of the semaphore.[7] One of those deputies was François Arago (1786-1853), representative from the Pyrenees Orientales and a member of the Paris Academy of Sciences.[8]

Even before Arago's agitation in the Chamber of Deputies, in 1842, the head of the telegraph service, Alphonse Foy (1797-1888),[9] urged the Minister of the Interior to consider the electric telegraph.[10] Foy wrote again to the Minister on 14 October 1844 and declared that semaphore systems would never succeed in overcoming winds and other meteorological phenomena but that the electric telegraph provided a solution independent of the weather or time of day. With the complete success of the electric telegraph in England, Foy declared, the Minister ought to test the electric telegraph in France.[11] On 8 November 1844, the Minister of the Interior named a special commission that consisted of members of the Academy of Sciences, the Chamber of Deputies, and the Telegraph Administration, to study the various systems of electrical telegraphy and the possibility of long distance telegraphy.[12] On 23 November 1844, in response to the Minister's report and but forty days after Foy's letter to the Minister, King Louis Philippe ordered the setting aside of an extraordinary credit to erect an experimental electrical telegraph line at least 120 kilometers long for the proposed study of electrical telegraphy.[13]

Completed in 1845, the first electrical telegraph line ran from Paris to Rouen. A second experimental line, built between 1846 and 1848, reached from Paris to Lille and replaced an antiquated and dilapidated semaphore line.[14] However, the erection of a second electrical line did not mean the end of semaphore construction. King Louis Philippe ordered an extension of the Bayonne line to the Spanish border[15] and construction of an entire network linking the towns of French-occupied Algeria.[16] By 1848 and the end of Louis Philippe's reign, then, the semaphore network continued to grow and the electrical telegraph appeared as an experimental alternative. The discussion and construction of Chappe telegraphs ended and the greatest impetus to the building of electrical telegraph lines began with the election to the presidency of the Second Republic in December 1848 of Louis Napoleon Bonaparte (1808-1873).

While imprisoned at Ham, Louis Napoleon had conducted a series of experiments relating to the theory of the voltaic pile. He wrote about his results to François Arago, who inserted the future President's report in the proceedings of the Paris Academy of Science.[17] The importance of Louis Napoleon in encouraging the growth of French telegraphy has not escaped the notice of historians.[18] Indicative of his enthusiasm for the electric telegraph is his speech to the

Legislative Assembly in 1850, stressing the necessary and prompt extension of the telegraph network.[19] While bills submitted to the National Legislative Assembly in 1849[20] and 1851[21] initiated construction of several lines, the greatest impetus to construction was Louis Napoleon's presidential decree of 6 January 1852 ordering the linking of Paris by telegraph with the major city in each department between 1852 and 1854.[22] With this impressive building project underway, the semaphores faced extinction: the electrical telegraph replaced the last semaphore line in 1855.[23]

Between 1845 and 1855, then, the French telegraph system comprised a mixed network of semaphoric and electric telegraph lines, the proportion of electrical lines increasing after 1851. The construction of the initial, experimental electrical lines assumed the co-existence of electrical and semaphore machinery and the technology adopted for the electrical lines reflected this assumption by imitating the manner in which the semaphores formed signals. By utilizing an electrical telegraph that aped the semaphore, Alphonse Foy hoped to avoid the retraining of employees.[24] The similarity of the two techniques thus permitted the transfer of personnel from semaphore to electrical lines, particularly between 1850 and 1855 when the electrical telegraph replaced the semaphore throughout the network. Despite Foy's desire to retain the semaphorists and transfer them to the electrical lines, for the most part, the shift to an entirely electrical service after 1850 resulted in the hiring of new personnel as operators, while former semaphorists found employment in other telegraph positions or simply retired.

The electrical version of the Chappe semaphore, called the French or Foy-Breguet telegraph, copied the manipulation and signal code of the semaphores. Situated atop the tallest building in a town or the highest point in the countryside, the Chappe telegraph consisted of three arms fixed to a scaffolding (Figure 1).[25] Brass cords and reversible pulleys connected to the arms above and cranks attached to two winches below permitted the operator to manipulate the tower's arms. The position of the crank handles indicated to the semaphorist the signal represented by the outside three arms. A locking mechanism in the semaphore machinery allowed the operator to turn the winches to a desired position and leave the mechanism locked onto a particular signal.

The arms of the Chappe semaphore were capable of assuming eight distinct positions 45° apart, but the Telegraph Administration used only seven since Chappe correctly believed that an arm at 0° and at 180° relative to the horizon would be indistinguishable from each other at a distance. The machinery formed signals using two arms fixed at either end of a third piece. Alone, the two arms produced

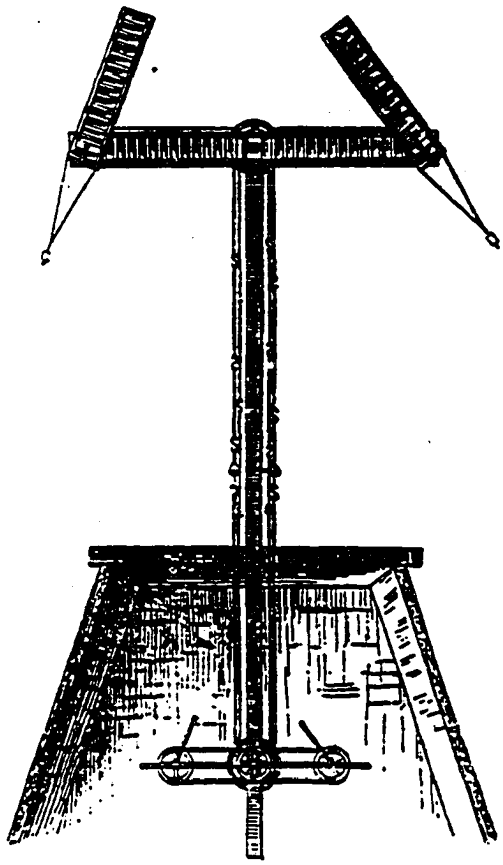


Figure 1. Chappe Semaphore

a total of 49 useable signs. The piece from which the two arms hung was capable of four distinct positions 90° apart (horizontal, vertical, and two oblique) and increased the total signal capacity of the Chappe semaphore to 196 combinations.[26] These combinations represented number groupings and the number groupings stood for phrases found in a three-volume code dictionary that permitted the encoding and deciphering of messages.[27]

The Foy-Breguet electric telegraph replicated the overall manipulation and signals of the Chappe semaphore. The receiving instrument (Figure 2)[28] displayed two movable needles that imitated the positions of the semaphore arms. An immobile bar painted on the apparatus' face represented the piece that supported the semaphore's arms. As electrical impulses arrived at the receiver, an electromagnet released a clockwork escapement mechanism that turned one of the needles to the desired position. Each apparatus required two line wires, two clockwork mechanisms, and two needles to imitate the Chappe signal code; if necessary, though, a single line wire and needle could display signals. In addition to the phrase code of the Chappe system, the Foy-Breguet telegraph represented letters and letter combinations (Figure 3).[29]

The Foy-Breguet sending device, like the semaphore's cranks that they resembled in appearance and construction, allowed the operator to transmit signals and simultaneously

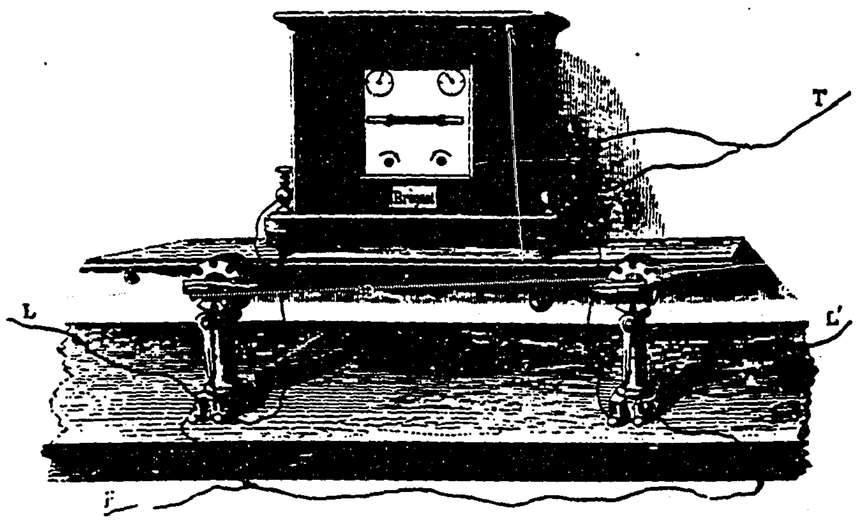


Figure 2. Foy-Breguet Telegraph

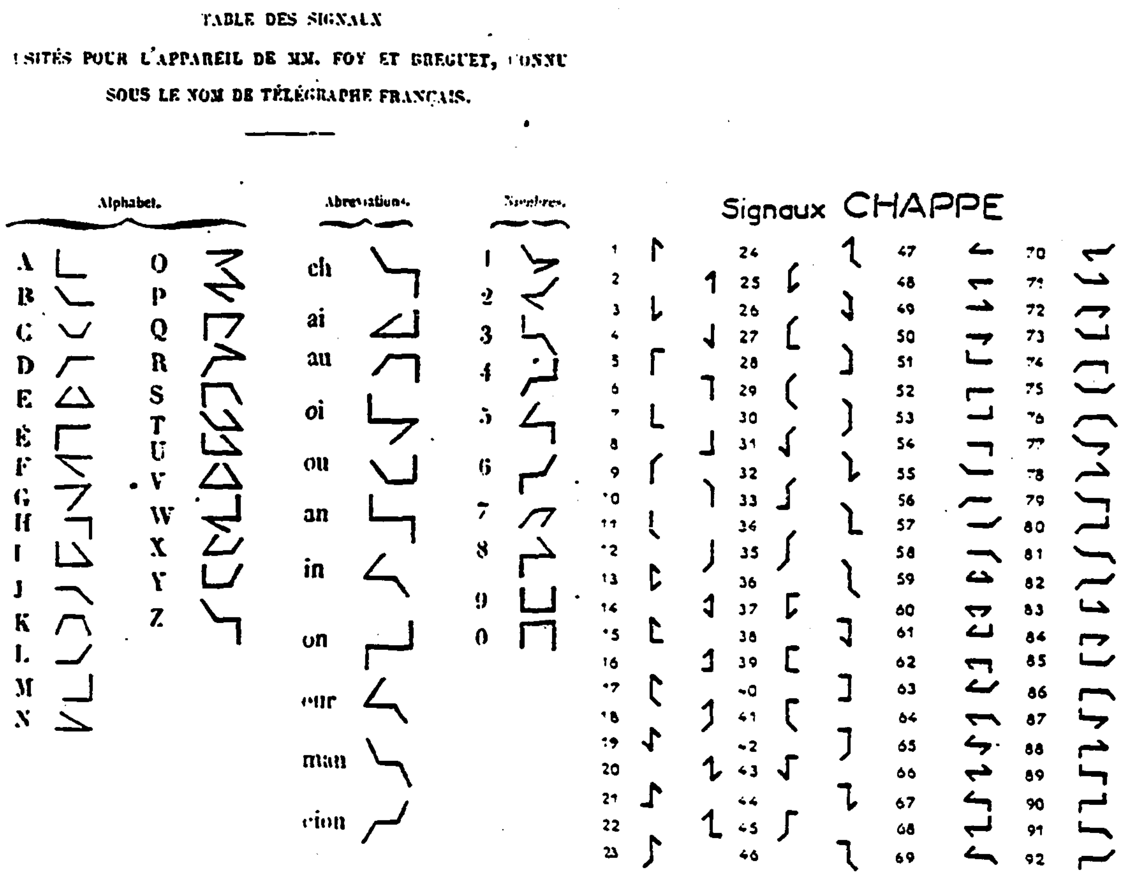
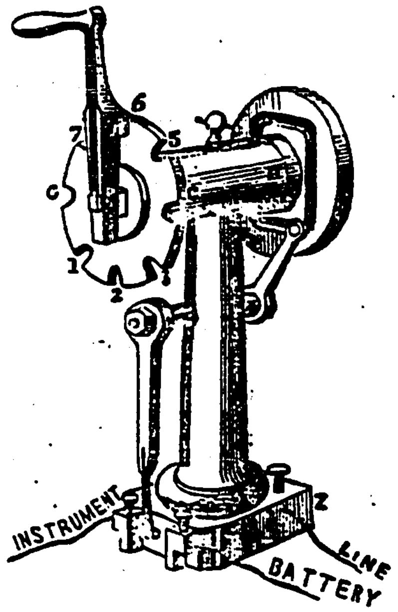


Figure 3. Foy-Breguet (left) and Chappe (right) Signal Alphabets



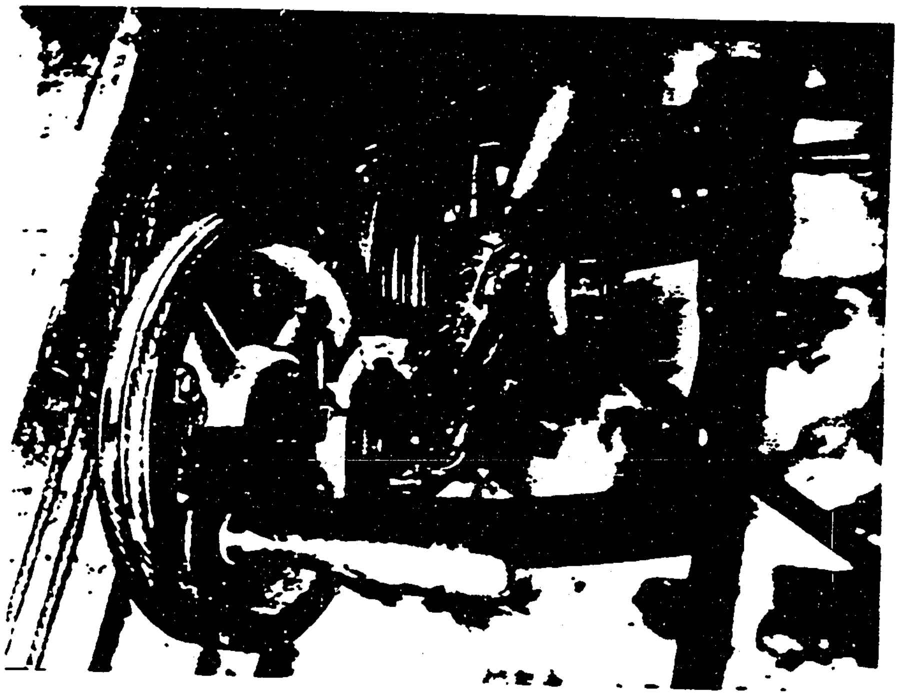


Figure 4. Comparison of Foy-Breguet (above) and Chappe (below) Transmitting Devices

know the signal sent (Figure 4).[30] The operator turned the Foy-Breguet transmitter in the same fashion as the semaphore cranks, with electrical pulses replacing the brass cords and reversible pulleys. Consequently, although the use of a rigid bar and an alphabetical code represented a departure from a strict imitation of the Chappe system, operation of the Foy-Breguet electrical telegraph was sufficiently close to the manipulation and code of the semaphore system to permit the state to retain its semaphore operators without retraining them. Anyone versed in the cranking of the semaphore machinery could crank the Foy-Breguet transmitter with equal agility, even though the signals generated might have new meaning to those responsible for coding and decoding dispatches.

Despite the adoption of an electrical technology intended to retain the semaphore operators and to avoid retraining them, the duties and responsibilities of those charged with passing signals necessarily changed. These new duties and responsibilities related to the repair and maintenance of the apparatus, the keeping of records, and the opening of the telegraphs to the public. The increased paperwork, especially, led to the alteration of hiring procedures. In the end, the electrical telegraph so changed the job of operator that semaphorists either found other telegraph positions or quit.

As a rule, semaphorists attempted to make repairs when the machinery broke down and, if the required repairs were beyond their ability, they notified their immediate supervisor, an inspector ("inspecteur").[31] In contrast, the rules imposed upon electric telegraph operators expressly forbade them from going inside the apparatus. Regardless of the type of breakdown, whether in the battery, the apparatus, or the line, the employee immediately notified the station director, the inspector, and the employees actually charged with making repairs.[32] Such a procedure would have been impossible under the semaphore system. The situation of most Chappe relay posts in inaccessible isolated rural settings suggests the reason for selecting individuals capable of repairing the machinery as employees. Once his apparatus failed to function, the semaphorist became incapable of communicating telegraphically with an inspector or a director. The placement of instruments, operators and supervisors at the same site permitted operators on electrical lines to notify others of the need for repairs and freed them to focus upon other matters, mainly paperwork.

Agents in the electrical service performed a far greater amount of paperwork than did the semaphore operators. Semaphorists recorded little more than the signals received from the next station while electrical operators maintained a small account book to keep track of the materials received and used in the making up and maintenance of the battery, in addition to all other supplies received for the office.[33] Other records that agents kept included meteorological observations, such as whether it were clear, cloudy, or rainy, and occurrences of atmospheric electricity, like lightning or the aurora borealis, that had an effect upon telegraph transmissions. The operators made these observations twice a day, between opening and 10:00 A.M. and again after 2:00 P.M., in conjunction with galvanometer readings taken to determine the normal relative amount of current on the line. In addition, like the semaphore operators, workers on electrical lines kept a log of all signals sent and received.[34]

More than the keeping of records, though, the opening of the telegraphs to the public enlarged the clerical role of the telegraph operators. A law of 2 May 1837 had made the semaphores the monopoly of the state and specifically excluded all private signal transmissions by any means.[35] Thus, individuals outside the government could not legally send telegraph messages until the passage of a second law on 29 November 1850 that opened the state's telegraph lines to the public starting 1 March 1851.[36] Operators accepted dispatches from the public and calculated the amount of charge for the service.

While electrical telegraph operators carried out more paperwork and fewer machinery repairs than their equivalent in the semaphore service, they did not become clerks unconcerned with technical matters. The preparation and maintenance of the station's battery became their responsibility. Each month, a different operator took his turn caring for the battery, following the instructions provided by the inspector. Failure to attend to the pile was a serious offense, punishable by a fine of up to 10 francs (about four to five days' wages) or suspension for a month.[37]

The presumed technical demands of an electrical service did not evoke an immediate testing of potential operators for a knowledge of science. However, their increased recordkeeping translated into the formal examining of the candidate's command of the language. Before becoming a paid employee, an agent entered the service as a trainee ("surnuméraire"). Inspectors selected candidates for the semaphore service who were between the ages of 18 and 30 and slightly older, between 20 and 30, for the electrical service. Aspirants to either service meeting the age criteria submitted a birth certificate and a testament from the local mayor of their good citizenship. In selecting prospective trainees for the semaphore lines, inspectors looked for those "knowing how to read and at least passably write, active, intelligent, and of good constitution."[38] In contrast, aspirants for the electrical corps were to come from applicants "knowing how to write correctly, neatly, and easily." Along with the other paperwork, moreover, inspectors had to submit a written dictation test taken by the candidate that included the number of minutes employed in executing it.[39] The Telegraph Administration's recruiters now emphasized writing ability since electrical telegraph operators had become recordkeepers.

The institution of a dictation test for prospective electric telegraph operators reflected, on another level, the need for new people in the electrical service. No matter how much Foy desired to retain the semaphore personnel, the semaphorists did not necessarily possess the qualifications required to be electric telegraph operators. Furthermore, electrical lines simply did not require as many operators as the semaphores. Whereas semaphores required signalers in those cities initiating or receiving messages plus hundreds of semaphorists to relay the dispatches from one place to another, the electric telegraph needed operators only in those places sending or receiving messages. For example, the electrification of the line between Paris and Chalons-sur-Marne reduced the number of semaphorists on the remainder of the line to Strasbourg from 105 to 71 and required only 4 electrical operators to do the work between Paris and Chalons-sur-Marne formerly carried out by 34 semaphore workers.[40] Thus, as the electric telegraph replaced the semaphore between 1850 and 1855, the number of places available for semaphorists diminished, while work on the electrical lines required qualifications not necessarily possessed by semaphore operators.

Semaphorists not wishing to become electrical telegraph operators could choose from a number of alternative jobs within the telegraph service. For example, although France had retired all semaphore lines by 1855, Algeria still had a semaphore service. Moreover, semaphorists working there received the added inducement of an salary of 1500 francs, double their pay in Continental France.[41] Nonetheless, of the semaphorists working in Algeria in 1858, only an eighth had entered the service before the introduction of the electric telegraph in 1845.[42] With the availability of the telegraph to the public, positions opened for individuals to carry messages. Also, the electric telegraphs hired line maintenance and repair personnel. Many semaphorists found jobs either delivering telegrams or as linemen. Certainly, a few semaphorists transferred to the electrical lines and even rose to become inspectors, as did Alexandre Louis Pouget-Maisonneuve (1821-1898).[43] However, transfers to Algeria and the electrical service and employment repairing telegraph lines or delivering messages accounts for only 554 of the operators working in 1858. In 1833, 993 operators worked for the semaphore lines.[44] Many, then, chose to quit or retire.

Any semaphore operator with 20 or more years of service received a monthly retirement check; checks in lesser amounts, depending upon their length of service, went to those with fewer years of service.[45]

Therefore, despite the adoption of an electrical telegraph intended to retain the semaphore personnel, the majority of those working as electric telegraph operators in 1858 had joined the service after the introduction of electrical telegraphy in 1845. In fact, only 97 of the 855 electrical telegraph operators employed at that time found their position before 1845.[46] In contrast to his aim to retain the semaphore operators, Alphonse Foy pursued a policy of hiring fresh staff for the cadre of inspectors charged with the electric telegraph apparatus, wires, batteries, and other materiel.[47] For the electrical lines, Foy hired inspectors from the Ecole polytechnique for their knowledge of science. The inspectors, more than the operators, had to interest themselves in the "why" of telegraphy and, consequently, needed an understanding of physical science, or at least of electricity.

The introduction of the electric telegraph did not alter the formal job responsibilities of inspectors. The duties of the inspectors encompassed all matters relating to the personnel, materiel, and accounting for the section of line on which they served. Among their personnel duties, inspectors recruited, hired, and fired (subject to the approval of the head of the telegraphs) all operators in their division. They withheld fines from the operators' pay and redistributed the money to the best workers each month. The accounting for a division demanded the writing of numerous reports. These reports amounted to seven each month plus nineteen each year or a total of 103 reports per year (about one every three days). Among the reports were the monthly payroll statement, addressed to the prefect who actually paid the division's payroll.[48]

The inspectors' responsibility for the good working order of all telegraph machinery, however, required an actual change in the nature of their duties. They had to make monthly rounds of their division for which they received a per diem in addition to their salary. Inspectors instructed the operators as to the number of elements and means for assembling and sustaining the battery. They also specified "the force of the current necessary for work" for each instrument and wrote the number of battery elements on the apparatus box. Moreover, inspectors examined each transmitter in order to equalize the instrument's electromagnets as much as possible.[49] Determining the amount of current required to work a particular telegraph line and showing operators how to put together and maintain an electrical battery required a certain knowledge of science.

Consequently, Foy believed in hiring science-educated inspectors for the electrical service, a significant departure from previous hiring requirements.

The written entrance test that applicants for semaphore inspector positions underwent covered only composition, linear design, map reading, arithmetic, and geometry.[50] Beginning in 1844, Alphonse Foy began recruiting inspectors for the electrical service exclusively from among the science-trained graduates of the Ecole polytechnique. Organized in 1794, the Ecole polytechnique taught science (mostly physics and chemistry), mathematics, and other courses to aspirants of positions in various military and civilian state services such as the Corps du génie (military engineering), the Corps des mines, and the Corps des ponts et chaussées.[51]

Although the telegraph organization law of 1833 permitted Ecole polytechnique graduates to enter the Telegraph Administration immediately after graduation and without taking the entrance examination, none did so before 1844.[52] Those polytechnicians who did enter the telegraphs before 1844 did so only as transferees from other state services,[53] and then only rarely. In 1830, the secretary of the Ecole polytechnique wrote that, whereas each year three graduates could find work as state architects, the Telegraph Administration took only one every four years.[54] Before

1844, then, the telegraphs were an unusual career choice for Ecole polytechnique graduates.

Ecole polytechnique students entered the telegraphs immediately upon graduation for the first time in 1844, exactly in time for the building of the first electric telegraph line. Beginning in 1850, in order to prepare for the projected network linking Paris with each department, the number of polytechnicians entering the telegraph service increased to 10 a year, more than double the annual rate between 1844-1849.[55] By 1858, Foy's rush to hire Ecole polytechnique graduates had left its mark on the Telegraph Administration's upper ranks, where they made up two-thirds of all inspectors.[56] As the abbé François Moigno (1804-1884) noted in 1849, "Foy has taken care to surround himself with an elite personnel composed of young savants from the Ecole polytechnique."[57] Relying upon their knowledge of science obtained at the Ecole polytechnique, the electrical service inspectors attempted to solve the technical problems posed by the new technology. From their work as telegraph inspectors, especially their search for solutions to the problems arising from the application of the telegraph on a large scale, these polytechnicians grew increasingly knowledgeable of electrical phenomena and, in the process, laid the foundation for the development of electrical engineering out of telegraphy.

Foy's attempt to harmonize semaphore and electrical personnel and technology was a failure. The inadequacy of the system became increasingly obvious after the opening of the telegraphs to the public in 1851. Within a week and a half after the public began utilizing the network on 1 March 1851, complaints about the service aired in the press. Gripes centered around the excessive formalities needed to send a telegram, an insufficient number of offices open to the public, and errors in transmission.[58] These complaints notwithstanding, a more important failure of the telegraph service was the lack of technical knowledge among station directors. Directors' duties concerned only the translation of dispatches sent to or from their bureau and management of their division.[59] As more telegraph offices opened after 1850, the number of station managers increased proportionally and their ignorance of technical matters became more apparent.

In 1853, as Foy himself complained in a circular, many of the directors of electrical offices had abandoned the running of their station almost entirely to the operators.[60] Furthermore, the lack of control and uniformity in the operators' instruction left many of them poorly fit for service.[61] Foy had entrusted understanding of the "why" of telegraphy entirely to the inspectors. Telegraph inspectors normally went out on their rounds or inspected new works and abandoned their base office for long periods. As a result, the office manager became the operators' only immediate source of technical advice. An example of what could, and did, happen is the case of the Rouen director in 1847. After receiving his instructions on battery preparation and maintenance from the Central Administration, the director complained about them because the battery constructed as per the instructions gave off an offensive odor. Also, he griped about the dilution of the pile's acid and the need to change the acid every eight days instead of ten. Foy replied that following the instructions would give a steady current and a saving of money, but admitted that he knew nothing about the odors.[62] The incident is instructive because it shows the potential weakness of the station directors in understanding technical points. Furthermore, Foy's response regarding the battery's offensive odor underlines his own misunderstanding of telegraph technology since the battery used (a Bunsen cell) normally emitted noxious fumes.

Station directors' ignorance of technical matters and the concentration of technical understanding in the inspectors, who were necessarily itinerant employees, were only part of the growing pains of the French telegraphs between 1845-1854. By 1854, the French system performed unsatisfactorily and, in the opinion of the Minister of the Interior in a report addressed to Emperor Napoleon III, the cause lay in the shortcomings of Alphonse Foy, who had employed the older semaphore pesonnel when the electric telegraph required "a new institution of young, numerous, and intelligent agents" to carry out the Emperor's wishes.[63] The Minister appointed a new telegraph chief who promptly reorganized the personnel hierarchy from top to bottom, introduced novel instruments, and established traffic flow patterns that provided for future growth. Where Foy's hiring of science-educated Ecole polytechnique graduates provided the personnel, the harmonization of personnel and technology that emerged starting in 1854 supplied the technology for the beginnings of electrical engineering out of telegraphy in France.

FOOTNOTES

[1]For biographical information on Chappe, see Edouard Gerspach, "Histoire administrative de la télégraphie aérienne en France," Annales télégraphiques 3 (1860): 51-52 and Biographie universelle ancienne et moderne, vol. 8 (Paris: Chez Michaud frères, 1813), pp. 66-67.

[2]Gerspach 3:353 and Claude Pouillet, "Rapport fait par M. Pouillet, sur le projet de loi relatif à un crédit extraordinaire de 408,650 fr., pour l'établissement d'une ligne de télégraphie électrique de Paris à Lille," Moniteur universel, 7 June 1846, p. 1699. The 29 cities served by the Chappe telegraph were Lille, Calais, Boulogne, Strasbourg, Metz, Chalons, Toulon, Marseille, Nimes, Montpellier, Avignon, Valence, Lyon, Besançon, Dijon, Bayonne, Bordeaux, Perpignon, Narbonne, Agen, Toulouse, Angouleme, Tours, Poitiers, Brest, Nantes, Rennes, Avranches, and Cherbourg.

[3]Moniteur universel, 11 May 1841, p. 1275.

[4]Moniteur universel, 16 & 17 May 1842, p. 1136.

[5]Moniteur universel, 19 May 1840, p. 1100 and supplement, 15 May 1842, p. iii. The 1842 vocabulary achieved a 20% increase in speed of transmission.

[6]These were the telegraphs of Dr. Jules Guyot (1807-1872) and Jacques Edouard Morris (1802-1859). For biographical information on Guyot, see B. W. Feddersen and A. J. von Oettingen, eds., J. C. Poggendorff's Biographisch-Literarisches Handwörterbuch zur Geschichte der Exacten Wissenschaften (Leipzig: Johann Ambrosius Barth, 1898), p. 568 (hereafter cited as Poggendorff); on Morris, F. Boyer, "M. Morris, inspecteur général des lignes télégraphiques," Annales télégraphiques 2,2 (1859): 654-656. Guyot described his semaphore in his De la télégraphie de jour et de nuit (Paris: Chez tous les marchands de nouveautés, 1840). Descriptions of Morris' telegraph are sketchy; the best, however, is that of François Arago in J. A. Barral, ed., Oeuvres complets de François Arago, 17 vols. (Paris: Gide et J. Baudry; Leipzig: T. O. Weigel, 1855), 5:469. The Telegraph Administration continually received ideas for new or improved semaphore telegraphs and signalling codes; these proposals are found in dossiers F(1a) 15, F(12) 2213, F(12) 6811, F(14) 3185, F(90) 1455*, F(90) 1465, and F(90) 1470, Archives Nationales, Paris.

[7]The first suggestion for an electrical telegraph in France that I have found is that made by the deputy from the Vendee, Sébastien Désiré Armand Aimé Fidèle Constant Luneau (1800-1880) during the 10 May 1841 meeting of the Chamber of Deputies. Moniteur universel, 11 May 1841, p. 1275. For Luneau, see René Bargeton, Pierre Bougard, Bernard Le Clère, and Pierre François Pinaud, Les préfets du 11 ventôse an VIII au 4 septembre 1870 (Paris: Archives Nationales, 1981), p. 204. The other suggestion came from François Arago during the 5 June 1842 Chamber debate on the Guyot and Morris telegraphs. Moniteur universel, 6 June 1842, pp. 1390-1391. That was the second and last suggestion that came up in the Chamber before construction of the first electrical telegraph line began.

[8]While the most recent biography of Arago is that of Horace Chauvet, François Arago et son temps (Perpignan: Amis de François Arago, 1954), the best is Maurice Daumas, Arago (Paris: N. R. F. Gallimard, 1913), pp. 273-275 of which contain a bibliographical essay. Arago's works are collected in Barral.

[9]For biographical information on Foy, see Louis Marcellin Bergon, "Alphonse Foy," Annales télégraphiques 3,15 (1888): 5-15 and "Foy, Vincent Louis Alphonse," pp. 54-55 in Adolphe Robert, Edgar Bourloton, and Gaston Cougny, Dictionnaire des parlementaires français, vol. 3 (Paris: Bourloton, 1890).

[10]Foy, "Note sur les télégraphes de nuit," signed manuscript dated 12 February 1842, F(90) 1456*, Archives Nationales, Paris: "il serait de la plus haute importance, au moment même où l'état s'apprête à tracer ces longues lignes de chemins de fer qui pourraient recevoir les fils continus des télégraphes électromagnétiques qu'elle les chargeait d'examiner par quels moyens et à quel prix, il serait permis d'atteindra à cette perfection de tout système télégraphique la continuité de transmission."

[11]Foy to the Minister of the Interior, 14 October 1844, F(90) 1440*, Archives Nationales, Paris.

[12]Moniteur universel, 12 November 1844, p. 2861.

[13]Both the minister's report and the royal ordinance are in the Moniteur universel, 24 November 1844, p. 2921.

[14]Moniteur universel, 19 June 1846, pp. 1830-1831.

[15]Moniteur universel, 10 July 1846, p. 2019.

[16]Gerspach 4:238-239. See also the report on Algerian telegraphs in the _Moniteur universel_, 13 October 1845, pp. 2547-2548 and Algeria, Service des postes, télégraphes et téléphones, _Exposé du développement des services postaux, télégraphiques et téléphoniques en Algérie_ (Paris: Larose, 1930).

[17]Louis Charles Napoleon Bonaparte, "Sur la théorie de la pile voltaîque," _Comptes rendus hebdodomaire des séances de l'Académie des sciences_ (hereafter, _Comptes rendus_) 16 (1843): 1180-1181.

[18]Catherine Bertho, _Télégraphes et téléphones: De Valmy au microprocesseur_ (Paris: Le Livre de Poche, 1981), p. 76. It would be extremely useful if the records of the Conseil d'Etat still existed since that body was responsible, during the Second Empire, for formulating bills that the legislature then considered. As Louis Napoleon and all the ministers formed part of the Conseil, the recorded deliberations of that body made up an important record of the Second Empire's inner workings. However, as Vincent Wright, _Le Conseil d'Etat sous le Second Empire_ (Paris: Presses de la Fondation Nationale des Sciences Politiques, 1972), p. 249, points out almost all the archives of the Conseil disappeared during the fires of the 1871 commune. Some papers surfaced in the Tuileries, namely AB (XIX) 173-178, Archives Nationales, Paris but an examination of those dossiers revealed nothing relating to telegraphy.

[19]Louis Napoleon Bonaparte, _Discours et messages de Louis Napoléon Bonaparte, depuis son retour en France jusqu'au 2 décembre 1852_ (Paris: Plon frères, 1853), p. 103: "Les nouvelles lignes télégraphiques, votées par la loi de février dernier, sont en voie d'exécution. Elles fonctionnent de Paris à Tours, à Rouen, à Valenciennes; mais il est nécessaire d'étendre ce réseau. La loi de la télégraphie privée, soumise en ce moment à l'Assemblée, réclame une prompte solution." Taken from the Message of the President of the Republic to the Legislative Assembly, 12 November 1850.

[20]_Moniteur universel_, 5 October 1849, p. 297 and 9 February 1850, pp. 469-470.

[21]_Moniteur universel_, 29 March 1851, p. 926.

[22]_Moniteur universel_, 7 January 1852, p. 32.

[23]Gerspach 4:258.

[24]François Moigno, Traité de télégraphie électrique (Paris: A. Franck, 1849), p. 60 (hereafter Moigno, Traité (1849)); Louis Breguet, "Essai sur la télégraphie électrique," undated manuscript, 4°Ca94, Conservatoire national des arts et métiers, Paris, p. 16 (hereafter L. Breguet, "Essai"); and Maxime DuCamp, "Le télégraphe et l'administration télégraphique," Revue des deux mondes 68 (1867): 478.

[25]Gerspach 4:240. While I have relied upon Gerspach for information on the construction and operation of the Chappe semaphore, a similar, though less detailed, description can be found in virtually any nineteenth-century work on French telegraphy. I also am indebted to Les Amis de l'Histoire des P.T.T. d'Alsace for their reconstruction of a Chappe tower at Haut-Bar near Saverne thanks to which, and the explanation offered by the society's young guide, I owe information on the machinery's operation generally difficult to locate in the literature. "Instruction sur le matériel et la comptabilité du matériel," undated, in Documents sur la télégraphie aérienne, vol. 2 (n.p., 1834-40) gives a list of parts for a Chappe telegraph and the cost of each part. The source of the figure is the History of Telecommunications Collection, Centre national d'Etudes des Télécommunications (C.N.E.T.), Paris.

[26]Gerspach 4:240-241 and Henri Gachot, Le télégraphe optique de Claude Chappe: Strasbourg-Metz-Paris et ses embranchements (Saverne: Imprimerie et Editions Savernoises, 1967), pp. 23-37.

[27]The Paris Archives Nationales possess a number of telegraph vocabularies. There is a four volume quarto edition of the Chappe code in F(90) 11,690. Another, undated work, used for translating and encoding and bound in a small green chest, is classified F(90) 11,693. For the Algerian campaign and the Crimean War, special military dictionaries came into play, F(90) 11,672-11,673 and 11,691-11,692. Other code vocabularies are to be found in the Bibliothèque de la Musée de la Poste, Paris, and the Library of the Ministry of P.T.T., Paris. Updating of the code books was an on-going enterprise. Circular no. 91, 6 June 1844, included a seven-page document dated 8 June 1844 and signed by Foy indicating new changes to the vocabulary, such as the addition of the word "caoutchouc", represented by the numbers/signals 3/76/68. A circular of 10 January 1850 included more insertions for the dictionary, an example being "California," represented by 4/1/30. Another circular, no. 165 of 26 January 1852, updated the section on terms and phrases

relating to the police. F(90) 1454*, Archives Nationales. Another circular relating to additions to the signal vocabulary is found in dossier F(90) 1469. Secondary sources discussing the various codes used are Louis Fouarge, "Vocabulaire et signaux," pp. 106-118 in Les Amis de l'Histoire des P.T.T. d'Alsace, ed., Le télégraphe aérien en Alsace de la Révolution au Second Empire (Strasbourg: Les Amis de l'Histoire des P.T.T. d'Alsace, 1968) and Gachot, pp. 23-37.

[28]The figure is from the History of Telecommunications Collection, C.N.E.T., Paris. For my description of the Foy-Breguet telegraph apparatus I have drawn upon the following sources: L. Breguet, Manuel de la télégraphie électrique à l'usage des employés des chemins de fer, 2d ed. (Paris: Carilian-Goeury et Victor Dalmont, 1853), pp. 41-47 (hereafter L. Breguet, Manuel); E. Montoriol, Les systèmes de télégraphie et téléphonie: origines-évolution-état actuel (Paris: Librairie J.-B. Baillière et fils, 1923), pp. 58-60; T. P. Shaffner, The Telegraph Manual (New York: Pudney and Russell, 1859), pp. 325-329; and E. E. Blavier and Eugène Gounelle, Cours théorique et pratique de télégraphie électrique, 2 vols. (Paris: Librairie Scientifique, Industrielle et Agricole de Lacroix-Comon, 1857), II: 122-125.

[29]The Chappe signals are from Gachot, p. 36, those for the Foy-Breguet from B. Miège and T. R. Ungérer, Vade-mecum pratique de télégraphie électrique à l'usage des employés du télégraphe (Paris: F. L. Mathias, 1855), p. 62.

[30]The figure of the Foy-Breguet transmitter is from Shaffner, p. 329. The photograph of the Chappe manipulator is from the History of Telecommunications Collection, C.N.E.T., Paris.

[31]"Ordonnance du roi portant règlement sur le service de la télégraphie," 24 August 1833, in Ministère de l'intérieur, Direction générale des lignes télégraphiques, ed., Lois et règlements, 16 vols. (Paris: Imprimerie Impériale, 1859), 1:n.p. contains no references to the duties of operators. Therefore, I have depended upon the "Règlement. Stationnaires," pp. 7-9 and "Règlement sur le service de MM. les inspecteurs du télégraphe (1834)," in Documents sur la télégraphie aérienne, 1:2-5.

The pages of the Lois et règlements were not numbered. Items were arranged within each volume in chronological order. As the date of a particular entry indicates its location in a particular volume and within that volume, I have adopted the following format for all future citations:

"Name of entry," Lois et règlements, date.

Throughout this work, I have used English cognates for the titles of French telegraph employees, in this case, "inspector" for "inspecteur". In the French telegraph service, the position title for operator changed from stationnaire, to employé, to commis. When relevant, I have made note of changes in title, namely, the case in which inspectors took on the title "ingénieur". Otherwise, the conservation of the French terms appears to serve no purpose within the framework of this dissertation.

32 Ministère de l'intérieur, Administration des lignes télégraphiques, Règlement pour le service des stationnaires du télégraphe électrique (Paris: Imprimerie Nationale, 1850), pp. 3 & 8. Hereafter referred to as Règlement des stationnaires (1850).

33 Règlement des stationnaires (1850), pp. 3 & 11.

34 Règlement des stationnaires (1850), pp. 6-7.

35 For a discussion of the monopoly law, as it is commonly called, see G. de Saint-Denis, "Autour de la loi du 2 mai 1837" and Michel Ollivier, "Comment naquit le monopole," Bibliothèque de la Musée de la Poste, Paris.

36 "Lois sur la correspondance télégraphique privée," Lois et règlements, 29 November 1850.

37 Règlement des stationnaires (1850), pp. 3 & 11.

38 Ministère de l'intérieur, Administration des lignes télégraphiques, Règlement sur le service des inspecteurs du télégraphe électrique (Paris: Imprimerie Nationale, 1850), p. 5 (hereafter cited as Règlement des inspecteurs (1850) and "Règlement sur le service de MM. les inspecteurs du télégraphe (1834)," in Documents sur la télégraphie aérienne, 1:1-2: "sachant lire et au moins passablement écrire, actifs, intelligents et d'une bonne constitution."

39 Règlement des inspecteurs (1850), p. 5: "sachant écrire correctement, proprement et facilement."

40 These figures come from the following budgets: Session de 1849, Ministère de l'intérieur, "Budget des dépenses de l'exercise 1850," AD XVIII(F) 471, Archives Nationales, Paris, and Session de 1850, Ministere de l'intérieur, "Budget des dépenses de l'exercise 1851," AD XVIII(F) 494, ibid.

41 Gerspach 4:238-239. An example of operators becoming

message deliverers is the order of 15 October 1855 making semaphorist Pierre Claude Hamelin a telegram carrier. Another one of 5 September 1855 made Alexis Brion, semaphore agent, a lineman. These and similar orders are in F(1a) 1985(2), Archives Nationales, Paris.

[42]M. Vallée, Annuaire des lignes télégraphiques suivi des décrets et arrêtés concernant les fonctionnaires et agents (Paris: Imprimerie Administrative de Paul Dupont, 1858), pp. 22-44, 48-61, 63-70, 72-78. Hereafter, Annuaire des lignes télégraphiques 1858.

[43]"Pouget-Maisonneuve," personnel folder, F(90) 20,543, Archives Nationales, Paris.

[44]"Ordonnance du roi portant règlement sur le service de la télégraphie," Lois et règlements, 24 August 1833 and Annuaire des lignes télégraphiques 1858, pp. 22-44, 48-61, 63-70, 72-78.

[45]Minister of the Interior to Foy, 12 February 1852, F(1a) 1985(3), Archives Nationales, Paris.

[46]Annuaire des lignes télégraphiques 1858, pp. 22-44, 48-61, 63-70, 72-78.

[47]Based upon the extant dossiers of those Foy hired as inspectors, namely, "P. E. Bardonnaut," F(90) 20,532; "Alphonse Baron," F(90) 20,532; "Henri Demeaux," F(90) 20,536; "Joseph Lagarde," F(90) 20,539; and "I. A. E. Trotin," F(90) 20,547, Archives Nationales, Paris.

[48]"Ordonnance du roi portant règlement sur le service de la télégraphie," Lois et règlements, 24 August 1833 and "Nomenclature des états à fournir à l'Administration," in Documents sur la télégraphie aérienne, 1:n.p. The "Nomenclature" provided inspectors with form reports that could serve on various occasions. The payroll form went to the prefect between the 25 and 30 of each month, suggesting that telegraph employees received monthly "pay checks".

[49]Règlement des stationnaires (1850), pp. 3 & 11 and Règlement des inspecteurs (1850), p. 10: "ils détermineront la force du courant nécessaire pour le travail".

[50]"Ordonnance du roi portant règlement sur le service de la télégraphie," Lois et règlements, 24 August 1833.

[51]On the Ecole polytechnique, see Jean Pierre Callot, Histoire de l'Ecole polytechnique (Paris & Limoges: Charles

Lavauzelle, 1982) and Terry Shinn, Savoir scientifique et pouvoir social: L'Ecole polytechnique, 1794-1914 (Paris: Presses de la fondation nationale des sciences politiques, 1980), pp. 225-243 of which contain an extensive bibliography.

[52] C. P. Marielle, Répertoire de l'Ecole impériale polytechnique (Paris: Mallet-Bachelier, 1855), p. 206 and "Ordonnance du roi portant règlement sur le service de la télégraphie," Lois et règlements, 24 August 1833.

[53] Marielle, p. 207.

[54] John Hubbel Weiss, The Making of Technological Man: The Social Origins of French Engineering Education (Cambridge, Mass.: The M.I.T. Press, 1982), pp. 21-22.

[55] Marielle, pp. 205-207 and P. Leprieur, Répertoire de l'Ecole impériale polytechnique (Paris: Gauthier-Villars, 1867), p. 63.

[56] Based upon a comparison of the names found in Marielle, pp. 205-207 and the Annuaire des lignes télégraphiques 1858, pp. 9-13.

[57] Moigno, Traité (1849), p. 281: "M. Foy a-t-il pris le soin de s'entourer d'un personnel d'élite, composé de jeunes savants sortis de l'école polytechnique". Moigno was editor of the popular science journal Le Cosmos and professor of mathematics at the Paris Jesuit Seminary. For biographical information on this somewhat eccentric science popularizer, see Poggendorff 2:174 and 3:928 and his obituary in the Annales télégraphiques 3,11 (1884): 289.

[58] Moniteur universel, 11 March 1851, p. 692, and 6 August 1853, p. 867; "Télégraphie électrique: organisation du service pour les correspondances privées," Journal des chemins de fer 10 (1851): 160-161; and "Télégraphie électrique privée," Journal des chemins de fer 10 (1851): 288-289.

[59] "Service des directeurs" and "Instructions," F(90) 1454*, Archives Nationales, Paris.

[60] Circular no. 186, dated 25 August 1853, F(90) 1454*, Archives Nationales, Paris.

[61] Telegraph director at Perigneux to Foy, 21 September 1853, F(90) 1458, Archives Nationales, Paris.

[62]Telegram, telegraph director at Rouen to Foy, 22 June 1847; telegram, Foy to telegraph director at Rouen, 23 June 1847; and, telegram, telegraph director at Rouen to Foy, 24 June 1847.

[63]<u>Moniteur universel</u>, 11 June 1854, p. 633: "malheuresement l'ancienne administration télégraphique ne fut pas à même de seconder les hautes pensées gouvernmentales de Votre Majesté. Prise de dépourvu, elle se vit forcée d'employer son ancien personnel, quand il aurait fallu à une institution nouvelle des agents jeunes, nombreux et intelligents. Il en est résulté que l'on ne put retirer immédiatemente de ce nouveau mode de transmission tous les avantages que l'on en devait légitimement attendre."

CHAPTER TWO

The Electrical Telegraph Network, 1854-1860

By 1854, Alphonse Foy's organization of telegraph apparatus and personnel was no longer adequate. During the relatively short period that followed, 1854-1860, two telegraph administrators radically transformed the network's personnel and technology. The novel technologies introduced comprised a two-tiered system of telegraph instruments, instead of the Foy-Breguet apparatus, as well as a reordering of the telegraph lines and the flow of traffic through the system. At the same time, operator, inspector, and station director positions changed, resulting overall in the augmented administrative role of inspectors. Though the bureacratic place of inspectors within the hierarchy improved, their recruitment from the Ecole polytechnique ceased while a policy of promotion from within prevailed and a concomitant decline in inspectors' science education prevailed. Nonetheless, the technological changes introduced between 1854 and 1860 paved the way for the adoption of increasingly more complex apparatus and furnished the technological milieu in which electrical engineering developed out of telegraphy.

On 28 October 1853, Jean Gilbert Victor Fialin, the Duke de Persigny (1808-1872), named his cousin, Henri Michon, the

Viscount de Vougy (1807-1891), head of the telegraph service.[1] Although nepotism undoubtedly played a role in his selection, de Vougy had been a successful politician (representative of the Puy, 1848-1852), administrator (prefect of the Haute Loire and the Nievre), and military officer (at one time aide-de-camp to the Minister of War). As chief of the telegraph network, de Vougy frequently expressed a preference for the "hierarchical channel" ("la voie hierarchique") in circulars and other bureaucratic notices, a reflection of his earlier career, 1827-1848, as an army officer.[2] Furthermore, de Vougy's reforms of the telegraphs mirror the pyramidal hierarchical structure of the military. During his first term as telegraph chief, the position of the telegraph bureacracy within the larger bureaucracy of the Ministry of the Interior increased from that of a simple "direction" to a "direction générale," a change that meant greater political power and leverage for the head of telegraphs to bring about changes.[3]

However, between 1857-1860, the telegraph bureaucracy reverted to a "direction" and a M. Alexandre served as telegraph director.[4] Alexandre had been an assistant administrator to Alphonse Foy between 1833 and 1848 and had worked with the Minister of War in planning the Algerian semaphore lines in 1842.[5] As telegraph director between 1857 and 1860, Alexandre reversed de Vougy's practice of not hiring inspectors from the Ecole polytechnique, but left intact the organizational and technological improvements his predecessor had introduced. Thus, with the exception of the hiring of polytechnicians, Alexandre's tenure as telegraph chief did not eliminate de Vougy's important organizational and technological transformations.

The reforms de Vougy introduced between 1854 and 1857 addressed the problems inherited from his predecessor, Alphonse Foy, and transformed the positions of operator, station director, and inspector.[6] These transformations redefined the places of operators, station directors, and inspectors within the personnel hierarchy and, on the whole, enhanced the administrative role of inspectors. The augmentation of their administrative functions occurred as station directors lost bureaucratic importance.

Besides the fact that many directors had abandoned their stations to the operators by 1854, the redefinition of the station directors' duties was necessary for economic reasons. The 1833 organization of the telegraphs had set the pay of station directors at 4,500 to 5,500 francs a year. Inspectors were subservient to the directors and received only 2,400 to 3,000 francs per year.[7] In 1836, there were only 21 directors,[8] but new construction, including two electrical lines, required the employment of 33 directors by 1849[9] and 43 in 1851.[10] If directors' pay had remained the same, the cost of their salaries would have amounted to 970,000 francs in 1862, when the network employed 200 station directors. As a result of de Vougy's reorganization of 1854, however, directors' pay fell to 2,000-3,000 francs a year and the payroll for the 200 directors amounted to only 200,000.[11]

With the downgrading of the director position came the elevation of the inspectors as administrators. Whereas under Foy the directors had been responsible for all aspects of a division ("division"), defined as a section of a given telegraph line,[12] inspectors took charge of the line sections, now called inspections ("inspections"), starting in 1854. In addition to overseeing the operators as before, inspectors became responsible for the station directors, line repairmen, and message deliverers within their administrative unit. De Vougy also organized the inspections into larger units managed by twelve principal directors ("directeurs principaux").[13] Throughout later modifications of the network,[14] the inspectors remained the fundamental administrators of the telegraph lines. Moreover, those charged with overseeing the inspectors came from the ranks of the inspectors.[15]

As inspectors became increasingly more important in the administration of the telegraphs, the recruitment of future inspectors underwent an important change. Instead of coming from the Ecole polytechnique, inspectors increasingly came from within the telegraph hierarchy after 1854. De Vougy's 1854 reorganization stipulated that station directors would be promoted to inspector positions and that operators would fill station director positions.[16] The operators thus formed the pool from which future inspectors came. Indicative of their new importance in the telegraph hierarchy was the uniform that operators wore beginning in 1854. Under Foy, operators had worn a uniform entirely different from the standard uniform that served as the model for the remainder of the telegraph corps. In 1854, de Vougy specified that operators would wear a variation on the uniform worn by station directors, inspectors, and other higher level agents, thus integrating operators (at least superficially) into the hierarchy and suggesting a continuum of grades (and career aspirations) reaching from the bottom (operators) to the top (inspectors and above).[17]

If operators were to form the pool from which future inspectors would come and if inspectors were to continue to have a knowledge of at least basic science, the testing of operator trainees needed to change. In 1855, de Vougy initiated a new system for examining operator trainee candidates that required a knowledge of basic chemistry and physics (particularly static and dynamic electricity) among other subjects.[18] Although Alexandre modified the science exam questions to cover only that portion of chemistry and physics that dealt with electric batteries,[19] a knowledge of physics and chemistry remained a requisite for becoming an operator trainee even after 1870.[20] Following a considerable number of years advancing through the ranks as an operator, an employee might gain a station directorship and have a chance to become an inspector. Nevertheless, before becoming an inspector, an employee had to pass a battery of tests.

In 1859, Alexandre instituted an examination of station directors who desired to become inspectors. Applicants over age 45, graduates of the Ecole polytechnique, and those having taken the inspector test set forth in 1833 (which did not include any science) were excused from taking the tests. The series of exams covered French composition, the rules and regulations applicable to operators and station managers, the drawing of plans and linear design, geography, mathematics (arithmetic, algebra, geometry, trigonometry), and science (mechanics, physics, chemistry). In addition to topics such as optics and heat, the physics test included electrical and magnetic theory, the construction and operation of batteries, generators (magnetos), galvanometers, current laws (including those for branched circuits), and electric telegraph apparatus used both in France and abroad. Anyone failing the exams did not receive a promotion to the grade of inspector.[21] Of the first eight station managers who took the tests in 1860, only four passed and became inspectors third class.[22]

The institution of science testing for operators and station directors between 1855 and 1860 provided a means for hiring inspectors through internal promotions rather than from the Ecole polytechnique. However, Alexandre restored the hiring of Ecole polytechnique graduates in 1858 and reserved at least a third of all inspector positions for them.[23] Upon Alexandre's death in 1860, de Vougy returned as head of telegraphs and, beginning in 1862, permitted polytechnicians into the service under two rather distasteful conditions: (1) that no more than two enter per year and (2) that they start as second class station chiefs after an apprenticeship of at least two years that paid the same as a first-class operator.[24] The low pay and status of inspector trainees discouraged Ecole polytechnique graduates from entering the telegraph service. Of the eight who entered in 1862-65, four quit the telegraphs almost immediately and, after 1865, polytechnicians ceased to enter the Telegraph Administration.[25]

With the discouragement of polytechnicians from the telegraphs and the practice of promoting from within, the level of science education possessed by inspectors necessarily dropped. An examination of extant personnel dossiers[26] reveals that an individual could enter the service as an operator and rise into office management, perhaps eventually becoming an inspector, with only a primary education.[27] The more frequently occurring case, though, was the candidate who entered with at least some instruction at a lycée in classical studies and leading to the bachelier-ès-lettres degree or in a bachelier-ès-sciences program.[28] Nonetheless, the Ecole polytechnique provided a more advanced instruction in the physical sciences than the lycées.

The preferential recruitment of inspectors from within the telegraph hierarchy, the institution of science testing for operator and inspector candidates, and the augmentation of the inspectors' administrative duties made up the changing personnel conditions that occurred as French telegraph technology underwent a far-reaching transformation. These technological changes included a fundamental revision of the disposition of telegraph lines and the flow of traffic through the system. This transformation of the telegraphic "workplace" and the accompanying substitution of a two-tiered system of telegraph instruments for the Foy-Breguet apparatus played at least as important a role in turning telegraph inspectors into electrical engineers as had Foy's extensive hiring of polytechnicians. The new telegraph instruments and traffic flow patterns concentrated transmissions in a small number of lines. The concentration of traffic necessitated the installation of high-speed, complex telegraph instruments and techniques which produced electrical phenomena on the telegraph lines that played a significant part in the development of telegraph theory.

The adoption of new telegraph instruments and techniques and the reformation of traffic patterns between 1854 and 1860 took place as the network underwent considerable growth. Building upon its initial network linking Paris with every department, the telegraphs added lines connecting the subprefectures, the cantons, and rural communities as well as lines serving railroad and other companies. Thus, between 1854 and 1859, the number of state telegraph stations grew from 128 to 240, the length of lines in use increased from 9,244 to 16,049 km, and the number of combined domestic and foreign dispatches handled rose from 236,018 to 598,701, yielding an augmentation in the dispatches per kilometer rate (a rough measure of overall traffic density) from 25.5/km to 37.3/km. Meanwhile, international traffic also played a growing role, accounting for about one-half of all telegraph receipts in 1858 and 1859.[29] While the multiplying number of offices aided considerably in expanding usage of the network, the lowering of telegram charges in 1854 and especially in 1858 helped too.[30]

When there had been fewer lines and less traffic, direct communication between bureaus posed little difficulty. A regulation of 1852 stated that telegaph transmissions always took place directly between the sending and receiving offices. Indirect communications were to take place only when line conditions (such as a broken wire) prevented a direct link. Nevertheless, the regulation stipulated, transmissions between stations generally should last no longer than 15 minutes, 30 minutes under unusual circumstances.[31] Direct communication between the originating station and the bureau of destination did not last long as a standard practice. In 1856, de Vougy introduced the idea of creating stations of principal and secondary deposit. Principal stations of deposit were those of highest traffic: Paris, Bordeaux, Limoges, Lyon, Marseille, Nantes, Orleans, Saint-Etienne, Strasbourg, Toulouse, and Tours. These stations freely communicated with each other directly, regardless of distance. Secondary deposit stations could not communicate among themselves except through the principal stations and branch offices likewise transmitted dispatches only through the stations of secondary deposit.[32]

The notion of centralizing deposit centers remained the organizing principle of the telegraphs after 1860. In 1861, de Vougy established the department as the basic administrative unit (as opposed to a section of line) and placed an inspector in charge of each department's lines.[33] He then divided the network into regions that consisted of a number of departments and placed a higher level inspector ("inspecteur général") at the head of each region.[34] De Vougy charged the inspectors with centralizing the service in their department. The idea of principal and secondary stations of deposit remained in effect. Each line became identified with its points of origin and destination and received a numerical label. Line no. 17, for instance, was a direct line from Paris to Marseille.

Furthermore, in 1862, de Vougy distinguished four categories of lines. The first and most important were the "direct wires," linking Paris with foreign cities and the urban centers of greatest traffic, such as Nantes, Bordeaux, Toulouse, Marseille, Lyon, Strasbourg, le Havre, and Paris. The "semidirect wires" connected the secondary and principal centers of deposit. "Omnibus wires" joined the major town in each department to other important urban centers in other departments. Finally, the "departmental wires" provided direct communication between the towns of a department and the department's chief city.[35] De Vougy's system of administrative departmental/regional organization and centers of deposit remained essentially the same into the 1870's,[36] although the actual flow of traffic changed to accommodate shifting patterns as the network grew.

The notion of centers of deposit within an administrative structure formed along departmental and regional lines staffed by inspectors provided more than just the fundamental organizing principle of the French telegraph network, however. Centers of deposit essentially separated lines into those of low and high traffic, in many cases increasing loads on those lines otherwise heavily utilized. The use of centers of deposit had the obvious benefit of keeping insignificant bureaus off lines of high-density traffic. Furthermore, the creation of stations of deposit and the development of a hierarchy of telegraph line categories permitted a more rational distribution of personnel. Previously, the more practiced operators worked in bureaus of lesser importance, while the least experienced worked in the larger stations. In 1864, de Vougy reversed this practice and transferred the more experienced operators into the busy centers of deposit and other large bureaus (where the more complex instruments worked) and less practiced agents into the offices of lighter activity.[37] Thus, on those lines with little traffic, the employment of less practiced (and lower paid) personnel came into use and permitted a rapid and extensive building of lines for railroad companies and rural communities. In contrast, highly seasoned (and higher paid) operators served on the high-density wires, particularly between centers of deposit.

The placement of personnel on different lines depending upon the extent of their experience (and cost to the telegraphs) and the creation of a hierarchy of lines and centers of deposit co-existed with and presumed the adoption of instruments capable of handling high- and low-density traffic. Starting in 1854, de Vougy replaced the Foy-Breguet telegraph with a two-tiered system that consisted of dial telegraphs on the lightly used lines and Morse apparatus on the lines with more traffic. Dial telegraphs required very little practice or instruction to operate, while the Morse necessitated a lengthier period of practice and instruction, especially for the memorization of a special code. Although more complex instruments and techiques came into use after 1860, the dial and Morse instruments remained the most common telegraphs on French lines into the 1870's.[38]

In France, the dial telegraph began with the railways. The French railroad companies developed an interest in the advantages of telegraphy for rail transportation early on and the benefits of telegraphy to railroading was an important selling point for early telegraph legislation in the Chamber of Deputies.[39] The railroad companies favored the telegraph instruments of Charles Wheatstone (1802-1875) and William F. Cooke (1806-1879)[40] of Great Britain as witnessed by the _Journal des Chemins de Fer_'s devoting more articles to their telegraphs than to any others.[41] In 1845, Wheatstone installed one of his telegraphs along the tracks of the Paris-Saint-Germain Railroad between Paris and Versailles,[42] but in ordering more telegraphs the railroad company asked

Louis Breguet (1804-1883), manufacturer of the state's telegraph instruments, to turn out a version of the Wheatstone that would overcome what they perceived to be the inconveniences of the British system.[43] These inconveniences gone, the French railways used the dial telegraph exclusively.[44]

Breguet's dial telegraph used the same principle of transmission and reception as the Foy-Breguet apparatus.[45] The transmitter consisted of a dial around whose face lay two concentric circles, one displaying the numbers 0 to 25 and the other the letters of the common alphabet plus a cross, a special mark used to indicate the instrument's "rest" position (Figure 5).[46] At each of the 26 positions around the dial was a notch into which the crank fit. Underneath the dial was a sinuous wheel consisting of 13 inward and 13 outward curves corresponding to the dial's 26 positions and connected to the crank in such a manner that turning the crank rotated the sinuous wheel. As the sinuous wheel turned, it deflected a lever that interrupted an electrical circuit in such a way as to send out electrical pulses. Thus, beginning with the instrument at the cross position and turning the handle to the "F" position, the sinuous wheel made three full oscillations and sent out electrical pulses that the receiving instrument registered as an "F". The receiving apparatus, like the Foy-Breguet telegraph, was a

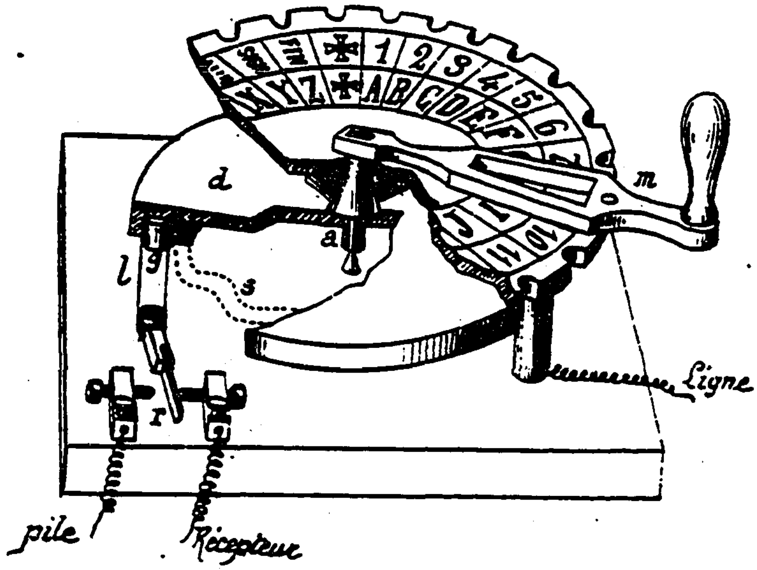


Figure 5. Dial Telegraph Transmitter

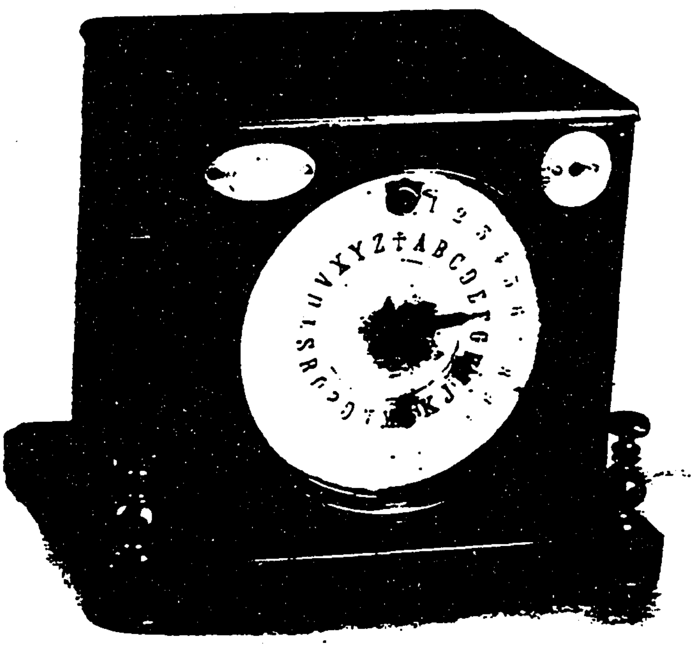


Figure 6. Dial Telegraph Receiver

needle rotated by a clockwork mechanism. The needle turned about the face of a dial with letters and numbers corresponding to those on the transmitter (Figure 6).[47] Incoming electrical pulses intermittently activated an electromagnet that released a detente on the clockwork mechanism by means of a lever.

The advantages of the dial telegraph were the use of the common alphabet to send and receive signals (instead of a code) and the simplicity of operation that permitted a large population to utilize it with very little training. As one American observer proclaimed of the Breguet dial telegraph, "The manipulation is so simple, that a person inexperienced in telegraphing may, at once, comprehend the system, at least be able to send dispatches."[48] Because the railways utilized regular rail agents as telegraph operators, those charged with working the instruments had various other duties.[49] These duties and the infrequency and irregularity of railroad telegraph traffic meant that rail employees did not watch over their telegraphs constantly. Moreover, the utilization of a dial telegraph incapable of making a record of any incoming message necessitated the introduction of a device that would alert the rail telegraph agent to the arrival of a message from another post. For this purpose, Louis Breguet invented an electric alarm, a clockwork mechanism that struck a small hammer against a hemispherically-shaped piece of metal whenever an operator sent a current over the telegraph line.[50]

In order to provide communication between the railroad telegraph stations and state telegraph bureaus, the Telegraph Administration purchased alarms and dial telegraphs. Therefore, as the use of telegraphs on the railroads increased, the state's use of the dial telegraph grew. Moreover, the state adopted the dial telegraph for the so-called electrosemaphoric network that provided ship-to-shore communications for the Navy and private interests beginning in 1862.[51] With the extension of the telegraph into the cantons and the building of municipal bureaus in the more rural areas of France as early as 1856,[52] the dial telegraph came into greater use.[53] The municipal and cantonal stations handled but a small portion of the total traffic. The state's offices accounted for 90% of all dispatches sent and received while the municipal, cantonal, and rail telegraphs shared the remainder.[54] The lack of any substantial traffic suggested the use of casual employees, as in the case of the railroads. Consequently, the municipal secretary and even the local postal clerk or school master in some cases became the telegraphist in such locations.[55] Although they handled a slight amount of the messages sent through the network, the dial telegraphs made up a significant portion of the instruments in use, their number increasing from 118 to 2,153 between 1857 and 1870.[56] The only instrument used more in France during that period was the Morse telegraph.

Although the Morse telegraph adopted in France originated in the United States, the Germans and the needs of international telegraphic communications were responsible for introducing the Morse into France. Authorized and unauthorized representatives of the Americans who invented and improved the Morse telegraph introduced the instrument to the governments of several German states. In turn, these German states adopted the Morse for their electric telegraph lines, but only after changing the form of the Morse instruments. Moreover, an inspector on one of the German semaphore lines altered the Morse code so that it better suited the needs of the German language. This revised version of the so-called Morse code later became accepted as the International Morse code.[57] With the opening of telegraphic communications between France and the states of the Austro-German Telegraph Union through a provisional agreement of 1851,[58] the utilization of different instruments and signal codes by the various Continental countries became a problem.

The solution to the problem that France and the German states adopted is typified by the agreement between France and Baden of 25 August 1852.[59] In France, the Foy-Breguet telegraph was in use and was incompatible with the Morse instruments used in Baden. The 1852 telegraph convention established one telegraph line between France and Baden over which the French Foy-Breguet instruments worked and another for the operation of Baden's Morse apparatus. At either end of the Foy-Breguet line was a French telegraph operator, one of whom necessarily lived in Baden. Similarly, a telegraph operator from Baden lived in France and worked a Morse line. A French dispatch going to Baden or another German state via Baden arrived at Strasbourg, where the German agent transmitted it on a Morse apparatus to his counterpart in Kehl, Baden, and thence to its destination. Before its transmission to Kehl, though, the operator might translate the telegram into German before "translating" it into Morse code.

In order to establish telegraph communications between the two countries, Baden sent France two Morse instruments "on loan" in 1853.[60] However, the French did not quite understand the power needs of the Morse apparatus and used the wrong kind of battery, which resulted in poor reception on the Baden end of the line.[61] The babel of telegraph codes and systems ended with the adoption of the Morse on all international telegraph lines by France, Belgium, Holland, and the states of the Austro-German Telegraph Union (Prussia, Austria, Bavaria, Saxony, Hanover, Wurtemburg, Baden, and Mecklenburg) in a telegraph convention of 29 June 1855 signed in Berlin.[62] The employment of the Morse telegraph and code as the standard for international telegraphy was the subject of an 1865 treaty signed by representatives of twenty countries in Paris and that marked the beginning of the International Telegraph (now Telecommunications) Union.[63]

The value of a standard instrument and code for international telegraphic communications was not the only reasons for utilizing the Morse in France. With the opening of the telegraphs to the public in 1851 and the airing of complaints about the quality of the service in the press, the Telegraph Administration sought an instrument that would record transmitted dispatches, since a transcription of the message (even in code) permitted a greater degree of quality control. The Foy-Breguet and dial apparatus then in use, unlike the Morse, did not record messages. Therefore, Henri de Vougy introduced the Morse on France's domestic lines.[64] Symptomatic of the shift from the Foy-Breguet to the Morse telegraph was the number of Morse relative to Foy-Breguet instruments in use. By the end of 1857, France had 149 Foy-Breguet compared to 427 Morse and, by the end of 1859, 875 Morse and zero Foy-Breguet telegraphs in use.[65] The utilization of the Morse grew rapidly after 1859, their number reaching 3,255 (56% of all instruments in use) in 1870.[66]

The Morse telegraph[67] transmitter consisted of a simple

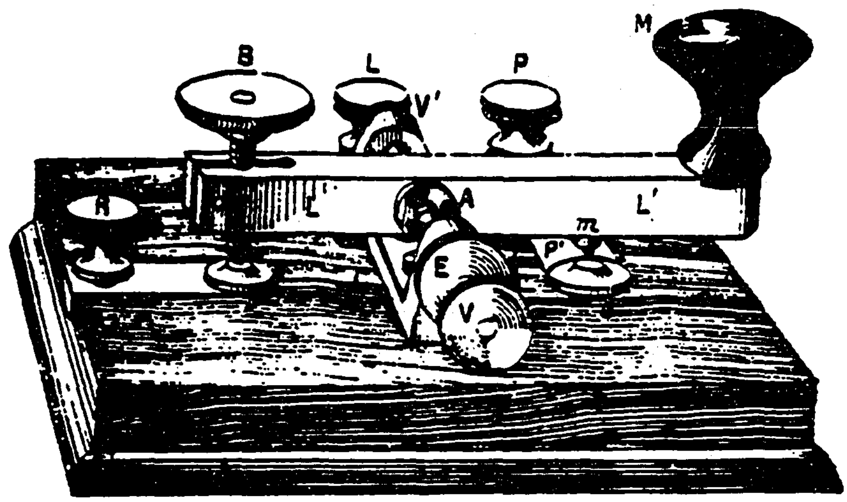


Figure 7. Morse Telegraph Transmitter

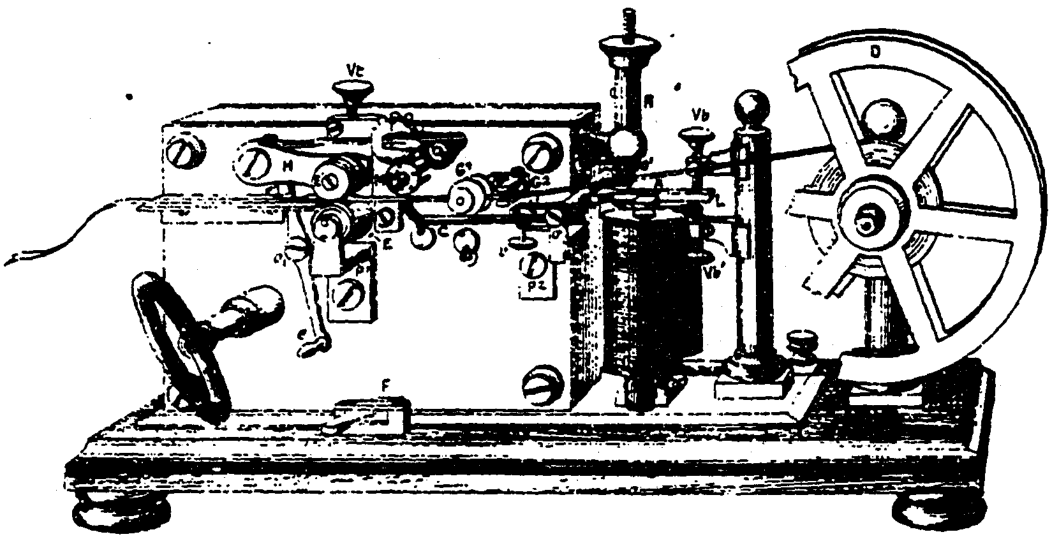


Figure 8. Morse Telegraph "A Molette"

device that allowed an operator to create the still familiar "dots," "dashes," and intervening spaces by interrupting an electric current (Figure 7). The Morse receivers (Figure 8) used in France fell into two categories: embossing ("à pointe sèche") and inking ("à molette"). The embossing recorders were the first employed. A clockwork (moved by a spring or weights) pulled a strip of paper forward between a pair of rollers at a uniform rate. As electrical impulses activated the instrument's electromagnet, the electromagnet pulled down a lever which had a fine point at the opposite end such that the downward motion of the lever at one end caused the lever's other end to rise upward and emboss a dot or dash (depending upon the duration of the electrical impulse) into the moving strip of paper.

The embossing Morse necessarily utilized a relay and extra battery current. Electricity from the line battery at the transmitting station arrived too weak to provide the power needed to emboss marks on a paper strip. Therefore, incoming signals passed through a relay (an electromagnet and lever) that closed a second circuit whenever sufficient electricity passed through the electromagnet. When the relay's lever closed the second circuit, a fresh battery (the so-called local pile) powered the receiving instrument. Thus, the dots and dashes embossed upon the instrument's paper strip corresponded to the impulses activating the electromagnet of the relay.

The marks scratched with the embossing Morse were difficult to read, especially in poor lighting. Also, the need for a relay complicated the apparatus and necessitated special adjustments and the expense of an additional battery (the local pile). Introduced in 1859, the inking Morse remedied these problems, facilitating the reading of recorded signals, eliminating the relay and local battery, and saving money. The inking apparatus resembled the embossing Morse with one difference. Instead of embossing when the lever pressed against the moving paper, it pushed the paper against an inked wheel. The force needed to just press against the paper was so much less than that needed to scratch marks that the inking Morse operated without a relay and local battery, providing a significant saving.[68] Consequently, the ink recording Morse replaced the embossing apparatus on all French telegraph lines.[69]

Although the inking instrument required fewer adjustments than the embossing Morse, both apparatus did necessitate the adjustment of certain springs and screws before operating correctly. The nature of these adjustments were such that operators could, and did, make them without using equipment of any kind and without any knowledge of electrical theory.[70] Thus, the mechanism of the Morse telegraphs did not demand the application of science to telegraphy. While opportunities for the application of theory did arise out of the need to improve the construction of telegraph apparatus, like the embossing Morse, a far more significant factor contributing to the study of electrical phenomena and the eventual development of electrical engineering out of telegraphy was the adoption of high-speed telegraph instruments and techniques after 1860. The Morse, like the dial telegraph, was a relatively slow instrument whose speed was governed by the ability of an operator to flex a metal key during a given period of time. The need for and adoption of high-speed technology, of course, grew directly out of de Vougy's principle of centers of deposit and the general growth of traffic after 1860.

FOOTNOTES

[1]"Décret portant nomination de M. le vicomte H. de Vougy, préfet de la Nièvre, aux fonctions de directeur de l'administration des lignes télégraphiques," *Lois et règlements*, 28 October 1853. My biographical information on Henri Michon comes principally from his prefect dossier, F(1b) I 176(17), Archives Nationales, Paris; other useful sources are *Journal des télégraphes* 3 (August, 1868): 2 and Honoré Farat, *Persigny: un ministre de Napoléon III, 1808-1872* (Paris: Hachette, 1957), p. 231. For Persigny, see Farat; Robert, Bourloton, & Cougny, 4:599-600; Paul Chrétien, *Le Duc de Persigny (1808-1872)* (Toulouse: Impr. F. Boisseau, 1943); and his memoires, *Mémoires du duc de Persigny* (Paris: E. Plon, Nourrit & Cie., 1896).

[2]Based upon an examination of various administrative documents signed by de Vougy in F(90) 1472, Archives Nationales, Paris. Bertho, p. 137, describes de Vougy as someone "qui semble avoir gardé de son passé d'officier du génie un gôut prononcé pour l'autorité sans réplique. Il dirige pendant près de vingt ans les lignes télégraphiques d'une main de fer".

[3]For a discussion of the difference between a "*direction*" and a "*direction générale*," see André Thépot, "La direction des Mines," pp. 122-129, in Francis de Baecque, general editor, *Les directeurs de ministère en France, XIXe-XXe siècles* (Geneva: Librairie Droz, 1976).

[4]Relevant materials are "Décret qui érige le service des lignes télégraphiques en direction du ministère de l'intérieur," *Lois et règlements*, 28 October 1853, "Décret qui règle les attributions des fonctionnaires et agents des lignes télégraphiques," *Lois et règlements*, 1 June 1854; "Décret qui nomme M. le vicomte de Vougy directeur général de l'administration des lignes télégraphiques," *Lois et règlements*, 1 June 1854; "Décret qui supprime les fonctions de directeur général des lignes télégraphiques," *Lois et règlements*, 24 June 1857; "Décret qui nomme M. Alexandre directeur des lignes télégraphiques," *Lois et règlements*, 5 July 1857; and, "Décret nommant M. le vicomte de Vougy directeur général des lignes télégraphiques," *Lois et règlements*, 24 December 1860. A search for biographical information has turned up only scattered references to M. Alexandre. Curiously, these references do not give his first name or the years that he lived and a necrological notice did not appear on him in the *Annales télégraphiques*. The most

useful source was Gerspach 4:232 & 238.

[5]Gerspach 4:232 & 238.

[6]De Vougy's reorganization affected other positions higher and lower in the personnel hierarchy, but those of operator, station director, and inspector are the only ones relevant to my thesis.

[7]"Ordonnance du roi portant règlement sur le service de la télégraphie," Lois et règlements, 24 August 1833.

[8]Session de 1836, "Propositions de lois concernant la fixation des budgets de dépenses et de recettes de l'exercise 1837," AD XVIII(F) 195, Archives Nationales, Paris, p. 358, provides no salary information but gives the number of directors as 21 and that of inspectors as 34.

[9]Session de 1848, Ministère de l'intérieur, "Budget des dépenses de l'exercise 1849," AD XVIII(F) 444, Archives Nationales, Paris, p. 36, states there were 33 directors (the figure does not include suppleants at Paris).

[10]Session de 1850, Ministère de l'intérieur, "Budget des dépenses de l'exercise 1851," AD XVIII(F) 494, Archives Nationales, Paris.

[11]Session de 1861, "Budget de l'exercise 1862: Projet de loi pour la fixation des recettes et des dépenses de l'exercise 1862," AD XVIII(F) 686, Archives Nationales, Paris, p. 274, furnishes the number of station directors and their pay rates.

[12]Gerspach 4:35. The personnel of a division consisted of one director, one inspector, and a sufficient number of operators.

[13]"Décret qui règle les attributions des fonctionnaires et agents des lignes télégraphiques," Lois et règlements, 1 June 1854.

[14]The major relevant personnel reorganizations were those of Alexandre (1858) de Vougy (1854 & 1862), and Pierret (1876), embodied in the following decrees: "Décret qui règle les attributions des fonctionnaires et agents des lignes télégraphiques," Lois et règlements, 1 June 1854; "Décret relatif à l'organisation administrative et à la règlementation du service extérieur des lignes télégraphiques," Lois et règlements, 29 November 1858; "Décret portant réorganisation du service télégraphique,"

Lois et règlements, 20 January 1862; and, "Décret instituant les directeurs de région et modifiant les titres et la situation de divers fonctionnaires et agents," Lois et règlements, 30 November 1876. While "Arreté ministèriel qui divise le réseau télégraphique en régions et qui les place respectivement sous le controle d'un inspecteur général," Lois et règlements, 11 July 1861 established the regional organization of the telegraph system, Pierret's decree of 1876 first employed the title "directeur de région".

15 A comparison of the Annuaire des lignes télégraphiques (1858) with Annuaire des lignes télégraphiques, 1 juin 1877 (Paris: Imprimerie Nationale, 1877) (hereafter Annuaire des lignes télégraphiques (1877) shows that many among the highest levels of the Telegraph Administration in 1877 had been inspectors in 1858. A comparison of the names in Annuaire des lignes télégraphiques (1877) with the graduates of the Ecole polytechnique from Marielle, pp. 205-207, and Leprieur, p. 63, also reveals the great concentration of polytechnicians in the highest grades of the telegraph service.

16 "Décret qui règle le traitement et l'uniforme des fonctionnaires et agents des lignes télégraphiques," Lois et règlements, 4 June 1854. Alexandre restated the principle in his "Décret relatif à l'organisation administrative et à la règlementation du service extérieur des lignes télégraphiques," Lois et règlements, 29 November 1858.

17 "Ordonnance du roi portant règlement sur le service de la télégraphie," Lois et règlements, 24 August 1833 and "Décret qui règle le traitement et l'uniforme des fonctionnaires et agents des lignes télégraphiques," Lois et règlements, 4 June 1854.

18 The other subjects were writing, linear design, arithmetic, geometry, the drawing of plans, and surveying. Extra examination points could be earned through a knowledge of one or more foreign languages, German, English, Italian, and Spanish. "Arrêté qui fixe le programme des connaissances exigées des aspirants au surnumérariat dans l'Administration des lignes télégraphiques," Lois et règlements, 15 November 1855.

19 "Arrêté ministériel qui ordonne que l'examen pour l'admission des surnuméraires stationnaires dans le service des lignes télégraphiques aura lieu dans les villes de Paris, Bordeaux, Toulouse, Marseille, Lyon, Strasbourg, Lille, Nantes et Alger," Lois et règlements, 25 June 1858.

[20]"Arrêté déterminant les conditions d'admission: 1° à l'emploi de surnuméraire des postes et télégraphes, 2° aux emplois supérieurs," Bulletin mensuel des postes et télégraphes 1 (1878): 366-370.

[21]"Arrêté ministériel qui règle les conditions de l'examen destiné à constater l'aptitude des directeurs de station aux fonctions d'inspecteurs," Lois et règlements, 27 May 1859.

[22]Annales télégraphiques 2,3 (1860): 233 & 350.

[23]"Décret relatif à l'organisation administrative et à la règlementation du service extérieur des lignes télégraphiques," Lois et règlements, 29 November 1858.

[24]"Décret portant réorganisation du service télégraphique," Lois et règlements, 20 January 1862.

[25]Marielle, pp. 205-207; Leprieur, p. 63; and E. Mercadier, "Les télégraphes," in Ecole polytechnique: Livre du centenaire, 1794-1894 (Paris: Gauthier-Villars et fils, 1897), 3: 283-284.

[26]Personnel dossiers, F(90) 20,531-20,549, Archives Nationales, Paris.

[27]As was the case of Marie Léon Ravasse and Jules Xavier Eugène Sieur, personnel folders in F(90) 20,544 and F(90) 20,546, Archives Nationales, Paris.

[28]Personnel dossiers, F(90) 20,531-20,549, Archives Nationales, Paris. Eight completed their bac degree as opposed to seven who did not. Of those with degrees, three had a bac-ès-sciences and four had a bac-ès-lettres, plus one person who had one of each.

[29]"Statistique de la télégraphie privée en France pendant l'année 1859," Annales télégraphiques 2,4 (1861): 78. Of course, traffic was not evenly distributed throughout the network. In 1858, 31% (145,536 out of 463,973) of all telegrams came out of Paris, which had 16.5% (12 out of 198) of all telegraph bureaus. The next busiest cities were (followed by the number of messages originating there): Marseille (39,830), Lyon (30,859), Bordeaux (19,369), Le Havre (18,980), Nantes (11,100), Lille (10,047), Rouen (8,434), and Toulouse (7,670). The remainder were all under 5,000. Edouard Pélicier, "Statistique de la télégraphie privée en France pendant l'année 1858," Annales télégraphiques 2,2 (1859): 356-362.

[30]Moniteur universel, 28 July 1854, p. 822 and Pélicier, pp. 376-379.

[31]Règlement des stationnaires (1852), pp. 7-8.

[32]"Etablissement de stations de dépôt pour les dépêches," Lois et règlements, 2 March 1856.

[33]"Arrêté ministèriel portant que les circonscriptions télégraphiques seront à l'avenir établies suivant la division départementale," Lois et règlements, 27 May 1861.

[34]"Arrêté ministèriel qui divise le réseau télégraphique en régions et qui les place respectivement sous le contrôle d'un inspecteur général," Lois et règlements, 11 July 1861.

[35]"Décret portant réorganisation du service télégraphique," Lois et règlements, 20 January 1862.

[36]Charles Bontemps, Les systèmes télégraphiques - aériens - électriques - pneumatiques (Paris: Dunod, 1876), pp. 208-210.

[37]Circular dated 1 October 1864, F(90) 1472, Archives Nationales, Paris.

[38]"Tableaux des produits des bureaux de l'Etat pour 1870," Lois et règlements, 31 December 1871.

[39]Moniteur universel, 6 June 1842, p. 1390; 19 June 1846, p. 1830; 7 October 1849, p. 3000; and, 5 February 1850, pp. 416-417.

[40]For biographical information on Wheatstone, see Proceedings, Royal Society of London 24 (1875-1876): xvi-xxvii; Brian Bowers, Sir Charles Wheatstone, F.R.S., 1802-1875 (London: H.M.S.O., 1975); and, Geoffrey Hubbard, Cooke and Wheatstone and the Invention of the Electric Telegraph (London: Routledge & Kegan Paul, 1965). For biographical information on Cooke, see S. P. Bell, ed., A Biographical Index of British Engineers in the Nineteenth Century (New York & London: Garland Publishing, 1975), p. 51.

[41]Of 26 articles on telegraphy in the Journal des chemins de fer, between 1842 when the periodical began to appear and 1846 when Breguet introduced his version of the Wheatstone dial telegraph (moreover, only three items on telegraphy appeared between 1847 and 1850), nine pertained to

Wheatstone's telegraphs: 2 (1843): 435-436; 2 (1843): 639; 3 (1844): 257-258; 3 (1844): 437; 3 (1844): 544; 3 (1844): 607-608; 4 (1845): 101-102; 4 (1845): 220-222; and, 4 (1845): 444-445.

[42]"Note de M. Wheatstone sur le télégraphe électrique qu'il vient d'établir entre Paris et Versailles," Comptes rendus 20 (1845): 1703-1704 and "Télégraphie électrique," Journal des chemins de fer 4 (1845): 444-445.

[43]Notice sur les travaux de M. L. Breguet (Paris: Bachelier, 1847), p. 8 (hereafter cited as Notice sur Breguet, 1847). The piece does not identify the inconveniences of Wheatstone's dial telegraph. A more complete discussion of Breguet will take place in a later chapter on telegraph instrumentmakers.

[44]According to "Notice sur la carrière administrative et les travaux scientifiques de E. E. Blavier," Annales télégraphiques 3,14 (1887): 7, the railroads used the dial telegraph exclusively. I believe this statement to be true as a general rule, particularly for the period before 1853, although later at least one other telegraph instrument came into use as well, namely, the printing telegraph of d'Arlincourt. "M. D'Arlincourt," Annales télégraphiques 3,11 (1884): 182.

[45]For my description of the Breguet dial telegraph, I have relied upon L. Breguet, Manuel; Moigno, Traité, pp. 422-425; Shaffner, pp. 334-345; and "Description des appareils télégraphiques employés sur les chemins de fer à une seule voie de la ligne du Midi," Bulletin de la société d'encouragement pour l'industrie nationale 54 (1855): 214-216 (hereafter referred to as "Description des appareils du Midi").

[46]The figure showing the transmitter is from J. Schils, "Appareils de télégraphie," (n.p., n.d.), Fig. 3, collection of drawings, 4°Cy88, Bibliothèque du Conservatoire national des arts et métiers, Paris. The photograph of the dial receiver is from the History of Telecommunications Collection, C.N.E.T., Paris.

[47]The figure is from the History of Telecommunications Collection, C.N.E.T., Paris.

[48]Shaffner, p. 342. Referring to the Wheatstone dial telegraph, "Galvanic Telegaph at the Great Western Railway," Mechanics' Magazine 31 (1839): 432 stated "The machinery and the mode of working it are so exceedingly simple, that a

child who could read would (after an hour or two's instruction) be enabled efficiently to transmit and receive information."

[49]Chemin de fer de Paris à Orléans, Ordre général pour la surveillance, l'entretien et l'usage du télégraphe électrique (Paris: Napoléon Chaix, 1854), pp. 3 & 20-21 and Chemins de fer de l'ouest, Règlement no. 10 pour le service télégraphique (Paris: Impr. Poitevin, 1861), pp. 8-10.

[50]L. Breguet, Manuel, pp. 59-64 & 72-77.

[51]The "Décret portant organisation du personnel du service électro-sémaphorique du littoral de l'Empire," Lois et règlements, 17 May 1862 set up the system. An article on the electrosemaphoric network appeared in M. Shaheen, "Télégraphie électro-sémaphorique," Les feuilles marcophiles 226 (1981): 29-33.

[52]"Conditions imposées aux villes qui demandent la création d'un bureau télégraphique," circular no. 112, Lois et règlements, 8 September 1856.

[53]Bertho, p. 106.

[54]Bertho, pp. 103 & 106.

[55]See the discussion in "Documents relatifs au projet de fusion des administrations des postes et télégraphes," Annales télégraphiques 2,7 (1864): 632-635. The municipal secretaries received a bonus for each dispatch sent or received. An article has appeared devoted exclusively to the utilization of school teachers as telegraphers: Raymond-Marin Lemesle, "Lorsque les instituteurs étaient également télégraphistes des bureaux municipaux," Relais 1 (1983): 34-35. The teachers' instruction in science usually meant that they were capable of handling a Morse, rather than a dial, telegraph. Beginning in 1866, some municipal bureaus were run by the local postal employee. See, for instance, Le mesle, "La fusion des services: sources des liens centenaires de solidarité sociale des postiers et des télégraphistes," Bulletin de la société des amis du musée de la poste 67 (1982): 41-42. In addition, starting in 1865, officers mustered out of service found work as telegraphers. Annales télégraphiques 2,7 (1864): 600-601 and Journal des télégraphes 1 (December, 1865): 10-11 and (January, 1866): 3. Finally, these rural bureaus became the employers of women as telegraphers, an excellent contemporary discussion of which appeared as "De la participation des femmes au service télégraphie," Journal des télégraphes 5 (1870): 29-31; 45-46;

78-80; and 90-95. Interestingly, women often managed telegraph offices in France. By 1870, women managed about 200 telegraph stations.

[56]"Tableaux des produits des bureaux de l'Etat pour 1870," Lois et règlements, 31 December 1871.

[57]Wolfgang Klein, "Aus der Entwicklung der elektromagnetischen Telegrafenapparate," Archiv für Deutsche Postgeschichte 2 (1979): 147-165 and Volker Aschoff, "Frühe Anfänge der Telegrafie im norddeutschen Küstenraum," Archiv für Deutsche Postgeschichte 3 (1979): 66-78. The diffusion and evolution of the Morse telegraph in Europe and the role of the German states is an area of research needing further examination.

[58]Moniteur universel, 5 June 1851, p. 1581.

[59]"Convention portant engagement provisoire pour l'échange de la correspondance télégraphique entre la France et le grand-duché de Bade," Lois et règlements, 25 August 1852. The largest states making up the Austro-German Telegraph Union at the time of this convention were: Austria, Bavaria, Saxony, and Prussia.

[60]Director of Posts and Railroads, Grand Duchy of Baden, to Alphonse Foy, 3 March 1853, F(90) 1452*, Archives Nationales, Paris.

[61]Director of Posts and Railroads, Grand Duchy of Baden, to Henri de Vougy, 21 January 1854, F(90) 1452*, Archives Nationales, Paris.

[62]Moniteur universel, 11 November 1855, p. 1249.

[69]"Décret impérial portant promulgation de la convention télégraphique internationale conclue à Paris le 17 mai 1865," Lois et règlements, 11 November 1865 contains a published text of the treaty. For a discussion of the founding of the International Telecommunications (originally Telegraph) Union (I.T.U.) see George A. Codding, Jr., and Anthony M. Rutkowski, The International Telecommunications Union: An Experiment in International Cooperation (Dedham, Mass.: Artech House, 1982).

[64]Bontemps, p. 81. See also circular no. 79, "Vérification de la correspondance télégraphique par l'appareil Morse," Lois et règlements, 24 January 1856.

[65]I. de la Taille, "Coup d'oeil sur l'état du matériel

télégraphique en France au 1er janvier 1858," Annales télégraphiques 2,2 (1859): 54 and de la Taille, "Note sur l'état du matériel télégraphique en France au 1er janvier 1860," Annales télégraphiques 2,4 (1860): 421.

66"Tableaux des produits des bureaux de l'Etat pour 1870," Lois et règlements, 31 December 1871. In comparison, the number of dial telegraphs in 1870 was 2,153, or 37% of all instruments in use. The combined percentage of dial and Morse instruments, therefore, was 93%.

67For the following discussion of the Morse telegraph, I have relied upon the following works: Jules Gavarret, Télégraphie électrique (Paris: Victor Masson et fils, 1861), pp. 176-191; Miège and Ungérer, 1:83-89 & 2:13-34, 38-50; Miège, Vade-mecum pratique de télégraphie électrique (Paris: Lacroix, 1862), pp. 55-67; E. E. Blavier and E. Gounelle, Résumé des cours faits à l'Administration des lignes télégraphiques, 2 vols. (Paris: Napoléon Chaix et Cie, 1858-59), 2:89-167, 171-175 (hereafter Blavier and Gounelle, Résumé des cours); and Blavier, Nouveau traité de télégraphie électrique, 2 vols. (Paris: Lacroix, 1865-67), 1:118-143, 170-204, & 207-211 (hereafter Blavier, Nouveau traité). The Morse transmitting key and receiving instrument are from Schils. A description of the numerous variations upon the two genres of Morse instruments is beyond the scope of this dissertation although, according to A. L. Ternant, Les télégraphes (Paris: Hachette et Cie, 1881), p. 282, "un volume intéressant, malgré sa longueur, pourrait être écrit sur ce sujet seulement." Figures 7 and 8 are from Schils, Figs. 23 and 12, respectively.

68According to Blavier, Nouveau traité, 1:247-248, an embossing Morse cost 320 francs and an inking Morse 340 francs. The price of a simple relay added another 100 francs.

69Gavarret, p. 191.

70Gavarret, p. 188.

CHAPTER THREE

The Beginnings of High-speed Telegraphy, 1860-1880

While the extensive hiring of Ecole polytechnique graduates starting in 1845 provided a base of personnel with an advanced science education, the two-tiered technological organization of French telegraphy consisting of dial and Morse instruments provided far less need to develop and adapt electrical theory to telegraphy than did the instruments introduced after 1860. Introduced as a solution to the growth of traffic handled by the network, rapid instruments furnished the technological milieu that altered the telegraphic workplace. Unlike slower instruments, high-speed telegraphs usually depended upon a system of synchronism between the sending and receiving apparatus. Thus, their construction and operation were far more complex than either the Morse or dial telegraphs. More signficantly, their speed revealed electrical characteristics of telegraph lines masked by the slower apparatus such as capacitive phenomena. Attempts to deal with the electrical occurrences associated with high-speed telegraphy, as well as other telegraph technologies like underwater lines (discussed in Chapter Seven), eventually led directly to the development and application of electrical theory to telegraphy and, consequently, to the emergence of electrical engineering out of telegraphy. An understanding of these fast instruments is necessary, therefore, for a complete study of the telegraphic origins of electrical engineering.

The need for high-speed telegraph technology developed out of a general growth of the network. The total number of messages handled, domestic and foreign, grew from 360,299 in 1856 to 2,842,554 in 1866 and 8,080,964 in 1876. Meanwhile, the number of bureaus increased from 167 to 1,209 then 2,890 in the same years.[1] As de Vougy reported to the Minister of the Interior on 4 July 1868, the need for more wires and instruments capable of transmitting faster intensified with rising traffic, especially on the busiest lines.[2] Rate reductions were an important factor in augmenting traffic. The cuts introduced in 1862 and 1868 made the cost of a basic message (20 words or less) 50 centimes if sent within the same department and 1 franc to anywhere else in France. In 1878, the cost of a telegram fell to 5 centimes a word regardless of its domestic destination (minimum charge 50 centimes).[3] The three lines that emerged as the busiest by 1878, those of Paris, Bordeaux, and Marseille,[4] were the lines on which the fastest telegraphs operated.

Out of the growth in traffic came a need to transmit at faster speeds. Under practical conditions, the Morse achieved 12-15 words per minute. Although forced speeds of 20-25 words per minute were achieved, these had no practical value because operators could not sustain them over any period of time.[5] Under experimental conditions, an inking Morse working without a relay over a line of 600 km could receive 48 words per minute,[6] demonstrating that transmission speed theoretically could be tripled. The first instrument adopted in France that surpassed the speed of the Morse in practice was the Hughes telegraph, initially transmitting about twice as fast as the Morse (31 words per minute on the average).[7] Because of its superiority to other telegraphs considered during the 1860s, the Hughes was the most popular instrument in France after the dial and Morse telegraphs.[8]

Named after its Welsh inventor, David E. Hughes (1831-1900),[9] who had taught music and natural philosophy in the United States, the Hughes telegraph enjoyed a brief popularity in America between 1855 and 1857, after which the inventor left to sell his telegraph in Great Britain. Unsuccessful there, Hughes travelled to Paris in 1860, where he signed an agreement with the government for the purchase of the rights to his improved telegraph in October.[10] By 1864, Hughes telegraphs operated on the lines between Paris, Le Havre, Lille, Bordeaux, Lyon, and Marseille.[11] Unlike the Morse and dial telegraphs, the Hughes recorded signals as letters printed on a strip of paper. In addition to saving labor by not having to decode Morse signals into ordinary language, the Hughes provided a printed version of the message that was cut into strips and pasted onto a blank telegram form.[12]

The transmitting portion of the Hughes telegraph consisted of a 28-key keyboard that resembled that of an abbreviated piano (Figure 9).[13] On each key was a number or letter of the alphabet arranged without regard to their frequency of use.[14] Whenever an operator depressed a key, the key exerted pressure downward upon a lever that, in turn, pushed up a vertically arranged piece (called a "goujon" or gudgeon) that ended as a pin and that was normally restrained by a spring (Figure 10).[15] The 28 gudgeons were in a cylindrical box with 28 holes in its top. In the center of the box was a rotating shaft the upper and lower halves of which were electrically insulated from each other. The upper portion of the shaft had a bevelled gear (labelled a in Figure 10) by which it received motion from a gear train set in motion by a 50 to 60 kg falling weight. The mechanism of the falling weight was such that an operator could maintain the continual operation of the Hughes instrument by simply depressing a foot pedal as the weight neared the end of its fall. A carriage attached to the rotating shaft and revolving freely with it (identified as c in Figure 10) contained two springs and a screw that brought the upper and lower halves of the shaft into electrical contact.

Between depressions of the keys, the instrument's

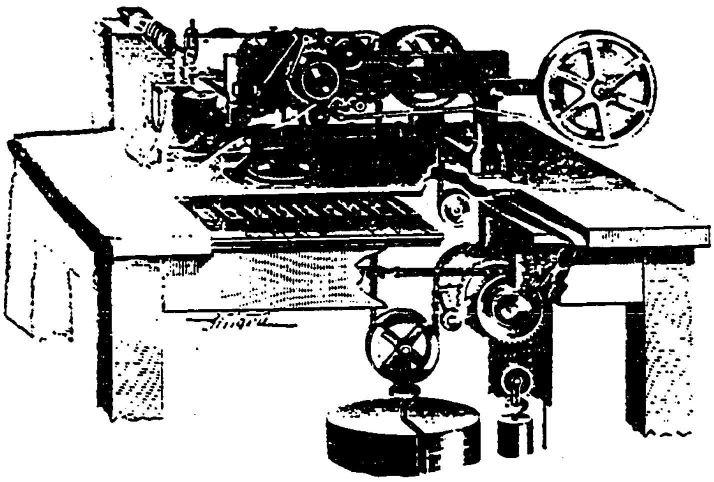


Figure 9. Hughes Telegraph

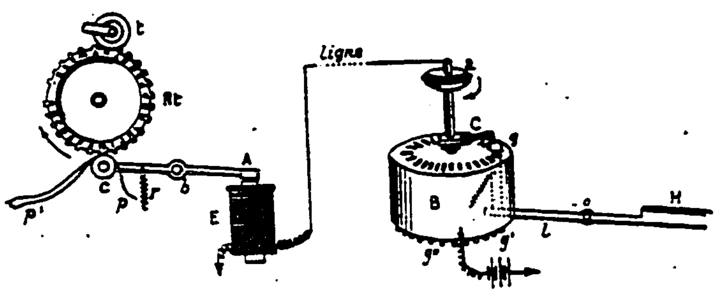


Figure 10. Diagram of Hughes Telegraph Mechanism

battery sent a negative current through the shaft halves and over the telegraph line (Figure 10). When an operator pressed a key and raised the corresponding gudgeon, the gudgeon broke the electrical contact formed by the carriage's two springs and screw between the upper and lower parts of the revolving shaft. A positive current then flowed from the instrument's key into the upper portion of the shaft and out to the telegraph line. At the receiving instrument, the positive electrical pulse first passed through the printing magnet (labelled as E in Figure 10), a combination of permanent and electromagnets, then the upper followed by the lower half of the revolving shaft, finally flowing to ground. The printing magnet released the printing mechanism and printed the appropriate letter since the gudgeon box and typewheel of the transmitting and receiving instruments turned in synchronicity.

The synchronous movement of the sending and receiving instruments' typewheels and gudgeon boxes was the essential principle of the Hughes telegraph. A flywheel maintained the speed created by the falling weight that drove the carriage and typewheel relatively constant. To place the instruments in synchronicity, one operator set the speed of his carriage, say, at 120 turns per minute, then transmitted the same letter over and over. If the operator at the other end received the same letter repeatedly, the instruments were synchronized to within 1/56th of a carriage turn. If the letters progressed forward through the alphabet, then the receiving post was turning too fast. If the letters received went backwards through the alphabet, the receiving post's operator increased the speed of his apparatus' carriage. By transmitting the same letter once every three turns of the sending carriage, operators could synchronize their instruments to within 1/168th of a turn.

Synchronicity was also the key feature of another telegraph instrument adopted in France during the 1860s, the facsimile telegraph, also called the autographic telegraph or the pantelegraph. Although the autographic was less a high-speed telegraph than a special service to the public, the improvement of the autographic by a French telegrapher led directly to the introduction of a new kind of high-speed telegraphy after 1870, the multiple telegraph, which involved working several instruments over the same line in either direction successively so that, say, six agents with six instruments in three different towns could use the same wire in what appeared to be the same time.[16] Without an adequate synchronizing mechanism, multiple telegraphy was impossible. The facsimile instrument introduced during the 1860s, therefore, was an important contribution to the contemporary technological milieu as another utilization of synchronicity in telegraphy and as a stepping stone for the creation of a new form of fast telegraphy.

In 1863, the Telegraph Administration introduced the Caselli pantelegraph between Paris and Marseille and, in 1865, extended service to lines between Paris and Lyon and Paris and Le Havre.[17] The invention of Giovanni Caselli (1815-1891), professor of physics at the University of Florence,[18] the autographic transmitted images from one point to another over telegraph lines. The cost of a facsimile "telegram" (Figure 11)[19] depended upon the size of the picture sent, the smallest being 30 cm^2. The sending party drew his visual message on metallic foil using an insulating ink supplied by the Telegraph Administration and the "message" arrived at its destination as a drawing of blue lines on a white background.[20]

The Caselli facsimile[21] used a "pen" that oscillated from side-to-side and from top to bottom of a metallic foil sheet by means of a cumbersome electromechanical contrivance that combined the movements of a clockwork mechanism and a pendulum (Figure 12). The horizontal and vertical motion of the "pen" over the image (Figure 13)[22] might be compared with the path of an electron beam in a television picture tube as it scans an arrays of phosphorescent dots. Whenever the "pen" touched the insulating ink, a current flowed from a battery directly to the telegraph line. At the other end, another "pen" scanned a chemically treated sheet of paper in

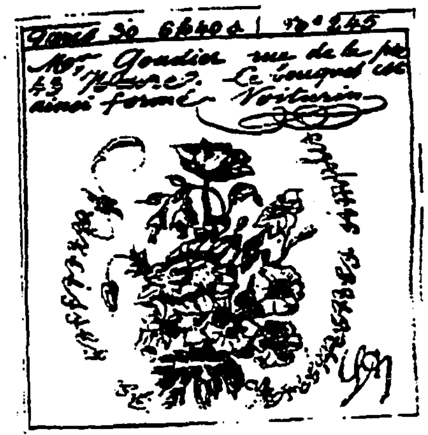


Figure 11. An Autographic "Telegram"

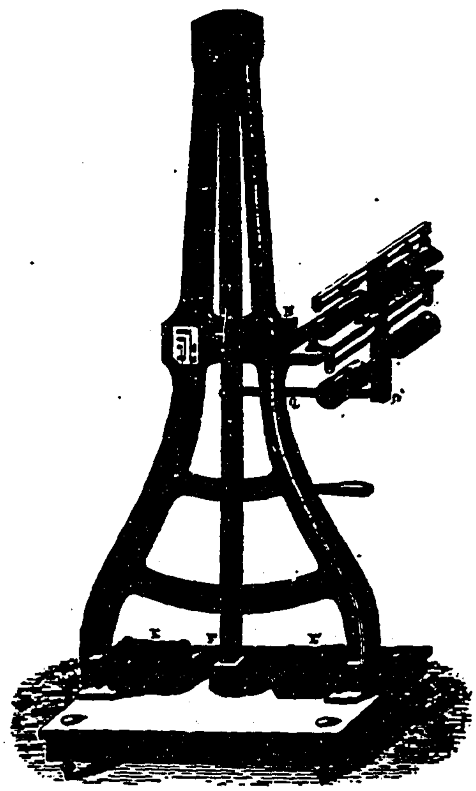


Figure 12. The Caselli Pantelegraph

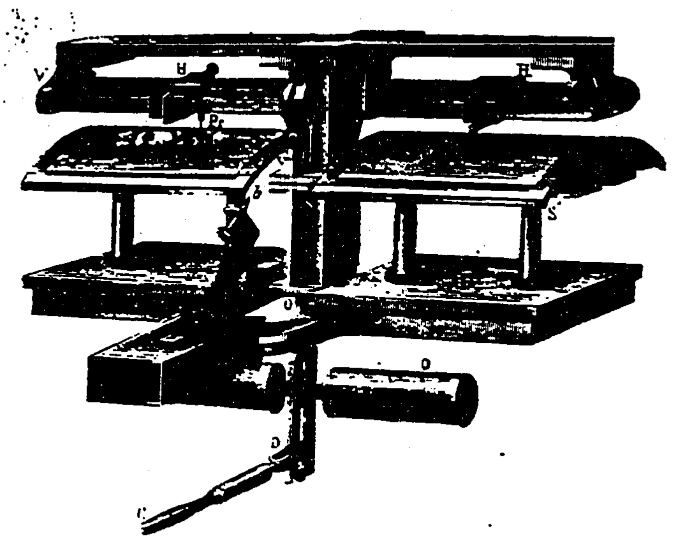


Figure 13. Scanning Mechanism of Caselli
Facsimile Telegraph

a similar fashion. The strong current sent when the transmitting apparatus "read" an insulated section arrived at the receiving apparatus and the "pen" decomposed the chemical in the paper, leaving a blue trace. The ensemble of blue traces recreated the image sent. The period of the Caselli pantelegraph pendulum was adjustable so that operators could synchronize the apparatus. The operator who wished to send placed a metallic sheet on which he had drawn a straight, vertical line using nonconducting ink on the transmitting surface. If the image received were a straight line, the instruments were synchronized. If the line fell to the right (too fast) or to the left (too slow), the operator adjusted the period of the receiving instrument's pendulum.

Although some interest in facsimile telegraphs continued into the 1870s, the thrust of instruments adopted in France was in another direction, faster speeds. For example, Morse telegraphs replaced dial instruments, the number of Morse increasing from 3,853 to 7,702 and of dial apparatus falling from 1,247 to 633 between 1876 and 1 July 1883. Moreover, where traffic justified the switch, Hughes telegraphs replaced Morse apparatus. While duplexing (that is, an arrangement of the line that permitted signals to pass in opposite directions simultaneously along the same wire) played some role in increasing the number of signals per unit of length and per unit of time that lines handled, few lines had a Morse working in duplex as late as 1884. In addition to the increased employment of Hughes telegraphs, new instruments provided still higher speeds. Introduced in 1876, the Wheatstone automatic transmitted 100 dispatches per hour (compared to 40 to 60 for the Hughes), but operated over only four lines by 1884. A numerically more important technology was that of multiple telegraphy in which several instruments worked over the same line successively in either direction at two or more locations. Although the Meyer multiple telegraph transmitted 75 dispatches per hour, its successor, the Baudot, regularly handled 200 messages an hour in 1878.[23]

In France, J. A. C. Rouvier (1825-1885), a graduate of the Ecole polytechnique and an inspector in the telegraph corps,[24] undertook pioneering work in multiple telegraphy. As he described it in 1858, Rouvier's telegraph was intended to be a practical means for simultaneously transmitting several dispatches on the same wire either in the same or opposite directions, although he imagined only two stations on the line.[25] Rouvier proposed synchronizing the sending and receiving apparatus (Figure 14)[26] by means of a pendulum in a fashion not too different from that later used in the Caselli pantelegraph. Improvement of the Caselli facsimile telegraph became the starting point of Bernard Meyer (1830-1884), the French telegraph operator who designed the first

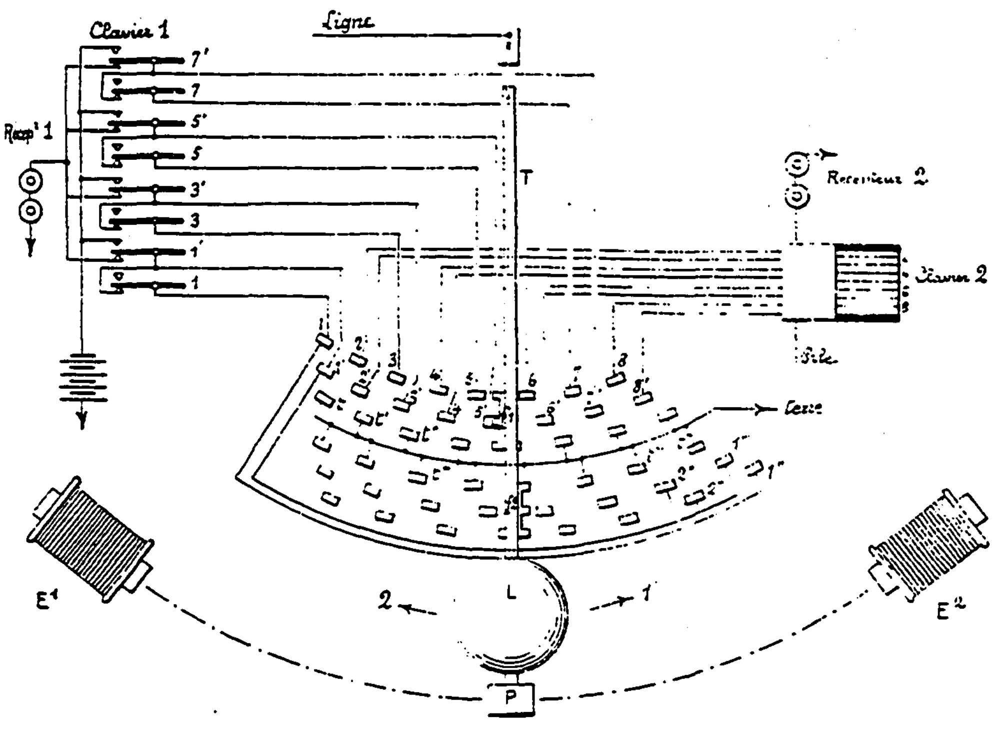


Figure 14. Rouvier's Multiple Telegraph

multiple telegraph actually put into use. Significantly, his multiple telegraph receiver employed an essential feature carried over from his work on the autographic.[27]

Overall, Meyer's improvement of the Caselli apparatus was a simplification of a mechanism that was bulky, heavy, and awkward. Meyer's autographic continued to use a pendulum to provide synchronicity between stations, but suspended the pendular mass with two chains that allowed the operator to regulate the synchronism of the apparatus.[28] More importantly for the development of multiple telegraphy, Meyer substituted a rotating cylinder for the "pen" in Caselli's receiving instrument. On the cylinder (Figure 15)[29] was a single spiral rib that wrapped around the cylinder once and that projected from its surface. A clockwork turned the cylinder. At the sending instrument, the cylinder's rib glided over a metallic sheet that contained an image formed with insulating ink in the same way as with the Caselli device. At the receiving apparatus, an ink-roller turned in contact with the edge of the cylinder rib. Just beneath the cylinder lay a band of paper on a continuous roll. The roll of paper and the metallic sheet at the transmitting end advanced a small fraction of an inch with every revolution of the cylinder.

In the sending and receiving instruments, the rib on the cylinder came in contact with only one point on the surface

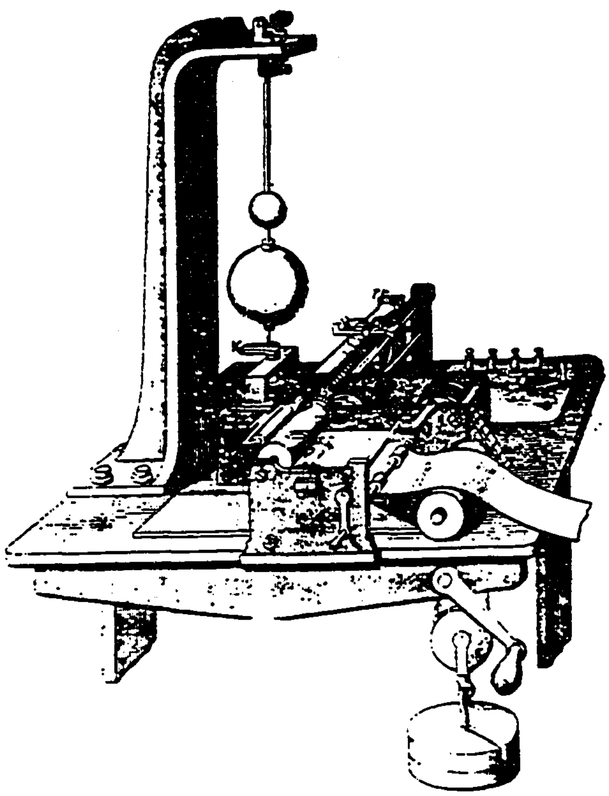


Figure 15. Meyer's Autographic Telegraph

of the metallic sheet or paper roll at any given time. As long as the transmitting and receiving devices remained synchronous, the points of contact on the two instruments always corresponded. As with the Caselli autographic, the transmitter sent a current to the line whenever and as long as the cylinder's rib made contact with the non-conducting ink on the metallic sheet. In contrast to the Caselli's electrochemical recording, however, the current at the receiving end passed through an electromagnet and raised a platen located directly under the cylinder. The platen pressed the paper roll against the inked edge of the cylinder's rib, thus printing the image in a fashion similar to the inking Morse.

As a result of Meyer's improvements, the facsimile telegraph transmitted a 30 cm^2 image in a minute and a half, compared to three and a half minutes with a Caselli, when it began operation between Paris and Marseille.[30] In 1872, Meyer's first multiple telegraph went into operation over a line between Paris and Lyon and transmitted 90 messages an hour between four instruments.[31] By 1876, the multiple between Paris and Lyon regularly handled 150 messages per hour over the same line. Although Meyer's multiple initially worked poorly over the 900 km between Paris and Marseille, a Paris telegraph operator surmounted the difficulty.[32] Later, Meyer connected Paris, Caen, and Cherbourg simultaneously over a single wire with a quadruple multiple telegraph installation. Paris communicated with each of the other towns while Cherbourg and Caen transmitted to each other. The Meyer system was adopted in other countries, notably in Germany, in 1884, and in Austria, in 1886.[33]

Synchronism between the sending and receiving apparatus, as with the autographic and Hughes telegraphs, was an important aspect of Meyer's multiple telegraph. The receiving instrument employed the rotating ribbed cylinder of his pantelegraph. Multiple telegraphy took advantage of the time between signals, a method of using the lines called the "division of time" ("division du temps").[34] After one instrument sent a signal or letter, another instrument transmitted followed by another until the first instrument sent a second letter. Meyer invented a device, called a distributor ("distributeur"), to permit the "timesharing" of a common, single telegraph line by several instruments.

The Meyer multiple telegraph[35] consisted of three parts: manipulators, a distributor, and receivers (Figure 16).[36] The number of manipulators and receivers used depended upon whether the system operated as a quadruple (4) or sextuple (6). The manipulator consisted of eight keys (four black to make dots and four white to make dashes) mounted on a common axis from which they were electrically insulated. Each key was connected to the pile and to a contact point on the

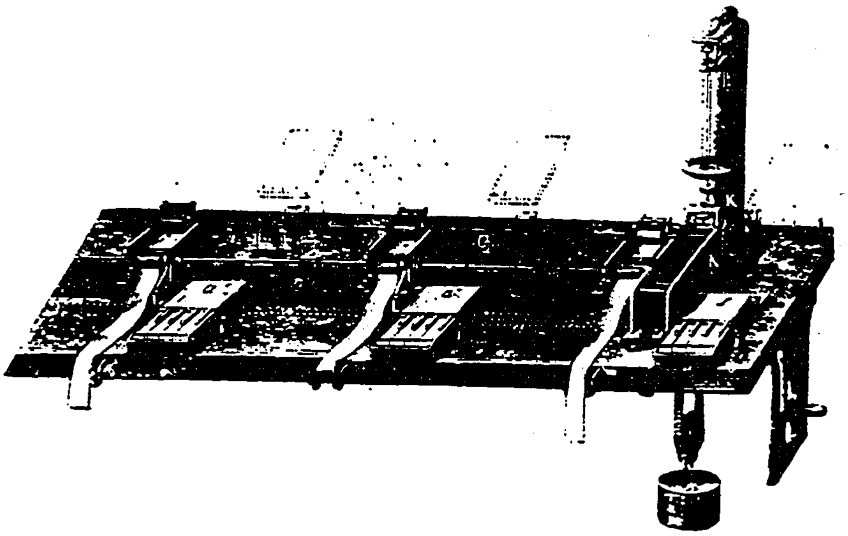


Figure 16. Meyer's Multiple Telegraph

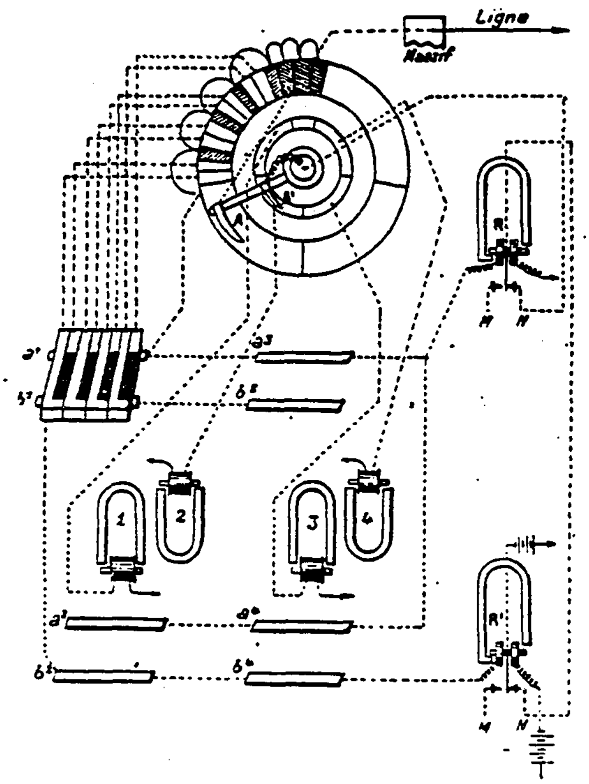


Figure 17. Distributor for Meyer Multiple Telegraph

distributor (Figure 17).[37] A rotating brush passed over the distributor contacts and permitted current to flow from the pile to the key and, through a distributor contact assigned to that particular manipulator, to the brush and finally the line. A special arrangement of the key mechanism sent brief single pulses over the line when the operator depressed a black (dot) key and longer double pulses when he depressed a white (dash) key.

The distributor comprised two metallic, concentric wheels over each of which travelled a brush. In the sextuple, the surface of the distributor was divided into seven sectors, six of which were equal in size and corresponded to the six manipulators worked by the operators. The seventh and smaller sector served to correct the synchronization. The outside wheel (labelled A in Figure 17) had 74 contacts insulated from each other with twelve sectors assigned to each apparatus; the two remaining sectors provided correction of synchronicity. The twelve contacts assigned to each apparatus consisted of four groups of three sectors each. The first of the three sectors in a given group communicated with a black (dot) key, the second with a corresponding white (dash) key, and the third with ground. The distributor brush travelled over the three contacts of a group, then passed on to the next group, and so on through the remainder of the distributor wheel. As the brush continued rotating and passed consecutively from one sector to the next, each of the six manipulators transmitted one letter (up to four dots and/or dashes, therefore the four groups of three sectors each).

The receivers utilized in Meyer's multiple telegraph (Figure 18)[38] clearly borrowed from his autographic apparatus. A cylinder furnished with a rib like that of the autographic, but taking up only 1/6th of the cylinder's circumference, and a roll of paper unreeled with a continuous movement were the basic features of the multiple receiver. The receivers were grouped in pairs and, in each of them, the cylinder's rib was arranged in such a way as to face the paper roll at the same time that the distributor brush rubbed across the group of sectors corresponding to that instrument. When a momentary current came over the line, it caused the printing electromagnet to raise an armature that brought a roll of paper in contact with the cylinder's inked rib and caused the recording of either a dot or dash. The dots and dashes of the Morse code appeared in parallel lines representing letters or numbers and spaced about 3 mm from each other.

Baudot's multiple telegraph took the Meyer system one step further and made it a letter printing instrument by combining the multiple and Hughes telegraphs.[39] The Baudot telegraph first operated on a line between Paris and

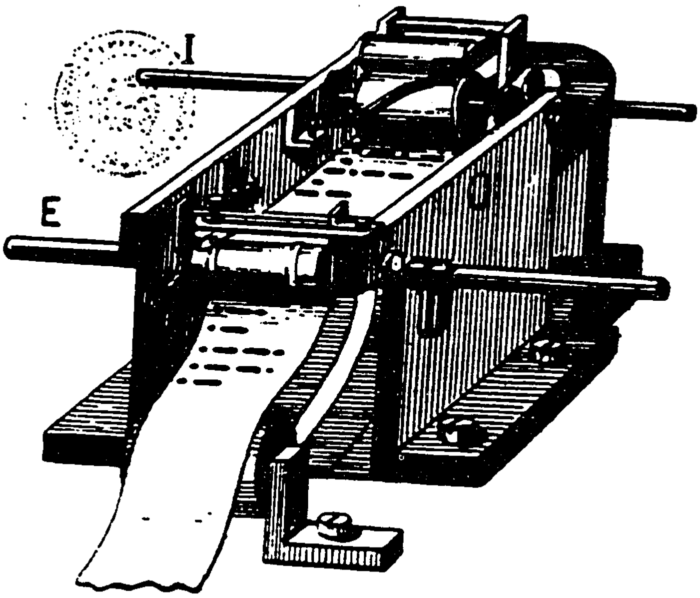


Figure 18. Receiving Apparatus for Meyer Multiple Telegraph

Bordeaux. By 1892, France had 101 Baudot printing multiple telegraphs in operation.[40] On 17 June 1874, Baudot took out a patent for his first system: the manipulators comprised six keys and utilized a 6-element code. Although the system of six keys worked suitably well, Baudot designed a simpler 5-element alphabet in order to use currents of one polarity for signals and currents of the opposite sign in order to clear the line between pulses, thereby protecting the receivers from the unwanted effects of capacitive phenomena that invariably accompanied high-speed transmissions. For the same reason, the Hughes telegraph had transmitted a negative current between the positive pulses generated by depressing the instrument's keys. In 1876, Baudot took out a second patent for a system similar to the first that formed signals from 5 instead of 6 elements.[41]

Baudot's 5-key keyboard used 31 of the 32 combinations possible with five elements (2^5-1), the unused combination (as in the 6-key system) being when all the keys were at rest. In Figure 19,[42] the table shows the meaning of each combination with black dots indicating depressed keys. The keys of each manipulator[43] in the first version were behind a small vertical board that supported an escritoire upon which rested the dispatches that were to be transmitted (Figure 20).[44] In 1882, Baudot placed the keys in a horizontal position, in the order 5-4-1-2-3 (Figure 21).[45] The keys

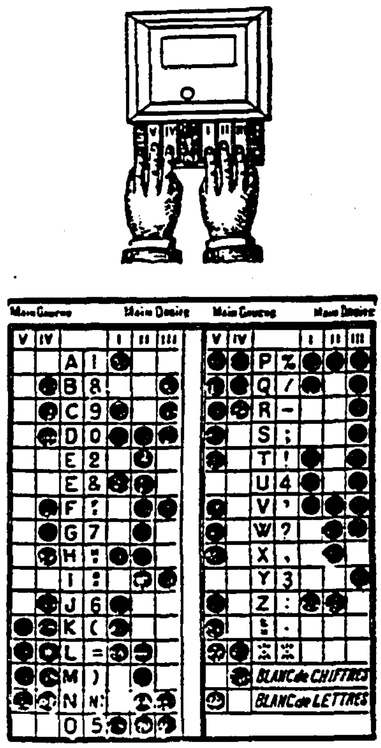


Figure 19. Table Showing Baudot Code and Fingering Order

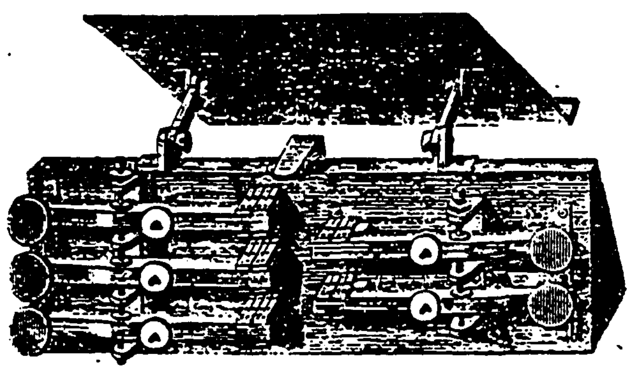


Figure 20. Baudot Manipulator, First Version

Figure 21. Baudot Manipulator, 1882 Model

were connected to five contacts on a distributor much as in the Meyer multiple, although the actual construction of the keys was significantly different in order to assure that, when two or more consecutive keys emitted currents of the same sign, the line was not charged with more than one current of the same sign and that the polarities of consecutive emissions were of opposing signs to combat capacitive action on the line that became a problem at such high transmission rates.

The brushes of the Baudot distributor (Figure 22)[46] turned in synchronism with those of a second similar distributor (Figure 23)[47] placed at the other end of the line. As in the Hughes telegraph, an operator depressed a foot pedal that kept a weight continually falling. The falling weight and a flywheel provided the distributor's regulated, synchronized, continuous rotation. If an operator depressed a series of keys at the same time, say the first, third, and fifth for the letter T (see Figure 19), the depressed keys allowed a current of one sign to flow through the distributor brush, over the line, and to the brush and distributor at the receiving end. The receiving instrument had a series of five electromagnets and levers of a special design, called polarized relays (identified as E_1 through E_5 in Figure 23). These polarized relays responded to currents of only one particular polarity, in this case, the polarity

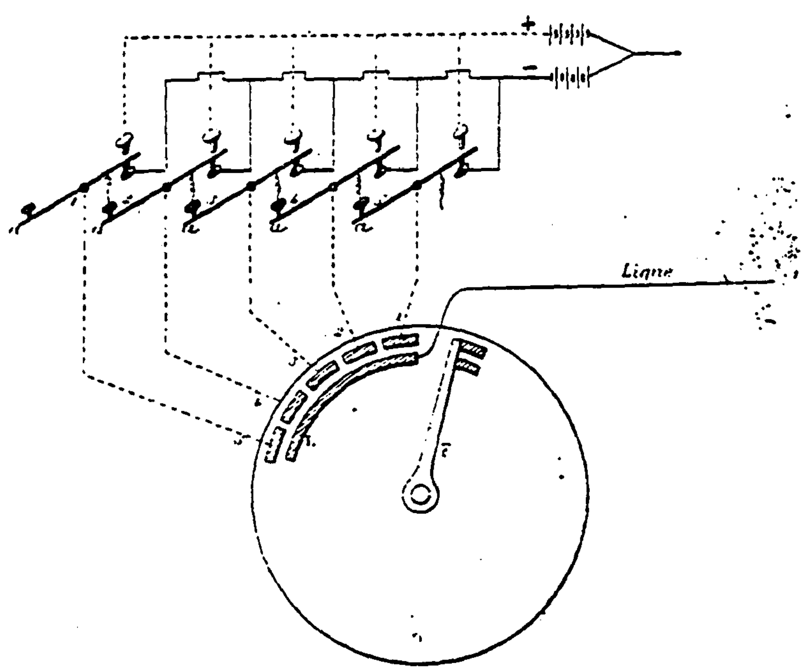


Figure 22. Diagram of Baudot Transmitting Distributor

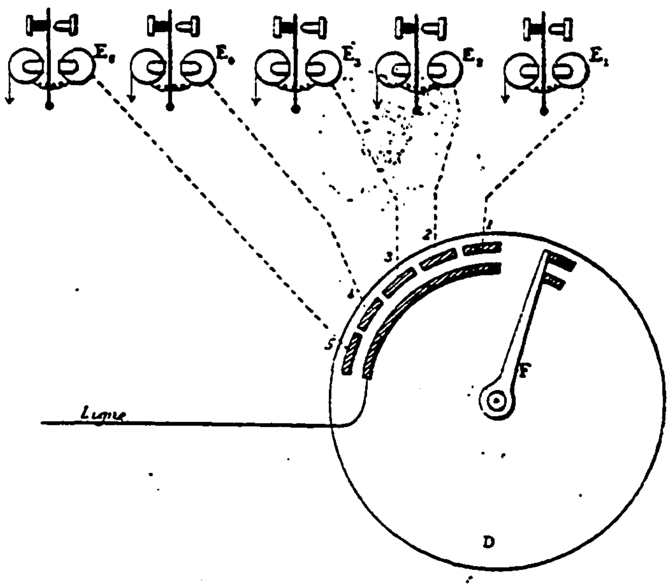


Figure 23. Schema of Baudot Receiver Showing Distributor and Polarized Relays

of the pulses sent when an operator depressed one of the manipulator keys. Provided the sending and receiving distributors were synchronized, each of the sending keys corresponded to one of the receiver's polarized relays. Thus, the state (activated or inactive) of the relays' electromagnets reproduced the combination of keys depressed at the transmitting end. At this point, the combiner came into play.

The combiner (Figure 24)[48] translated the combinations of signals received over the line into typographical characters. As originally designed, the combiner comprised an ebonite cylinder on three-fourths of whose circumference were five rows of metallic contacts (Figure 25).[49] A brush traversed each row of flat contacts. In 1879, Baudot replaced the flat contacts with raised points and depressions and substituted a comb for the five brushes. In both models, the arrangement of metallic contacts was that of Figure 25, which is a flat representation of the cylinder and its contacts. The five rows of contacts were arranged on the combiner's cylinder so as to reproduce the 31 key combinations used in sending signals. The black squares indicate areas corresponding to activated polarized relays (and depressed transmitting keys); all black areas were electrically united to each other and to one contact of a corresponding relay. The white squares were also connected

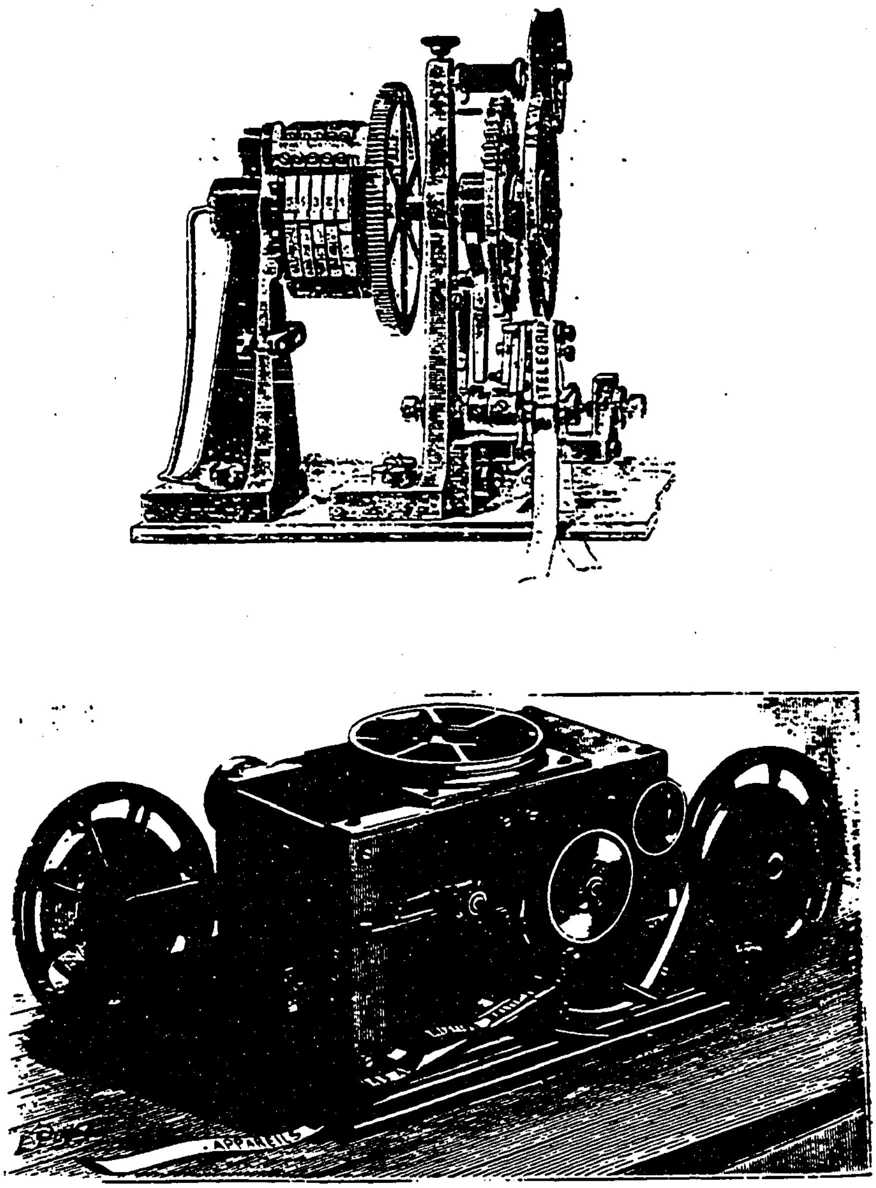


Figure 24. Baudot Combiner, Showing Typewheel (Above)

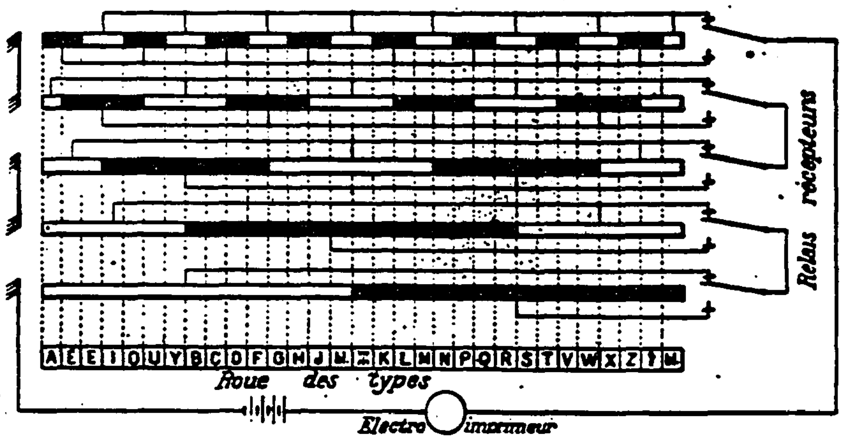


Figure 25. Schema of Baudot Combiner Cylinder Contacts

to each other and to the other contact of the appropriate relay electromagnet.

A typewheel mounted on the axis of the brushes had typeface arranged on its circumference in the same order as the combinations of contacts on the combiner cylinder. From the distributor, a signal combination passed to the combiner, where the combiner's brushes "read" the appropriate signal combination. The letter corresponding to that combination now faced a paper strip and, the imprinting circuit closed, the printing armature came into play and impressing the inked typeface image onto the paper strip.

In addition to multiple telegraphs like those of Baudot and Meyer, another form of high-speed transmission adopted in France during the 1870s was the automatic. In automatic telegraphy, an agent prepared messages before transmission by punching holes in a paper strip. Feeding the perforated strip into a transmitter allowed the sending of signals at a much higher rate than that attained by manual transmission. A number of French and foreign inventors sought to design automatic telegraphs before 1870,[50] but they worked satisfactorily only under "laboratory" ("cabinet") conditions.[51] Charles Wheatstone presented an automatic to the Telegraph Administration as early as January 1859,[52] but a later, improved version began operation in 1876 between Paris and Marseille after a demanding test on a 1,300 km stretch of wire from Paris to Marseille via Bordeaux.[53]

The Wheatstone automatic consisted of three separate apparatus: a perforator, a transmitter, and a receiver.[54] The perforator (Figure 26)[55] punched configurations of holes representing the dots, dashes, and spaces of the Morse code into a strip of paper. The resemblance of the punched paper strip to the cards of the Jacquard loom led French telegraphers to dub his automatic "Wheatstone's electric Jacquard".[56] Smaller holes in the center of the paper served to move it through the transmitter. A drive wheel with teeth and a pressure disk put in motion by an escapement mechanism fed the paper through the transmitting device. As the perforated paper travelled through the transmitter, it passed over a pair of vertically arranged levers (one for each row of holes in the paper strip) fixed to a rocking beam (V, V′, and K in Figure 27).[57] The presence or absence of a hole in the paper gave motion to these levers, which in turn imparted motion to the rocking beam. The rocking beam possessed three pins, the left one connected to the line, the right to ground, and the center insulated. As the beam rocked, the pins brought a lever into contact with one of two metallic arms (C and Z in Figure 27). One of these arms was in contact with a negative current and the other with a positive current. When a hole in the punched paper strip passed over the levers, one of the levers rose through the hole and

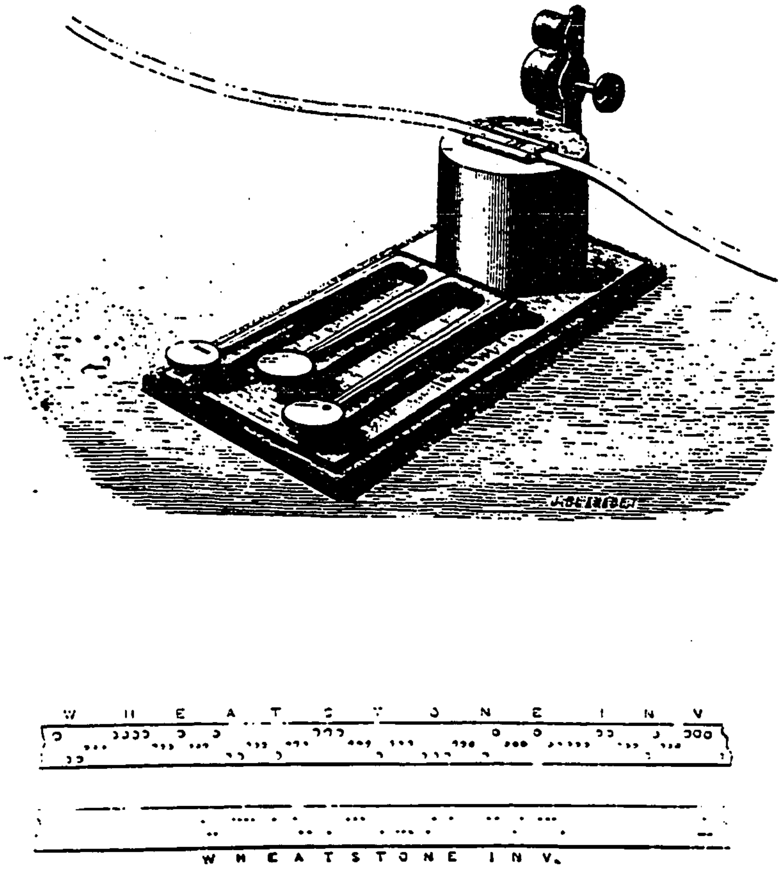


Figure 26. Wheatstone Automatic Perforator (Above) and Example of Punched Tape (Below)

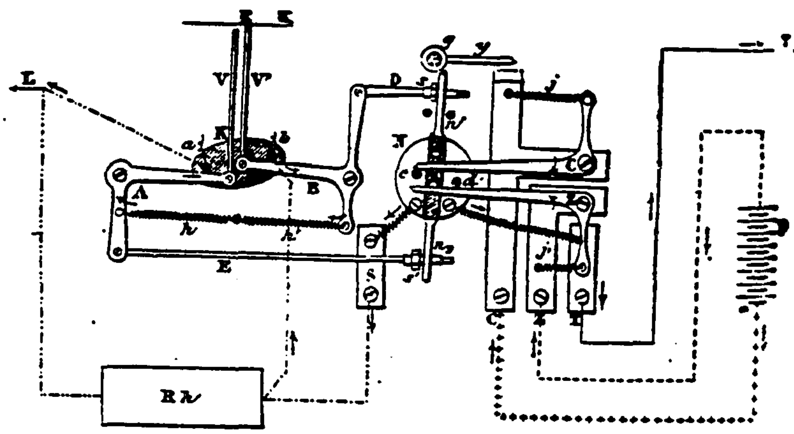


Figure 27. Schematic of Wheatstone Automatic Transmitter

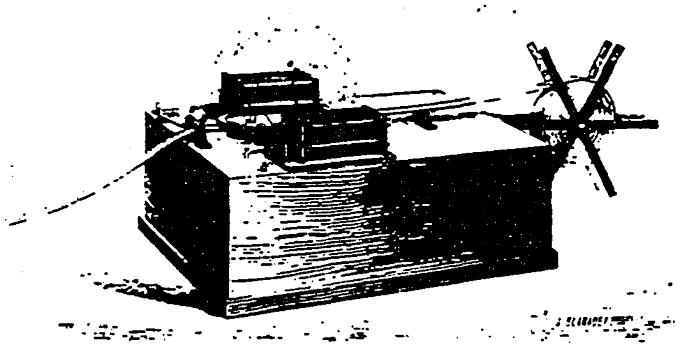


Figure 28. Wheatstone Automatic Receiving Instrument

rocked the beam below. This motion brought into play the metallic arms and a positive pulse went out over the line. The levers, pins, and rocking beam also acted to send a negative current over the line between dots and dashes (as the Hughes and Meyer instruments did) so as to counteract the effect of capacitive phenomena that beleaguered rapid telegraphy. The Wheatstone automatic receiver (Figure 28)[58] essentially performed the same function as that of an inking Morse, but at a much higher speed. The transmission of signals of alternating signs necessitated the use of a polarized relay with the receiver.

In addition to automatic and multiple telegraphy, the French telegraphs experimented with techniques of simultaneous transmission. A duplexed telegraph line allowed an instrument at one end of a given line to transmit to a receiver at the other end where another operator simultaneously transmitted to the first instrument. Although other methods existed previously,[59] the American telegrapher, Joseph B. Stearns (1831-1895)[60] resolved the difficulties of simultaneous transmission in a fashion sufficiently satisfactory that the French telegraphs undertook a study of it. The French tested Stearns' two systems of duplexing, operating a Morse instrument with the differential method and a Hughes telegraph with the Wheatstone bridge technique. The differential duplex used a relay whose electromagnetic coils received currents of opposite polarity (Figure 29). The bridge duplex equalized currents in the two halves of the circuit using the familiar Wheatstone bridge (Figure 30). Both methods used capacitors to counterbalance the effects of charging and discharging the line with each signal.[61] Tests of Stearns′ bridge duplex on a Hughes line between Paris and Lille failed to give dependable results, however. An examination of the differential technique on a Morse line gave good results, but not if the key were opened and closed rapidly.[62] The failure of Stearns′ duplexes in France even on Morse lines underscored the electrical phenomena that rapid transmission made apparent and the need to apply electrical theory to telegraphy.

The solution to adapting the duplex to the Hughes telegraph came from the French telegraph inspector and Ecole polytechnique graduate, François Ailhaud (1924-1879).[63] In 1877, Ailhaud worked out a method for duplexing over the underwater telegraph cable between Marseille and Algers that combined a relay with a differentially wound electromagnet and a Wheatstone bridge arrangement.[64] In the same year, he resolved the problem of duplexing the Hughes again using a combination of the differential and bridge systems, but with the added advantage of eliminating the use of condensers (see Figures 29 and 30). The Ailhaud duplex quickly and successfully went into regular operation between Paris and

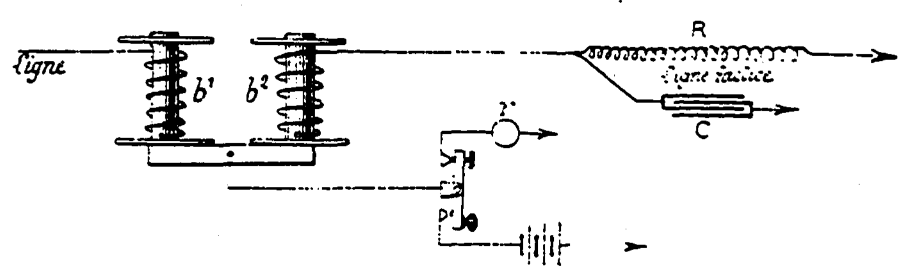


Figure 29. Stearns/ Differential Duplex

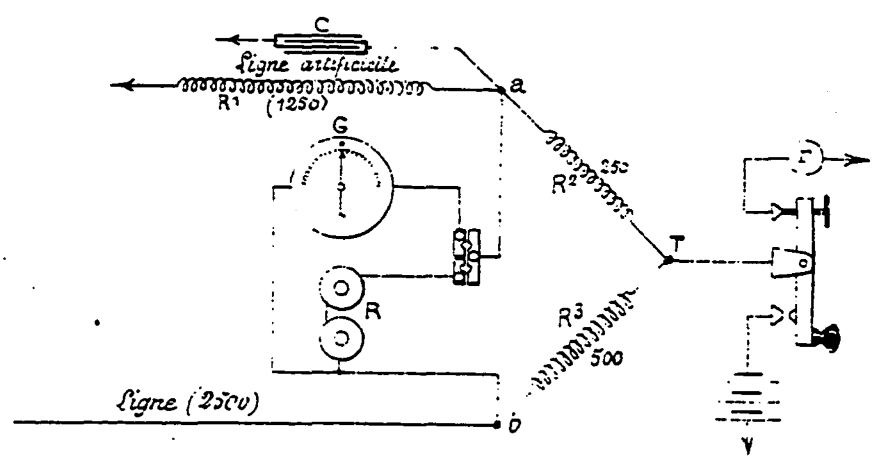


Figure 30. Stearns´ Duplex, Wheatstone Bridge Method

Marseille, Paris and Lyon, and Lyon and Marseille.[65] Ailhaud's duplex for Hughes telegraphs consisted of adding three cams to the instrument that opened and closed three circuits. By proper adjustment of the cam timing, the cams altered the local circuit in a series of three steps that first counteracted the effect of charging the line, then provided a cascaded current whose sign was opposite that of the discharge current.[66]

Ailhaud's duplex clearly demanded an understanding of electrical theory, particularly notions regarding the propagation of electricity through a conductor and capacitive phenomena. The use of currents of alternating polarities in the Wheatstone automatic, the Meyer multiple telegraph, and the Hughes instrument equally depended upon electrical theory. The use of high-speed techniques, like the duplex, and telegraphs, like the Hughes, Meyer, and Baudot, thus provided a technological milieu for operators and inspectors in which electrical theory played an important role. As Gustave Séligmann-Lui (1855-1915), French telegraph _ingénieur_ and Ecole polytechnique graduate,[67] wrote in 1881: "The increasingly general use of rapid instruments with sensitive parts, of simultaneous transmission, and of multiple systems has led electricians <i.e., the _ingénieurs_ of the French telegraphs) to attach a great importance to certain properties of telegraph lines that they did not have to take

into account as long as Morse or other equally simple apparatus were the only ones in use."[68]

The high-speed technology introduced after 1860 also placed special demands upon those charged with operating the instruments. Duplexing a Wheatstone automatic, for example, required one employee just to watch over the duplexing equipment and to make adjustments.[69] The carriage mechanism of the Hughes telegraph covered several gudgeons at one time and so restricted the letters that an operator could send in succession.[70] The tempo of transmission was important for the Meyer multiple telegraph since any one manipulator could send only once every revolution of the distributor. Therefore, the manipulators had a kind of metronome that indicated when to transmit.[71] Similarly, the Baudot signalled the operator when to strike the manipulator keys; the manipulator introduced in 1895 even had a small telephone receiver that produced a particular sound at each passage of current.[72]

High-speed techniques and technologies thus created a telegraphic workplace that made special manipulative demands of the operators and required of inspectors (*ingénieurs* after 1878) a knowledge of electrical theory. An important consequence of these demands was the development of courses in telegraph instruction for operators and inspectors that eventually led to the founding of the Ecole supérieure de

Télégraphie, France's first school to offer a program in electrical engineering.

FOOTNOTES

[1]"Statistique de la télégraphie priveé en France pendant l'anneé 1859," Annales télégraphiques 2,4 (1861): 78; "Tableau des produits des bureaux de l'Etat en 1866," Lois et règlements, 1 May 1867; and "Tableaux des produits des bureaux de l'Etat pour l'année 1871," Lois et règlements, 1 July 1872.

[2]Journal des télégraphes 4 (October 1869): 7.

[3]Annales télégraphiques 2,4 (1861): 326; Journal des télégraphes 3 (June 1868): 2; and "Loi relative à la taxe télégraphique," Lois et règlements, 21 March 1878.

[4]"Appareils télégraphiques employés en France," Annales télégraphiques 3,5 (1878): 339.

[5]Louis Bergon, "De la transmission automatique," Annales télégraphiques 2,3 (1860): 115.

[6]Charles Lemoyne, "Des moyens employés pour augmenter la vitesse de transmission des dépêches télégraphiques," Annales télégraphiques 2,3 (1860): 376-377 & 379. See also, Charles Marie Guillemin, "Note sur le maximum de signaux télégraphiques élémentaires qu'on peut transmettre dans un temps donné, au moyen de l'appareil Morse," Annales télégraphiques 2,4 (1861): 495-499, where speeds of 36 to 60 and even 72 words per minute were attained over actual telegraph lines.

[7]Blavier, Nouveau traité, 2:258.

[8]The number of Hughes telegraphs in use was 29 in 1862 and 374 in 1870. "Tableaux des produits des bureaux de l'Etat pour 1870," Lois et règlements, 31 December 1871.

[9]A number of biographical notices exist for Hughes, including G. Burniston Brown, "David Edward Hughes, F.R.S.," Notes and Records of the Royal Society of London 34 (1980): 227-239; "Obituary: David Edward Hughes," Journal of the Institution of Electrical Engineers 29 (1899-1900): 951-954; S. Evershed, "The Life and Work of David Hughes," Ibid. 69 (1930-31): 1245-50; and "David Edward Hughes," in Dumas Malone, ed., Dictionary of American Biography (New York: Charles Scribner's Sons, 1960), 5:347-348.

[10]Annales télégraphiques 2,4 (1861): 328 & 583; 2,7

(1864): 602-604; Bergon, "Note sur un nouvel appareil imprimant présenté récemment par le professeur Hughes," Annales télégraphiques 2,3 (1860): 373-375.

[11]Annales télégraphiques 2,7 (1864): 602-603.

[12]Annales télégraphiques 2,8 (1865): 368-369.

[13]For my description of the Hughes telegraph, I have relied upon Blavier, Nouveau traité, 2:237-269 and Louis Borel, Etude du télégraphe Hughes: Cours théorique et pratique (Paris: E. Donnaud, 1873). The photograph comes from the History of Telecommunications Collection, C.N.E.T., Paris.

[14]There were suggestions for rearranging the Hughes keyboard letters in order to speed transmission, but they were not adopted. Lemoyne, "Note sur un meilleur arrangement des lettres dans les appareils Hughes et dans les appareils à cadran," Annales télégraphiques 2,5 (1862): 47-52 and Emile Joseph Caël, "Moyen d'améliorer le rendement de l'appareil Hughes," Annales télégraphiques 3,2 (1875): 223-233.

[15]Figure 10 is from the History of Telecommunications Collection, C.N.E.T., Paris.

[16]I use the term "multiple telegraphy" in the sense described in the text, namely, successive emissions by two or more instruments over the same wire, in one or both directions. As Montoriol, p. 235, pointed out, multiple systems "marquent une étape dans l'évolution de la télégraphie et constituent une branche essentiellement française de cette science." In the United States, multiple telegraphy was a generally neglected technology and competent writers devoted either little or no coverage to multiple telegraphy. For example, William Maver, American Telegraphy: Systems, Apparatus, Operation (New York: J. H. Bunnell & Co., 1892), devoted chapters 11-16 (pp. 169-267) to duplexing and quadruplexing and chapter 21, pp. 336-343, to what the author called "synchronous multiplex telegraphy," but omitted all discussion of what the French call multiple telegraphy. Similarly, George B. Prescott, Electricity and the Electric Telegraph, 2 vols. (New York: D. Appleton & Co., 1892) provided a lengthy discussion of simultaneous transmission. His only discussion of multiple telegraphy was a study of Meyer's system, pp. 898-902, in a chapter titled "Edison's Quadruplex Telegraph."

[17]Annales télégraphiques 2,8 (1865): 365 and "Loi relative à la correspondance télégraphique par les sémaphores

et par l'appareil Caselli," Annales télégraphiques 2,6 (1863): 390-393.

[18]See "Giovanni Caselli," in Alberto M. Ghisalberto, Chief Editor, Dizionario biografico degli Italiani (Rome: Istitute della Enciclopedia Italiana, 1978), 21:331-3352, for other biographical information.

[19]From the History of Telecommunications Collection, C.N.E.T., Paris.

[20]Instruction sur l'emploi de l'appareil autographique (Paris: Impr. Impériale, 1865); and Annales télégraphiques 2,8 (1865): 365-368 and "Loi relative à la correspondance télégraphique par les sémaphores et par l'appareil Caselli," Annales télégraphiques 2,6 (1863): 390-393.

[21]For my description of the Caselli pantelegraph, I relied upon patent no. 32,897, issued 7 July 1857, and additional certificate of 12 February 1858; patent no. 39,546, issued 22 January 1859, and additional certificates of 5 March 1860 and 7 April 1862; Théodose DuMoncel, "Description des télégraphes électro-chimiques de MM. Caselli et Bonelli," Annales télégraphiques 2,6 (1863): 209-245; and Blavier, 2: 274-301. A more recent discussion of the Caselli autographic is that of Robert Soulard, "Caselli et Lambrigot," Revue d'histoire des sciences et leurs applications 22 (1969): 76-78.

[22]Figures 12 and 13 are from the History of Telecommunications Collection, C.N.E.T., Paris.

[23]Adolphe Cochery, "Rapport adressé au président de la République sur l'organisation des services des postes et des télégraphes avant et depuis l'année 1878," Journal officiel de la République française, 19 June 1884, p. 3176.

[24]Montoriol, p. 233. No necrological notice appeared in the Annales télégraphiques on Rouvier. His dates come from Montoriol, p. 711, which lists him as a division director. Annuaire des lignes télégraphiques, 1877, p. 15, and Annuaire des lignes télégraphiques, 1858, p. 11, describe him as an inspector, first class, and state that he joined the service on 1 November 1847. Marielle, p. 206, shows him as a graduate of the Ecole polytechnique, class of 1847.

[25]Patents no. 37,986, issued 8 September 1858, and additional certificate of 22 February 1859 and no. 37,987, issued 8 September 1858. Rouvier published an article on his proposed telegraph, "Moyen de transmettre simultanément

plusieurs dépeches par un même fil électrique," Annales télégraphiques 2,3 (1860): 5. According to Blavier, "De la transmission sumultanée de plusieurs dépêches par un même fil," Annales télégraphiques 2,4 (1861): 147, Rouvier had attempted transmission of the signals from both sides of a Foy-Breguet telegraph over a single wire as early as 1852. After 1860, Rouvier patented a number of improvements to the Hughes telegraph: no. 74,675, issued 6 February 1867, and additional certificates of 11 April, 4 October, and 26 October 1867, and 5 February 1868; no. 86,094, issued 16 June 1869, and additional certificate of 11 June 1870; no. 94,173, issued 20 February 1872, and additional certificates of 10 May and 14 October 1872 and 27 February and 11 July 1873.

[26]Rouvier, "Moyen de transmettre simultanément plusieurs dépêches par un même fil électrique," Annales télégraphiques 2,3 (1860): 5-26. Figure 14 is from Schils, Fig. 148.

[27]Montoriol, pp. 235-236; Paul Charbon, "Bernard Meyer, 1830-1884," pp. 153-155, in Chroniques téléphoniques et télégraphiques (hereafter, Charbon, "Meyer"); and Jules Raynaud, "Appareil autographique Meyer," Annales télégraphiques 3,1 (1874): 30-45. Annuaire des lignes télégraphiques, 1877, p. 32, states he entered the service 1 June 1858. Annuaire des lignes télégraphiques, 1858, p. 41, states he was an operator third class stationed at Mulhouse. Necrological note, Annales télégraphiques 3,11 (1884): 289-290.

[28]For my description of Meyer's autographic I drew upon: Raynaud, "Appareil autographique Meyer," Annales télégraphiques 3,1 (1874): 30-47; Edme Hardy, "Note sur quelques perfectionnements apportés au télégraphe autographique Meyer," Annales télégraphiques 3,1 (1874): 48-50; "Rapport fait par M. le comte du Moncel, au nom du comité des arts économiques, sur le télégraphe autographique de M. Meyer," Bulletin de la société d'encouragement 72 (1873): 377-390; and patent no. 68,154, issued 27 July 1865, and additional certificate of 27 July 1866.

[29]Figure 15 comes from the History of Telecommunications Collection, C.N.E.T., Paris.

[30]Ernest Saint-Edme, "Physique industrielle: Télégraphie électrique: le télégraphe électrique de M. Meyer," Annales industrielles 1 (1869): 502-504 and Raynaud, "Appareil autographique Meyer," p. 45.

[31]Montoriol, pp. 235-236, and Charbon, "Meyer," p. 156.

[32]"Application des courants inversés à l'appareil Meyer," Annales télégraphiques 3,3 (1876): 96 and C. R. J. Willot, "Application des courants inversés à l'appareil multiple," Annales télégraphiques 3,3 (1876): 309-314

[33]Montoriol, p. 236, and "Transmission multiple entre plusieurs villes," Journal télégraphique 4 (1879): 412-416.

[34]The expression appears, for example, in Raynaud, "La transmission multiple," p. 189.

[35]For my description of the Meyer multiple telegraph, I have drawn upon the following sources: Bernard Meyer, "Système d'appareil télégraphique automatique universel," Annales télégraphiques 13 (1889): 67-71 & 95-101; Raynaud, "La transmission multiple," pp. 187-224; and patent no. 93128, issued 26 October 1871.

[36]The illustration is from the History of Telecommunications Collection, C.N.E.T., Paris.

[37]The figure is from the History of Telecommunications Collection, C.N.E.T., Paris.

[38]Figure 18 comes from the History of Telecommunications Collection, C.N.E.T., Paris.

[39]Pierre Lajarrige, "Baudot et son appareil télégraphique," in Chroniques téléphoniques et télégraphiques, p. 144, and Pierre Beguinot, "Un Haut-Marnais célèbre: Emile Baudot," Les Cahiers Haut-Marnais 147 (1981): 151.

[40]"Rapport de M. Raymond, sur les titres de M. Emile Baudot à la grande médaille d'Ampère," Bulletin des la société d'encouragement 88 (1889): 36 and "Statistique télégraphique comparative de 1892," Journal télégraphique 19 (1895): 131-132. In comparison, there were 699 dial, 11,622 Morse, 749 Hughes, 3 Wheatstone automatic, 2 duplex, and 219 unnamed other telegraphs in use by 1892.

[41]Patent no. 103,898, issued 17 June 1874, and additional certificate of 17 June 1875; and no. 111,719, issued 2 March 1876, and additonal certificate of 13 December 1876.

[42]The table is from Montoriol, p. 246.

[43]For my discussion of the Baudot telegraph, I have

drawn upon "Télégraphe multiple imprimeur de M. Baudot," Annales télégraphiques 3,6 (1879): 354-389; patent no. 103,898, issued 17 June 1874, and additional certificate of 17 June 1875; and patent no. 111,719, issued 2 March 1876, and additonal certificate of 13 December 1876.

[44]From Montoriol, p. 254.

[45]The illustration comes from the History of Telecommunications Collection, C.N.E.T., Paris.

[46]The drawing comes from the History of Telecommunications Collection, C.N.E.T., Paris.

[47]The schema is from the History of Telecommunications Collection, C.N.E.T., Paris.

[48]The top illustration comes from Montoriol, p. 261, and the lower one from the History of Telecommunications Collection, C.N.E.T., Paris.

[49]From the History of Telecommunications Collection, C.N.E.T., Paris.

[50]For a discussion of the automatic telegraphs presented to the Telegraph Administration, see Bergon, "De la transmission automatique," Annales télégraphiques 2,3 (1860): 113-134 and Raynaud, "Des moyens d'augmenter le rendement des fils télégraphiques desservis par des appareils écrivants," Annales télégraphiques 3,1 (1874): 329-349.

[51]The opinion, for example, of E. Gounelle, "Notice sur quelques appareils télégraphiques apportés récemment en France par M. Wheatstone," Annales télégraphiques 2,2 (1859): 184 (Hereafter cited as Gounelle, "Notice sur quelques appareils").

[52]Gounelle, "Notice sur quelques appareils," p. 174.

[53]Albert Le Tual, Etude du télégraphe automatique de Sir Ch. Wheatstone (Paris: Dunod, 1876), p. 247, and Cochery, p. 3176.

[54]For my discussion of the Wheatstone automatic, I have drawn upon the following sources: "Le Jacquard électrique de Wheatstone," Annales télégraphiques 3,3 (1876): 354-365; Félix François Carème, "Le télégraphe automatique de Sir Charles Wheatstone," Annales télégraphiques 3,3 (1876): 397-485; and Le Tual, passim.

[55]The figure is from the History of Telecommunications Collection, C.N.E.T., Paris.

[56]See, for example, "Le Jacquard électrique de Wheatstone," pp. 354-365.

[57]The schematic drawing comes from Montoriol, p. 208.

[58]The figure is from the History of Telecommunications Collection, C.N.E.T., Paris.

[59]For an earlier discussion of simultaneous transmission in France, see Blavier, "De la transmission sumultanée de plusieurs dépêches par un même fil," pp. 145-165.

[60]Biographical material on Stearns: "Obituary: Joseph Barker Stearns," The Electrical Engineer 20 (1895): 37 and John B. Taltavall, Telegraphers of Today (New York: Club Press, 1894), p. 354; and Journal télégraphique 19 (1895): 215.

[61]H. N. Cailleret, "Transmission sumultanée de deux dépeches en sens contraire par un seul fil," Annales télégraphiques 3,3 (1876): 525-537. Figures 29 and 30 are from Schils, Figs. 145 and 144 respectively.

[62]Caël, "Expose sommaire et critique d'essais de transmission simultanée, système Stearns," Annales télégraphiques 3,3 (1876): 540-547 and "Essais de communication simultanée entre Paris et Lille," Annales télégraphiques 3,3 (1876): 599.

[63]For biographical information, see his obituaries in Annales télégraphiques 3,6 (1879): 493-496 and Journal télégraphique 4 (1879): 497.

[64]J. H. F. Grammaccini, "La transmission simultanée appliquée aux lignes sous-marines," Annales télégraphiques 3,4 (1877): 56-63.

[65]"Transmission simultanée sur les lignes aériennes avec l'appareil Hughes," Annales télégraphiques 3,4 (1877): 198-199; Grammaccini, "La télégraphe double à la station de Marseille," Annales télégraphiques 3,4 (1877): 497-508; and François Ailhaud, "Suppression des condensateurs dans la télégraphie double," Annales télégraphiques 3,4 (1877): 596.

[66]Ailhaud, "Suppression des condensateurs dans la télégraphie double par l'appareil Hughes," pp. 5-8; "Le Hughes duplex sans condensateurs," Annales télégraphiques 3,5

(1878): 106; and L. V. F. Mandroux, "Transmission double sans condensateurs appliquée à l'appareil Hughes (système Ailhaud)," Annales télégraphiques 3,5 (1878): 363-368.

[67]For biographical information, see his personnel dossier, F(90) 20,545, Archives Nationales, Paris, and his obituary in Journal télégraphique 39 (1915): 287.

[68]G. Séligmann-Lui and M. Tongas, "Notice sur les essais électriques des lignes télégraphiques," Annales télégraphiques 3,8 (1881): 216: "L'emploi, tous les jours plus général, d'appareils rapides à organes délicats, de transmission simultanées, de systèmes multiples, a conduit les électriciens à attacher und grande importance à certaines propriétés des lignes télégraphiques, dont on avait pu ne point tenir compte tant que le morse ou d'autres appareils également simples avaient été les seuls en usage."

[69]Carème, pp. 482-483.

[70]Borel, pp. 254-258.

[71]Raynaud, "La transmission multiple," pp. 208-209.

[72]"Télégraphie multiple imprimeur de M. Baudot," p. 387 and Emile Baudot, "La télégraphie multiple," Journal télégraphique 19 (1895): 241-247, 265-270; 20 (1896): 5-10, 28-33 & 57-62.

CHAPTER FOUR

From Telegraph Instruction to the Ecole supérieure de Télégraphie

The adoption of high-speed, complex telegraph apparatus and techniques demanded the employment of knowledgeable agents and, while admissions requirements could screen for desired applicants, good operators resulted from practice and instruction, not testing. Therefore, with the introduction of increasingly more complex technologies came the establishment of telegraph courses for operators. The hiring of inspectors from among station managers, who in turn rose from the ranks of the telegraphists, made the instruction of operators, particularly regarding theoretical matters, that much more important. Nonetheless, until the 1860s, the instruction of operators remained largely *ad hoc* and dispersed. The instruction of inspectors, on the other hand, began and remained centralized in Paris and culminated in the founding of the Ecole supérieure de Télégraphie in 1878 in response to needs arising directly out of the unification of the postal and telegraph bureaucracies.

Beginning in 1854, an operator's instruction in telegraphy began after he successfully passed the battery of tests required for admission into the Telegraph Lines as an apprentice ("*surnuméraire*"). In the semaphore system and the electrical service before 1854, trainees learned solely from an operator appointed for this purpose by the inspector. His instruction comprehended the operation, maintenance, and repair of the telegraph equipment, the signal code, and the rules and regulations of the service and took place in any telegraph bureau.[1] Besides oral explanation, the most typical mode of instruction was practice on the instruments. While learning, the candidate did not transmit dispatches without advance authorization from the station director or the inspector.[2] Practice took place on instruments not in use and intended specifically for instruction or replacement. After acquiring some skill in the manipulation of the apparatus, a trainee proceeded to transmit over the lines at the opening of the workday. The sending of these practice signals ("signaux d'exercise") also formed an important part of a regular operator's daily duties. A circular of 1837, for example, instructed semaphore operators to pass practice signals twice a day, 150 to 160 signals at a time between 1 March and 1 October and 75 to 80 between 1 October and 1 March. Naturally, the instruction expressly prohibited the sending of personal messages as exercises.[3] In 1846, Foy ordered the Rouen station director to transmit more exercise signals, namely, about 1500 signals per day on the electric apparatus.[4]

With the rapid adoption of the Morse on domestic lines after 1854, the operation of telegraph instruments frequently fell into the hands of agents whose practical and theoretical knowledge of the Morse was incomplete, the result being numerous interruptions in service, loss of time, and transmission errors.[5] In order to cope with the operators' inadequate training on the Morse, the Telegraph Administration instituted a school for operators in Paris in 1854[6] and introduced the use of textbooks. The founding of the school marked a tendency away from the informal and mainly verbal training offered in local bureaus toward a more structured instructional form with teachers and textbooks in a central location. Although the creation of centralized formal telegraph instruction for operators coincided with the general adoption of the Morse on domestic lines, the establishment of the operator school, not uncoincidentally, came at the same time as de Vougy's decision to recruit inspectors from within rather than from the Ecole polytechnique, a policy adopted in 1854.

With a ministerial order of 8 June 1854, an "*école des surnuméraires*" became a part of the Central Administration in Paris[7] and the extension of formal "schooling" to operators was underway. Although required initially only for operators in Paris,[8] the courses became mandatory for all operator trainees by 1863 when failure to show up for the *école* meant the Administration automatically dropped the candidate.[9] The instructors of novice operators attending the classes were station directors.[10] In order to assure the trainee's understanding of the course material and practical lessons, the aspiring operator had to pass another set of exams at the end of the apprenticeship period.[11] Unlike previous operator instruction, the "<u>école des surnuméraires</u>" used a textbook. The practice of distributing written instructions to operators in local offices dated from the semaphore and continued when the lines went electrical.[12] A typical instruction of the electrical service was that of 1866 regarding the construction and maintenance of the Marié Davy cells.[13] In contrast to these instructional circulars, the "<u>école des surnuméraires</u>" used a textbook which was essentially a printed version of the classroom lectures.[14]

The textbook adopted initially consisted of two parts, the first covering the material offered in the "<u>cours élémentaire</u>" and the second providing a thorough grounding in the theory and practice of the Morse telegraph.[15] The special Morse course reflected the exigencies of instructing a large number of operators with the general and rapid introduction of the Morse on domestic telegraph lines. The 1862 revised edition of the textbook assumed the adoption of the Morse and integrated the expanded Morse lessons of the special course into the "<u>cours élémentaire</u>".[16] As new telegraphs came into use, the Administration introduced special courses such as that set up for the Hughes telegraph.[17] In addition to practical lessons on the apparatus (dial, Foy-Breguet, and Morse), both editions of the "cours élémentaire" included basic principles of magnetism, static electricity, batteries, electromagnetism, and current laws,[18] thereby insuring the operators' knowledge of fundamental theory necessary for their work as operators and for advancement through the hierarchy.

Although the establishment of an "école des surnuméraires" and the adoption of textbooks suggest a tendency toward the formalization of operator instruction, those courses were only for those trainees who were to become full-time operators. The largest number of telegraph offices employed agents whose attention to the sending and receiving of messages was either peripheral to other, more pressing duties, such as was the case with municipal bureau operators and railroad telegraphers, or traffic did not demand much of the operator's skill or knowledge. Consequently, the majority of incoming operators continued to receive the kind of instruction that typified the period before 1854.[19] Between 1854 and 1870, the Telegraph Administration began recruiting inspectors from among station directors and these from among the operators. This system of promoting from within placed pressure upon the quality of operators hired and, to a certain extent, provided another reason for creating the "<u>école des surnuméraires</u>". Nevertheless, the Telegraph Administration failed to provide instruction for operators desiring to become station directors, their theoretical and practical instruction coming from a self-directed study of telegraph literature.

With the change of governments and telegraph administrators that followed the war against Prussia, the instruction of telegraph operators after 1870 underwent considerable extension to meet the demands created by the entry of large numbers of operators into the service and the proposed unification of the telegraph and postal bureaucracies. While reducing costs was the dominant theme in the merging of the two services, the accompanying technological decisions had the largest impact upon the development of operator instruction. Moreover, beginning in 1878, the fusion of the posts and telegraphs led to further changes in the instruction of operators and opened up career possibilities that previously had not existed. As a result, for the first time, the instruction of operators dovetailed with that of the inspectors.

Following quickly on the war against Prussia and the suppression of the Paris commune, on 26 April 1871, by order of the President of the Council of Ministers, Henri Pierre Pierret (1823-1879) became the new general director of French telegraphs.[20] Unlike Foy and de Vougy, Pierret was a graduate of the Ecole polytechnique and had worked his way up through the administrative ranks of the Central Administration, having been at one time head of the accounting department.[21] Consequently, Pierret lacked the political leverage of his predecessors. The government of the Third Republic frequently expressed a desire to reduce telegraph expenses to those strictly necessary, demanding no budgetary increases,[22] and particularly favored combining the postal and telegraph bureaucracies as a cost saving measure.[23] Under de Vougy, the greatest extension of the telegraph network had resulted from opening the so-called municipal bureaus whose numbers increased from 12 in 1863 to 1,279 in 1870.[24] Clearly, then, a substantial reduction in personnel (and office maintenance) costs could be achieved by uniting these operations with those of the posts. In fact, the Telegraph Administration eliminated 484 positions as a consequence of unification and realized substantial savings in the personnel budget.[25] Thus, despite the objections of the chief of the Telegraph Administration,[26] but in accordance with a law voted by the National Assembly in 1873, Pierret and the Third Republic embraced a plan to unite the telegraph and postal bureaucracies.

The 1873 decision to turn the municipal telegraph bureaus over to the postal service necessitated the conversion of a large number of postal workers into telegraphers. In turn, this demanded the creation of special telegraph courses.[27] Although the adoption of dial instruments would have facilitated the retraining of postal workers, the Telegraph Administration chose to employ the Morse in all offices, preferring an instrument that recorded messages. Henceforth, all new offices would install the Morse instruments and, by 1878, Morse apparatus would replace dial telegraphs throughout France.[28] Therefore, more than the need to instruct postal workers in telegraphy, the technological decision to adopt the relatively more complex and more difficult to operate Morse became the occasion for the establishment of telegraph operator instruction on a large scale.

In order to handle the task, in 1873 the Telegraph Administration ordered the opening of practical and theoretical telegraph courses in the chief town of every department. The courses lasted two months and consisted of two parts. The first part ran from April 1 through May 15 and consisted of practice in keying and reading Morse code plus individual instruction on the installation of the apparatus, maintenance of the battery, and rules of the service (including exercises in the determination of the appropriate rate to charge customers). Lessons in theory and a review of material covered in the first half made up the coursework taken from May 15 to 31. The program was "very elementary and essentially practical" with instructors coming from the ranks of the telegraph service, wherever possible from those already teaching telegraphy to the Administration's operators. A three-man commission tested graduates and usually consisted of an inspector and a sub-inspector as well as the instructor himself.[29]

While these courses only served to transform postal workers into telegraphists, the growing number of regular candidates admitted into the Telegraph Administration after 1870 necessitated a methodical organization of telegraph instruction.[30] A ministerial decision of 27 October 1871[31] ordered the institution of a two-tiered system of telegraph courses for operators distinct from those intended for postal workers. Departmental "schools," called "<u>écoles du premier degré</u>" ("schools of the first degree") and numbering sixteen by 1884,[32] offered courses that were predominantly practical for operator trainees and employees insufficiently knowledgeable of the apparatus. Those employees excelling in the provincial "<u>écoles du premier degré</u>" and, preferably, having at least two years of experience as an operator, could attend an advanced course ("<u>cours supérieur</u>") in practical and theoretical telegraphy held in Paris.

A second ministerial decision of 11 September 1877 specified the contents of the telegraph courses offered in Paris and the provinces. The program of the "<u>écoles du</u>

premier degré" lasted five months and ran under the direction of either a regional director or departmental inspector, depending upon the school's location. Instructors were graduates of the "cours supérieur" in Paris. The departmental courses focused upon such topics as the sending and reading of Morse code, battery maintenance, the construction and testing of lines, the location and identification of line and equipment malfunctions, the organization of the network, the rules and regulations of domestic and international telegraphy, and the drawing or sketching of apparatus. Only a small portion of the course considered general notions of electricity and magnetism such as the two-fluid theory, conductability and resistance, quantity versus tension (amperage versus voltage), natural magnets, the magnetization of steel versus soft iron, and electromagnetism.[33]

The "cours supérieur" in Paris, lasting six months during the winter (November 1 to April 30), generally had about 25 students a session chosen from among those who excelled in the departmental course. The Paris course was equally concerned with practice, but had a slightly different emphasis, covering batteries, electric currents and their measurement, magnetoelectric machinery, French and foreign telegraph apparatus, the construction of telegraph lines (including submarine and underground lines), the organization of the network, applications of the telegraph, geography and elementary topography, geometric design, and the sketching of apparatus as well as more sophisticated elements of electrical and magnetic theory.[34]

The "_écoles du premier degré_" and the "_cours supérieur_" pointed to a new direction in operator instruction which the fusion of the posts and telegraphs made possible, a direction that led to the training of agents solely for technical careers. Whereas the "_écoles du premier degré_" provided practical instruction to a large number of operators, the "_cours supérieur_" served to prepare a few operators for inspector positions. The two-tiered system reflected a desire to hire inspectors from among the operators. In 1878, in order to accommodate the last phase of the fusion of the two bureaucracies, the Telegraph Administration instituted a complete overhaul of operator instruction in such a way that, for the first time, operator and inspector instruction dovetailed and furnished operators a career ladder leading, within a few years, to a job as a telegraph _ingénieur_.

Prior to 1878, the telegraph instruction of inspectors took place in Paris as well as in the field. The practical instruction of inspectors generally involved little more than following an inspector as he made his rounds and focused upon such administrative matters as Telegraph Administration rules and regulations and accounting.[35] A trainee acquired theoretical instruction over a six month period from two inspectors stationed at the Paris Central Administration who received a pay supplement for the work.[36] An inspector trainee entered the service as an "_élève-inspecteur_" ("student inspector"), a salaried position.[37] In contrast, operators did not receive any financial compensation while undergoing their training and, beginning in 1863, had to assure the Administration that they had sufficient financial resources (1200 francs) to support themselves during their one year apprenticeship.[38]

Although before 1878 two inspectors at the Central Administration continued to instruct "_élève-inspecteur_" in telegraph theory, as early as November 1845 telegraph chief Alphonse Foy had recognized the need for inspectors to have a deeper, more up-to-date, and more regular instruction. Foy argued that student inspectors especially needed to study the latest theories of electromagnetism and electrical currents, learn the best procedures for insulating lines, and research the best means for protecting lines from the effects of meteorological electricity. He believed, furthermore, that a school of telegraphy was a necessity, the personnel of which was to consist of a _surveillant des études_, a telegraph employee who would supervise the school and teach; an inspector who was to share the teaching load with the _surveillant des études_; and a _professeur de physique_ *appliquée à la télégraphie*. In addition to teaching, the *professeur de physique appliquée à la télégraphie* was to facilitate the students' research into electromagnetism and other areas as dictated by the needs of the Telegraph Administration, thereby turning the school into a research establishment as well.[39] The budget committee of the Chamber of Deputies killed Foy's proposed telegraph school.[40]

Despite the failure of Foy's telegraph school, the Telegraph Administration achieved some success in advancing the quality of instruction provided inspector trainees at the Central Administration. By 1859, a telegraph "museum" became associated with these courses.[41] More likely than not, the museum consisted of telegraph apparatus purchased by the Administration and used for demonstrations in the courses of the Central Administration.[42] Judging from the reputation of the instructors as researchers, the quality of instruction at the Central Administration, for a period at least, was rather high. Between 1858 and 1862, two inspectors who had graduated from the Ecole polytechnique taught the inspector courses, E. E. Blavier (1826-1887) and Eugène Gounelle (1821-1863).[43] Blavier and Gounelle were excellent choices for the teaching of telegraphy, both having performed important research in electricity and telegraphy. Gounelle, for example, assisted Hippolyte Fizeau (1819-1896) in his work on the speed of electricity.[44] Beginning in 1862, however, de

Vougy placed the inspector courses in the hands of Claude Marie Guillemin (1822-1874), physics and chemistry teacher at the Ecole militaire de Saint-Cyr, and Joseph Lagarde (1829-1897), a telegraph inspector and graduate of the Ecole polytechnique. Neither a graduate of the Ecole polytechnique nor an employee of the Telegraph Admninistration, Guillemin had conducted a series of important experiments with Emile Burnouf (1821-1907), professor of ancient literature, on the propagation of electric currents.[45]

Although the Central Administration's telegraph courses for inspectors became the responsibility of new teachers, the textbook remained the same, that written by Blavier and first published in 1857.[46] In 1859, the Administration sent a copy of Blavier's textbook to all telegraph offices so that employees could benefit from it,[47] perhaps to provide for the instruction of station directors desiring a place as an inspector. The telegraph course for the inspectors initially consisted of two parts, the "<u>cours théorique</u>" and the "<u>cours pratique</u>", the theoretical course preceding the practical and comprehending the basic principles and measuring instruments of electricity, magnetism, and electromagnetism (including a study of Ampere's hypothesis). The practical course fell into three chapters. The first dealt exclusively with batteries, the second with the magnetic actions of currents and their measurement and the laws of electric currents. The third chapter examined dial, Foy-Breguet, and Morse telegraphs literally piece by piece, giving instructions on such aspects as maintenance, adjustment, and operation.[48] The second edition, published 1865-1867, kept the size of the theoretical section constant while greatly expanding practical content. Still covering batteries, current laws and measurement, and detailed descriptions of the major French telegraph apparatus (including the Hughes), the practical course included foreign telegraph instruments as well as the construction of overhead, underground, and submarine lines.[49]

With the fusion of the postal and telegraph administrations in 1878, the instruction of inspectors underwent a radical change. A presidential decree of 27 February 1878 transferred the telegraphs from the Ministry of the Interior to the Ministry of Finances and a presidential decree of 20 March 1878 organized the administrative council of the posts and telegraphs.[50] Replacing Pierret as head of the telegraphs was Adolphe Cochery (1820-1900), whose title was "Sous-secrétaire d'état" to the Minister of Finances, a position he held until 30 January 1879 when he became the first Minister of Posts and Telegraphs (replaced 7 January 1886).[51] Cochery finally established a distinction between the administrative and technical services of the posts and telegraphs, the last, in Cochery's words, requiring "the special science of an engineer".[52] Desiring agents "not only knowledgeable of current science, but even prepared to hasten its progress,"[53] a ministerial decision of 12 July 1878 established the Ecole supérieur de Télégraphie (EST) to instruct _ingénieurs_.[54] After successful completion of the two-year program of the Ecole supérieure de Télégraphie, graduates achieved the title "_sous-ingénieur_" in the postal and telegraph administration,[55] the term "_inspecteur_" per se no longer in use. Whereas inspectors had been primarily administrators in a technical bureacracy, charged with technological and bureaucratic duties, the _ingénieurs_ graduating from the EST assumed positions whose duties were primarily technical: an engineering specialty had emerged.

Candidates for admission to the school had to be between 20 and 30 years of age (although employees of the posts and telegraphs could ignore the age requirement) and needed certificates of birth and good behavior as well as a medical examination.[56] Unlike telegraph instruction previously offered employees, the courses of the Ecole supérieure de Télégraphie were available to individuals outside the service, "_auditeurs libres_", who could attend the lectures without the benefit of a position in the administration upon graduation. The _auditeurs libres_ even included students from other countries.[57] Those eligible to compete for places in the Ecole supérieure de Télégraphie and a "_sous-ingénieur_" position in the posts and telegraphs included those holding a *licencié ès sciences* degree, that is, individuals who held a degree permitting them to teach in a French university.[58] Also, graduates of the Ecole polytechnique and some of its associated *écoles d'application* (the Ecole des mines, the Ecole des ponts et chaussées, and the Ecole forestière), as well as graduates of the Ecole normale and the Ecole centrale des arts et manufactures having passed the school's graduation examinations could compete for places in the school. Competing on an equal basis with these for entry into the Ecole supérieure de Télégraphie were all postal and telegraph employees with at least two years' experience.[59]

Admission into the Ecole supérieure de Télégraphie was not automatic for graduates of the "*grandes écoles*"; a series of entrance examinations was mandatory. Nonetheless, the tests were such as to favor the polytechnicians' educational background. All applicants had to take a four-part battery of tests, the first, French composition, being the eliminating exam.[60] Those passing the composition test continued through the examination series, first taking a physics and chemistry examination, then a test of the applicant's mechanical drawing ("*dessin graphique*") ability. The final portion of the testing was oral and covered a wide range of topics, including integral and differential calculus, mechanics (kinematics, statics, and dynamics), physics (heat, dynamic electricity, acoustics, and optics), chemistry (metals and organic chemistry), mechanical drawing, a foreign language (German or English), and the subjects covered in the lycée class of special mathematics.[61]

The lycée "_classe de mathématiques spéciales_" covered various mathematical topics as geometry, trigonometry, descriptive geometry, algebra, and "pre-calculus" such as the idea of limits, as well as elementary notions of physics (basic mechanics, static electricity, and magnetism) and chemistry.[62] The special mathematics class prepared students for admission to the Ecole polytechinque, the contents of the course being explicitly cited in the annually published list of required subjects for admission to the Ecole.[63] Thus, graduates of the Ecole polytechnique ought to have been able to answer any questions asked them on their oral examinations for admission to the Ecole supérieur de Télégraphie relating to the contents of the "_classe de mathématiques spéciales_," giving them an advantage over anyone else, especially telegraph service employees, applying for places in the Ecole supérieure de Télégraphie.

Telegraph inspectors who had graduated from the Ecole polytechnique and entered the service under Foy taught all courses and ran the school.[64] Students at the Ecole supérieure de Télégraphie attended classes for two years. In the first year, students took telegraph and postal operations (separate courses), telegraph apparatus, "_physique appliquée à la télégraphie_", and a seminar in military telegraphy. Courses in line construction, electrical measurement, "_chimie appliquée à la télégraphie_", and practical exercises in electrical measurement made up the second year's curriculum. From time to time, seminars covering a wide range of topics, such as the theory of quaternions, applications of electricity, and meteorology applied to the prediction of weather became available.[65] Of the regular courses, that treating telegraph apparatus covered all forms of instruments, with special attention devoted to the more complex, namely the Hughes (11 lessons), Wheatstone (4 lessons), and Baudot (3 lessons) telegraphs. The course in "_chimie appliquée à la télégraphie_" discussed only conductors, resistors, insulators, and battery theory, while "_physique appliquée à la télégraphie_" dealt exclusively with electricity, magnetism, and electromagnetism and, unlike the other Ecole supérieure de Télégraphie courses, demanded students handle advanced mathematical expressions.[66]

The course program and entrance requirements of the Ecole supérieure de Télégraphie were very demanding. Adolphe Cochery hoped to make attendance possible for all those telegraph and postal employees of all levels who desired to attend since, he believed, experience had shown how many useful improvements came from agents in modest positions.[67]

In order that the school's high entrance standards did not prevent employees in low level jobs from attending the Ecole supérieure de Télégraphie, Cochery created a preparatory school for the Ecole supérieure de Télégraphie.[68] However, entrance into the preparatory school was not easy. In order to gain admission, candidates had to have at least two years of service and pass a battery of exams covering four areas: (1) handwriting and spelling; (2) geography; (3) mechanical drawing; and (4) the knowledge of mathematics, physics, and chemistry contained in the program of the special mathematics class of the lycées.[69] The courses lasted one year and covered differential and integral calculus, mechanics, physics, and chemistry.[70]

Although few passed the admission requirements (only four in 1878), those entering the preparatory school were all operators, not station directors.[71] With the fusion of the posts and telegraphs in 1878, Adolphe Cochery had then separated the technical and bureaucratic services of the posts and telegraphs and, through the Ecole supérieure de Télégraphie and its associated preparatory school, created a new career ladder whereby operators could enter directly into the ranks of inspectors, now called <u>ingénieurs</u>, without first waiting years to become station directors. The elimination of the long wait to rise from operator to inspector also reflected the separation of the bureaucratic and technical services within the Telegraph Administration and the creation of a specialty, that of <u>ingénieur</u>. The opening of "inspector" instruction to operators while they were still young, however, was only part of the dovetailing of operator and "inspector" instruction that Cochery started in 1878.

Cochery realized that the fusion of the posts and telegraphs permitted a unified recruitment program for the two services. The former telegraph admission standards requiring that operator trainees have a minimal knowledge of physics and chemistry no longer held since postal workers had no need of a science background for their work. Consequently, in 1879, Cochery established a two-tiered system that permitted the recruitment of agents for both the posts and telegraphs at one level and the screening out of potential technical personnel at another level. All candidates for postal and telegraph employment at the entry level now had to pass a set of tests consisting of (1) a page of dictation; (2) the same page recopied by hand; (3) composition of a note or letter on a given subject; (4) formation of a statistical table in accordance with a given model; (5) elementary arithmetic (the four basic operations, fractions, and the metric system) and (6) general French and world geography.[72] The skills tested suggest the clerical nature of postal work.

Also starting in 1879, candidates could choose to take a series of exams in addition to the general clerical admission test that led specifically to the technical service. The fields tested comprehended: (1) geography (railroads, posts, and telegraphs); (2) arithmetic proportions; (3) elementary algebra; (4) geometry; (5) elementary physics and chemistry; (6) linear design and drawing; (7) foreign languages; and (8) postal and telegraph rules and regulations.[73] After passing these extra exams, aspirants for technical positions had to attend operator school, a five to six month program provided at Paris, Brest, Bordeaux, and Montpellier. The courses covered such mathematical topics as elementary algebra, including equations of the first order; fractions; rules of proportion; and simple geometry (measurement of surfaces and volumes). Besides general notions of chemistry and physics (only the fundamentals of static electricity, current electricity, and batteries), the trainees studied the essentials of mechanics, centers of gravity, levers and transmissions of movement, and clockwork mechanisms. Practical subjects taught operator trainees included drawing, rules and regulations of the postal and telegraph services, and detailed studies of telegraph apparatus, including a separate course on the Hughes instrument.[74]

After completing the operator training course, an aspirant for an advanced position in the technical service began to accumulate the two years of service required in order to qualify for the EST preparatory school admissions tests. If he passed those tests and passed his courses at the preparatory school, he could try for admission into the Ecole supérieure de Télégraphie and a position as a _sous-ingénieur_. The fusion of the posts and telegraphs in 1878, therefore, permitted the overhauling of telegraph instruction by distinguishing, for the first time, between technical and administrative personnel and functions. Cochery's reorganization of instruction resulted in the establishment of a two-tiered examination procedure for those who were not graduates of a "_grande école_" and who aspired to a position in the technical service. Cochery had abolished the long wait through the numerous operator and station director grades. However, the system of examinations and instruction set up in 1879 went beyond its overt task, the definition of a technical career ladder in the telegraphs. By opening the Ecole supérieure de Télégraphie to individuals outside the hierarchy of the posts and telegraphs, the Ministry of Posts and Telegraphs created the first electrical engineering program in France and began the creation of French electrical engineering institutions.

FOOTNOTES

[1]"Règlement sur le service de MM. les inspecteurs du télégraphe (1834)," in Documents sur la télégraphie aérienne, 1:1-2 specifies the content and manner of operator training for the semaphore service, while the same instructions, according to Règlement des stationnaires (1850), p. 10, held true for the early electrical lines.

[2]Règlement des stationnaires (1850), p. 10.

[3]Unnumbered circular dated 5 March 1837, F(90) 1453*, Archives Nationales, Paris.

[4]Telegram, Foy to telegraph director at Rouen, 9 and 25 January 1846, F(90) 1451*, Archives Nationales, Paris.

[5]"Mesures à prendre pour compléter l'instruction théorique et pratique des stationnaires," Lois et règlements, 25 November 1856.

[6]The first reference to a school for operator trainees that I have encountered is "Arrêté du ministre de l'intérieur réglant l'organisation des bureaus de l'administration des lignes télégraphiques," Lois et règlements, 8 June 1854.

[7]"Arrêté du ministre de l'intérieur réglant l'organisation des bureaus de l'administration des lignes télégraphiques," Lois et règlements, 8 June 1854.

[8]"Décret relatif à l'organisation administrative et à la réglementation du service extérieur des lignes télégraphiques," Lois et règlements, 29 November 1858.

[9]"Arrêté du Directeur général déterminant le programme des conditions exigées pour concourir à l'admission au surnumérariat," Lois et règlements, 8 September 1863 and "Arrêté relatif à l'examen d'admission des surnuméraires," Annales télégraphiques 2,7 (1864): 165-168.

[10]Journal des télégraphes 1 (January 1866): 8 gives Marie Charles Antoine Orban (1832-?) as instructor at the école, his date of birth coming from the Annuaire des lignes télégraphiques, 1858, p. 17. I obtained the names of Charles Benjamin Miège (1821-?) and Théophile Réné Ungérer (1830-?) from the école's 1855 textbook, Miège and Ungérer. "M. Moudurier," Annales télégraphiques 3,2 (1875): 611-612, states that Augustin Edme Moudurier (1827-1875) was charged

with the practical instruction of operator trainees at the Central Administration. An unidentified form dated 8 November 1862 in the personnel folder of Joseph Lagarde, F(90) 20,539, Archives Nationales, Paris, states that Lagarde (1829-1897) was charged with the theoretical instruction of surnuméraires. His "feuille personnel", ibid., states that he was a station manager at the time he taught operator trainees.

[11]Journal des télégraphes 4 (March 1869): 1.

[12]See, for instance, Instruction à l'usage des stationnaires télégraphiques, concernant le mécanisme et autres parties du matériel (Paris: Imprimerie de Béthune, 1827).

[13]"Instruction sur la pile Marié Davy," dated 15 October 1866, F(90) 1472, Archives Nationales, Paris.

[14]Miège and Ungérer.

[15]Miège and Ungérer. Part One was entitled "Cours élémentaire professé à l'Administration centrale des lignes télégraphiques"; the second and last part treated "Etudes pratiques sur le système et l'appareil Morse."

[16]Miège, Vade-mecum pratique de télégraphie électrique à l'usage des employés des lignes télégraphiques, 2d ed. (Paris: E. Lacroix, 1862).

[17]Cochery, p. 3164, refers to the establishement of these special courses.

[18]Miège and Ungérer, passim, and Miège, passim.

[19]Inspector at Valence to Station manager at Privas, 30 April 1868, F(90) 1472, Archives Nationales, Paris, for example, outlines the kind of instruction being given to a trainee in a local office, the trainee being a woman in this instance. Her instruction was to consist of such practical knowledge as the dial and Morse instruments as well as the various rules and regulations of the service.

[20]Journal officiel de la République française, 30 April 1871, p. 826. Pierret's obituary notice in the Annales télégraphiques 3,6 (1879): 207-208, provides biographical information.

[21]Annuaire des lignes télégraphiques, 1858, pp, 6-7 lists Pierret as head of the accounting department.

Marielle, p.178, gives the year of his graduation from the Ecole Polytechnique as 1844.

[22]For example, Session de 1875, Budget de l'exercise 1876, "Projet de loi pour la fixation des recettes et des dépenses de l'exercise 1876," AD XVIII(F) 918, Archives Nationales, Paris, states: "L'Administration, préoccupée de réduire ses dépenses au strict nécessaire, n'a demandé pour les exercises 1874 et 1875 aucune augmentation sur le crédit de 8,058,600 francs, qui avait été ouvert sur le budget de 1873 pour les traitements de ses fonctionnaires et agents."

[23]See, for example, the discussions of fusion in Commission chargée d'examiner le projet de fusion des Postes et Télégraphes, Rapport du 7 avril 1865 (Paris: n.p., 1865); Charles Rolland, "Rapport fait au nom de la commission des services administratifs (postes et télégraphes)," Journal officiel de la République française, 10 July 1872, p. 4700-4704; and Blavier, Considérations sur le service télégraphique et sur la fusion des administrations des postes et des télégraphes (Nancy: Sordoillet et fils, 1872).

[24]"Tableaux des produits des bureaux de l'Etat pour 1870," Lois et règlements, 31 December 1871.

[25]Cochery, p. 3161.

[26]Referred to in Blavier, Considérations, pp. 88-89.

[27]"Décret portant règlement d'administration publique pour l'exécution de la loi du 6 décembre 1873," Lois et règlements, 10 July 1876.

[28]"Décret portant règlement d'administration publique pour l'exécution de la loi du 6 décembre 1873," Lois et règlements, 10 July 1876, and "Instruction pour l'application du décret du 10 juillet 1876," Lois et règlements, 15 September 1876, which specified that the Morse would be obligatory for all new posts and that elsewhere dial telegraphs would be phased out and the Morse brought in by 1878. However, the dial telegraph did not disappear immediately. In 1892, France had 11,622 Morse and 699 dial telegraphs in use. "Statistique télégraphique comparative de 1892," Journal télégraphique 19 (1895): 127-149.

[29]"Décret portant règlement d'administration publique pour l'exécution de la loi du 6 décembre 1873," Lois et règlements, 10 July 1876, "Instruction sur l'organisation du cours à l'usage des agents des postes, instituté par l'article 2 du décret du 10 juillet 1876," Lois et

<u>règlements</u>, 25 January 1877; and "Instruction pour l'application de décret du 10 juillet 1876," <u>Lois et règlements</u>, 15 September 1876, which states: "Le cours qui sera fait aux candidats agrées par l'Administration des postes devra être très-élémentaire et essentiellement pratique".

[30]"Instruction sur l'organisation des cours de télégraphie," <u>Lois et règlements</u>, 1 October 1877.

[31]"Application de la décision ministérielle instituant un cours pratique et un cours supérieur de télégraphie avec allocation de primes aux employés classés les premiers," <u>Lois et règlements</u>, 1 July 1872. "Arrêté ministériel instituant des cours et écoles de télégraphie," <u>Lois et règlements</u>, 11 September 1877, gives the date of this ministerial decision as 27 October 1871.

[32]Cochery, p. 3164.

[33]"Arrêté ministériel instituant des cours et écoles de télégraphie," <u>Lois et règlements</u>, 11 September 1877; "Instruction sur l'organisation des cours de télégraphie," <u>Lois et règlements</u>, 1 October 1877; "Programme des leçons élémentaires de télégraphie dans les écoles de région," <u>Lois et règlements</u>, 1 October 1877; and "Programme d'un cours pratique sur les appareils usuels," <u>Lois et règlements</u>, 1 October 1877.

[34]"Instruction sur l'organisation des cours de télégraphie," <u>Lois et règlements</u>, 1 October 1877, and "Arrêté ministériel instituant des cours et écoles de télégraphie," <u>Lois et règlements</u>, 11 September 1877.

[35]Alphonse Foy, "Rapport à M. le Ministre de l'intérieur," dated 8 November 1845, F(90) 1454*, Archives Nationales, Paris, and <u>Moniteur universel</u>, 21 May 1846, supplement, p. ix.

[36]Foy, "Rapport à M. le Ministre de l'intérieur," dated 8 November 1845, F(90) 1454*, Archives Nationales, Paris. An examination of the telegraph budgets between 1845 and 1853, AD XVIII(F) 348-349, 368-369, 388-389, 408-409, 429-431, 444, 455-457, 471, 494, 500-502, and 520-521, Archives Nationales, Paris, reveals an annual expenditure for two "<u>inspecteurs instructeurs</u>".

[37]"Ordonnance du roi portant règlement sur le service de la télégraphie," <u>Lois et règlements</u>, 24 August 1833.

[38]"Arrêté du Directeur général déterminant le programme des conditions exigées pour concourir à l'admission au surnumérariat," Lois et règlements, 8 September 1863.

[39]Foy, "Rapport à M. le Ministre de l'intérieur," dated 8 November 1845, F(90) 1454*, Archives Nationales, Paris.

[40]Moniteur universel, 26 May 1845, supplement, p. IX, and 12 June 1845, p. 1666.

[41]"Envoi de l'état des circonscriptions télégraphiques dressé en exécution du décret du 29 novembre 1858," Lois et règlements, 10 March 1859, and "Etat des circonscriptions télégraphiques au 1er janvier 1860," Lois et règlements, 27 March 1860, refer to this museum ("musée"). De Vougy to the Minister of the Interior, 7 April 1857, Archives Nationales, Paris, asks for 200 francs to repair the glass in an electrical machine owned by the Direction Générale, explaining that "Dans la collection d'instruments de physique que possède la Direction Générale, une machine électrique avait naturellement sa place." Probably, the instrument collection is the "museum" and, most certainly, served for the instruction of telegraph employees.

[42]"Appareils achetés par l'administration française à l'Exposition universelle," Annales télégraphiques 1,1 (1855): 167, refers to the purchasing of instruments at the 1855 Paris International Exposition by the Telegraph Administration. According to Cochery, p. 3164, by 1884, the Administration owned a number of old apparatus dating from the origins of telegraphy in France and which could be "consultée avec fruit". M. Henriquez-Phillipe, "Un musée de télégraphie," La Nature 41 (1913): 146-149, refers to the opening to the public that year of a telegraph museum at the P & T Central Administration (107 rue de Grenelle). I suspect that the P & T museum's collection consisted of those apparatus used in the Administration's telegraph courses.

[43]They were the instructors according to Circulaire no. 227, Lois et règlements, 11 March 1859. Marielle, pp. 20 & 101, indicates their graduation from the Ecole polytechnique. Gounelle's obituary provides biographical data. See Blavier, "Eugène Gounelle," Annales télégraphiques 2,7 (1864): 92-96. A large number of biographical articles on Blavier exist, the lengthiest and most useful being that in the Annales télégraphiques 3,13 (1886): 566-574; 3,14 (1887): 5-44, 369-401; 3,16 (1889): 97-114 & 193-218.

[44]Gounelle and H. Fizeau, "Recherches sur la vitesse de propagation de l'électricité," Comptes rendus 30 (1850): 437-

440. Also appeared in Poggendorff's Annalen der Physik 80 (1850): 150-157 & 287-292. For biographical information on Fizeau, see Alfred Cornu, "Notice sur l'oeuvre d'Hippolyte Fizeau," Bureau des Longitudes, Annuaire pour l'année 1898 (1898): 1-40 and the notices published in The American Journal of Science 2 (1896): 398; The Astrophysical Journal 4 (1896): 367-368; The Electrician 37 (1896): 699-700; and Nature 54 (1896): 523-524.

[45] Blavier's replacement in 1862 is confirmed in "Rapport sur les appareils télégraphiques de l'Exposition d'électricité de 1881," Archives, Academy of Science, Paris, which states that Blavier taught telegraphy from 1858 through 1862. Although Jules Bourdin, "Blavier et son oeuvre," La lumière électrique 23 (1887): 645 gives Guillemin and Burnouf as the instructors replacing Blavier and Gounelle, I doubt that Burnouf actually taught telegraphy in Paris for two reasons: (1) the "Tableau des membres composant l'Académie de Stanislas suivant l'ordre de réception," for 1862 through 1865 lists Burnouf as a "membre titulaire" and as "Professeur de Littérature ancienne à la Faculté des Lettres," at Nancy, since he would have to have been residing in Nancy in order to be a "membre titulaire" of the Académie. Mémoires de l'Académie de Stanislas (1862): 473; (1863): 669; (1864): 421; and (1865): 463 and (2) an unidentifiable form dated 8 November 1862 in personnel folder, "Lagarde," F(90) 20,539, Archives Nationales, Paris states that Joseph Lagarde, a graduate of the Ecole Polytechnique, taught the theoretical course at that time. Also, there appears to be a problem with Guillemin's first name. Bourdin and "M. Alexandre Guillemin," Annales télégraphiques 3,1 (1874): 114 give his first name as Alexandre while Poggendorff calls him Claude Marie. The same biographical information, moreover, appears in both Poggendorff and the Annales télégraphiques, suggesting that Alexandre and Claude Marie were the same person. Information on Guillemin's not being a graduate of the Ecole polytechnique or a telegraph employee comes from looking his name up in the Annuaire des lignes télégraphiques, 1858; the Annuaire des lignes télégraphiques, 1877; and Marielle.

[46] Circulaire no. 227, Lois et règlements, 11 March 1859. The circular probably referred to Blavier and Gounelle, Résumé des cours, although an earlier 1857-58 version existed as Cours théorique et pratique de télégraphie électrique (Paris: Librairie Scientifique, Industrielle et Agricole de Lacroix-Comon, 1857-58). The last edition was Blavier, Nouveau traité.

[47] Circulaire no. 227, Lois et règlements, 11 March 1859.

[48]Blavier and Gounelle, Résumé des cours, passim.

[49]Blavier, Nouveau traité, passim.

[50]"Bulletin administratif," Annales télégraphiques 3,5 (1878): 227-228. I do not want to write a history of the unification of the postal and telegraph authorities here, merely indicating important dates and administrative changes. Nevertheless, a good historical overview of the fusion can be found in Cochery, pp. 3153-3161.

[51]Michel de Cheveigné and Pierre Lajarrige, "Le téléphone ce jeune centenaire," Chroniques téléphoniques et télégraphiques, p. 93. Biographical sketches of Cochery can be found in S. de Vandières, L'Exposition universelle de 1878 illustrée (Paris: C. Lévy, 1879), pp. 63-64; Bulletin de la Société internationale des électriciens 1,17 (1900): 411; Robert, Bourloton, and Cougny, 2:143-144; and Pierre Pierrard, Dictionnaire de la IIIe République (Paris: Larousse, 1968), pp. 69-70.

[52]"Circulaire no. 17," dated 12 July 1878, Bulletin mensuel des postes et télégraphes 1 (June 1878): 143: "la science spéciale de l'ingénieur".

[53]"Circulaire no. 17," p. 144: "l'enseignement technique . . . donnera à l'Etat des fonctionnaires non-seulement au courant de la science actuelle, mais prêts encore à en hâter les progrès."

[54]"Ecole supérieur de Télégraphie," Annales télégraphiques 3,5 (1878): 558 and "Circulaire no. 17," p. 144.

[55]"Circulaire no. 17," p. 146.

[56]"Circulaire no. 17," pp. 145-146.

[57]Cochery, p. 3164 states: "Plusieurs étrangers ont déjà été envoyés par les gouvernements des différents pays pour profiter des cours de l'école supérieure de télégraphie."

[58]In 1882, Georges Adolphe Rheins, licencié ès sciences physiques et mathématiques, entered the Ecole supérieure de Télégraphie as a student. Journal officiel de la République française, 24 September 1882, p. 5210.

[59]"Circulaire no. 17," pp. 145.

[60]"Circulaire no. 17," p. 146.

[61]"Programme des connaissances exigées pour l'entrée à l'Ecole supérieur de Télégraphie," Annales télégraphiques 3,5 (1878): 561-566 and "Circulaire no. 17," p. 146.

[62]"Programme des connaissances exigées pour l'admission à l'Ecole polytechnique, 1872," Journal officiel de la République française, 5 February 1872, pp. 838-843.

[63]Mortimer d'Ocagne, Les grandes écoles de France (Paris: Gauthier-Villars, 1887), p. 101.

[64]Based upon a comparison of the names of the school's teachers from "Personnel de l'Ecole supérieure de Télégraphie pour l'année scolaire 1878-1879," Annales télégraphiques 3,5 (1878): 567 with those in Marielle.

[65]Annales télégraphiques 3,8 (1881): 112 refers to La Météorologie appliquée à la prévision du temps, a publication of lectures on the subject given at the Ecole supérieure de Télégraphie by the directeur du bureau central météorologique. J. R. F. E. Sarrau, "Théorie des quaternions," Annales télégraphiques 3,8 (1881): 52-66 & 113-136, according to the title pages, 52 & 113, was a publication of "conférences" delivered at the Ecole supérieure de Télégraphie. Charles Bontemps, "Applications diverses de l'électricité; conférences faites à l'Ecole supérieure de Télégraphie par M. Marcel Deprez," Annales télégraphiques 3,5 (1878): 558-568.

[66]Ministère des Postes et Télégraphes. Ecole Supérieure de Télégraphie: Sommaire des cours, 1880-1881 (Paris: Ministère des Postes et Télégraphes, 1881).

[67]"Circulaire no. 17," p. 143.

[68]"Circulaire no. 17," p. 144.

[69]"Ecole supérieure de Télégraphie," p. 561.

[70]"Ecole supérieure de Télégraphie," pp. 558 & 561.

[71]Bulletin mensuel des postes et télégraphes 1 (October 1878): 310.

[72]"Arrêté déterminant les conditions d'admission," Bulletin mensuel des postes et télégraphes 2 (November 1879): 716.

[73] *Ibidem*.

[74] *Ibid*., p. 721 and Cochery, p. 3164.

CHAPTER FIVE

Telegraph Industry and Education

Telegraph instrument manufacturers played an important role in the creation of French electrical engineering institutions. For example, the first president of the French electrical engineering society and one of its several secretaries (the society had six) were officers of the same company, the Maison Breguet.[1] Before any electrical engineers could emerge from the telegraph manufacturing industry, the industry itself had to come into existence. In France, telegraph manufacturing began as a monopoly of the Breguet firm, but soon developed into a competitive enterprise concentrated in Paris. Moreover, telegraph manufacturers contributed significantly to the growing electrical apparatus manufacturing industry by introducing new electrical products and spinning off new industries.

Telegraph manufacturing and the Breguet company's monopoly began with the construction of the first telegraph line, 1844-45. From the moment the Minister of the Interior named the Telegraph Commission to study the electric telegraph, Alphonse Foy conceived how the telegraph apparatus ought to function and confided its construction to Louis Breguet (1804-1883).[2] While the choice of Breguet was ostensibly at the recommendation of Arago as a member of the

Telegraph Commission[3] (and Arago had been a close friend of Breguet's grandfather),[4] there were a number of other good reasons for selecting Breguet above anyone else. He was a proven competent maker of scientific instruments. In 1840, Louis Breguet had drawn Arago's attention with a temperature recording device presented to the Academy of Science, which he had adapted from a similar instrument invented by his grandfather.[5] For his work in 1843 on the velocity of light, Arago chose Breguet as his instrumentmaker. With a shop employee named F. Boquillon, Breguet devised a rotative mirror capable of 2000 turns per second.[6] In 1844, as further demonstration of his confidence in Breguet as an instrumentmaker, Arago had Breguet appointed instrument builder to the Board of Longitudes, an agency attached to the Paris Observatory.[7] The Maison Breguet product catalogue for the national exhibition of 1844, moreover, described an electrical device for measuring the speed of a steam engine.[8]

Besides being a competent instrumentmaker in a shop that was making electrical apparatus by 1844, another good reason for his selection as the state's sole constructor of telegraph instruments was Louis Breguet's pioneering work in electrical telegraphy and contribution to electrical theory. In 1838, in conjunction with physics professor Antoine Masson (1806-1860),[9] Breguet had constructed and operated an electric telegraph over about 600 meters of railway track, using an electromagnetic generator for a source of current and galvanometers for receiving intruments.[10] During these tests, Masson and Breguet noticed a discharge from their generator that resembled that of a Leyden jar.[11] The observation led them to a joint investigation of the identity of static electric discharges of electromagnetic and electrostatic generators.[12] The article published from their research was important in the study of induction phenomena and provided the theoretical basis for the induction device called the Ruhmkorff coil.[13]

The Maison Breguet manufactured telegraph instruments for the French state without rivalry from 1844 until 1853.[14] Its monopoly of the market extended beyond the sale of telegraphs to the state, moreover, for the company seized immediately upon the railway market. The French railroads used the so-called dial telegraph exclusively.[15] Breguet adapted the Wheatstone dial instrument to the French railway market.[16] Breguet´s pioneering work with the railroads assured him a foothold in the market. As an index of his success, Breguet sold over 400 of the portable version of his railroad telegraph, which he invented in 1852, and, on the Nord and Orleans Railway lines, no train left the station without one of Breguet´s portable telegraphs in its baggage car.[17] With his conquest of the railroad and state telegraph market, Breguet´s monopoly of telegraph instrument manufacturing was complete, but not long-lived.

The termination of the Breguet monopoly and the development of a competitive telegraph manufacturing industry began in 1853. Rivals emerged from the firm's own ranks at first, then from notable Parisian scientific instrumentmakers and horologists. The most significant force transforming telegraph manufacturing into a competitive enterprise was the state's project to link Paris telegrapically with the major city of every department between 1852 and 1854. The planned network increased demand for telegraph instruments far beyond any previous level and beyond the capacity of the Maison Breguet to produce.

Increased demand meant more and more orders for the Maison Breguet, which the firm gladly attempted to fill. By September 1854, however, the strain on the Breguet production facilities was clear: the Telegraph Administration reduced a contract dated 10 June 1854 for the furnishing of telegraph supplies from 12,580 francs to 10,000.[18] Although Breguet expanded his operation, renting a new shop and employing extra workers,[19] the state contracted with an additional party for the manufacture of its instruments. On 21 October 1854, the Telegraph Administration signed a contract with J. F. V. Mouilleron (n.d.) for the construction of telegraph instruments.[20] Mouilleron was one of Breguet's shop chiefs as well as owner of the principal machines and renter of one of the shop's floors. While the details of the Mouilleron contract remain unclear, the transfer of business proved costly for Louis Breguet's father, owner of the family business.[21]

The extant records of the Telegraph Administration's payments to and agreements with entrepreneurs, extending from March 1853 to July 1857,[22] do not indicate any contracts between the Telegraph Administration and Mouilleron prior to that of 21 October 1854, which called for Mouilleron to supply the state with several Foy-Breguet telegraph instruments. These were the instruments developed by Breguet in cooperation with Alphonse Foy of the Telegraph Administration and which Breguet had supplied exclusively to the state prior to this time. Also, there were other payments to Mouilleron between 1854 and 1857 for various ancillary telegraph apparatus such as switches and instrument bases.[23] Nonetheless, Breguet always received more per instrument and, overall, the value of Foy-Breguet contracts awarded Breguet outstripped those ceded to Mouilleron.[24] However, with the onset of Morse telegraph production in 1854, the two firms received about equal contract amounts through 10 July 1857, the last date for which information is available, and each constructor received a roughly equal price per instrument.[25] With production of the Morse instrument, then, Mouilleron emerged as a clear rival to his former employer, the Maison

Breguet.

Many other employees of the Breguet firm left and founded independent careers in telegraph manufacturing,[26] but not all new telegraph manufacturers emerged from the Breguet ateliers. Competition also arose from scientific instrumentmakers, such as Gustave Froment (1815-1865).[27] In 1860, when David Hughes arrived in Paris to sell his telegraph to the government, he showed it to Froment, who had earned a high reputation as a constructor of scientific instruments.[28] Froment improved Hughes' telegraph[29] and, when the Telegraph Administration adopted it, they conceded production of the Hughes instrument to Froment.[30] Later, in 1875, the firm of P. Dumoulin-Froment, successor to Froment, improved and constructed the Baudot telegraph.[31]

In addition to builders of scientific apparatus, competition also came from horologists, like Jean Didier (n.d.) and Bastien Théodore Digney (1823-1903).[32] The Digney brothers initially entered telegraph manufacturing in 1856 with a version of the Breguet dial telegraph that could also print messages. The month after his competitors obtained their patent, Breguet patented his own version of the Digney brothers' apparatus.[33] However, the Digneys built an international reputation on an improved Morse telegraph. Instead of embossing dots and dashes on a strip of paper like the first Morse telegraphs utilized in France, the Digneys' invented the inking Morse which the telegraphs in France, Belgium, and Spain adopted by 1859. In Germany, the Digneys ceded construction to the Berlin firm of Siemens-Halske.[34] Thus, horologists, scientific instrumentmakers, and employees setting out on their own from the Maison Breguet contributed to the development of the French telegraph manufacturing industry.

The telegraph industry in France was centered in Paris.[35] Most companies remained in the same location, usually expanding to occupy more and more rooms within a building. Some firms, such as Breguet, Froment, and Edme Hardy (1831-?),[36] required more space than was available at their original location and relocated to a new address, always southward from their original location, but remaining within the city limits.[37] Although the Paris city business directory did not begin to list a separate section for telegraph manufacturers, installers, and suppliers until 1861, when 26 firms claimed to be in the telegraph business, by 1868 there were 39 listings and 53 in 1881.[38] While these numbers indicate a strong growth in the industry, the number of firms involved in telegraphy doubling over a 20-year period, the number of actual manufacturers of telegraph instruments was rather small as the directory's listing included installers and suppliers too. Most of those firms listed furnished batteries and battery supplies, ceramic insulators, wire and cable, and other telegraphic supplies.

An important characteristic of the French telegraph industry was its development of international markets. From its beginnings, for example, the Maison Breguet sold horological wares to an international market eager to possess them. Thus, before the introduction of electrical telegraphy, Breguet already understood how to sell a product in another country. Later, as a matter of course, he sold scientific instruments to individuals in other countries.[39] The first Breguet contract to furnish telegraph instruments to another country was a major agreement with the Portuguese government to supply its newly organized lines shortly before 1855.[40] The firm ultimately sought out markets in other countries, selling telegraphs to the governments of Peru, Brazil, and many other American and European countries, plus Japan.[41] Other French telegraph manufacturers followed the Breguet lead. The Digney brothers, for instance, sold to Spain, Belgium, Greece, Turkey, the Indies, and Mexico and Edme Hardy vended telegraph apparatus in Austria, Switzerland, Holland, Italy, and Germany.[42]

International sales were sufficiently important to Breguet and other telegraph manufacturers that they took out patents in other countries.[43] Moreover, in order to handle orders from abroad, the Breguet company opened offices in London, Edinburgh, Halifax, Munich, and Vienna and published its catalogue in English and German, as well as French.[44] While figures on foreign sales are not available for the Maison Breguet, those for other telegraph manufacturers are and indicate the extent to which foreign sales contributed to total receipts for French telegraph manufacturers. In 1877, the Digney brothers' total receipts for the sale of telegraph and other instruments overseas amounted to 150,000 francs compared to 200,000 francs for domestic sales, while Hardy's firm counted one-fourth of its receipts as being from foreign sales.[45]

In addition to seeking out international markets, the Paris-centered telegraph manufacturing industry exploited new domestic markets and, in the process, spun off new industries based upon new products that contributed to the growth of electrical manufacturing. Much of this growth took place with the development of markets beyond railroad companies to include business, industrial, and private home use.

Because the railways utilized regular rail agents as telegraph operators, those charged with working the instruments had various other duties. These duties and the infrequency and irregularity of railroad telegraph traffic meant that rail employees did not watch over their telegraphs constantly. Moreover, the utilization of a dial telegraph incapable of leaving a record of the message necessitated the introduction of a device that would alert the rail telegraph agent to the arrival of a message from another post. For this purpose, Louis Breguet invented an electric alarm bell, a clockwork mechanism that struck a small hammer against a hemispherically-shaped piece of metal whenever an operator sent a current over the telegraph line.[46] In order to communicate with the railroad telegraph stations, the Telegraph Administration purchased these alarms from Breguet and Mouilleron at the cost of 100 francs apiece.[47]

J. Mirand (n.d.), an employee of the Maison Breguet,[48] founded his reputation and fortune upon the manufacture of the "sonnerie électro-télégraphique",[49] an improved version of the Breguet electric alarm. Mirand's genius was to reduce the cost of the device and to define a new use and market for it, thereby creating a new branch of electrical manufacturing and opening a pandora's box of competition. By eliminating the clockwork mechanism, Mirand manufactured a cheaper alarm, costing only 50 francs. Furthermore, he correctly believed that his alarms would find an immense market in a variety of applications as doorbells or "annunciators" in homes, businesses and commercial enterprises, hotels, and government offices.[50] After patenting it in 1852, Mirand ceded construction of his alarm to a newcomer to electrical manufacturing, P. D. Prud'homme (n.d.), who did the actual manufacturing and who supplied electrical alarms to the state for only 40 francs each.[51]

The rapid growth of the electric alarm industry, an offshoot of the telegraph manufacturing industry, is apparent from the Paris business directory which, in 1860, began to list "sonneries électriques" as a separate profession. The number of manufacturers, suppliers, and installers of electric door bells listed in the directory increased to 42 by 1881.[52] The intensity of competition manifested itself in the use of advertizing[53] and one of the rare court cases that arose in matters relating to telegraphy. Prud'homme twice unsuccessfully sued Breguet and other electrical alarm manufacturers for violation of the Mirand patent.[54] Despite the legal difficulties presented by Prud'homme's suits, Breguet and others continued to install, manufacture, and supply electric alarms.

Symptomatic of the contribution of telegraph instrument builders to the overall growth of electrical manufacturing was the Maison Breguet's 1873 product-catalogue. The catalogue listed an impressive range of electrical supplies, including electrical measuring instruments, comprehending devices for measuring electrical resistance like the Wheatstone bridge; tangent, sine, and differential galvanometers; and voltmeters, calculated to be suitable for experimenters as well as lecture demonstrators, not to mention the obvious commercial markets offered by the Telegraph Administration. Railroad signalling equipment, applicable on the many kilometers of track crisscrossing France (and elsewhere), also appeared in the catalogue. For civil engineering and mining operations, the firm offered electrical detonators and to others its electrical meteorological recording instruments. Physicians could select among a variety of electrophysiological and electromedical apparatus. And anyone wishing to replenish their electrical supply could obtain batteries and battery supplies.[55]

In order to concentrate on electrical manufacturing, the Breguet firm had phased out production of nonelectrical horological items. From its founding in the 18th century, the Maison Breguet had built watches and other timepieces. Its reputation for quality had made the name "Breguet" synonymous with the word "watch".[56] In 1870, the company dropped its horological operation, ceding this business to an employee who retained the Breguet name.[57] The firm continued to sell electric clocks along with other electrical equipment, however. With the decision to cease production of nonelectrical timepieces, the only nonelectrical item in the firm's 1873 catalogue was a brief line of thermometers, barometers, and other meteorological apparatus.[58]

While separating its traditional horological interests in order to focus more attention upon the development of electrical technologies, the Maison Breguet also played a significant role in introducing new electrical technologies to France that kept the company on the cutting edge of the electrical arts. For example, the firm was responsible for introducing the telephone into France.[59] More significantly, however, for it manifestly placed the Maison Breguet in the forefront of electrical technology, was the company's role in creating the French lighting industry. Although certainly not the earliest French device for providing power for electrical lighting,[60] the Gramme dynamo was one of the most successful, winning a 3000 franc prize in 1873 offered by the Society of Encouragement for National Industry for a device capable of replacing 60 to 80 Bunsen cells economically and safely.[61] The dynamo's inventor was the Belgian, Zénobe Théophile Gramme (1826-1901), a carpenter who came to Paris and studied to become a modelmaker. Gramme apprenticed at various scientific instrumentmakers' ateliers around Paris, perhaps including that of Breguet, and began patenting a number of dynamo designs. Eventually, in the early 1870s, the Société des machines électro-magnétiques Gramme was formed. It made the Maison Breguet the manufacturer and distributor of the Gramme dynamo.[62] With its commitment to the Gramme dynamo, the Maison Breguet took off into electrical lighting and the challenges of a new field.

The telegraph manufacturing industry developed by seeking out new products and new markets as well as through collaboration with scientists. As an offshoot of the scientific instrument building and horological industries, science and scientists formed an integral part of the telegraph manufacturer's world. Breguet's work with Arago has already been noted; Froment furnished the apparatus with which Hippolyte Fizeau (1819-1896) measured the velocity of electricity,[63] while the construction of telegraph instruments also brought manufacturers into collaborative ties with such foreign scientists as Wheatstone, Hughes, and Caselli. Collaboration between manufacturers and scientists, however, did not mean that the scientists possessed knowledge of theory and the manufacturers did not. On the contrary, science played a significant part in the manufacturers' education and the most important manufacturers, Breguet, Froment, and Hardy attended classes at the prestigious Ecole polytechnique and Ecole centrale.

The education of Louis Breguet, like that of his father and grandfather, did not lead necessarily to the Ecole Polytechnique. Rather, his instruction had emphasized the practical training of apprenticeship and noticeably lacked science courses. Breguet's memory of his schooling omits any reference to science instruction[64] and, as one biographer asserted, at the age of 18, Louis was a "very skillful worker, but quite poorly schooled."[65] In 1832, however, François Arago showed Breguet how to construct an electromagnet in order to demonstrate the identity of the electrical and magnetic "fluids".[66] Following Arago's advice, Breguet followed the courses in mechanics, physics, and mathematics at the Ecole polytechnique as an "external auditor" (<u>auditeur externe</u>).[67] Unlike students enrolled in the school's regular program, auditors neither took entrance exams nor had hopes of reaping the benefits of an Ecole polytechnique diploma, namely, a military or civil position with the State. At the time Breguet attended, only five or six external auditors followed the Ecole polytechnique courses.[68] Becoming an auditor required only the permission of a professor of the school. It was probably Arago, professor of geometry 1810-1815, analysis 1816-1829, and machines 1816-1831 as well as head of the school in 1830,[69] who gave Breguet permission to attend the Ecole polytechnique as an external auditor.

Louis Breguet clearly appreciated the benefits of Ecole polytechnique courses for that is where he sent his son, Antoine (1851-1882). After attending the lycées Saint Louis and Bonaparte and obtaining the degree of bachelier-ès-sciences in 1868, Antoine Breguet entered the Ecole polytechnique in 1872. Graduating in 1874, Antoine became subdirector ("<u>sous-directeur</u>") of the Maison Breguet the following year.[70] Another telegraph instrument manufacturer who graduated from the Ecole polytechnique was Gustave

Froment. Froment attended the lycée Sainte Barbe and the collège Louis le Grand. He attended the Ecole polytechnique beginning in 1835 and graduated in 1837. As part of his admission application to the Ecole polytechnique, Froment submitted drawings of an electrical motor which he designed after seeing Pixii's electrical generator.[71] Jules Carpentier (1851-1921), another graduate of the Ecole polytechnique, took over Ruhmkorff's shop and constructed the Baudot telegraph, among many other electrical apparatus like the d'Arsonval galvanometer.[72] P. J. Emile Vinay (1828-?), successor to Mouilleron, also graduated from the Ecole polytechnique.[73]

Telegraph manufacturers also graduated from the Ecole centrale des arts et manufactures. Founded in 1830, the goal of the Ecole centrale was to train civil engineers and managers for private industry.[74] Edme Hardy, manufacturer of Meyer's facsimile and multiple telegraphs among other instruments, graduated from the Ecole centrale des arts et manufactures.[75] A Belgian student of the Ecole centrale, Louis Mors (?-1917), took over Prud'homme's atelier and manufactured and installed electrical alarms and signals and a Spanish graduate became a general inspector in the telegraph service of his native country. Charles Louis Curchod (1826-1889) became a telegraph inspector in his native Switzerland, first director of the International

Telegraph Union in 1865, and head of the board of directors of the Société du câble transatlantique française. The majority of Ecole centrale graduates entering an electrical field, however, chose the electrical lighting industry for the most part, with a few going into telephony.[76]

Not all telegraph instrument manufacturers attended the Ecole centrale or polytechnique.[77] Because of a general lack of biographical information on telegraph manufacturers,[78] the source of their science instruction, if any, is not available. Certainly, many of them, like J. Mirand, learned telegraphy in Breguet's shop since, as one observer declared in 1855, Breguet "has become the head of a French School of Telegraphy; many students from his model ateliers have become masters already famous."[79] And one of his obituaries echoed: "It is from his company that have come the majority of the skillful manufacturers who work in the electrical apparatus industry in Paris."[80] While Breguet likely provided instruction in the manufacture of telegraph apparatus to his workers, the city of Paris, where the French telegraph industry centered, offered several institutions where a telegraph manufacturer - or anyone else - could acquire a knowledge of electrical theory, though not specifically related to telegraphy, as part of a course on physics. In addition, any literate and ambitious person could read one or more of a growing number of telegraph handbooks.

The Conservatoire national des arts et métiers (CNAM) became one of France's most important centers for advanced training in electrical technology, offering annual certificates starting in 1903 and engineering diplomas in 1925.[81] Founded during the Revolution, the CNAM offered free classes to any adult wishing and willing to attend for the six month period between November and April. Professors gave two, hour and a half lessons each week in the evenings.[82] In 1829, the CNAM added two new positions, a _démonstrateur des machines_ and a professor of "_applications faites aux arts des principes de la physique expérimentale_," with Claude Pouillet (1791-1868) filling both positions and serving as CNAM director from 1829 to 1849.[83] Pouillet's physics text was adopted throughout France's secondary school system, going through numerous editions until 1856. While at the CNAM, Pouillet also taught at the Ecole polytechnique, the University of Paris (Sorbonne), and the Collège de France.[84] Beginning with the fourth (1847) edition, Pouillet's textbook furnished a concise discussion of contemporary French telegraphic technology (including how to erect a line) and relevant electrical theory.[85]

Although Pouillet furnished telegraph instruction through his textbook at other educational institutions and as part of his CNAM course, he left the CNAM in 1852 because of his staunch Orleanist beliefs and political opposition to the presidency of Louis Napoleon Bonaparte.[86] Pouillet's chair, changed to that of professor of "physics applied to the arts" ("*physique appliquée aux arts*"), fell to Edmond Becquerel (1820-1891), who retained the position until 1891.[87] Edmond was the son of Antoine Becquerel (1788-1878), who taught at the Museum of Natural History, and had studied at the Ecole polytechnique. Gaston Planté (1834-1889), celebrated for his work on the secondary battery and who worked for the plating firm of Christofle as a technical advisor, served as his *préparateur* beginning in 1854.[88] Between 1853 and 1866, the years for which figures are available, more students attended Becquerel's "physics applied to the arts" lectures than any other CNAM course, with an average of 484 to 597 students attending any given lesson.[89] Although information on the students taught by Becquerel is lacking, of those attending in 1917, 50% had failed the entrance examinations to the *grandes écoles*, 25% were foremen, owners of small shops, or employees, and 10% were graduates of *grandes écoles*.[90]

Around 1855, Becquerel's course[91] covered the basic telegraph instruments used on the state lines in France: Breguet's dial telegraph, the Foy-Breguet apparatus, and the embossing Morse instrument. In addition to electrical signalling systems employed by the railroad companies, the course described telegraphs from other countries, notably

Great Britain and Prussia, and included a discussion of the erection of telegraph lines, insulation, duplexing, and the Calais-Dover underwater telegraph cable, and explanations as to the applicability of electrical theory to telegraphy. In order to provide visual instruction, Becquerel had the CNAM's rich collection of electrical and telegraphic apparatus upon which to draw.[92] As late as 1872, the tradition of teaching telegraphy at the CNAM continued.[93]

Beyond the CNAM, a knowledge of electrical theory, though not necessarily tied specifically to telegraphy, could be acquired anywhere in Paris where physics was taught, such as at the popular lectures offered at the Museum of Natural History or at the University of Paris or the Collège de France.[94] Free evening courses in physics were also available from the Association philotechnique and the Association polytechnique. Founded in 1848, the Association Philotechnique drew its faculty largely from the faculties of the University of Paris and the city's various lycées and collèges and offered free adult courses in arithmetic, geometry (including descriptive geometry), algebra, trigonometry, linear design, chemistry, mechanics, and physics, among other subjects.[95] Relying upon subscriptions for financial support, the Association Philotechnique did not receive any subscriptions from telegraph manufacturers until 1864, when Dumoulin-Froment subscribed 5 francs. In 1878, the director of the Maison Breguet began subscribing 20 francs annually.[96] The Association Polytechnique offered a similar program of free adult instruction. Founded by faculty members of the Ecòle Polytechnique, the Association offered courses in arithmetic, algebra, descriptive and applied geometry, physics, chemistry, and applied mechanics, as well as other subjects. Among the members of the school's consultative committee was Louis Breguet. By 1890, moreover, the school and the Association philotechnique offered a course in the history of telegraphy.[97]

Formal courses in physics were not the only means available for a telegraph manufacturer to learn about electrical theory and telegraphy. Numerous textbooks and handbooks provided explanations of the operation of telegraph instruments and the electrical theory associated with telegraphy to anyone who wished to teach themselves. For example, in 1851, Louis Breguet published a manual on electric telegraphy that included a section on electrical theory (batteries, electromagnetism, induction, and condùctability plus other topics). A second, third and fourth (1862) edition followed.[98] An 1849 Breguet book furnished a discussion of telegraph technology and an essay on "electricity applied to telegraphy" that encompassed the theory of batteries and electromagnets as well as rules of thumb such as the one which stated that the power of an electromagnet varies proportionally with the number of turns of wire used to form it.[99] Works by individuals other than Breguet appeared in print and a literature came into existence, in French, German, and English, to which the autodidact could turn for instruction in electrical theory (but not general physics) and its connection to telegraphy. A list of such telegraph works prepared by the Telegraph Administration in 1855 noted nine books published in French.[100] By 1881, the list had grown considerably.[101]

In addition to telegraph manuals and handbooks, an autodidact could obtain information on telegraphy by attending any one of the international expositions held in Paris in 1855, 1862, 1867, 1878, or the international electrical exhibition of 1881. These expositions always featured shows of the latest telegraph instruments and apparatus used in France as well as in other countries, including Great Britain, Germany, Japan, and the Ottoman Empire. Another source of information on telegraph technology was patent descriptions and models. French patent law stipulated that the Ministry of Commerce would make available, free of charge, all patent descriptions, drawings, and models beginning with the second year of the patent. After the expiration of the patent, the Ministry turned these over to the CNAM.[102] The CNAM's patent collection was open to the public every day between 10 AM and 3 PM, except

Monday, and the galleries containing apparatus collected from international expositions and other sources were available to the public, free, every Tuesday, Thursday, Saturday, and Sunday, noon to 4 PM.[103]

While the existence of a telegraphic and electrical literature, international expositions, and the CNAM's patent and technology collection played a role in the diffusion of knowledge, their contribution to the development of the French telegraph manufacturing industry was less significant than that of the schools providing formal instruction. From the Ecole centrale and Ecole polytechnique came the most important of the telegraph manufacturers: Breguet, Froment, Hardy, Carpentier. Starting in the 1880s, programs in electrical engineering at other institutions furnished industry with graduates. In 1883, the Ecole de physique et de chimie industrielle de Paris graduated its first electrical engineers, followed by the Ecole supérieure d'électricité, in 1893, and the university science faculties at Grenoble, Lille, Nancy, and Toulouse, between 1897 and 1909.[104] Thus, before the emergence of electrical engineering instruction at these institutions and prior to the Paris International Electrical Exposition of 1881, the Ecole supérieure de Télégraphie (starting in 1878), the Ecole polytechnique, and Ecole centrale trained individuals for employment in the electrical industry.

FOOTNOTES

[1]"Comité d'administration" and "Liste des membres fondateurs" Bulletin de la Société internationale des électriciens 1 (1884): 22-24 & 33-63.

[2]L. Breguet, "Essai sur la télégraphie électrique," manuscript, 4° Ca 94, Conservatoire national des arts et métiers, Paris, p. 16. Hereafter referred to as L. Breguet, "Essai". For biographical information on Louis Breguet, see Amiral Georges Charles Cloué, "Discours prononcé sur la tombe de M. Breguet," Bulletin de la Société d'encouragement 83 (1884): 20-22; Ernest de Jonquières, "Notice sur la vie et les travaux de Louis François-Clément Breguet, Membre de l'Académie des sciences, né à Paris le 22 décembre 1804, mort le 27 octobre 1883," Comptes rendus 103 (1886): 5-14; his obituary in Annales télégraphiques 3,10 (1883): 568-569; Claude Breguet, "Louis Breguet: Constructeur de télégraphes électriques," Diligence d'Alsace no. 28 (1983): 20-24 & 29-31 (hereafter cited as C. Breguet, "Louis Breguet"); and C. Breguet, "La Maison Breguet: Du Quai de l'horlogerie au boulevard Montparnasse," Annuaire de la Société historique du quatorzième arrondissement de Paris 6 (1962): 65-78 (hereafter, C. Breguet, "Maison Breguet").

[3]Moniteur universel, 12 November 1844, p. 2861 and François Moigno, "Un de nos grand maîtres en télégraphie électrique, une des gloires françaises de l'horlogerie: télégraphes électriques, et montre merveilleuse de M. Breguet," Le Cosmos 7 (1855): 213. Hereafter cited as Moigno, "Breguet".

[4]Cloué, p. 21.

[5]Notice sur les travaux de M. L. Breguet (Paris: Bachelier, 1847), pp. 3-4 (hereafter cited as Notice sur Breguet, 1847) and de Jonquières, p. 7. For a discussion of the grandfather's thermometers, see George Daniels, The Art of Breguet (London & New York: Sotheby Parke Bernet, 1975), pp. 91-92.

[6]Notice sur Breguet, 1847, p. 5; Cloué, p. 21; de Jonquières, p. 7; C. Breguet, "Louis Breguet." p. 21; and C. Breguet, "Maison Breguet," p. 77. I have found nothing on Boquillon. In 1843, Boquillon and Breguet jointly received a silver medal from the Society of Encouragement. See F. Calla, "Rapport sur un appareil propre à tailler les dents des engrenages hélicoïdes, de MM. Breguet fils et

Boquillon," Bulletin de la Société d'encouragement 42 (1843): 331-337. "Liste des membres de la Société admis pendant l'année 1847," Bulletin de la Société d'encouragement 46 (1847): 715 lists a member named Boquillon who was librarian at the Conservatoire des arts et métiers. I do not believe that they were the same person.

[7]"Etablissements Breguet," in Julien Turgan, ed., Les grandes usines de France: Tableau de l'industrie française au XIXe siècle par Turgan, 20 vols. (Paris: A. Bourdilliat et Cie, 1874), 11:8. Hereafter, Turgan.

[8]Exposition de 1844: Produits de la Maison Breguet, Neveu et Cie. (Paris: V. Janson, 1844).

[9]For biographical information on Masson, see Louis Jovignot, "Un grand savant bourguignon du XIXe siècle: Antoine Masson," Revue d'histoire des sciences 1 (1948): 337-350, according to which Masson's thesis was on the "Théorie physique et mathématique des phénomènes dynamiques et du magnétisme".

[10]"Lettre de M. Masson sur un essai de télégraphe électrique fait au collège de Caen," Comptes rendus 7 (1838): 88 and Masson and L. Breguet, "Paquet cacheté portant pour suscription: Description d'un nouveau télégraphe électrique (8 October 1838)," Archives of the Academy of Science, Paris, hereafter cited as Masson and L. Breguet, "Paquet cacheté".

[11]Masson and L. Breguet, "Paquet cacheté".

[12]Masson and L. Breguet, "Mémoire sur l'induction," Comptes rendus 13 (1841): 426-427 presents only the conclusions extracted from the article's end. The entire item appeared in the Annales de chimie et de physique 3,4 (1842): 129-152 and in English in Sturgeon's Annals of Electricity 8 (1842): 346-353. I used a copy of the memoire as originally presented to the Academy of Science from the Breguet Collection, Paris.

[13]Cloué, p. 21; Notice sur les travaux de M. L. Breguet (Paris: Mallet-Bachelier, 1857), p. 12; and, de Jonquières, p. 7 attribute the Ruhmkorff coil to the theoretical work laid out in the memoire of Masson and Breguet. In considering Heinrich Ruhmkorff (1803-1877) for the Volta Prize in 1863, the Prize Commission considered Masson and Breguet to have preceded Ruhmkorff in the invention of the induction coil, but concluded that their device worked poorly. "Commission de la Pile de Volta: Procès-verbal de la séance du 26 mai," F(17) 3101, Archives Nationales, Paris.

For biographical information on Ruhmkorff, see Emil Kosack, Heinrich Daniel Rühmkorff, ein deutscher Erfinder (Leipzig and Hannover: Hahn, 1903).

[14]Moigno, "Breguet," p. 213.

[15]According to "Notice sur la carrière administrative et les travaux scientifiques de E. E. Blavier," Annales télégraphiques 3,14 (1887): 7, the railroads used the dial telegraph exclusively. I believe this statement to be true as a general rule, particularly for the period before 1853, although later at least one other telegraph instrument came into use as well, namely, the printing telegraph of d'Arlincourt. "M. D'Arlincourt," Annales télégraphiques 3,11 (1884): 182.

[16]Notice sur Breguet, 1847, p. 8.

[17]"Télégraphe électrique mobile," Comptes rendus 34 (1852): 649-651 and Moigno, "Breguet," pp. 217-218.

[18]"Rapport à Monsieur le Ministre de l'intérieur," dated 20 September 1854, F(1a) 1985(6), Archives Nationales, Paris.

[19]C. Breguet, "Maison Breguet," p. 78.

[20]"Rapport à Monsieur le Ministre de l'intérieur," dated 9 February 1855, F(1a) 1985(6), Archives Nationales, Paris. I have found no other information on Mouilleron than that found in C. Breguet, "Louis Breguet," p. 29.

[21]C. Breguet, "Louis Breguet," p. 29.

[22]These records are in dossiers F(1a) 1985(3) and 1986(1), Archives Nationales, Paris.

[23]"Rapport à Monsieur le Ministre de l'intérieur," dated 9 February, 9 May, 15 May, 30 May, 7 July, 4 August, and 19 October 1855, F(1a) 1985(6), Archives Nationales, Paris.

[24]Based upon an examination of payments made for Foy-Breguet telegraph instruments to Breguet and Mouilleron during the period 29 May 1854 and 19 October 1855, F(1a) 1985(6), Archives Nationales, Paris. Breguet received 90,780 francs for Foy-Breguet telegraphs and Mouilleron obtained payments of 16,305.50 francs for Foy-Breguet telegraphs and all other associated telegraph apparatus. Records prior to 29 May 1854 are not available and the surviving archival records do not indicate further Foy-Breguet apparatus purchases after 19 October 1855. According to the payments

made for Foy-Breguet telegraph instruments to Breguet and Mouilleron during the period 29 May 1854 and 19 October 1855, F(1a) 1985(6), Archives Nationales, Paris, Breguet received 210 francs per telegraph compared to 200 francs for Mouilleron.

[25]An examination of account records between the Telegraph Administration and the firms of Breguet and Mouilleron, F(1a) 1985(6) and 1986(1), Archives Nationales, Paris, shows that Breguet received 105,310 francs compared to Mouilleron's 103,224 francs for production of Morse telegraphs.

[26]L. Breguet's obituary notice in Annales télégraphiques 3,10 (1883): 569 and Moigno, "Breguet," p. 213: "Il <Breguet> est devenu le chef d'une Ecole française de télégraphie; plusieurs élèves sortis de ses ateliers modèles sont devenus des maîtres déjà célèbres."

[27]For biographical information on Froment, see A. Laussedat, Notice biographique sur Gustave Froment (Paris: J. Hetzel, 1865); "Mort de M. Froment, membre du conseil de la Société d'encouragement," Bulletin de la Société d'encouragement 64 (1865): 74-80; and, H. E. Tresca, "Paroles prononcées au nom du Conseil de perfectionnement du Conservatoire impérial des arts et métiers aux funérailles de M. G. Froment," Annales du Conservatoire des arts et métiers 1,5 (1864): 337-340. A list of his accomplishments submitted for the Volta Prize competition is in the folder, F(17) 3101, Archives Nationales, Paris.

[28]He had won a special Council Medal at the 1851 London Crystal Palace Exhibition for his theodolites and an hors concours medal (he was a member of the jury) at the 1855 Paris International Exposition for his electric clock. <1851 London International Exhibition>, Reports of the Juries (London: William Clowes & Sons, 1852), p. lxiii and <1855 Paris International Exhibition>, Rapports du jury mixte international, publiés sous la direction de S. A. I. le prince Napoléon, président de la commission impériale (Paris: Imprimerie Impériale, 1856), p. 459.

[29]Annales télégraphiques 2,7 (1864): 602.

[30]Bertho, pp. 107-109.

[31]Jacquet and Lajarrige, "Procès Baudot-Mimault," p. 40 and Laussedat, p. 23.

[32]Although I have found no biographical information on

Jean Didier Digney, an obituary for his brother, Bastien Théodore, is in Journal télégraphique 27 (1903): 191. The Annuaire général du commerce, de l'industrie, de la magistrature et de l'administration (Paris: Firmin-Didot frères, 1863), p. 857 (hereafter, Annuaire du commerce (year)), lists them as horologists as does Tardy, Dictionnaire des horlogers français (Paris: Tardy, 1972), p. 185. According to a questionnaire the firm filled out in 1878, the company was founded in 1855. Dossier F(12) 3409, Archives Nationales, Paris.

[33]Patent no. 28,983, issued 2 September 1856. The patent even specified that it was based upon the Breguet dial telegraph. Breguet's patent was no. 29,537, issued 22 October 1856.

[34]"Rapport fait par M. Th. du Moncel, au nom du comité des arts économiques, sur le télégraphe imprimeur du système Morse présenté par MM. Beaudoin <sic> et Digney," Bulletin de la société d'encouragement 58 (1859): 8-10. For a recent, English-language history of the Siemens-Halske company, see Sigfrid von Weiher and Herbert Goetzeler, The Siemens Company: Its Historical Role in the Progress of Electrical Engineering, trans. G. N. J. Beck (Berlin and Munich: Siemens Aktiengesellschaft, 1977).

[35]François Pierre Le Roux, "Instruments de précision à l'usage des sciences," in <France> Commission supérieure à l'Exposition universelle de Vienne, 1873, Rapports, 5 vols. (Paris: Imprimerie Nationale, 1875), 5:119.

[36]Hardy was a scientific instrumentmaker and founded his firm in 1855. Hardy's response to a questionnaire in F(12) 3409 and his Legion of Honor dossier, F(12) 5166.

[37]I searched the telegraph listings in the Annuaire du commerce for the period 1847 through 1881 but did not find a section for telegraph manufacturers, suppliers, and installers until the 1861 edition. Upon compiling the addresses of every firm listed, I noticed that telegraph manufacturers usually relocated. Although a major firm, the Digney brothers never moved from their original location on Poitevins, numbers 6 & 8. However, the Annuaire du commerce does make it clear that their expansion involved becoming the sole residents at number 8 Poitevins, replacing the previous tenants with whom they had shared the building. A few manufacturers did the same as the Digney brothers. Others moved to a new building and these companies were usually the largest, the Digney brothers being an obvious exception. As for relocation patterns, the firms that did move began in

various quarters of Paris, mostly near the Cité, and relocated to the south. Breguet, for example, moved from the Quai de l'Horloge to the Boulevard Montparnasse, Hardy from Rue de Sèvres to the Avenue La Mothe Piquet, and Froment from Ménilmontant to Notre Dame des Champs. Despite the reconstruction of the city under the Second Empire, I was able to locate these and other addresses on city maps found at the Bibliothèque Historique de la Ville de Paris, Paris.

[38]Annuaire du commerce (1861), p. 1038; ibid. (1868), pp. 1270-1271; and, ibid., pp. 1668-1669.

[39]For example, L. Breguet, "Note sur un appareil destiné à mesurer la vitesse d'un projectile dans différents points de sa trajectoire," Comptes rendus 20 (1845): 157-162 describes a scientific instrument that Breguet sold to a Russian military officer. For their international sales of watches, see, for example, Daniels, p. 4.

[40]Moigno, "Breguet," p. 213, dated 1855, reports that the contract with Portugal was "recent".

[41]C. Breguet, "Louis Breguet," p. 30 states that the Maison Breguet built telegraph instruments for all of Europe, Brazil, and Japan. "Telegraphs in South America," The Telegrapher 4 (1867): 60-61 relates the installation of Breguet instruments on Peru's telegraph lines.

[42]Annuaire du commerce (1879), p. 1544 and ibid. (1861), p. 1038.

[43]Two examples of Breguet's British patents are those issued 5 December 1854, for his mobile dial telegraph, and on 17 March 1855, for an electrical regulator of steam, water, or other pressure. British Commissioners of Patents, Abridgements of Specifications relating to Electricity and Magnetism, 2 vols. (London: George E. Eyre and William Spottiswoode, 1859), 1:452 & 470. Ibid., 1:557-558 & 607 list two more Breguet British patents. I found no references to Breguet having German patents in Dingler's Polytechnisches Journal or United States Patents in U. S. Commissioner of Patents, comp., Index of Patents Relating to Electricity granted by the United States prior to July 1, 1881 (Washington: Government Printing Office, 1882), although both sources listed several telegraph patents assigned to other Frenchmen.

[44]L. Breguet, Catalogue illustré (Paris: Imprimerie Simon Raçon et Cie, 1873) is in French, English, and German and, on its back cover, gives the names and addresses of the

firm's foreign agents as: Adams and Son, 57 Haymarket Street and 41 Marshall Street, London; Edward Gilbert, Telegraph Engineer, 4 Princes Street, Edinburgh; Louis J. Crossley, Dean Clough Mills, Halifax; Prof. Carl, Physikalische Anstalt, Munich; and Lenoir of Vienna.

[45]These figures come from a questionnaire distributed to the participants of Class 65 (telegraphy) of the 1878 Paris International Exposition by Antoine Breguet, Secretary of the Installation Committee for the Class, F(12) 3409, Archives Nationales, Paris.

[46]L. Breguet, Manuel, pp. 59-64 & 72-77.

[47]"Rapport à Monsieur le Ministre de l'intérieur," dated 9, 15 & 30 May, 12 June 1855, 22 January, and 31 March 1856, F(1a) 1985(6) and 1986(1), Archives Nationales, Paris.

[48]I have found no biographical information on Mirand except Moigno, "Breguet," p. 213 which states that he was a "celebrated master" and a former Breguet employee.

[49]See "Rapport fait par M. Clerget, au nom du comité des arts économiques, sur des sonneries électro-télégraphiques de M. Mirand," Bulletin de la Société d'encouragement 53 (1854): 165, for example. Cited hereafter as Clerget.

[50]"Rapport à Monsieur le Ministre de l'intérieur," dated 6 May 1856, F(1a) 1986(1), Archives Nationales, Paris and Clerget, pp. 165-166 & 168-169.

[51]Mirand's electric alarm patent was issued 1 November 1852, French patent no. 14,604. "Article 1026: Brevets Mirand: Sonnerie électrique: Changement de forme et de matière," Annales de la propriété industrielle artistique et littéraire 10 (1864): 88-90 states the Mirand conceded of his invention to Prud'homme and relates the ensuing patent battle. The Annuaire du commerce (1862), p. 1079, lists Prud'homme as the manufacturer of "sonneries électriques, système J. Mirand". "Rapport à Monsieur le Ministre de l'intérieur," dated 26 June and 4 July 1857, F(1a) 1986(1), Archives Nationales, Paris gives the price the state telegraphs paid for Mirand's alarms as manufactured by Prud'homme. I have found no biographical information on Prud'homme. By 1879, Louis Mors had taken over the firm, with representatives in 16 foreign cities, including Boston. Moreover, he represented the Maison Breguet in Belgium. Annuaire du commerce (1879), p. 1506. Later on, Mors went into the business of manufacturing electrical automobiles. David Landes, The Unbound Prometheus: Technological Change

and Industrial Development in Western Europe from 1750 to the Present (Cambridge, England: Cambridge University Press, 1969), p. 448 and Mors' obituary in the *Bulletin de la Société d'encouragement* 116 (1917): 505.

[52] *Annuaire du commerce* (1858), p. 822 and (1881), pp. 1505-1506.

[53] Prud'homme ran his ad in a section at the rear of the *Annuaire du commerce* printed upon unnumbered yellow pages and called the "Revue industrielle."

[54] "Article 1026: Brevets Mirand: Sonnerie électrique: Changement de forme et de matière," *Annales de la propriété industrielle artistique et littéraire* 10 (1864): 88-90. A search of the journal *Annales de la propriété industrielle artistique et littéraire* and the patent case catalogue of the Institut national de la propriété industriale (INPI, the French patent office) revealed only one other court case involving telegraphy. See "Article 3023: Brevet d'invention: Principe scientifique: Application nouvelle: Résultat industriel: Contrefaçon," *Annales de la propriété industrielle artistique et littéraire* 30 (1885): 321-334, which relates the famous Mimault-Baudot case involving the priority of invention of two telegraph employees.

[55] L. Breguet, *Catalogue illustré*, pp. 1-7, 16-18, 43-55, 73-74, 77-78, 85-98, 102-104.

[56] For an interesting and nicely illustrated discussion of the original Breguet production line, see Daniels or Alfred Chapuis and C. Breguet, *A.-L. Breguet pendant la Révolution française* (Neuchatel: Editions du Griffon, 1953). A more recent, though far briefer and less satisfying survey is that of Alen Kurzweil, "Man of Many Faces: A Wily Wizard and his Time Machines," *Smithsonian* 16 (1985): 92-101. C. Breguet, "Maison Breguet," p. 75 gives four literary references in which "Breguet" was synonymous with the word "watch".

[57] C. Breguet, "Louis Breguet," p. 30.

[58] L. Breguet, *Catalogue illustré*, pp. 81-84.

[59] C. Breguet, "Antoine Breguet, du téléphone de Bell au photophone (1880-1882)," no. 30 *Diligence d'Alsace* (1984): 2-23 and Michel de Cheveigné and Jacquet, "Le téléphone ce jeune centenaire: Les debuts en France: 1877-1881," in *Chroniques téléphoniques et télégraphiques*, pp. 77-83.

[60]For an early proposal to illuminate private residences with electricity using the arc light, see Marc Gaudin, "Note sur l'application de la lumière Drummond à l'éclairage public et privé," _Comptes rendus_ 6 (1838): 861-863.

[61]"Prix de 3,000 francs pour la construction d'un appareil donnant un courant électrique constant en direction et en intensité (pile ou machine magnéto-électrique), dont la force électro-motrice et la conductibilité seraient comparables à celles d'une pile à acide azotique de 60 à 80 éléments de grandeur ordinaire, et présentant des conditions de supériorité, tant comme économie que comme salubrité, sur les appareils qui sont aujourd'hui en usage," _Bulletin de la Société d'encouragement_ 69 (1870): 468-469 and "Compte rendu des prix mis au concours par la Société d'encouragement pour l'industrie nationale pour être décernés en 1873," _Ibid_. 72 (1873): 259 & 271-276.

[62]W. James King, "The Development of Electrical Technology in the 19th Century: The Early Arc Light and Generator," _United States National Museum Bulletin_ no. 228 (1962): 380 and Turgan, pp. 28-32. The Gramme dynamo is an item in L. Breguet, _Catalogue illustré_, pp. 105-106, costing 600 francs. François Breguet, "La Maison Breguet: du boulevard Montparnasse à la rue Didot," _Annuaire de la Société historique du quatorzième arrondissement de Paris_ 6 (1962): 82 suggests the possibility that Gramme was a Breguet employee. For biographical information on Gramme, see O. Colson, "Zénobe Gramme: sa vie et ses oeuvres," _Wallonia_ 11 (1903): 261-279; Jean Pelsener, _Zénobe Gramme, notice bio-bibliographique, suivie de la description de la dynamo par son inventeur et d'autres documents_ (Brussels: Office de la publicité, 1941); Louis Chauvois, _Histoire merveilleuse de Zénobe Gramme, inventeur de la dynamo_ (Paris: Albert Blanchard, 1963); and "Gramme (Zénobe Théophile)," in _Biographie Nationale publiée par l'Académie royale des sciences, des lettres et des beaux-arts de Belgique_ (Brussels: Etablissements Emile Bruylant, 1957), 29:627-634.

[63]From the list of Froment's accomplishments submitted for the Volta Prize, dossier F(17) 3101, Archives Nationales, Paris. For biographical information on Fizeau, see the note by Emile Picard, "La vie et l'oeuvre d'Hippolyte Fizeau," _Revue scientifique_ (26 January 1924): 33-42, as well as the necrologies that appeared in _The American Journal of Science_ 2 (1896): 398; _The Astrophysical Journal_ 4 (1896): 367-368; _The Electrician_ 37 (1896): 699-700; and _Nature_ 54 (1896): 523-524.

[64]L. Breguet, "Récit historique depuis l'âge de huit ans

jusqu'à seize ans," Breguet Collection, Paris.

[65]The quote is from Cloué, p. 21: "Son père l'avait placé en apprentissage à Neuchâtel, en Suisse, et il revint à Paris à l'âge de dix-huit ans, très habile ouvrier, mais fort peu instruit."

[66]C. Breguet, "Louis Breguet," pp. 22-23.

[67]Cloué, p. 21 and Ecole polytechnique, Livre du centenaire, 1794-1894, 3 vols. (Paris: Gauthier-Villars et fils, 1897), 3:584.

[68]Ecole polytechnique, Livre du centenaire, 3:583-584.

[69]Callot, pp. 473 & 475-476.

[70]Antoine Breguet file, Breguet Collection, Paris.

[71]Laussedat, pp. 3-5, 9-10, & 12. For Pixii's generator, see "Nouvelle construction d'une Machine électro-magnétique," Annales de chimie et de physique 50 (1832): 322-324. I have found no biographical notices for Pixii (or even his first name).

[72]Obituaries in Bulletin de la société d'encouragement 120 (1921): 1208-1209 and Journal télégraphique 45 (1921): 139.

[73]Marielle, p. 223, and Annuaire du commerce (1862), p. 1079.

[74]According to a report on the school published in the Moniteur universel, 27 May 1857, p. 578, the Ecole centrale was designed to turn out "ingénieurs civils, des directeurs d'usines, des chefs de manufactures." For a history of the Ecole centrale, see Léon Guillet, Cent ans de la vie de l'Ecole centrale des arts et manufactures, 1829-1929 (Paris: M. de Brunoff, 1929); Charles de Comberousse, Histoire de l'Ecole centrale des arts et manufactures depuis sa fondation jusqu'à ce jour (Paris: Gauthier-Villars, 1879) and Weiss.

[75]Raynaud, "Appareil autographique Meyer," p. 43, and Hardy's Legion of Honor folder, F(12) 5166, Archives Nationales, Paris.

[76]Annuaire de l'Association amicale des anciens élèves de l'Ecole centrale des arts et manufactures (1909), pp. 500-501 and 507 and "Curchod," Bulletin de l'Association amicale des anciens élèves de l'Ecole centrale 21 (1889-90): 83-84.

For Mors, see footnote 51 above.

77 Based upon a comparison of the names given in the Paris Annuaire du commerce as being telegraph manufacturers with the list of Ecole centrale graduates given in Annuaire de l'Association amicale des anciens élèves de l'Ecole centrale des arts et manufactures (1909) and Ecole polytechnique graduates found in Marielle; Leprieur; and the Annuaire de l'Ecole polytechnique, 1868-1881 for the later years.

78 The major biographical sources for French telegraph manufacturers are the Annales télégraphiques, the Journal des télégraphes and the Journal télégraphique. In addition to these, I examined electrical, as well as general technological, industrial, and scientific journals of the period, and consulted various encyclopedias and dictionaries, newspapers, exposition catalogues, and standard finding aids in the history of technology and science. Realizing in advance the difficulty of locating biographical information on French manufacturers and engineers, I also examined every work used in writing this thesis for possible biographical information and kept a record of all items found, which has amounted to very little.

79 Moigno, "Breguet," p. 213: "Il <Breguet> est devenu le chef d'une Ecole française de télégraphie; plusieurs élèves sortis de ses ateliers modèles sont devenus des maîtres déjà célèbres."

80 L. Breguet's obituary in the Annales télégraphiques 3,10 (1883): 569: "C'est de sa maison qui sont sortis la plupart des habiles constructeurs qui exploitent à Paris l'industrie des appareils électriques."

81 Georges Albert Boutry, Maurice Daumas, Jean Fourastié, Paul Guérin, Jacques Payen, Louis Ragey, eds., Cent-cinquante ans de haut enseignement technique au Conservatoire national des arts et métiers (Paris: Presses du Palais Royal, 1970), pp. 134-138, and Maurice Soubrier, Les industries électriques d'hier et de demain (Paris: H. Dunod et E. Pinat, 1918), p. 154.

82 For background on the CNAM, see Recueil des lois décrets, ordonnances, arrêtés, décisions et rapports relatifs à l'origine, à l'institution, à l'organisation et à la direction du Conservatoire national des arts et métiers, et à la création des cours publics de cet établissement (Paris: Imprimerie Nationale, 1889); (hereafter referred to as Recueil des lois, CNAM) Anatole de Monzie, Le Conservatoire

du peuple (Paris: Société d'Editions d'Enseignement Supérieur, 1948); René Tresse, "Les origines d'une institution nationale: le Conservatoire des arts et métiers," Revue de l'histoire des sciences et de leurs applications 5 (1952): 246-264; Notice historique sur l'ancien prieuré de Saint-Martin des champs et sur le Conservatiore nationale des arts et métiers (Paris: Dunod, 1882); and Boutry.

[83]Recueil des lois, CNAM, pp. 100-102, 128 & 130. For biographical information on Pouillet, see Poggendorff, 2:512 and the sketch in Boutry, pp. 78-80.

[84]Poggendorff, 2:512.

[85]Pouillet's textbook first appeared as Elémens de physique expérimentale et de météorologie, 4 vols. (Paris: Béchet jeune, 1827). The seventh and last edition appeared in 1856 through L. Hachette and consisted of two volumes of text and another solely for illustrations. Ministère de l'éducation nationale, Catalogue général des livres imprimés de la Bibliothèque nationale, vol. 141 (Paris: Imprimerie Nationale, 1937), pp. 828-833. The 5th (1847) 1:834-847, 6th (1853) 1:758-800, and 7th (1856) 1:714-773 editions discussed telegraphy.

[86]Boutry, pp. 78-80.

[87]Boutry, pp. 40 and 118. For biogrpahical information on Edmond Becquerel see Muséum national d'histoire naturelle, "Célébration du centenaire de la chaire de physique du Muséum national d'histoire naturelle," Revue générale des sciences pures et appliquées 50 (1939): 120-132; Henri Becquerel, "La chaire de physique du Muséum," Revue scientifique 49 (1892): 673-678; Jules Violle, "L'oeuvre scientifique de M. Edmond Becquerel," Revue scientifique 49 (1892): 353-360 as well as the various obituaries in the Annales du Conservatoire des arts et métiers 3 (1891): 101-106 and 4 (1892): 113-130; The Electrician 27 (1891): 73-74; La lumière électrique 40 (1891): 395-396; Comptes rendus 113 (1891): 882-883; Séances de la Société française de physique 19 (1891): 158-160; Revue scientifique 47 (1891): 635; and Proceedings, Royal Society of London 51 (1892): xxi-xxiv.

[88]Director of the CNAM to the Minister of Agriculture, Commerce and Public Works, 29 November 1854, F(12) 4863, Archives Nationales, Paris, states that Planté became Becquerel's assistant in accordance with the Minister's proposition of 18 November 1854. For biographical information on Gaston Planté, see his obituaries in the Bulletin de la Société internationale des électriciens 1,6

(1889): 287; the Annales télégraphiques 3,16 (1889): 288; The Electrician 23 (1889): 89; La lumière électrique 32 (1889): 446; and The Telegraphic Journal and Electrical Review 24 (1889): 650-651.

[89]Tables and reports of the number of students attending, but not their names, are found in dossier F(12) 4861, Archives Nationales, Paris.

[90]Soubrier, p. 155.

[91]In place of lecture notes, I have relied upon the textbook prepared by Edmond and his father Antoine, Traité d'électricité et de magnétisme, leurs applications aux sciences physiques, aux arts et à l'industrie, 3 vols. (Paris: Firmin Didot Frères, 1855-56), 3:273-329 of which discusses telegraphy. Unfortunately, I have found no later works by Edmond Becquerel with passages relating to telegraphy.

[92]Arthur Morin, Conservatoire des arts et métiers: Catalogue des collections (Paris: Imprimerie de Guiraudet et Jouaust, 1852), pp. 137-139 lists the electrical apparatus used at the CNAM for lecture demonstrations.

[93]Announcement on courses offered at the CNAM beginning November 1872 in Journal officiel de la république française, 30 October 1872, p. 6741.

[94]For the history of physics at the Museum of Natural History, see Muséum national d'histoire naturelle, "Célébration du centenaire de la chaire de physique du Muséum national d'histoire naturelle," Revue générale des sciences pures et appliquées 50 (1939): 120-132; and Henri Becquerel, "La chaire de physique du Muséum," Revue scientifique 49 (1892): 673-678. For the Collège de France, see Abel Lefranc, Le Collège de France (1530-1930): Livre jubilaire composé à l'occasion de son quatrième centenaire (Paris: Presses Universitaires de France, 1932), pp. 61-79. Jean Bonnerot, La Sorbonne, sa vie, son rôle, son oeuvre à travers les siècles (Paris: Presses Universitaires de France, 1927); Sébastien Charléty, L'Université de Paris, du moyen âge à nos jours (Paris: Larousse, 1933); and most recently Harry W. Paul, From Knowledge to Power: The Rise of the Science Empire in France, 1860-1939 (Cambridge: Cambridge University Press, 1985) provide references to science teaching at the University of Paris.

[95]Association philotechnique, Distribution des prix (Paris: n.p., 1852) for 1851-52 lists the courses given.

Later, other courses were offered, such as in foreign languages. The Bibliotheque Historique de la Ville de Paris, Paris, has announcements of the school's curriculum and the prizes awarded to the various deserving students for the school years 1849-50 through 1878-79. For a history of the school, see Association philotechnique (n.p., 1984?), p. 16, the pamphlet handed out to prospective students for the school year 1984-1985. According to that pamphlet, physics and chemistry are no longer available, but a diversity of courses from yoga and musical comedy to criminal law and accounting form the present curriculum, suggesting a radical change in the nature of adult education in the last century.

96 Association philotechnique, Distribution des prix (Paris: n.p., 1865), p. 7 and Ibid., 1879, pp. 9 & 14.

97 Association polytechnique, Distribution des prix aux élèves de l'Association polytechnique . . . le dimanche 18 février 1866 (Paris: L. Dupont, 1866), p. 6. This is the only year for which I have been able to find information and, unfortunately, it lists just prize winners, not students. Louis Naud, Histoire de la télégraphie en France depuis ses origines jusqu'à nos jours: cours professé à l'Association philotechnique et l'Association polytechnique par M. Louis Naud (Paris: Bureaux du courrier des examens, 1890). Association polytechnique, Histoire de l'Association polytechnique et du développement de l'instruction populaire en France (Paris: Chaix, 1880), is a history of the school.

98 L. Breguet, Manuel. Subsequent editions were much lengthier: the second edition, (Paris: Carilian-Goeury et V. Dalmont), pp. 106; the third edition, (Paris: V. Dalmont, 1856), pp. 107; and the fourth edition, (Paris: L. Hachette, 1862), pp. 252.

99 L. Breguet and Victor Séré, Télégraphie électrique: son avenir, poste aux lettres électrique, journaux électriques, suivi d'un aperçu théorique de télégraphie (Paris: L. Mathias, 1849).

100 Miège and Ungérer, the text used to teach state telegraph operators, pp. xi-xii, furnished a "Nomenclature des ouvrages les plus recommandables, à consulter sur l'électricité et la télégraphie électrique". The French-language works cited were: Antoine and Edmond Becquerel, Traité d'électricité et magnétisme, 3 vols.; Auguste De la Rive, Traité d'électricité théorique et appliquée, 2 vols. (Paris: J. Baillière, 1854-58); Théodose Du Moncel, Exposé des applications de l'électricité, 2 vols. (Paris: Hachette, 1853-54); Du Moncel, Considérations nouvelles sur l'électro-

magnétisme, et de ses applications aux électro-moteurs et à l'anémographie électrique (n.p.); Du Moncel, Notice sur l'appareil de l'induction électrique de Rumhkorff, et les expériences que l'on peut faire avec cet instrument (Paris: Hachette, 1855); Adolphe Ganot, Traité élémentaire de physique expérimentale et appliquée et de météorologie, 5th edition (Paris: Chez l'auteur, 1855); François Moigno, Traité de télégraphie électrique (Paris: A. Franck, 1852); Claude Pouillet, Elémens de physique expérimentale et de météorologie, 6th edition, 2 vols. (Paris: L. Hachette, 1853); Alfred Vail, Le télégraphe électro-magnétique américain, trans. Hippolyte Wattemare (Paris: L. Mathias, 1847).

[101] One can trace the accumulation of works dealing with telegraphy from the "Bibliographie" section of the Annales télégraphiques. An excellent source for works on electrical theory of the period, though certainly not complete, is William D. Weaver, ed., Catalogue of the Wheeler Gift of Books, Pamphlets and Periodicals in the Library of the American Institute of Electrical Engineers (New York: American Institute of Electrical Engineers, 1909).

[102] E. Pouillet, pp. 826-827.

[103] Recueil des Lois, CNAM, p. 69.

[104] Terry Shinn, "Des Corps de l'Etat au secteur industriel: genèse de la profession d'ingénieur, 1750-1920," Revue française de sociologie 19 (1978): 61-65.

CHAPTER SIX

Telegraphy and Institutions for the Advancement of Science, Technology, and Industry

Before the creation of institutions concerned solely with electrical engineering after 1881, several organizations both inside and outside the Telegraph Administration whose goal was the advancement of French science, industry, and technology concerned themselves with telegraphy. These institutions facilitated interaction between employees of the telegraph service, manufacturers of telegraph instruments, and savants who were either members of the Academy of Science, professors in the University system, or both. At the center of these institutions were the men of science, many of whom played a part in the founding of French electrical engineering institutions after 1881. Before 1881, moreover, the same professors and Academy members played a role in the development of telegraph theory and technology. For example, Edme Hippolyte Marié-Davy (1820-1893), professor of physics at the Faculty of Science in Montpellier beginning in 1844 and, from 1857, professor of physics and chemistry at the Lycée Bonaparte in Paris, invented and patented a wet cell that the Telegraph Administration adopted on its lines.[1] Thus, these savants and their institutions form part of the development of electrical engineering from telegraphy before

1881.

The first institution outside of the Telegraph Administration to play a part in advancing telegraph theory, technology, and industry was the Academy of Science. Later, with the opening of the telegraphs to the public, the Society of Encouragement for National Industry became interested in promoting electrical telegraphy. The Volta Prize, a competition intended to promote electrical technology and industry and which lasted off-and-on from the 1850s into the 1880s, and the French Physics Society, founded in 1873 by French university professors, further promoted telegraph technology and industry. Finally, the Telegraph Administration's own _conseil de perfectionnement_ furnished additional opportunities for exchanges between savants, manufacturers, and telegraph agents and provided an institutional context for the organization of telegraph research.

The oldest French institution concerned with the advancement of science, technology, and industry was the Paris Academy of Science, established by royal decree in 1666 for the purpose of providing the state with scientific and technological assistance.[2] Although a creation of the state, the savants constituting the Academy served both state agencies, such as the Telegraph Administration, and private industry, including telegraph manufacturers and inventors.

In its role as a _corps d'état_,[3] _académiciens_ (members of the Academy of Science) served as expert advisors, as in their role on the Minister of the Interior's 1844 Telegraph Commission.[4] A few _académiciens_ travelled to Great Britain in 1849 to study and bring back to France information on telegraph technology there,[5] thus providing an avenue for the transfer of technology between countries. In 1852, as the Telegraph Administration prepared to extend the network to the chief town of every department, the Minister of the Interior asked the Academy of Science to form a new telegraph commission to determine the best instrument to adopt.[6]

Besides its function as an information gatherer and evaluator for state agencies like the Telegraph Administration, the Academy of Science operated as a diffusor of scientific and technological knowledge through its journal, the _Comptes rendus_. Between 1835 (when the journal first appeared) and 1881, the _Comptes rendus_ published more items on telegraphy than the other major French scientific journal, the _Annales de chimie et de physique_.[7] While the _Annales_ were concerned primarily with the development and diffusion of electrical theory not specifically applicable to telegraphy, the _Comptes rendus_ published items concerned explicitly with telegraph technology as well as electrical theory pertinent to telegraphy.

An examination of the notes and other items dealing with telegraphy and published in the Academy's journal reveals the mixture of French inventors and manufacturers, foreign and French scientists, as well as state officials from the Telegraph Administration and other technical corps d'état concerned with technology (such as the Corps des ponts et chaussées) interested in telegraphy. Moreover, the three individuals whose articles and notes on telegraphy appeared more often than those of anyone else in the Comptes rendus between 1835 and 1881 illustrate the mixture of savants, manufacturers, and inventors drawn to the Academy of Science: Louis Breguet, telegraph manufacturer (12 articles); François Arago, scientist (13 items), and Pierre Antoine Dujardin (1809-1886), a prolific telegraph inventor,[8] (16 articles).[9]

The preponderance of items in the Comptes rendus originating from a manufacturer (Breguet) and an inventor (Dujardin) reflected the relationship between the Academy and private industry, and between the Academy and inventors. Although the Academy existed as a state-sponsored institution, that sponsorship did not preclude, in fact it insisted upon (at first for mercantilistic reasons), the Academy's encouraging industry and invention. One way in which the Academy of Science promoted industry and inventors in particular was the extension of patent protection through the sealed envelope ("paquet cacheté"). The deposit of a sealed envelope with the secretary of the Academy acted like the American caveat by protecting an idea before the inventor could obtain a patent. French patent law acknowledged the validity of the sealed envelope for establishing the priority of an inventors' idea. Unlike a French patent, the <u>paquet cacheté</u> system required no annual fee and did not obligate the inventor to industrialize his idea or lose government protection of it.[10] Essentially, these "caveats" consisted of a dated description of an invention, sometimes including drawings, which the author sealed with wax. The Academy maintained a record of the date of deposit and kept it sealed until ordered opened by the depositor of the item. A number of these "<u>paquet cachetés</u>" related to telegraphy, such as those deposited by Louis Breguet and Dujardin.[11]

In addition to accepting caveats, the Academy served manufacturers and inventors (as well as the Telegraph Administration) by evaluating inventions. An individual with a new or improved telegraph instrument presented a model of his invention or a copy of a memoir or note on his invention to the Academy of Science through one of its members. The Academy member (if he thought it worthy) then presented the invention to the Academy which, in turn, sent the invention to a committee for examination. Typical of the system was Gustave Froment's presentation in 1850, through <u>académicien</u> Claude Pouillet, of a telegraph capable of recording signals on a strip of paper. The Academy then set up a committee of two members, one of which was Pouillet, to evaluate Froment's telegraph.[12]

The "coincidence" of having the member presenting an invention also serve on the committee charged with its examination was not unusual. Moreover, an examination of the committees established to evaluate telegraph proposals between 1845 and 1881 reveals that a small number of Academy members consistently received assignments to those committees.[13] Of the relatively few members who served on the committees charged with examining telegraph proposals, two members, Claude Pouillet and Edmond Becquerel, were assigned more frequently than any of their colleagues. These académiciens also taught telegraphy as part of their "applied physics" course at the Conservatoire des arts et métiers. Either alone or jointly, Becquerel and Pouillet sat on 63 of the 76 telegraph committees. Other members of the Academy who served frequently on these committees also had ties as promoters of French telegraphy, such as Arago, whose role in the introduction of the electric telegraph has been noted above, and Victor Regnault (1810-1878), who arranged a demonstration of Wheatstone's telegraph at the Collège de France in 1841.[14]

Although the Academy of Science hoped to promote telegraph technology and industry and serve the Telegraph Administration, with rare exception, neither telegraph manufacturers nor telegraph agents became members.[15] Elected a membre libre in 1874 after failing his election to a seat in the Section de Mécanique in 1847, 1857, and 1873,[16] Louis Breguet's membership represented less his assuming his grandfather's place in the Academy of Science than his contributions to the development of French science that included a study of induction phenomena with Masson, the determination of the speed of sound in iron with Wilhelm Wertheim (1815-1861),[17] and a study of the role of the earth in telegraph circuits.[18] As for agents of the Telegraph Administration, only one gained membership in the Academy of Science. Théodose Du Moncel (1821-1884) was an upper-level employee of the Telegraph Administration whom the Academy of Science elected as a member in 1874.[19]

The paucity of telegraph manufacturers and employees of the Telegraph Administration among its members, however, clearly did not prevent the Academy of Science from advancing telegraph technology and industry in France. Moreover, another institution, established privately and equally concerned with promoting technology and industry, furnished greater opportunities for telegraph manufacturers and agents to participate in the advancement of telegraphy on the same basis as scientists. That institution, the Society of Encouragement for National Industry, did not begin to interest itself in electric telegraphy until 1851. While the telegraphs remained a monopoly of the state, the Academy of Science retained sole interest in the promotion of French telegraphy outside the Telegraph Administration itself. With the opening of the telegraphs to the public in 1851, the state ceased to be the only party concerned with telegraphy. Moreover, the expansion of the telegraph network after 1851, as discussed above, prompted the transformation of telegraph manufacturing from a monopoly to a competitive enterprise and created a telegraph manufacturing industry. With the state no longer the sole user of the French telegraphs after 1851 and the ensuing development of an expanding market for telegraph instruments, the business of telegraphy attracted the attention of the Society of Encouragement.

Founded in 1801,[20] the Society of Encouragement for National Industry was, unlike the Academy of Science, a privately founded, operated, and funded institution that aspired to bring together manufacturers and businessmen, inventors, university faculty and other savants, and government officials in an effort to encourage and improve manufactures. The Society of Encouragement supported itself through subscriptions. The funds thus raised advanced the Society's work through the awarding of prizes to encourage workers and inventions, the introduction of useful foreign technologies, the diffusion of learning through publications, models, and training, the judging of the utility of new inventions, and aiding inventors to put their ideas into effect.

Membership was relatively easy to obtain. Members proposed candidates and, after approval by the Conseil d'administration, the candidate joined by paying an annual subscription fee. Between 1845 and 1881, an average of 50 new members joined the Society of Encouragement each year.[21] Unlike the Academy of Science, there were no restrictions as to the number of members permitted. All members made up the General Assembly, but the actual day-to-day functioning of the Society of Encouragement, and particularly the judging of inventions and the handing out of awards, was in the hands of a few committees, each with its own secretary, and meeting at a time of their choice. During the period of this study, 1845-1881, there were six such committees: the mechanical arts, the "economic arts," the chemical arts, the agricultural, the commercial, and (beginning in 1876) the construction and beaux-arts applied to industry committees.

In the words of the Society of Encouragement's President in 1864, the Society was "directed by an elected Council to which one calls the representatives of theory and practice on an equal basis, an alliance which is everywhere useful and which is indispensable in an academy of applied science."[22] The founders of the Society of Encouragement explicitly desired to create an "alliance of practice and theory".[23]

While suggesting a parallel with the Academy of Sciences, the title "academy of applied sciences" and the notion of an "alliance of practice and theory" also drew attention to the Society of Encouragement as an institution for improving technology and industry by bringing theory to bear upon practice. Representative individuals from science, government, and industry certainly formed the general membership of the Society of Encouragement. However, the real work of the Society was carried out by the Society's committees. Thus, any consideration of how savants, telegraph manufacturers, and telegraph agents interacted within the framework of this "academy of applied science" must examine committee membership.

Telegraph manufacturers actively participated in the Society of Encouragement by joining and taking subscriptions. The first to do so was Louis Breguet, who originally subscribed in 1833. Gustave Froment and P. Dumoulin (Froment-Dumoulin) entered in 1854, P. D. Prud'homme in 1857, the Digney Brothers in 1858, Edme Hardy in 1865, and Jules Carpentier in 1878, to mention just the most prominent.[24] However, telegraph manufacturers never became members of that "alliance of practice and theory" that directed the Society of Encouragement and rarely served on the Society's committees charged with evaluating inventions. By 1881, only two telegraph manufacturers had served on any of those committees.[25] Although a member since 1833, Louis Breguet did not attain committee membership until 1866, when he became an adjoint member of the mechanical arts committee. In 1874, he became a regular member ("membre titulaire") of the committee.[26] Gustave Froment moved into a committee position much faster. He joined in 1854 and became an adjoint member of the mechanical arts committee in 1855, then a regular member of the same committee in 1864.[27] While Froment and Breguet served on committees charged with reviewing inventions, neither reported on any of the telegraph inventions and projects submitted to the Society of Encouragement; Breguet, for example, critiqued horological work.[28] This may not reflect any concern on the part of the Society to avoid possible conflicts of interest arising out of a telegraph manufacturer evaluating an apparatus submitted by his competitor for two reasons: 1) the reviewing of telegraph inventions was the role of a different committee, the "economic arts" committee, and 2) an agent of the Telegraph Administration reviewed most telegraph inventions, as will be seen below.

An examination of the telegraph projects presented to the Society of Encouragement, 1845-1881,[29] reveals a certain regularity of operation. Of the various telegraph inventions and improvements brought before the Society, with little exception, all went to the economic arts committee. The exceptions involved railroad telegraphs and went to the economic and mechanical arts committees jointly. Although all telegraph proposals went to a committee, only a third were sufficiently useful to warrant a committee report (20 out of 59). Even fewer received a medal of "encouragement". Manufacturers sought out the Society of Encouragement's awards of gold, silver, and platinum medals for their advertizing value[30] and the economic arts committee rewarded telegraph manufacturers with several of these highly desireable medals, though not always for their telegraphs. In 1852, for instance, Froment received a gold medal for the overall quality of his measuring, scientific, and telegraph instruments. The first medal awarded to a manufacturer for a specific telegraph was a gold medal presented to the Digney Brothers in 1860 for their inking Morse telegraph. Edme Hardy also won gold medals in 1873 for his manufacture of Meyer's autographic telegraph and in 1876 for the all-around quality of his telegraphic and scientific apparatus.[31]

The consistency with which telegraph projects came before the economic arts committee enhanced its importance for the advancement of French telegraphy. Moreover, of the several members of the economic arts committee who studied telegraph inventions submitted to the Society of Encouragement, usually by telegraph manufacturers or employees of the Telegraph Administration, only one member presented the committeés report. Before 1857, the committee published only three such reports, always by different individuals. Beginning in 1857, however, with two exceptions (railroad telegraphs), the reporter was the same individual, Théodose Du Moncel, who had joined the Society of Encouragement in 1847 and become an adjoint member of the economic arts committee in 1852.[32]

Du Moncel was unusual in that, with E. E. Blavier (who joined in 1860), he was the only telegraph employee in the Society of Encouragement between 1845 and 1881.[33] More significantly, though, he was an employee of the Telegraph Administration who reported on telegraph projects for the Society of Encouragement at the same time. Clearly, there was no perception of a conflict of interest arising out of the situation. Moreover, Du Moncel's position as telegraph evaluator for the Society of Encouragement permitted him to look out for telegraph inventions and improvements that might be useful to the Telegraph Administration. In the case of telegraphy, then, the "alliance of practice and theory" aspired to by the "academy of applied science" did not bring together representatives of practice and theory on an equal basis in the committees charged with evaluating inventions. Society of Encouragement committees operated in the same fashion as those of the Academy of Science: a savant member of a _corps d'état_ (not a member of the Academy of Science until 1874 in Dumoncel's case) evaluated the work of telegraph manufacturers and inventors.

Although Du Moncel, acting through the economic arts committee of the Society of Encouragement, very likely functioned informally on behalf of the Telegraph Administration to single out and promote those inventions that the telegraph service wanted, or even to encourage selected telegraph manufacturers and employee-inventors, the Telegraph Administration had its own institution for evaluating and promoting inventions. Furthermore, unlike the Society of Encouragement and the Academy of Science, this institution actually did bring together on an equal basis individuals from science, telegraph manufacturing, and the telegraph service in a single organization, the _Conseil de perfectionnement_. More significantly for the contribution of telegraphy to the development of electrical engineering, the _Conseil de perfectionnement_ directed necessary practical and theoretical research. In this respect, the _Conseil_ resembles the Centre national d'études des Télécommunications (CNET). Founded in 1944 and directed by an engineer in the telecommunications corps, the CNET focused French telecommunications research within a single organization. CNET research took place (and continues to take place) in both state-owned laboratories, such as the Laboratoire national de radioélectricité, and private industrial research centers, the research serving the needs of civilian and military branches of the state as well as French industry.[34]

The Telegraph Administration had an obvious interest in the improvement of telegraph technology as the major purchaser and user of telegraph instruments and supplies in France. This interest dated back to the era of the semaphore service, when the head of the Telegraph Administration and his two adjoints regularly met to consider proposals for telegraph improvements submitted to it along with all other telegraph business.[35] When de Vougy reorganized the telegraph network in 1854 to accommodate the changes necessitated by the electric telegraphy, he proposed a council to examine telegraph inventions. Making up de Vougy's contemplated council were four general inspectors ("inspecteurs généraux"), plus an unspecified number and type of special individuals ("hommes spéciaux) appointed by the Minister of the Interior from outside the Telegraph Administration.[36] Actual creation of this council waited another four years, however.

In response to a request from M. Alexandre, the head of the Telegraph Administration, the Minister of the Interior instituted the Conseil de perfectionnement on 25 June 1858 and charged it with studying telegraph projects and memoirs. Unlike any other previously created or proposed committee or council for studying telegraphs, the Conseil de perfectionnement was also to specify a program of explicit telegraph improvements required by the Telegraph Administration and to encourage their invention.[37] The Conseil de perfectionnement initially consisted entirely of Telegraph Administration personnel: a principal director ("directeur principal"), who presided over the council, seven inspectors and one station director. With the exception of the principal director, all members were graduates of the Ecole polytechnique.[38] Soon, telegraph manufacturers also received appointments to the Conseil de perfectionnement. For example, in 1859, Gustave Froment and, in 1866, Edme Hardy joined.[39]

In addition to telegraph manufacturers, other "hommes spéciaux forming the Telegraph Administration's Conseil de perfectionnement included the Belgian telegraph engineer, Julien Vinchent (1822-1887), who joined in 1859.[40] Vinchent had directed the construction of Belgium's first telegraph line and became head of Belgian telegraphs in 1852, a position he held even after the merger of the Belgian posts and telegraphs in 1877.[41] Another special individual serving on the Conseil de perfectionnement was Edmond Becquerel, professor of "applied physics" at the Conservatoire des arts et métiers and member of the Academy of Science. In 1869, Becquerel was the council's president.[42] Dr. Jules Gavarret (1809-1890) joined the Conseil de perfectionnement in 1867.[43]

A graduate of the Ecole polytechnique, Gavarret taught physics at the Paris Ecole de médecine and had written a well-informed treatise on telegraphy in 1861 as well as a thorough, two-volume work on electrical theory published in 1857-1858.[44] The combination of savants, including members of the Academy of Science, telegraph manufacturers, and agents of the Telegraph Administration among the members of the _Conseil de perfectionnement_ thus made it an institutional framework within which representatives of theory and practice operated on an equal basis.

In 1858, the _Conseil de perfectionnement_ began its job of defining and promoting needed technological improvements with an appeal to all telegraph agents to invent a means for allowing transmitting operators to turn on Morse receiving instruments without the intervention of an operator at the receiving end.[45] Over the years, the _Conseil de perfectionnement_ took up a variety of suggestions submitted by telegraph employees for improving sending and receiving instruments plus associated telegraph apparatus, such as better underground cables, lightning arrestors, galvanometers, switches, relays, and batteries.[46] At its 21 July and 4 August 1869 meetings, for example, the _Conseil de perfectionnement_ considered J. A. C. Rouvier's modification of the Hughes telegraph that yielded a speed increase of 60% and, of the three facsimile telegraphs presented to it, decided that Bernard Meyer's was the best.[47] For particularly excellent contributions, like the Society of Encouragement, the Conseil de perfectionnement awarded medals, such as that granted the Digney brothers in 1860 for the invention of the inking Morse telegraph.[48]

In addition to delimiting and encouraging needed inventions, the Conseil de perfectionnement directed and undertook research for the Telegraph Administration. Of course, telegraph research had been undertaken previously by various individuals associated with the Telegraph Administration by invitation of the head of the service.[49] Moreover, the telegraph network itself served as a kind of laboratory where tests of new instruments could take place.[50] Also, the testing of equipment helped to resolve important theoretical questions. For example, in 1860, Alexandre asked C. M. Guillemin, instructor of telegraph inspectors and member of the Conseil de perfectionnement,[51] to undertake a study of underwater telegraph cables that the Telegraph Administration had just had manufactured. Alexandre wanted to know (1) how capacitive phenomena and signal retardation varied with the length of the conductor and the thickness and nature of the insulating substance and (2) whether capacitance was the only cause of signal retardation.[52]

In 1860, the Telegraph Administration hired an individual who would be part of the Conseil de perfectionnement and who was to undertake telegraph research, particularly of a theoretically nature, on a full-time basis. The position was that of ingénieur électricien and carried an annual salary of 6000 francs, more than that paid inspectors (twice that of an inspector third class).[53] From 1860 until 1874, when he became a membre libre of the Academy of Science and resigned his position with the Telegraph Administration, Théodose Du Moncel worked as the Conseil de perfectionnement's first ingénieur électricien.[54] His initial projects dealt with a variety of theoretical and practical telegraph questions: a study of the role of the earth in telegraph circuits, electric batteries and the determination of line current strength, the best method of constructing electromagnets for telegraph apparatus, the relationship between speed of transmission and capacitive phenomena on telegraph lines, and an evaluation of Caselli's facsimile telegraph.[55]

The Telegraph Administration continued to fund the ingénieur électricien position into the 1870's.[56] Although in 1872 the Administration temporarily employed two ingénieurs électriciens,[57] in 1873 research became part of "special services," a hodgepodge that included underwater telegraph lines and the Telegraph Administration's repair shops.[58] Telegraph research did not come to an end with the elimination of the ingénieur électricien position, however.

Inspectors continued to carry out Telegraph Administration research projects and, in 1876 and 1877, for example, expended 140,000 francs on "improvements of apparatus; studies and various tests," a figure which represented about 1% of the Telegraph Administration budget.[59] Furthermore, the _Conseil de perfectionnement_, which directed and instigated research for the Telegraph Administration, was still in existence at least until 1886.[60]

Thus, while the Society of Encouragement and the Academy of Science contributed to the promotion of French telegraphy, the _Conseil de perfectionnement_ provided an institutional focus for the organization of practical and theoretical research and the advancement of telegraph technology. In 1873, the French Physics Society joined the constellation of institutions encouraging French telegraphy. The founders of the French Physics Society were a handful of science professors from the Ecole normale supérieure, a school founded in 1794 to train teachers for the French University (lycées and higher).[61] University instructors made up the bulk of the Society's membership in 1873, its first year of existence (65% or 129 out of 199 members).[62] Nonetheless, the French Physics Society encouraged manufacturers of scientific apparatus to join and meet at the Sorbonne's Gerson room because it was near "the shops of the principal constructors".[63] Among those instrumentmakers who joined the

Society in 1873 were the telegraph manufacturers Louis Breguet and Eugène Adrien Ducretet (1844-1915).[64] By 1881, other manufacturers of telegraph apparatus had joined: Antoine Breguet (1874), Eugène Deschiens (1874), Louis Mors (1876), P. Dumoulin-Froment (1877), Jules Carpentier (1878) and J. Molteni (1880).[65]

In addition to telegraph manufacturers, employees of the Telegraph Administration joined the French Physics Society. In 1873, they represented a small fraction of those making up the Society, 7 out of 199 or 3.5% of the total membership.[66] By 1881, however, 30 out of a total of 535 members, or 5.6%, were telegraph agents. Therefore, although the overall size of the Society's membership increased 2.7 times between 1873 and 1881, the number of telegraph employee members had grown 4.3 times.[67] While most of the telegraph employees who joined the Society were inspectors, some important lower-level agents became members too, notably Bernard Meyer, in 1875, and Emile Baudot, in 1878.[68] Telegraph agents played an active, even prominent, role in the activities of the Society. For example, the president of the French Physics Society in 1878 was inspector E. E. Blavier.[69] Finally, a number of the papers and demonstrations presented at the meetings of the French Physics Society dealt with telegraphy, such as Meyer's demonstration of his multiple telegraph at the meeting of 27 March 1874 and papers delivered on a new battery and relay.[70]

No discussion of the institutional milieu within which French telegraphy developed would be complete without at least a passing reference to the Volta Prize. Unlike the French Physics Society, the <u>Conseil de perfectionnement</u>, the Society of Encouragement, and the Academy of Science, the Volta Prize was not an institution, strictly speaking. Initially, the Volta Prize was the creation of Napoleon I in 1801,[71] but his nephew, Napoleon III, revived it by a decree of 23 February 1852.[72] The reincarnated Volta Prize was a one-time, five-year competition that offered a 50,000 franc award to the person who found the best application of current electricity. Later imperial and (under the Third Republic) presidential decrees re-established the five-year Volta Prize competition in 1858, 1866, 1871, 1876, and 1882 (to be awarded in 1887).[73] Thus, as a more-or-less recurring competition, the Volta Prize aspired to promote electrical technology and industry over a period of thirty-five years. Those judging Volta Prize entries generally came from the Academy of Sciences and included some of those who had dealt with telegraph matters presented to the Academy, like Edmond Becquerel. In 1887, the Minister of Public Instruction and Beaux-Arts, who was in charge of the Prize competition, also considered E. E. Blavier, an engineer in the telegraph corps, as a Volta Prize judge, but substituted telegraph engineer J.

Raynaud because Blavier passed away that year.[74]

Competitors for the Volta Prize came from all over Europe, the United States, and Canada. Their entries dealt with new batteries, dynamos, electrophysiological and electromedical appliances, metalplating techniques, electric lighting and power equipment, motors, phonographs, telephones, and telegraphs.[75] Under the Second Empire, telegraph entries received special attention from the Volta Prize jury. Emperor Napoleon III made it clear to the 1863 Volta Prize Commission, for example, that he wanted telegraphy singled out as a field worthy of attention.[76] Several entries examined in the 1858 and 1863 judgings related to telegraphy, including those presented by Théodose Dumoncel and Gustave Froment.[77] Froment, in particular, had received special attention from the Emperor, who visited his atelier in 1857,[78] and from the Volta Prize commissioners, who examined his shop on 28 February 1864. The judges were especially interested in the Hughes and Caselli telegraphs that Froment manufactured. Froment was the foremost candidate for the Volta Prize after Heinrich Ruhmkorff (1803-1877), manufacturer of an improved induction coil. However, the Commission voted 6 to 3 not to split the cash award (following the Emperor's wishes) and presented the first Volta Prize to Ruhmkorff in 1864.[79]

Later Volta Prize competitions continued to draw telegraph entries. In 1871, for example, the telegraphs of Hughes and Caselli figured among the eight given serious consideration for the Prize and the 1882 competition included a posthumous presentation of Bernard Meyer's multiple telegraph from his widow.[80] The three winners of the Volta Prize were Ruhmkorff for his improvement of the induction coil, Zénobe Gramme for his dynamo, and Alexander Graham Bell (1847-1922) for his telephone.[81] Although nobody ever received the Volta Prize for a telegraph invention or improvement, the recurring re-institution of the five-year competition provided another organization that brought together savants, telegraph service employees, and instrument manufacturers together for the advancement of French telegraphy before the creation of electrical engineering institutions.

FOOTNOTES

[1]Poggendorff, 3:871-872; patent no. 41,245, 7 June 1859; and J. M. Gaugain, "Examen comparatif des piles usitées dans la télégraphie," Annales télégraphiques 3.3 (1876): 148-162.

[2]For the Academy of Science, see Roger Hahn, The Anatomy of a Scientific Institution: The Paris Academy of Sciences, 1666-1803 (Berkeley, Los Angeles, & London: University of California Press, 1971); Joseph Bertrand, L'Académie des sciences et les académiciens de 1666 à 1793 (Paris: J. Hetzel, 1869); L. F. Alfred Maury, L'Ancienne Académie des sciences (Paris: Didier et Cie, 1864); Pierre Gauja, L'Académie des sciences de l'Institut de France (Paris: Gauthier-Villars, 1934); Institut de France, Troisième centenaire de l'Académie des sciences Paris, 2 vols. (Paris: Gauthier-Villars, 1967); and Institut de France, Index biographique des membres et correspondants de l'Académie des sciences de 1666 à 1939 (Paris: Gauthier-Villars, 1939), pp. i-ix.

[3]Hahn, pp. 22-24 & 70, uses the term "corps d'état" in referring to the Academy of Science.

[4]Moniteur universel, 12 November 1844, p. 2861.

[5]Armand Séguier, "Note sur la télégraphie électrique," Bulletin de la Société d'encouragement 48 (1849): 411-412.

[6]Comptes rendus 35 (1852): 757.

[7]Based upon an examination of the items listed under the rubrics "télégraphes électriques"; "télégraphes, télégraphie"; and "télégraphie" in the tables of the Comptes rendus and the Annales de chimie et de physique for 1835-1881. The Annales de chimie et de physique published at least as many, if not more, articles on electrical theory than the Comptes rendus. I believe that the Comptes rendus devoted more space to telegraph technology because of the interest of the Academy's patron, the state.

[8]Although Dujardin published more items on telegraphy in the Comptes rendus than anyone else, held several telegraph (and other) patents, and successfully sold his telegraphs in Great Britain, I have found no biographical note on him. Several notices of his inventive activity exist in Moigno's Le Cosmos. A succinct account of his telegraph inventions is in his Legion of Honor dossier, F(12) 5134, Archives

Nationales, Paris.

[9]I compiled a list of items relating to telegraphy and listed under the headings "télégraphes électriques"; "télégraphes, télégraphie"; and "télégraphie" in the tables of the Comptes rendus for the period 1835-1881. Usually, the item indicated who the contributing individual was and, in as many cases, the names already had become familiar to me from other sources. Of the 245 names that appeared associated with items dealing with telegraphy, only 47 occurred more than once and but 19 more than twice. The identification of a category "inventors" was difficult since many of those presenting inventions to the Academy were, in fact, agents of the Telegraph Administration, manufacturers, or savants.

[10]Eugène Pouillet, Théorique et pratique des brevets d'invention et de la contrefaçon (Paris: Marchal et Billard, 1879), p. 7. An inventor could deposit his "paquet cacheté" with any "société savant." However, the sealed envelope practice did not provide any of the rights of a patent.

[11]See, for instance, Comptes rendus 25 (1847): 35 for Dujardin and Ibid. 21 (1845): 1119 for Breguet.

[12]"Physique appliquée.- Télégraphie électrique," Comptes rendus 30 (1850): 562. The commission consisted of Pouillet and Regnault; their report did not appear in the Comptes rendus.

[13]Based upon a survey of memoirs and telegraphs submitted to the Academy of Sciences for their consideration and recorded in the Academy's Comptes rendus for the period 1845-1881.

[14]Moigno, p. 56. Biographical notices relating to Regnault's contribution to the development of French telegraphy are found in the Journal télégraphique 4 (1878): 20 and Annales télégraphiques 3,5 (1878): 124-126. The procès-verbaux of the Collège de France for 1834 through 1848, F(17) 13,551, Archives Nationales, Paris, fail to indicate the reported demonstration of Wheatstone's telegraph.

[15]Based upon a search for names of telegraph agents and manufacturers among the membership of the Academy of Science as furnished in Institut de France, Index biographique.

[16]de Jonquières, pp. 12-15.

[17]Although born in Vienna, where he became a medical

doctor in 1839, Wertheim obtained a docteur-ès-sciences degree in Paris, taught in the Faculty of Science of the University at Montpellier (1854) and, beginning in 1855, examined candidates for admission to the Ecole polytechnique. Poggendorff, 2:1302-1303.

[18]Notice sur Breguet, 1847, pp. 10-11 and Notice sur les travaux de M. L. Breguet (Paris: Mallet-Bachelier, 1857), pp. 11-12 (hereafter Notice sur Breguet, 1857).

[19]Annales télégraphiques 2,3 (1860): 688 announced the hiring of Du Moncel. Biographical information can be found in Poggendorff, 3:387-388; Annales télégraphiques 3,11 (1884): 83-87; Journal télégraphique 8 (1884): 38; Electrician 12 (1884): 373; Les Mondes 7 (1884): 365-368; La lumière électrique 11 (1884): 341 & 381-385; Nature 29 (1884): 412-413; Comptes rendus 98 (1884): 453-456 & 100 (1885): 481; The Telegraph Journal and Electrical Review 14 (1884): 155-156; Bulletin de la Société d'encouragement 83 (1884): 113-120; Bulletin de la Société internationale des électriciens 1,1 (1884): 104-109. His dossier, Archives, Academy of Science, Paris, is also helpful for illuminating the political fighting that took place as aspirants vied for Academy membership.

[20]The following discussion of the organization of the Society of Encouragement comes from Histoire de la fondation de la Société d'encouragement pour l'industrie nationale (Paris: Bouchard-Huzard, 1850), pp. 6-7, 18, 21-24, 28-29, 59, 118 & 123. Hereafter cited as Histoire de la Société d'encouragement. A more recent history of the Society of Encouragement is Le cent-cinquantième anniversaire de la Société d'encouragement pour l'industrie nationale et les problèmes actuels de l'économie française, 1801-1951 (Paris: Société d'Encouragement pour l'Industrie Nationale, 1951).

[21]Based upon the list of new members published annually in the Bulletin de la Société d'encouragement, 1845-1881. During those 37 years, a total of 1,845 new members joined.

[22]"Discours de M. le Sénateur Dumas, Président," Bulletin de la Société d'encouragement 63 (1864): 2: "<The Society> est dirigée par un Conseil élu, dans le quel on appelle, à titres égaux, les représentants de la théorie et ceux de la pratique, alliance qui est utile partout et qui, dans une académie des sciences appliquée, est indispensable."

[23]Histoire de la Société d'encouragement, p. 14, refers to the uniting of savants and artists, "l'alliance de la pratique et de théories."

[24]"Liste des membres de la Société admis pendant l'année 1833," Bulletin de la Société d'encouragement 32 (1833): 468; "Liste des membres de la Société admis pendant l'année 1854," Ibid. 53 (1854): 786; "Liste des membres de la Société admis pendant l'année 1854," Ibid. 56 (1857): 825; "Liste des membres de la Société admis pendant l'année 1858," Ibid. 57 (1858): 813; "Liste des membres de la Société admis pendant l'année 1865," Ibid. 64 (1865): 759; and "Liste des membres de la Société admis pendant l'année 1854," Ibid. 77 (1878): 713.

[25]Based upon an examination of the names of committee members published annually in the Bulletin de la Société d'encouragement between 1845 and 1881.

[26]"Nomination d'un membre adjoint au comité des arts mécaniques," Bulletin de la Société d'encouragement 65 (1866): 320. The first year Breguet appears as a regular member in the annually published list of titulary, adjoint, and honorary members in the Bulletin de la Société d'encouragement is 1874.

[27]These are the first years Froment's name appears in those positions in the list of titulary, adjoint, and honorary members published annually in the Bulletin de la Société d'encouragement.

[28]See, for example, "Rapport fait par M. Breguet, au nom du comité des arts mécaniques, sur un nouveau système de rouage de pendule imaginé par M. Hoyau, rue de Turenne, 49," Bulletin de la Société d'encouragement 74 (1875): 161-162.

[29]Based upon a survey of telegraph items appearing in the Bulletin de la Société d'encouragement between 1845 and 1881. Of course, proposals for telegraphs appeared before the Society of Encouragement well in advance of 1851, but these were all mechanical telegraphs (semaphores).

[30]In the Annuaire du commerce, manufacturers listed the medals earned from the Society of Encouragement, as well as at various national and international exhibitions.

[31]"Tableau des prix et Médailles décernées depuis l'origine de la société," Bulletin de la Société d'encouragement 51 (1852): 51; "Liste des différentes médailles décernées pour des inventions ou des perfectionnements industriels," Ibid. 59 (1860): 211; and "Médailles," Ibid. 72 (1873): 284 and Ibid. 75 (1876): 379 & 383-384.

[32]"Liste des membres de la Société admis pendant l'année 1847," Bulletin de la Société d'encouragement 46 (1847): 717. "Liste des membres titulaires, des adjoints et des membres honoraires composant le Conseil d'administration de la Société d'encouragement," Bulletin de la Société d'encouragement 57 (1858): 253 lists Du Moncel as an adjoint member of the Committee and having entered the position in 1852.

[33]"Liste des membres de la Société admis pendant l'année 1860," Bulletin de la Société d'encouragement 59 (1860): 745. Based upon an examination of the membership list published annually in the Society's Bulletin from 1845 to 1881.

[34]Bertho, pp. 408-409, 416-417 & 422-423, recounts the early work of the CNET. To my knowledge, no history of the CNET has been written. Laws and regulations relating to the Centre's first ten years of existence can be found in the Journal officiel de la République française, 9 November 1944, p. 1239; 5 April 1947, p. 3193; 26 August 1947, p. 8447; 27 October 1948, p. 10,435; 4 November 1948, p. 10,675; 23 August 1949, pp. 8369-8370; 18 April 1951, pp. 3921-3922; 31 May 1952, pp. 5526-5527; 17 November 1953, p. 10,269; 17 February 1954, pp. 1595-1596.

[35]"Ordonnance du roi portant règlement sur le service de la télégraphie," Lois et règlements, 24 August 1833.

[36]"Décret qui règle les attributions des fonctionnaires et agents des lignes télégraphiques," Lois et règlements, 1 June 1854.

[37]Annales télégraphiques 2,1 (1858): 92.

[38]Based upon a comparison of the names in the Annales télégraphiques 2,1 (1858): 92 with those in Marielle.

[39]Annales télégraphiques 2,2 (1859): 442 and Hardy's Legion of Honor dossier, F(12) 5166, Archives Nationales, Paris.

[40]Annales télégraphiques 2,2 (1859): 442.

[41]Annales télégraphiques 3,13 (1886): 566 and "Vinchent (Julien)," in Biographie nationale publiée par l'Académie royale des sciences des lettres et des beaux-arts de Belgique (Brussels: Etablissements Emile Bruylant, 1936-38), 26:775-776.

[42]Journal des télégraphes 4 (August 1869): 1.

[43]Journal des télégraphes 2 (March 1867): 4.

[44]Ecole polytechnique, Livre du centenaire, 3:403-407 and his notice in the Bulletin de la Société d'anthropologie de Paris 4,1 (1890): 645-651. The titles of the works mentioned in the text are Gavarret, Télégraphie électrique (Paris: Victor Masson et fils, 1861) and Traité d'électricite, 2 vols. (Paris: Victor Masson, 1857-1858).

[45]Annales télégraphiques 2,1 (1858): 302-303.

[46]Journal des télégraphes 4 (February 1869): 2; 4 (August 1869): 1-3; 4 (October 1869): 1-7; and, 5 (1870): 17, 33-35, 49-50, and 97-99.

[47]Journal des télégraphes 4 (August 1869): 1-3 and 4 (October 1869): 1-3.

[48]Annales télégraphiques 2,3 (1860): 347.

[49]For instance, see the report on the transatlantic cable by E. E. Blavier and E. Gounelle in F(90) 20,847, Archives Nationales, Paris.

[50]See the correspondence relating to the testing of Dujardin's telegraph between Paris and Lille in F(90) 1451*, Archives Nationales, Paris, for example.

[51]"M. Alexandre Guillemin," Annales télégraphiques 3,1 (1874): 114.

[52]C. M. Guillemin, "Recherches sur la transmission de l'électricité dans les fils télégraphiques," Annales télégraphiques 2,3 (1860): 611-612 & 616-617.

[53]"Décret impérial qui crée près le Conseil de perfecionnement des lignes télégraphiques un Emploi d'Ingénieur électricien," Lois et règlements, 24 November 1860: "pour exécuter et suivre les expériences utiles au progrès de la science, conformément au programme qui sera réglé par ce conseil." Ibidem gives the salary for the ingénieur électricien, while "Arrêté ministériel fixant l'assimilation à établir, pour l'exécution du décret du 29 novembre 1858, entre les grades et les classes determinés par ce décret et ceux qui existaient antérieurement," Lois et règlements, 7 January 1859. The pay rate of 6000 francs was the same as that for a directeur divisionnaire, second class.

[54]Annales télégraphiques 2,3 (1860): 688 and "Th. Du Moncel," The Telegraphic Journal and Electrical Review 14 (1884): 156.

[55]Th. Du Moncel, "Lois relatives au groupement des piles en séries composée chancune de plusieurs éléments," Annales télégraphiques 2,3 (1860): 384-393; "Recherches sur les constantes des piles voltaîques," ibid. 2,4 (1861): 166-183; "Recherches sur les transmissions électriques à travers le sol dans les circuits télégraphiques," ibid. 465-494; "Note sur le rôle qui remplit la partie centrale du noyau de fer des électro-aimants par rapport à l'attraction qu'ils exercent," ibid. 2,5 (1862): 465-469; "Description des télégraphes électrochimiques de MM. Caselli et Bonelli," ibid. 2,6 (1863): 209-245; "Note sur une nouvelle méthode de mesure des résistances des couples voltaîques," ibid. 2,7 (1864): 147-150.; "Recherches sur les électro-aimants à fil nu," ibid. 2,8 (1865): 203-221; "Note sur les durées de fermeture des circuits télégraphiques," ibid. 2,8 (1865): 309-317.

[56]According to Session de 1870, Budget de l'exercise 1871, "Projet de loi pour la fixation de recettes et des dépenses ordinaires et extraordinaires de l'exercise 1871," AD XVIII(F) 869, Archives Nationales, Paris, p. 307, the Telegraph Administration was still spending 6,000 francs a year on an ingénieur électricien.

[57]Session de 1872, Budget de l'exercise 1872, "Projet de loi pour la fixation des recettes et des dépenses de l'exercise 1872," p. 261, AD XVIII(F) 886, Archives Nationales, Paris.

[58]Session de 1874, Budget de l'exercise 1875, "Projet de loi pour la fixation des recettes et des dépenses de l'exercise 1875," p. 174, AD XVIII(F) 911, Archives Nationales, Paris.

[59]Session de 1876, "Projet de loi portant fixation du budget général des dépenses et des recettes de l'exercise 1877," pp. 355 & 366, AD XVIII(F) 934, Archives Nationales, Paris.

[60]A note dated 14 April 1886 in the personnel dossier of E. Mercadier, F(90) 20,542, Archives Nationales, Paris, refers to the Conseil de perfectionnement.

[61]d'Ocagne, pp. 337-340. The most recent book-length work on the Ecole normale supérieure is Robert J. Smith, The Ecole Normale supérieure and the Third Republic (Albany:

State University of New York Press, 1982). More relevant to this study is Craig Zwerling, "The Emergence of the Ecole Normale Supérieure as a Centre of Scientific Education in the Nineteenth Century," pp. 31-60, in Robert Fox and George Weisz, eds., The Organization of Science and Technoloigy in France, 1808-1914 (London & New York: Cambridge University Press, 1980). "Rapport de M. Lissajous," Séances de la Société française de physique 1 (1873): 5-7 and Marcel Brillouin, "Les débuts de la Société française de physique," pp. 5-18, in Le Livre du Cinquantenaire de la Société française de physique (Paris: Editions de la Revue d'Optique Théorique et Expérimentale, 1925) provide a history of the Society's founding.

[62]Based upon the membership roster published in "Liste des membres de la Société," Séances de la Société française de physique 1 (1873): 97-102.

[63]"Rapport de M. Lissajous," pp. 7-8: "tenir ses séances dans la salle Gerson où a lieu la réunion actuelle. Ce local a l'avantage d'être voisin de la Sorbonne, du Collège de France, de l'Ecole normale, des lycées et des ateliers des principaux constructeurs".

[64]"Liste des membres de la Société," pp. 97-102. E. A. Ducretet was a manufacturer of scientific instruments who specialized in electrical apparatus. He held patents for electric lamps and an electric motor (no. 128,173, 30 December 1878; no. 129,063, 11 February 1879; and no. 133,248, 20 October 1879) and was one of the first manufacturers in France to build telephone equipment. E. Ducretet, "Poste téléphonique et sonnerie avertisseur avec contrôle d'appel," Annales télégraphiques 3,6 (1879): 564-567 and Ducretet, "Téléphone à sifflet-signal fixe," ibid., pp. 568-569. However, he is far better known for his work in the 1890s on the development of French radio technology. Montoriol, pp. 658, 666, 668, 672-674, 679, 682, & 692. Ducretet did not appear in the telegraphy section of the Annuaire du commerce until 1870. His entries in the Annuaire du commerce during the 1870s indicated that he made and sold electric doorbells and signals and installed telegraph lines for the use of businesses, industrial establishments, and government agencies.

[65]Based upon a comparison of names given as telegraph manufacturers in the Annuaire du commerce with those in the "Liste des membres de la Société," Séances de la Société française de physique 2 (1874): 117-122; ibid. 3 (1875): 140-146; ibid. 4 (1876): 214-221; ibid. 5 (1877): 162-171; ibid. 6 (1878): 224-235; ibid. 7 (1879): 253-266; ibid. 8 (1880):

220-234; ibid. 9 (1881): 330-345.

Although I have found no biographical information on J. Molteni, a catalog of products he manufactured and sold exists. J. Molteni, Catalogue et prix courant des principaux produits (Paris: J. Molteni, 1859). On the catalog's title-page is the statement that the Molteni firm was founded in 1782. International Exhibition 1862, Medals and Honourable Mentions awarded by the International Juries (London: George Edward Eyre and William Spottiswoode, 1862), p. 203, states that he received an honorable mention for the good workmanship of his mathematical instruments. At the 1878 Paris International Exposition, Molteni exhibited some naval compasses. "Exposition universelle de 1878," Annales télégraphiques 3,5 (1878): 453.

E. Deschiens began manufacturing telegraph instruments in 1868 and received numerous medals. Response to questionnaire, F(12) 3409, Archives Nationales, Paris, and E. Deschiens, Catalogue général illustré (Paris: Deschiens, 1876).

[66] Based upon "Liste des membres de la Société," Séances de la Société française de physique 1 (1873): 97-102.

[67] From the "Liste des membres de la Société," Séances de la Société française de physique 1 (1873): 97-102 and ibid. 9 (1881): 330-345.

[68] "Liste des membres de la Société," Séances de la Société française de physique 3 (1875): 144 and ibid. 6 (1878): 225.

[69] Séances de la Société française de physique 5 (1877): 161 gave the officers for the next year.

[70] Meyer, "Appareil télégraphique à transmissions multiples par le même fil," Séances de la Société française de physique 2 (1874): 35-42; F. Tommasi, "Nouveau relais," ibid. 5 (1877): 86-88; Alfred Niaudet, "Pile de M. Camacho," ibid., pp. 94-95.

[71] Maurice Crosland, "La Science et le pouvoir: de Bonaparte à Napoléon III," La Recherche 7 (1976): 845. Also useful are Raymond J. Maras, "Napoleon: Patron of Science," Historian 21 (1958): 46-62; Edgar C. Smith, "The Centenary of Napoleon," Nature 107 (1921): 302-303; and, L. Pearce Williams, "Science, Education and Napoleon I," Isis 47 (1956): 369-382.

[72] I have found no article or other secondary work devoted to the Volta Prize of Napoleon III except E. Mascart,

"Prix Volta," pamphlet dated 1888, F(17) 3103, Archives Nationales, Paris. Some of the documents relating to Napoleon III's Volta Prize are in dossiers F(17) 3100 through F(17) 3104, Archives Nationales, Paris.

73 Mascart, "Prix Volta," p. 1.

74 Lists of Volta Prize Commissioners in dossiers F(17) 3100-3104 and Draft of arrêté, by Minister of Public Instruction and Beaux-Arts, dated 21 January 1887, F(17) 3103, Archives Nationales, Paris. Blavier died on 15 January 1887.

75 Based upon an examination of the Volta Prize competition dossiers F(17) 3100 through F(17) 3104, Archives Nationales, Paris.

76 "Commission de la Pile de Volta: procès-verbal de la séance du 26 mai <1863>," F(17) 3101, Archives Nationales, Paris.

77 Dossiers F(17) 3100 and 3101, Archives Nationales, Paris.

78 "Le pouvoir et la science," Le Cosmos 10 (1857): 495-497 describes Napoleon III's visit and the electrical motors and other equipment making up Froment's shop.

79 From the reports of the Volta Prize Commission meetings in F(17) 3101, Archives Nationales, Paris. For a biography of Ruhmkorff, see Emil Kosack, Heinrich Daniel Rhümkorff, ein deutscher Erfinder (Leipzig: Hahn, 1903). Obituary notices appeared, among other places, in the Annales télégraphiques 3,5 (1878): 121 and the Comptes rendus 85 (1877): 1211-1212.

80 Dossiers F(17) 3101 and 3104, Archives Nationales, Paris.

81 Bell used his Prize money to found a research laboratory called the Volta Laboratory. Robert V. Bruce, Bell: Alexander Graham Bell and the Conquest of Solitude (Boston: Little, Brown & Co., 1973), p. 341.

CHAPTER SEVEN

The Application of Electrical Theory to Telegraphy

Both the management and construction of the French telegraph network and the design of telegraph apparatus relied heavily upon electrical theory. For example, the location of current leaks along telegraph lines required the application of circuit analysis formulas such as those of Ohm and Kirchhoff derived from mathematical physics. While some of the electrical theory came out of the telegraph industry, more of it was the offspring of the research of mathematical physics. The institutional means through which this mathematical physics passed into the world of inspectors concerned with the day-to-day demands of telegraphy is integral to the application of electrical theory to telegraphy.

The case of Kirchhoff's Laws demonstrates how a discovery in mathematical physics could take on a new life as an engineering rule-of-thumb. The formulas called Kirchhoff's Laws are about as essential to our understanding of electrical circuitry as Ohm's Laws and just about every modern-day electrical engineering textbook contains these equations in one form or another:[1]

> 1. The algebraic sum of the currents entering any junction (node) in a network of conductors is always zero ($\Sigma I = 0$).

> 2. The algebraic sum of the potential drops around any closed loop in a network of conductors is always zero ($\Sigma E = 0$).

First formulated by the German scientist Gustave Kirchhoff (1824-1887)[2] in 1845, a period of over twenty years passed before their initial use by French telegraph employees. As one French telegraph inspector noted in an 1872 article on Kirchhoff's Laws, agents of the French Telegraph Administration had previously ignored Kirchhoff's formulas.[3] Their failure to use the equations prior to 1872 was not unique to France, moreover. The article on electricity in the 1860 edition of the Encyclopedia Britannica failed to mention Kirchhoff's formulas, but by the appearance of the next edition in 1879, they had become sufficiently commonplace that his laws of "current distribution in a network of linear circuits" were associated with Kirchhoff's name and explained in the article on electricity.[4] How, then, after more than twenty years of being unsung and nameless, did the name of an eminent mathematical physicist and his equations for electrical circuits become part of the vocabulary of practicing electricians, specifically telegraph inspectors, in France?

Gustav Kirchhoff had been interested in electrical theory from his earliest work as a student under Professor Franz Neumann (1798-1895) in 1845 until his death on 17 October 1887.[5] In four articles published between 1845 and

1848, Kirchhoff extended Ohm's law for linear conduction to the case of electrical conduction in three dimensions (through a wire instead of along a straight line).[6] To do this, he employed an analogy between the flow of heat and electricity based upon the concept of potential and derived his formulas through the mathematical language of the calculus.

Although he suggested statements of his laws as early as 1845, Kirchhoff did not fully prove them until his 1848 article, "On the Application of Formulas for the Intensity of Galvanic Force," in which he gave the following algebraic statement of his two laws:[7]

> Let the system consist of n wires, in which the resistances are w_1, w_2 . . w_n, and in which the intensities of the currents are J_1, J_2, . . J_n, . . . then whenever wires 1, 2, . . r form a closed figure <a loop>, $w_1 J_1 + w_2 J_2 + . . + wJ_r$ equals the sum of all the potential differences . . . <and> when wires 1, 2, . . meet in a point: $J_1 + J_2 + . . J_p = 0$.

Neither the mathematics nor the German language posed a barrier to their discovery by French telegraph inspectors. Both the original 1845 and the later 1848 articles were translated and appeared in the French scientific journal the <u>Annales de chimie et de physique</u>, though not until 1854.[8] Furthermore, the large numbers of Ecole polytechnique graduates employed as inspectors by the Telegraph

Administration between 1845 and 1854 could read German and understand the mathematics. Entry to the Ecole polytechnique was dependent upon passing an oral examination in German and both German and the calculus formed part of the school's curriculum.[9]

Taking classes at the Ecole polytechnique did not, however, ensure that a telegraph inspector or any other student learned Kirchhoff's formulas. The textbooks used to teach the physics course, for example, did not include a discussion of Kirchhoff's Laws.[10] Student inspectors also encountered a similar absence of Kirchhoff's name and his circuitry equations in the textbook that the Telegraph Administration used to teach inspector trainees.[11] The lack of these formulas in the Ecole polytechnique and Telegraph Administration courses taken by inspector trainees did not necessarily mean that those who worked as telegraph inspectors were totally unaware of the Kirchhoff articles. Edouard Ernest Blavier and Eugène Gounelle, both graduates of the Ecole polytechnique, telegraph inspectors, and instructors of inspector trainees, wrote an article on the propagation of electrical current through variously-shaped media, such as planes and cylinders. Their article appeared in several issues of the Telegraph Administration's own <u>Annales télégraphiques</u> during 1859 and 1860 and discussed at some length the ideas embodied in Kirchhoff's 1845 and 1848 articles, referring specifically to their publication in the original German articles. Yet they failed to mention Kirchhoff's circuitry equations.[12]

Thus, French telegraph inspectors, in particular those responsible for instructing inspector trainees, were aware of Kirchhoff's work, but failed to pay attention to the circuitry equations. More than the German or mathematical languages of Kirchhoff's articles, the real obstacle to their integration into the vocabulary of French telegraph inspectors was practice. In the case of a problem, such as a broken wire, the intertwining of two wires, or the breakdown of insulation, Kirchhoff's Laws could have provided general equations for the mathematical analysis of the circuit and a determination of the location of the problem on the line. Nonetheless, as long as telegraph lines remained relatively simple and in the air, Ohm's Law and equations derived from it provided a sufficient mathematical means for analyzing telegraph circuits.

The mathematical method for ascertaining the point at which current deviated from a telegraph line, as taught to inspectors as late as 1868,[13] depended upon certain assumptions about the nature of the telegraph circuit and the application of Ohm's Law. The same solution applied regardless of the cause for current leaking from the line: crossed wires, bad insulation, or a broken wire. In order to use the technique, the inspector assumed that the resistance from the point of current deviation to the ground was expressable in the same units of resistance as the line wire, that is, the standard unit of resistance adopted by the Telegraph Administration, one kilometer of iron wire 4mm in diameter. An inspector also assumed that the resistance of the earth in the circuit was null and that the emf of the battery was equal to one. In the case of longer lines, inspectors assumed that the resistance of the battery was zero. Before the advent of the problem, the amount of current on the line, following Ohm, was $I = 1 / a$, where I was the current, 1 the emf of the battery, and a the resistance of the line including the electromagnet of the receiving instrument. The circuit from the fault to ground and thence to the next station being considered as a single wire, the telegraph line thus became a branched circuit capable of being treated as a special application of Ohm's Law.

With this extension of Ohm's Law to the location of telegraph line faults, French telegraph inspectors did not need or use Kirchhoff's Laws for the approximate quarter of a century that followed publication of the equations. However, after 1867, knowledge of his laws, and their identification with Kirchhoff's name, spread quickly and became a part of the inspectors's vocabulary and set of mathematical tools.

The reasons for this change were the coming of underwater telegraph cables, the French commitment to laying, owning, and maintaining its own cables, the numerous ruptures to which these cables were susceptible, and a graduate of the Ecole polytechnique.

The first underwater telegraph cable of any considerable length anywhere was that laid between Great Britain (Dover) and France (Calais) in 1851.[14] From that beginning, the construction and ownership of international underwater telegraph cables rapidly became a British monopoly.[15] In France, the construction and immersion of underwater telegraph cables took place on a far more modest scale, initially being concerned principally with crossing rivers or connecting the land network with offshore islands. In 1859, for instance, the Telegraph Administration laid a total of 28 such underwater cables with an entire length that totaled 180 km, but by 1889, these cables amounted to only 265 km.[16] More significant for the telegraphic application of Kirchhoff's Laws, and the development of French underwater telegraphy, were those cables that connected France to North Africa.

In 1853, the French government signed an agreement with the British entrepreneur of the Dover-Calais cable for the construction and laying of an underwater telegraph cable between France and Algeria. The cable was to cross the

Mediterranean Sea indirectly by way of Corsica and Sardinia. After one cable rupture too many and the entrepreneur's failure to complete the project in a timely fashion, the French government contracted with another British firm, Glass, Elliot & Co., on 13 April 1860. Glass, Elliot & Co. had built the first, but unsuccessful, Atlantic telegraph cable and planned to run the French Mediterranean cable across the island of Menorca. They began in April 1860, hoping to finish by the end of August, but a ship accident postponed work until January 1861, when the cable broke. The French government signed another contract with Glass, Elliot & Co. for a "direct" cable to Algeria. The company succeeded in connecting France and Algeria through Menorca, but a storm interrupted the cable between Menorca and Algeria on 25 September 1862.[17]

The French government immediately planned another underwater telegraph cable to connect with North Africa. In July 1863, an expedition took soundings for a cable to run from Oran (Algeria) to Cartagena (Spain), the purpose of landing in Spain being to shorten the route and thus lessen the chances of failure. Charged with manufacturing and immersing the Oran-Cartagena cable was the Berlin firm of Siemens & Halske.[18] Furthermore, for the first time, the French took an active part in the laying of an underwater telegraph cable. For the purpcse of submerging and maintaining the Oran-Cartagena and future cables, the French government purchased a British steamer, refitted it in London with cable-laying equipment, and re-christened her the Dix-décembre (the Ampère after 1870). The Dix-décembre began laying the cable on 12 January 1864. After a few hours, the cable broke. The expedition began again on 28 January 1864 and, after twelve hours, the cable broke once more.[19]

The French government's increased commitment to the development of a French underwater telegraph cable technology and industry, which had resulted in the purchase of the Dix-décembre, also led to the creation of a center for the laying and repair of underwater telegraph cables in Toulon. Overseeing the Toulon works was François Ailhaud, the telegraph inspector who later successfully duplexed the Hughes telegraph.[20] Among those working under Ailhaud was a recent graduate of the Ecole polytechnique, Jules Raynaud (1843-1888).[21]

At the Toulon works, Raynaud became responsible for electrical measurements,[22] work that involved both the analysis of telegraph circuits and electrical units. Electrical measurement, particularly of resistance, grew in importance with underwater telegraphy. The frequent ruptures of underwater electric telegraph cables led the French government to carry out a number of experiments regarding the determination of the breaking point of underwater conductors.[23] In testing cables, telegraph inspectors charged with overseeing the manufacture and immersion of underwater cables measured (1) the resistance of the conductor(s), (2) the resistance of the insulating covering, and (3) the capacitance of the cable. Once a cable was submerged, though, the locating of a current deviation required an unprecedented level of precision.[24] The standard unit of resistance adopted by the Telegraph Administration, one kilometer of iron wire 4mm in diameter, varied widely with temperature and the kind of iron used. Resistance units exhibited by Breguet and Digney at the 1862 London International Exposition, for example, measured 9.266 and 10.420 Siemens resistance units, respectively.[25] Thus, underwater cables demanded the redefinition of the unit of electrical resistance.[26]

The location of points along a submerged cable where current escaped through the insulating coat also posed new problems. The resistance of the path followed by such currents was extremely small in relation to the resistance of the entire cable and made use of the usual electrical measurement techniques difficult and insufficiently reliable.[27] Like those for finding current deviations on overhead lines, the methods for locating cable faults relied upon the application of Ohm's Law.[28] Therefore, when Raynaud began working on electrical measurements at the Toulon cable center, he undertook a long series of experiments and an extensive study of the literature regarding the applications of Ohm's Law to telegraphy.[29]

While undertaking his study of underwater telegraphy and electrical measurement, Raynaud also wrote a thesis on the application of Ohm's law to underwater telegraph cables (published in 1870) for which he received the degree of <u>docteur ès sciences physiques</u> from the University of Paris.[30] Raynaud's coursework at the Ecole polytechnique equipped him with the mathematical language and physics theory of electrical potential needed to understand and take advantage of Kirchhoff's electrical articles. Raynaud discovered these articles as part of his investigation of Ohm's law, either on his own or through Henri Sainte-Claire Deville (1818-1881), professor of chemistry at the Ecole normale and the Faculty of Science in Paris.[31] Sainte-Claire Deville assisted in the direction of Raynaud's thesis[32] and had supervised the work of Lucien de la Rive at the chemistry laboratory of the Ecole normale.[33] In 1863, a year after Raynaud's graduation from the Ecole polytechnique, de la Rive published an article employing Kirchhoff's formulas,[34] suggesting the possibility that Sainte-Claire Deville may have brought de la Rive's article and the utility of Kirchhoff's equations to Raynaud's attention. Nonetheless, any independent and complete search of the literature, including the pages of the <u>Annales</u>

<u>télégraphiques</u> as indicated above, would have uncovered Kirchhoff's articles and their formulas.

Raynaud first brought Kirchhoff's Laws to light in an 1867 article published in the French Academy of Sciences' <u>Comptes rendus</u>, "On a Practical Means of Determining the Voltaic Constants of a given Pile," in which he showed the practicality of using "the laws of Ohm and Kirchhoff" to find an unknown resistance in a fashion similar to that employed in the Wheatstone bridge.[35] In addition to drawing attention to Kirchhoff's equations and his own work in the prestigious and widely circulated journal of the Paris Academy of Sciences, Raynaud further spotlighted his 1867 article (and indirectly Kirchhoff's Laws) with a letter of 1872 to the Royal Society of London, in whose pages he pointed out the existence of his 1867 article and the usefulness of its subject matter.[36]

Raynaud demonstrated the utility of Kirchhoff's formulas to a far greater extent in his thesis, published in 1870 as "Experimental Research on Ohm's Laws and their Application to Electrical Tests on Underwater Cables," in which he stated Kirchhoff's laws as follows:[37]

> 1° "If several conductors meet in a point, the sum of the intensities of the currents which cross it is equal to zero, considering as positive the currents which flow toward the junction point and as negative those that flow from it."

> 2° "In a series of conductors forming a closed figure <a loop>, the sum of the products of the intensities <currents> and the resistances is equal to the sum of the electromotive forces in the same circuit."

After introducing these two principles for the analysis of any given network of conductors, Raynaud stated that:[38]

> These two laws furnish a certain number of equations that permit the resolution of the most complicated problems of networks, among which the following is very remarkable, in that it provides a precise means of measuring the resistance of a circuit.

What followed was a demonstration of the applicability of Kirchhoff's Laws to the simplification of the calculations of Wheatstone's bridge (with applications for underwater telegraphy), the determination of the difference in electromotive forces of two voltaic piles, the location of a break in an underwater cable, and the reckoning of the quantity of charge in an underwater telegraph cable, among other uses.[39] Raynaud further diffused knowledge of Kirchhoff's equations in 1872 and 1873, when he published three articles in the Journal de physique,[40] a publication of the French Physics Society. As in his thesis, upon which he based these articles, Raynaud gave the reader a verbal, rule-of-thumb version of the two laws, as well as the now famous mathematical shorthand form of them: "$\Sigma i = 0$" and "$\Sigma(i\ r - e) = 0$".[41] These articles continued the diffusion of

Kirchhoff's Laws and their practical utility, ironically in a journal of mathematical physics. Kirchhoff's Laws had emerged from their obscurity but had yet to find their place (and their name) in the routine instruction of telegraph inspectors.

The opening of the Ecole supérieure d'électricité in 1878 furnished the means for routinely training telegraph inspectors in the nature and use of Kirchhoff's Laws. In the second year of the school's curriculum, students took two courses that dealt with electrical measurement, one of which consisted of practical laboratory exercises. Raynaud taught both measurement courses and included a discussion of Kirchhoff's Laws and their applicability for telegraphy.[42] Through Raynaud, then, as a graduate of the Ecole polytechnique and the University of France, as a telegraph inspector challenged by the new difficulties posed by underwater telegraph cables, and, finally, as a teacher of telegraph inspectors, the name of Kirchhoff ceased to be associated solely with mathematical physics and became a part of the telegraph practitioner's vocabulary as Kirchhoff's Laws in France.

Once Kirchhoff's equations joined the collection of mathematical tools used by telegraph inspectors in the analysis of circuits, they took on a life of their own as telegraph engineers, as they were called after 1878, continually re-adapted them to the needs of telegraph practice. Complex circuits and the omnipresent need to make electrical measurements made Kirchhoff's Laws increasingly more valuable over time. The process of telegraph engineers recasting Kirchhoff's equations to fit changing needs led to the expansion of telegraph engineering theory independently of work being done in mathematical physics. The begetting of Thevenin's Theorem from Kirchhoff's Laws by a French telegraph engineer thus illustrates how telegraph engineers created new practical knowledge without borrowing directly from science. Thevenin's Theorem can be found in any modern introductory electronics textbook.[43] It is a handy means for simplifying and analyzing any complex DC circuit (presently adapted for AC circuits too) composed solely of resistances and a power source and is particularly useful when dealing with a complex circuit to which one adds a single new element.

Léon Charles Thévenin (1857-1926)[44] graduated from the Ecole polytechnique in 1876.[45] He joined the telegraph service and was one of the first students when the Ecole supérieure de Télégraphie opened in 1878.[46] Necessarily, therefore, Thévenin took Raynaud's courses in electrical measurement and learned Kirchhoff's Laws. Thévenin developed an interest in electrical measures and, with Raynaud, undertook a translation of a British work on the subject that the two published in 1883.[47] The translation of foreign, particularly British, works was routinely done at the Ecole supérieure de Télégraphie and, for instance, provided the means by which James Clerk Maxwell's _A Treatise on Electricity and Magnetism_ appeared in France.[48] In the same year that Thévenin's translation appeared, three scientiftic journals, the _Comptes rendus_, the _Journal de physique_, and the _Annales télégraphiques_ published his first article, "Extension of Ohm's Law to complex electrical circuits."[49] The article contained a statement, explicitly set forth as a theorem, which soon became known among telegraph engineers as Thévenin's Theorem:[50]

> THEOREM.- Being given any system of linear conductors connected in such a manner that to the ends of each one of them there is connected at least one other and containing whatever electromotive forces E_1, E_2, . . . E_n, distributed in whatever manner, one considers two points A and A′ belonging to the system and possessing the potentials V and V′. If one unites points A and A′ with wire ABA′ whose resistance is r and which contains no electromotive force, the potentials of points A and A′ take on the new values V and V′, but the current i which circulates in this wire is given by the formula i = V - V′ / r + R, in which R represents the resistance of the original system measured between points A and A′ considered as electrodes.

Quickly, Thévenin published three more articles in 1883.

The first dealt with the use of a galvanometer (an instrument for measuring amperage) to determine potential and was a practical extension of his theorem.[51] The usual instrument for measuring potential was the voltmeter, a device which required special aptitude and a long time to obtain satisfactory results. The galvanometer was a far simpler apparatus to use and the application of Thévenin's Theorem to measuring emf with a galvanometer therefore simplified and shortened the technique for determining potentials in a circuit. Thévenin followed his second article, which dealt with a resistance-measuring technique called "looping" ("boucler"),[52] with another on the Wheatstone bridge. In discussing the Wheatstone bridge method for measuring an unknown resistance, Thévenin pointed out that Kirchhoff's equations provided the best mathematical technique, but furnished the experimenter with six sets of equations.[53] Thévenin proceeded to demonstrate a method that avoided the long and tedious equations furnished by Kirchhoff's Laws, yet constructed a bridge that was as sensitive as possible. Although the second and third articles demonstrated Thevenin's continuing interest in problems of electrical measurement, they did not provide an amplification of his theorem.

The theorem that Thévenin had set forth in his first article quickly became known as "Thévenin's theorem," as demonstrated by the article in the Annales télégraphiques of 1889 titled, "Note sur le théorème de Thévenin."[54] While publication of Thévenin's article in the journal of the telegraph service and in two important scientific periodicals assured diffusion of the theorem to a wider scientific audience, Thévenin himself spread knowledge about his theorem and assured its incorporation into the routine instruction of telegraph engineers. As early as 1882, he began teaching his fellow telegraph engineers at the Ecole supérieure de Télégraphie and, in 1896, became the school's director.[55] Thus, as the case of Thévenin's Theorem demonstrates, with such engineering institutions as a specialized journal (the Annales télégraphiques) and a school for telegraph engineers, like the Ecole supérieure de Télégraphie (or its predecessor courses provided inspectors at the Central Administration of the telegraph service), the ongoing creation of telegraph theory could take place independently of mathematical physics.

The application of electrical theory to telegraphy also concerned the construction of telegraph apparatus. The Hughes, Meyer, Baudot, and other telegraphs alternated current polarities in order to diminish the effects of capacitive phenomena that became apparent as transmission speed increased. Another example of the application of electrical theory to the construction of telegraph apparatus is Louis Breguet's invention of a lightning arrester. At 5:00 PM one day in June, 1847, during a hard rain, the alarm at a railroad telegraph station began to ring. The telegraphist believed that a message was about to arrive and, indeed, his dial instrument began to register some letters, but without making any sense. Just as he was about to answer that he did not understand the message, a lightning bolt struck nearby. The telegraph wires inside the station disintegrated and left blackened traces where they once had been. The wires of the instrument's electromagnets were destroyed. Fortunately, the telegraph operator received only a strong shock and survived.[56]

The storm, and particularly the damage caused to the telegraph wires and instruments, demonstrated the need for a device to protect telegraph equipment from lightning. The event suggested to Louis Breguet "the idea of applying a well-known fact in physics, which is that the more a wire is a poor conductor, the more it heats up with the passage of an electrical current and that this can lead even to fusion."[57] The "well-known fact" was, although Breguet did not use the expression, Joule's Law, which mathematically expresses the relationship between the amount of heat generated by a current in a conductor and the conductor's resistance. James Prescott Joule (1818-1889) first published the equation now associated with his name in an article that appeared in the

Philosophical Magazine of Great Britain in 1841.[58]

Although Breguet did not indicate how he learned of the relationship now called Joule's Law, a number of sources likely served to inform him of the existence and nature of the law. In 1842, for example, a French translation of Joule's Philosophical Magazine article appeared in the Archives de l'électricité.[59] It also appeared in the British journal, Annals of Electricity, in 1842,[60] a journal that Breguet had read on at least one occasion.[61] Therefore, Breguet could have learned of Joule's Law through either a French- or an English-language journal. By 1844, moreover, knowledge of the relationship between the quantity of heat given off by a current passing through a conductor and the conductor's resistance had become sufficiently widespread that the subject formed part of the physics course at the Ecole polytechnique.[62] From Breguet's writings,[63] furthermore, it is clear that he read widely, especially about electrical theory. Consequently, he may have learned about Joule's Law and other useful electrical formulas and theories through a variety of printed sources. Regardless of how he discovered the relationship between conductivity, current, and the heat generated in an electrical circuit, Breguet clearly believed that he was applying the concept embodied in Joule's Law in his creation of a lightning arrester for telegraph lines.

The creating and improving of telegraph apparatus, like any other form of technology or engineering, involved more than just the application of theory. Engineering and technological invention and improvement are largely creative ventures analogous to the creative activities of artists and writers. Some historians of technology have begun to refer to this aspect of invention and engineering under the rubric of "design" and have signalled the importance of nonverbal thinking.[64] In order to undertake a proper study of technological and engineering creativity, the imagination's means of communication - the nonverbal, visual "language" of laboratory notebooks, sketches, mechanical drawings, among others - is necessary. These forms of historical evidence are especially useful in revealing what might be called the technological equivalent of the "thought experiment" of scientists. Furthermore, just as a published book, a completed sculpture, or a finished building provide only the final product of the imagination, an examination of available telegraph artifacts without accompanying sketches or drawings only partially furnishes an insight into technological creativity and nonverbal thinking. For French telegraphy, these ancillary materials are lacking.[65]

Nevertheless, some general observations about the nature of technical creativity can be made solely from an examination of the artifacts. One such observation is that new technologies tend to resemble old technologies, suggesting that the creative process involves the borrowing of mechanical solutions from existing technologies. In designing the Foy-Breguet telegraph, for example, Louis Breguet borrowed the instrument's clockwork and detente mechanisms from the technology that he was trained in, horology. His dial telegraph largely borrowed the Foy-Breguet mechanism, but increased the number of positions from four to thirteen. In the telegraph invented by David Hughes, who had taught music in Kentucky,[66] the arrangement of the transmitting keys utilized the well-known piano keyboard form. Finally, once Bernard Meyer improved the facsimile telegraph with a rotating ribbed cylinder, he applied the same technical solution to the design of his multiple telegraph.

Nonverbal, visual elements are also present in the published telegraph literature, the most obvious example of which is the recurring use of engravings and plates in textbooks and manuals to illustrate the construction and operation of telegraph apparatus. The representations of resistances, capacitors, electromagnets, and other components in electrical circuit diagrams also indicate the existence of visual thinking and the development of a "language" of graphic communications.[67] A survey of these circuit symbols in works dealing with telegraphy suggests that the portrayal of electrical components began with drawings that closely resembled the objects that they stood for and gradually grew into increasingly more idealized forms. Textbooks, moreover, resorted to the utilization of imagery to portray such abstract concepts as the relationship between the flow of an electrical current and the direction of its accompanying electromagnetic field (Figure 31)[68] and to assist the mind's eye in picturing the phenomena.

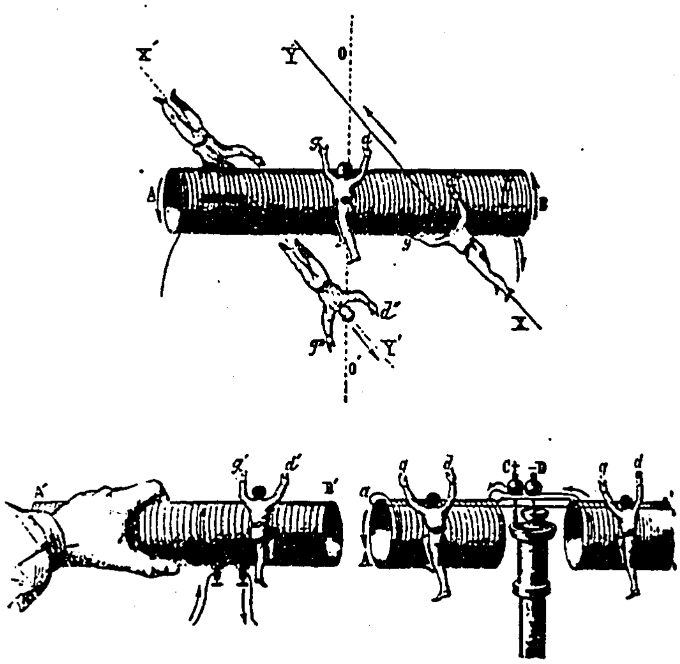


Figure 31. Examples of Nonverbal Communication

FOOTNOTES

[1]The following, for instance, are electrical engineering textbooks presently used in teaching college-level electrical engineering, with page numbers indicating the introduction of Kirchhoff's laws into the course matter: William H. Hayt, Jr. and Jack E. Kemmerly, Engineering Circuit Analysis, 3d ed. (New York: McGraw-Hill Book Co., 1978), pp. 34-37; Jacob Millman, Microelectronics: Digital and Analog Circuits and Systems (New York: McGraw-Hill Book Co., 1979), pp. 708-709; Robert Grover Brown, Robert A. Sharpe, William Lewis Hughes, and Robert E. Post, Lines, Waves, and Antennas: The Transmission of Electrical Energy, 2d ed. (New York: John Wiley & Sons, 1973), p. 13; Eugene C. Lister, Electric Circuits and Machines, 5th ed. (New York: McGraw-Hill Book Co., 1975). pp. 31-32; and, A. E. Fitzgerald, David E. Higginbotham, and Arvin Grabel, Basic Electrical Engineering, 5th ed. (New York: McGraw-Hill Book Co., 1981), pp. 24-28.

[2]For biographical information on Kirchhoff, see Robert von Helmholtz, "A Memoir of Gustav Robert Kirchhoff," trans. Joseph de Perott, pp. 527-540 in Annual Report of the Board of Regents of the Smithsonian Institution to July, 1889 (Washington: Government Printing Office, 1890); A. S. Everest, "Kirchhoff, Gustav Robert, 1824-1887," Physics Education 4 (1969): 341-343; and, L. Rosenfeld's article on Kirchhoff in Charles Coulton Gillispie, ed., Dictionary of Scientific Biography (New York: Charles Scribner's Sons, 1973), 7:379-383.

[3]Jules Raynaud, "Des lois de la propagation de l'électricité dans l'état permanent," Journal de physique 12 (1872): 305.

[4]The Encyclopedia Britannica: A Dictionary of Arts, Sciences and General Literature, 9th ed. (Edinburgh: Adam and Charles Black, 1879), 8:42-43 states Kirchhoff's "laws of current distribution in a network of linear circuits". Nowhere did the earlier 1860 edition mention them, however. See James D. Forbes, "Dissertation Sixth: Exhibiting a General View of the Progress of Mathematical and Physical Science, Principally from 1775 to 1850," I:982-987, which contains a discussion of electrical circuit theory in The Encyclopedia Britannica or Dictionary of Arts, Sciences and General Literature, 8th ed. (Edinburgh: Adam and Charles Black, 1860).

[5]During the 1850s, Kirchhoff published electrical works

in the *Annalen der Physik*. As late as the 1870s and 1880s, he continued to publish works on electrical theory, including five articles in the *Monatsberichte der Königlich Preussichen Akademie der Wissenschaften zu Berlin*. He also took an active part in electrical institutions and attended international electrical congresses, such as that in Paris 1881 (Ministère des Postes et des Télégraphes, *Congrès international des Electriciens, Paris 1881* (Paris: G. Masson, 1882), p. 17), and joining organizations such as the International Society of Electricians, of which he was a founding member. "Liste des Membres Fondateurs (15 Janvier 1884)," *Bulletin de la Société internationale des Electriciens* 1 (1884): 49.

For Franz Neumann, see Luise Neumann, *Franz Neumann: Erinnerungsblätter von seiner tochter* (Tubingen & Leipzig: J. C. B. Mohr, 1904); W. Voigt, "Gedachtnissrede auf Fran Neumann," I:1-19, in *Franz Neumanns Gesammelte Werke* (Leipzig: B. G. Teubner, 1906); and Paul Volkmann, *Franz Neumann: Ein beitrag zur Geschichte deutscher Wissenschaft* (Leipzig: B. G. Teubner, 1896).

[6] Kirchhoff, "Ueber den Durchgang eines elektrischen Stromes durch eine Ebene, insbesondere durch eine kreisförmige," *Annalen der Physik* 64 (1845): 497-514; Kirchhoff, "Nachtrag zu dem Aufsatze: Ueber den Durchgang eines elektrischen Stromes durch eine Ebene, insbesondere durch eine kreisförmige," *ibid*. 67 (1846): 344-349; Kirchhoff, "Ueber die Auflösung der Gleichungen, auf welche man bei der Untersuchung der linearen Vertheilung galvanischer Ströme geführt wird," *ibid*. 72 (1847): 497-508; and, Kirchhoff, "Ueber die Anwendbarkeit der Formeln für die Intensitäten der galvanischen Ströme in einem Systeme linearer Leiter auf Systeme, sie zum Theil aus nicht linearen Leitern bestehen," *ibid*. 75 (1848): 189-205.

[7] Kirchhoff, "Ueber die Anwendbarkeit der Formeln," p. 205: "Besteht das System aus n Drähten, deren Widerstände $w_1, w_2 . . w_n$ sind, und deren Ströme die Intensitäten $J_1, J_2, . . J_n$ haben . . . dass immer, wenn die Drähte 1, 2, . . r eine geschlossene Figur bilden, $w_1J_1 + w_2J_2 + . . + wJ_r$ gleich der Summe aller Spannungsdifferenzen ist . . . wenn die Drähte 1, 2, . . p in einem Punkte zusammenstofsen: $J_1 + J_2 + . . J_p = 0$."

[8] *Annales de chimie et de physique* 40 (1854): 115-127 and *Ibid*., pp. 327-333.

[9] d'Ocagne, pp. 98, 101 & 103.

[10] Bravais; Jules Jamin, *Cours de physique de l'Ecole*

polytechnique, 3 vols. (Paris: Mallet-Bachelier, 1858-1866); Jamin, Cours de physique de l'Ecole polytechnique, 3 vols., 2d ed. (Paris: Mallet-Bachelier, 1863-1869); Jamin, Cours de physique de l'Ecole polytechnique, 3 vols., 3d ed. (Paris: Mallet-Bachelier, 1868-1871).

[11]Blavier and Gounelle, Résumé des cours, I:145-159, treated branched circuits and Blavier, Nouveau traité, I:425-468, contains the section that deals with the location of faults along overhead and underwater telegraph lines. Neither work mentions Kirchhoff's circuitry equations.

[12]E. E. Blavier and E. Gounelle, "Théorie de la propagation de l'électricité," Annales télégraphiques 2,2 (1859): 218-244; 381-404; 2,3 (1860): 26-45 & 135-156. Ibid. 2,2 (1859): 241-243 specifically referred to Kirchhoff's solution to the general case of branched circuits, but failed to mention what his solution was.

[13]Blavier and Gounelle, Résumé des cours, I:153-159 and Blavier, Nouveau traité, I:91-94 and 338-347.

[14]John Watkins Brett, Origin and Progress of the Oceanic Electric Telegraph (London: Johnson, 1858) provides a history of the Calais-Dover cable by the entrepreneur responsible for the manufacture, laying, and maintenance of the cable.

[15]A. L. Ternant, "Les câbles sous-marins," Annales industrielles 2 (1870-71): 1141. "Nomenclature des câbles sous-marins du globe," Journal télégraphique 13 (1889): 214-243 provides an overview of world underwater telegraph cables that quantitatively demonstrates the British control of cables.

[16]Annales télégraphiques 2,2 (1859): 444 and "Nomenclature des câbles sous-marins du globe," p. 218.

[17]Eugène Wünschendorff, Traité de télégraphie sous-marine (Paris: Baudry et Cie, 1888), pp. 9-14, 17, 28-30 and Maurice du Colombier, "Notice sur le câble d'Alger," Annales télégraphiques 2,5 (1862): 105-140.

[18]For a history of Siemens & Halske, see Sigfrid von Weiher and Herbert Goetzeler, The Siemens Company: Its Historical Role in the Progress of Electrical Engineering, trans. G. N. J. Beck (Berlin & Munich: Siemens Aktiengesellschaft, 1977).

[19]Wünschendorff, pp. 30-35; Rupture du câble d'Algérie," Annales télégraphiques 2,6 (1863): 107-109; Henri

Blerzy, "Revue de télégraphie sous-marine," _ibid._, pp. 407-408 & 584-601, and _ibid._ (1864): 174-190 & 760-761; and Session de 1870, Budget de l'exercise 1871, "Projet de loi pour la fixation des recettes et des dépenses ordinaires et extraordinaires de l'exercise 1871," AD XVIII(F) 869, Archives Nationales, Paris.

[20]_Journal télégraphique_ 4 (1879): 497 and _Annales télégraphiques_ 3,6 (1879): 493.

[21]"M. F. E. J. Raynaud," _Journal télégraphique_ 12 (1888): 18.

[22]_Ibid._, p. 19.

[23]Jules Raynaud, _Recherches experimentales sur les lois de Ohm et leurs applications aux essais électriques des câbles sous-marins_ (Paris: A. Parent, 1870), p. 7.

[24]Blerzy, "Essais électriques des câbles sous-marins," _Annales télégraphiques_ 2,5 (1862): 332-335.

[25]A. L. Ternant, _Manuel pratique de télégraphie sous-marine_ (Paris: E. Lacroix, 1869), p. 87. The Siemens (Siemens & Halske) unit of resistance was the resistance of a column of mercury one meter long and one square millimeter in area at 0° C. Blerzy, "Essais électriques," p. 337. The Siemens unit was a far more reliable unit of resistance than that used by the Telegraph Administration.

[26]Blerzy, "Essais électriques," p. 336.

[27]Blavier, _Nouveau traité_, I:355.

[28]Blerzy, "Essais électriques," pp. 340-361.

[29]_Journal télégraphique_ 12 (1888): 19 and Raynaud, _Recherches experimentales_, p. 7.

[30]Jules Raynaud, _Recherches experimentales_. According to Albert Maire, _Catalogue des thèses de sciences soutenues en France de 1810 à 1890 inclusivement_ (Paris: H. Welter, 1892), p. 67, Raynaud did his thesis work at the University in Paris. The title-page of his thesis states that Raynaud was a graduate of the Ecole polytechnique and _licencié ès sciences physiques et ès sciences mathématiques_.

[31]Poggendorff, II:737-738 & IV:1162-1163, and _Revue scientifique_ 3 (1882): 1-8.

[32]Raynaud, Recherches experimentales, title page, states that Raynaud's two examiners were Jules Jamin (Raynaud's physics professor at the Ecole polytechnique) and Henri Sainte-Claire Deville.

[33]Lucien de la Rive, "Méthode de M. W. Thomson pour la mésure de la conductibilité électrique: Applicationn aux métaux fondus," Comptes rendus 57 (1863): 700, states that de la Rive worked at the Ecole Normale chemistry laboratory under Henri Sainte-Claire Deville. I have found no biographical information on Lucien de la Rive.

[34]Lucien de la Rive, "Sur le nombre d'équations indépendantes dans la solution d'un système de courants linéaires," Archives des sciences physiques et naturelles 17 (1863): 105-112.

[35]Raynaud, "Sur un moyen de déterminer les constantes voltaîques d'une pile quelconque," Comptes rendus 65 (1867): 170-172.

[36]"On a mode of Measuring the Internal Resistance of a Multiple Battery by adjusting the Galvanometer to Zero," Proceedings, Royal Society of London 20 (1872): 159, states that Raynaud's letter to Secretary Stokes was received 11 January 1872.

[37]Raynaud, Recherches experimentales, p. 16: "1° 'Si plusieurs conducteurs concourent en un même point, la somme des intensités des courants qui les traversent est égale à zero, en considerant comme positifs les courants qui se dirigent vers le point de jonction, et comme negatifs ceux qui s'éloignent. . . . 2° 'Dans une série de conducteurs formant une figure fermée, la somme des produits des intensités par les resistances est égale à la somme des forces électro-motrices dans le même circuit.'"

[38]Ibid., p. 17: "Ces deux lois fournissent un certain nombre d'équations qui permittent de résoudre les plus compliqués des dérivations, parmi lesquels le suivant est très-remarquable, en ce qu'il donne un moyen précieux de mésurer la resistance d'un circuit."

[39]Ibid., pp. 17, 30, 56 & 112.

[40]Raynaud, "Des lois de la propagation," pp. 305-321; "Courants dérivés; Lois de Kirchhoff," Journal de physique 2 (1873): 86-98; and "Résolution des équations fournies par les lois de Kirchhoff, pour la distribution des courants électriques dans un système quelconque de conducteurs

linéaires," _ibid._, pp. 161-171.

[41] Raynaud, "Courants dérivés," p. 92.

[42] "Personnel de l'Ecole supérieure de Télégraphie pour l'année scolaire 1878-1879," _Annales télégraphiques_ 3,5 (1878): 567 and Ecole supérieure de Télégraphie, _Sommaire des cours, 1880-1881_ (Paris: Ministère des Postes et des Télégraphes, 1881), Library of the Ministry of P.T.T., Paris.

[43] Later came the application of Thévenin's Theorem to AC circuits. For some citations of Thévenin's Theorem in introductory electronics textbooks, see William A. Lynch and John G. Truxal, _Introductory System Analysis: Signals and Systems in Electrical Engineering_ (New York: McGraw-Hill, 1961), pp. 184-186; Reginald Ralph Benedict, _Electronics for Scientists and Engineers_, 2d ed. (Englewood Cliffs, NJ: Prentice-Hall, 1976), pp. 13-15; and Paul Burton Brown, Gunter N. Franz, and Howard Moraff, _Electronics for the Modern Scientist_ (New York: Elsevier, 1982), pp. 62-63. Donald G. Fink, editor-in-chief, _Electronics Engineers' Handbook_, 2d ed. (New York: McGraw-Hill, 1982), p. 3-4 and Institute of Electrical and Electronic Engineers, _IEEE Standard Dictionary of Electrical and Electronics Terms_, 3d ed. (New York: IEEE, 1984), p. 939 also contain references to Thévenin's Theorem as part of current electrical engineering practice.

[44] Charles Suchet, "Léon Charles Thévenin, (1857-1926)," _Electrical Engineering_ 68 (1949): 843-844.

[45] Société amicale de secours des anciens élèves et société des amis de l'Ecole polytechnique, _Annuaire des anciens élèves de l'Ecole polytechnique_ (Paris: Gauthier-Villars, 1952), p. P.1.

[46] "Admission à l'Ecole supérieure de Télégraphie," _Annales télégraphiques_ 3,5 (1878): 568.

[47] Joseph David Everett, _Unités et constantes physiques_, trans. Jules Raynaud and Léon Charles Thévenin (Paris: G. B. de La Touanne et E. Massin, 1883).

[48] The translation appeared as _Traité d'électricité et de magnétisme_, 2 vols., trans. Gustave Séligmann-Lui (Paris: Gauthier-Villars, 1885-1887). For Séligmann-Lui, see his personnel dossier, F(90) 20,545, Archives Nationales, Paris.

[49] _Annales télégraphiques_ 3,10 (1883): 222-224; _Comptes rendus_ 97 (1883): 159-161; _Journal de Physique_ 2 (1883): 418-

419.

[50]"Extension de la loi d'Ohm aux circuits électromoteurs complexes," Annales télégraphiques 3,10 (1883): 222: "THEOREME.- Etant donné un système quelconque de conducteurs linéaires reliés de manière qu'aux extremités de chacun d'eux en aboutisse au moins un second, et renfermant des forces électromotrices quelconques E_1, E_2, . . . E_n, réparties d'une manière quelconque, on considère deux points A et A' appartenant au système et possédant actuellement des potentiels V et V'. Si l'on vient à réunir les points A et A' par un fil ABA' de résistance r, ne contenant pas de force électromotrice, les potentiels des points A et A' prennent des valeurs différentes de V et V', mais le courant i qui circule dans ce fil est donné par la formule i = V - V' / r + R, dans la quelle R répresente la résistance du système primitif mesurée entre les points A et A' considérés comme électrodes."

[51]Thévenin, "Sur la mesure des différences de potentiel au moyen du galvanomètre," Annales télégraphiques 3,10 (1883): 446-449 and Comptes rendus 97 (1883): 453-455.

[52]Thévenin, "Sur la mesure de la résistance spécifique des fils par la méthode de la boucle," Annales télégraphiques 3,10 (1883): 167-178.

[53]Thévenin, "Sur les conditions de sensibilité du pont de Wheatstone," Annales télégraphiques 3,10 (1883): 225-234 & 552-557.

[54]Marius Cailho, "Note sur le théorème de Thévenin," Annales télégraphiques 3,16 (1889): 320-326.

[55]Suchet, p. 843.

[56]Moniteur universel, 16 June 1847, p. 1582.

[57]Breguet, Manuel, pp. 83-84: "Cet événement nous suggéra l'idée d'appliquer un fait bien connu en physique: c'est que plus un fil est mauvais conducteur, plus il s'échauffe par le passage d'un courant électrique, et que cela peut même aller jusqu'à la fusion. C'est là que nous fîmes la première application de ce principe, laquelle depuis a été adoptée partout."

[58]James Prescott Joule, "On the Heat evolved by Metallic Conductors of Electricity, and in the Cells of a Battery during Electrolysis," The Philosophical Magazine 19 (1841): 260-277 and reproduced in Annals of Electricity 8 (1842):

287-301. For a discussion of Joule's early work, see Gordon Jones, "Joule's Early Researches," Centaurus 13 (1968): 198-219, although A. Schuster, "Biographical Byways: John Prescott Joule (1818-1889)," Nature 115 (1925): 55-57 deals specifically with the development of Joule's Law. For biographical information, see T. E. Thorpe, "Scientific Worthies XX: James Prescott Joule," Nature 26 (1882): 617-621.

59"Sur la chaleur développée dans les conducteurs métalliques et dans les auges d'une pile sous l'influence de l'électricité," Archives de l'électricité 2 (1842): 54-79.

60Annals of Electricity 8 (1842): 287-301.

61The Comptes rendus 24 (1847): 45-46 refers to Breguet's reading the Annals of Electricity.

62Bravais, 2:119, gives the formula for heat produced by a wire where the amount of heat generated is directly proportional to the square of the current (amperage) and a coefficient assigned to each conducting metal (1 for copper wire) and indirectly proportional to the square of the conductor's area and its conductivity. Thus, the Ecole polytechnique equation expressed the same notion as Joule's Law, but used the reciprocal of resistance, namely, conductivity.

63L. Breguet, "Essai sur la télégraphie électrique," 4° Ca 94, Conservatoire National des Arts et Métiers, Paris, pp. 12, 25-27, 34, 38 & 45, cites the usual French scientific journals, Annales de chimie et de physique and the Comptes rendus as well as the German scientific journals, the Annalen der Physik und Chemie and the Jahrbuch der Physik.

64A good introductory discussion of design in engineering is Edwin T. Layton, Jr., "Science and Engineering Design," Annals of the New York Academy of Sciences 424 (1984): 173-181. Design and invention is taken up in Reese V. Jenkins, "Elements of Style: Continuities in Edison's Thinking," ibid., pp. 149-162. An earlier and certainly no less important work is Eugene S. Ferguson, "The Mind's Eye: Nonverbal Thought in Technology," Science 197 (1977): 827-836. While Eda Fowlks Kranakis, "Technological Styles in America and France in the Early Nineteenth Century: The Case of the Suspension Bridge," (Ph.D. dissertation, University of Minnesota, 1982) discusses national technological styles, she does not tackle the problem of the visual in technological or engineering design.

[65]Of those materials yet extant dealing with the Maison Breguet furnished me by Claude Breguet, none provide insight into the visual aspects of telegraph instrument design. Of course, artifacts can clarify questions raised by traditional written documentary evidence and, conversely, verbal sources can illuminate artifacts. The question here is the use of artifacts as historical documentation as well as means for illustrating and analyzing technical and engineering creativity.

[66]"Hughes, David Edward," in Dictionary of American Biography, 5:347.

[67]Yves Deforge, Le graphisme technique: son histoire et son enseignement (Seyssel: Champ Vallon, 1981) discusses both the history and teaching of visual "language" in engineering.

[68]The illustrations are from Jamin, 2d. ed., 3:222, fig. 584, and 3:224, fig. 587.

CHAPTER EIGHT

From *inspecteur* to *ingénieur*

Beginning in 1878, telegraph inspectors began to use the term "*ingénieur*" as part of their official title. The change from *inspecteur* to *ingénieur* took place as a consequence of the fusion of the postal and telegraph bureaucracies. However, the adoption of the new title was not merely a reshuffling of personnel titles: it signalled the emergence of a new specialty within the broad spectrum of engineering work. The background to this change from *inspecteur* to *ingénieur* was an on-going dispute between civilian engineers employed privately and those working for the state. The recruiting of students from both the Ecole polytechnique and the Ecole centrale for the Ecole supérieure de Télégraphie reflected an attempt to bridge this rift. Meanwhile, the take-off of the French electrical lighting industry during the 1870s and the introduction of the telephone in 1879 increased the numbers of those privately employed in positions related to electrical technologies. These privately employed individuals showed signs of playing the dominant role in the formation of French electrical engineering institutions, such as in the sponsorship of an abortive international electrical exhibition. However, the Ministry of Posts and Telegraphs and its corps of *ingénieurs* organized and ran the first international electrical exposition in 1881. Under the guidance of the Ministry, this exposition provided the springboard for the founding of the Laboratoire centrale d'électricité, the nation's largest electrical testing laboratory, and the Société internationale des Electriciens, the French electrical engineering society.

Before examining the role of the Ministry of Posts and Telegraphs in the organization of French electrical engineering institutions, it is necessary to understand the differences between certain French and English cognates. In the United States before 1890, the word "electrician" generally referred to the technical personnel of telegraph companies and to electrical inventors. The use of the term "electrical engineer" came into use sometime before 1892 and distinguished engineers from "bell hangers."[1] Although cognate titles existed in French, namely "_ingénieur-électricien_" and "_électricien_," they did not signify the same concepts as the words used in America. In particular, the use of the expression "_ingénieur-électricien_" did not signal the emergence of electrical engineering in France. Instead, these words reflected the distinctive French milieu within which telegraphy grew into electrical engineering.

The title "_ingénieur-électricien_" referred to a specific position in the hierarchy of the Telegraph Administration created in 1860. As _ingénieur-électricien_, Théodose Du

Moncel undertook theoretical and practical telegraph research for the Conseil de perfectionnement. In addition to indicating a government official charged with conducting electrical research, the term took on a different meaning outside the Telegraph Administration. In 1862, the Paris city directory listed an E. Grenet (n.d.) as an "ingénieur-électricien".[2] Also, an 1868 list of new members of the Society of Encouragement included an ingénieur-électricien. By 1881, five such ingénieurs-électriciens had joined the Society, three of them in 1875.[3] What these ingénieurs-électriciens had in common was that they were inventors of electrical apparatus. Grenet, for example, had invented a rather unique battery that he hoped to sell to physicians as a "galvanocaustic" surgical instrument, that is, an electrical means for cauterizing wounds.[4] From at least as early as the 1830's, the word "ingénieur," either alone or added to an occupational title, indicated an individual who invented or improved something; thus, for example, an "ingénieur-machiniste" was an inventor or improver of machines and an "ingénieur-électricien" was an inventor or improver of electrical apparatus.[5]

However, when telegraph inspectors adopted the title "ingénieur," the implication was not that they were state technical officials or inventors. The title suggested, at least partly, a connection between telegraph inspectors and the *ingénieurs* of the Corps des ponts et chaussées. Certainly, the term "*ingénieur*" was not new to the telegraphs. Claude Chappe's title as founder and head of the telegraph service had been "*ingénieur des télégraphes*" and, before 1830, the telegraphs had been under the Corps des ponts et chaussées.[6] Even after 1830, telegraph personnel continued to wear uniforms copied from that worn by the *ingénieurs* of the Corps des ponts et chaussées and the system of identifying lines adopted in 1860 copied the system that the Corps used to label roads.[7] Thus, the adoption of the title "*ingénieur*" by telegraph personnel in 1879 continued the association of telegraph agents with the *ingénieurs de l'état* and the Corps des ponts et chaussées in particular.

An ongoing dispute between these *ingénieurs de l'état* (all graduates of the Ecole polytechnique) and privately-employed engineers provided the background for the development of electrical engineering institutions in France. The rift usually expressed itself as antipathy toward the Ecole polytechnique and its graduates and had been mounting for some time before telegraph inspectors adopted the title "*ingénieur*". In 1867, for example, an article in *l'Avenir national* attacked the extensive use of Polytechnicians in government, and asked:[8]

> what does transcendental mathematics have to do with the manufacture and purchase of tobacco? with the

> establishment of telegraph lines? . . . Also in the telegraphs, for example, one remarks that among the numerous functionaries graduated from the school, there is not found any outstanding inventor or any electrician. The apparatus in use: the Morse system, the Hughes system, are due to foreigners, and all the improvements introduced, to the simple employees of the French administration.

In 1872, the recruitment of state engineers exclusively from the graduates of the Ecole polytechnique became an issue of heated and extensive debate at the meetings of the Society of Civil Engineers of France (<u>Société des Ingénieurs civils de France</u>). Founded in 1848,[9] the Society of Civil Engineers of France drew its membership from a variety of sources. Although most members were graduates of the Ecole centrale des arts et manufactures, many were graduates of the Ecole polytechnique. The Society's debate over the Ecole polytechnique began with the submission of a report to the Society's membership from its <u>comité sur le système de recrutement des ingénieurs de l'état</u> in December 1871. The committee, not unexpectedly, demanded that the state recruit its civilian engineers from outside the Ecole polytechnique and recommended that the state hire through a system of competitive exams given to anyone who applied. The report further suggested that the Ecole polytechnique grant only a diploma, not a job, to its graduating students, who would have to compete with other engineering school graduates for government jobs.[10] The ensuing deliberations and attacks on the Ecole polytechnique at the meetings of the Society of Civil Engineers of France reached such proportions during 1872 that, in the opinion of one writer, the Society was occupying itself excessively with the Ecole polytechnique.[11]

Nonetheless, despite the request of the Society's honorary president that criticism of the Ecole polytechnique remain outside of the discussion, especially in light of the large number of Polytechnicians among the Society's membership,[12] virtually the entire debate consisted of attacks on the school. These assaults centered upon a few points aimed at "reforming" the school, the most constructive suggestions being: to make the school either all military or all civilian; to include practical instruction in the curriculum; to increase the number of students admitted annually; and to eliminate the upper age limit for entry to the school.[13]

When not griping specifically about the Ecole polytechnique, the members turned to the actual order of the day, the state's recruitment of engineers entirely from the Ecole polytechnique. In order to become a civil engineer with the state, students from the Ecole polytechnique entered the three-year program of the Ecole des ponts et chaussées. The state guaranteed civil engineering positions in the Corps des ponts et chaussées to all those who successfully completed the latter school's program. But the Society of Civil Engineers' comité sur le système de recrutement des ingénieurs de l'état and many members of the Society wanted to eliminate the monopoly (their term) of state engineering jobs granted to graduates of the Ecole polytechnique and the Ecole des ponts et chaussées and to make all government civil engineering positions available on a competitive basis. One of the more radical members even proposed taking the nation's roads, canals, and rivers from the state and putting them in the hands of private companies.[14]

However, as another member pointed out,[15] the motivation of the Society's members in discussing the state's engineer recruiting policy was not to gain entry into government engineering. Aside from a general introspective mood stemming from France's recent humiliating loss in the Franco-Prussian War, the cause of the engineers' complaints about the Ecole polytechnique was the growing number of Polytechnicians who were taking jobs in private employment. As early as 1837, a book on manufacturing noted that the Ecole polytechnique "had already rendered immense service to French industry".[16] As some members of the Society of Civil Engineers bitterly pointed out, when state engineers entered private employment, they obtained a leave that permitted them to remain with the corps of state engineers and thereby retain all retirement rights. Worse, they argued, given the extensive interaction between the state and industry in France, the existence of state engineers in private industry doubtlessly led to favoritism and was not in the interest of stockholders, the public, or the country.[17]

Competition between graduates of the Ecole Polytechnique and the Ecole Centrale for private employment was a particular problem in the railroad industry where 107 of the 788 Corps des ponts et chaussées engineers found positions in 1871.[18] Moreover, these state engineers hired to work for the railroad companies had a particular advantage over Centralians when it came to telegraphy. As part of the usual curriculum, students at the Ecole des ponts et chaussees took a course in telegraphy taught by an inspector from the Telegraph Administration.[19] The invasion of Polytechnicians into private employment extended even to the nascent French electrical lighting industry. Although few Centraliens found positions connected with electrical technology prior to 1870, the growth of the electrical lighting industry during the 1870s provided an increasing source of employment for them, with five graduates in 1872 and nine in 1881 landing jobs with electrical lighting companies.[20] State engineers also found jobs in electrical lighting. In 1859, the Corps des ponts et chaussées began testing an electrical generator for use in France's lighthouses and, throughout the 1860s and later, the Corps installed several generator-driven arc lamp systems in lighthouses.[21] Consequently, the head of the Corps' lighthouse authority became somewhat of an expert on electrical lighting, authoring articles on the subject and becoming one of the founding members of the French electrical engineering society.[22] In addition to running lighthouses, such Ecole polytechnique graduates as Paul Lemonnier (1836-1894)[23] and Marcel Deprez (1843-1918)[24] played major roles in the early history of the French electrical lighting industry.

As with electrical lighting, Polytechnicians (like Froment and Carpentier) and Centralians (like Hardy and Mors) entered the telegraph instrument manufacturing industry. The invasion of state engineers into private employment also involved employees of the Telegraph Administration. For example, Ernest Lami de Nozan (1795-?) entered the Telegraph Administration in 1833 as a station director, became an inspector in 1854, and retired in 1863. Beginning in 1859, however, and with the permission of the Minister of the Interior, Lami de Nozan began a career as director of the Compagnie du télégraphe sous-marin de la Méditerannée. The company did very well until the Italian government "purchased" its lines, operating them for its own profit but without paying Lami de Nozan's company with the result that, by a judgement of 2 November 1866, the tribunal of commerce of the Seine declared the company dissolved. For four years, however, Lami de Nozan ran a privately-owned telegraph cable company and at the same time was an inspector in the Telegraph Administration from which he began to draw a pension in 1866.[25]

Another telegraph inspector who found private employment outside the Telegraph Administration was Gustave Marqfoy (1831-?), a graduate of the Ecole polytechnique. Marqfoy's work as an inspector brought him in close contact with the railroad companies which, at that time, were largely responsible for the construction of French telegraph lines. In 1854, Marqfoy asked for and received a three month leave of absence during which time he worked for a railroad company as an engineer. Because Marqfoy failed to return to work at the end of three months, de Vougy removed him from the ranks of the telegraph service in March 1855.[26] Marqfoy had little trouble finding work with various railroad companies after his dismissal from the Telegraph Administration.[27]

Obtaining an extended leave from the Minister of the Interior in order to enter private employment was a privilege attainable by all Telegraph Administration employees under de Vougy and Alexandre. In 1858, Alexandre informed all inspectors through a circular that the Minister of the Interior would authorize leaves for them to take positions in private employment or in other countries. These special absences were to last no longer than five years. Employees on special leave lost their right to advancement but retained retirement benefits provided that they deposited the appropriate amount with the Treasury during their absence.[28] Although the number of employees entering private employment is not known, by 1861, de Vougy complained that too many agents were taking leaves.[29] A decree of 20 January 1862 placed the granting of special leaves in the hands of de Vougy instead of the Minister of the Interior and, henceforth, any employee granted an absence to work for a company or in another country could return to the Telegraphs only if a position were available.[30]

While the increasing employment of Polytechnicians in industry provided the background for the organization of electrical engineers and electrical engineering institutions in France, the immediate reason for telegraph inspectors adopting the title "ingénieur" was the fusion of the postal and telegraph administrations. The unification of the two bureaucracies was an old issue that telegraph inspectors had always resisted. Nevertheless, when the two authorities did join in 1878, the bureacratic changes made possible by the combining of the two hierarchies permitted the creation of a purely technical service and a specialized corps of telegraph agents.

As early as 1828, the head of the French post office had proposed joining the telegraphs to the postal administration. After a second unsuccessful attempt in 1847, the proposition came up again in 1864 when the government named a mixed commission of members of the Senate, the Corps législatif (the lower house), and the Conseil d'état.[31] The commission studied the personnel and materiel of the postal and telegraph services to determine whether unification of the two bureaucracies would reduce operating costs. The commission concluded that no savings of materiel would be realized except in small post offices. Since (1) the work of the telegraph inspectors "imperatively required a very extensive amount of scientific knowledge which had no use in the postal service" and, consequently, this knowledge was notably lacking among postal workers, and (2) personnel in both administrations were working to their limits, the commission concluded that unification would not bring savings of personnel except possibly in the smallest of bureaus.[32] In addition to the commission's report, the heads of the postal and telegraph services submitted their own reports to their respective ministers. The chief of the postal service argued that union would "democratize" the telegraph which was, he claimed, available only to the rich. De Vougy presented budgetary, political, and bureaucratic reasons against unification, but without reference to the need for specially trained staff in the telegraph service.[33]

After the war against Prussia, a proposal for uniting the two bureaucracies resurfaced and a new commission reported on the project to the National Assembly in 1872. Since 1864, Germany, Switzerland, Belgium, and Britain had combined their postal and telegraph bureaucracies in some fashion and their example proved decisive in forming the commission's opinion.[34] In delineating the personnel reductions that fusion would allow, the commission singled out, among other positions, that of the two electrical engineers ("ingénieurs-électriciens") who, the report complained, "have no other duties, it seems to us, than to conduct experiments to hasten the development of the telegraphic art."[35] Although the creation of the ingénieur-électricien position seems to have been wise from the point of view of the beginnings of electrical engineering and the organization of research, at least one politician of the Third Republic believed the opposite. The commission's insensitivity to the special technical requirements of the telegraph service evoked a response from telegraph inspector Edouard Ernest Blavier, who examined the merger question in a 126-page work.

After destroying every economic argument put forward for unification, including the advantages of joining the services in the smallest offices, Blavier argued that a good telegraph inspector must possess a technical and theoretical instruction which had nothing in common with that required of equivalent postal employees.[36] Telegraphy, he explained, was based upon the laws and properties of electricity and each new discovery in physics could lead to improvements. Furthermore, telegraphy was so dependent upon science that few issues of the <u>Comptes rendus</u> of the Academy of Sciences did not contain material dealing directly or indirectly with telegraphy and, in recognition of the relationship between telegraphy and science, Alphonse Foy had recruited inspectors from the Ecole polytechnique. Conversely, he declared, the telegraph network was a vast instrument for making observations of electrical phenomena useful to the advancement of science.[37]

Despite the objections raised by Blavier and the report submitted by Henri Pierre Pierret, director of the Telegraph Administration,[38] the lure of reduced bureaucratic costs and the apparent success of other countries like Britain led the National Assembly to vote the unification of the postal and telegraph authorities into law on 6 December 1873. After lengthy planning, a <u>règlement</u> published 10 July 1876 specified the conditions under which the two administrations would combine. With a decree of 22 December 1877, Adolphe Cochery took control of the postal service and, by a decree of 27 February 1878, control of the telegraphs as well, with the title <u>Sous-secrétaire d'Etat aux Finances</u>. A decree of 5 February 1879 removed the postal service and telegraphs from the Ministry of Finance and created the Ministry of Posts and

Telegraphs, with Cochery as head.[39]

First under the Ministry of Finance then as the first Minister of Posts and Telegraphs, Cochery took advantage of the potential for change made possible by the combining of the two administrations: he created a specialized corps within the Ministry of Posts and Telegraphs concerned solely with technical matters and instructed in the latest science. This technical corps, called the _Direction technique des lignes télégraphiques_, required "the special science of an engineer," agents "not only knowledgeable of current science, but even prepared to hasten its progress."[40] The _Direction technique_ was bureaucratically distinct from the remainder of the telegraph and postal workers and consisted of regional _directeurs-ingénieurs_ overseeing the work of the _ingénieurs_, as the inspectors now came to be called. Beneath the _ingénieurs_ were the _sous-ingénieurs_ and other technical personnel such as the line and apparatus repairmen.[41] With their unique use of the title _ingénieur_ among postal and telegraph employees and their knowledge of "the special science of an engineer," the _directeurs-ingénieurs_, _ingénieurs_, and _sous-ingénieurs_ formed a body of specialized engineers within the Ministry of Posts and Telegraphs and a new engineering specialization had emerged.

The recruiting of _ingénieurs_ for Cochery's _Direction technique_ seemed to address two questions. The first was the dispute between state and private engineers. The Ecole supérieure de Télégraphie, which trained sous-ingénieurs for the corps, accepted graduates from the Ecole centrale and other schools as well as from the Ecole polytechnique, thereby opening ingénieurs de l'état positions to non-Polytechnicians. The second question involved the hiring from within versus hiring from the Ecole polytechnique. Cochery created a preparatory school for the Ecole supériure de Télégraphie that permitted lower level agents to rise into inspector positions. Further changes he instituted abbreviated the time required to advance into an ingénieur position.

Before Cochery's reorganization, an employee took a long time to rise from operator to inspector, as illustrated by the example of Léon Tamisier (1832-1876). After holding the chair of mathematics at the collèges of Poligny, Saint-Claude, and Louis-le-Saulnier, Tamisier entered the telegraph service as an operator in 1853. He became a station director in 1855, sub-inspector in 1866 and, in 1875, head of the telegraph service in Algeria.[42] Therefore, it took Tamisier thirteen years to become a sub-inspector. Such waits were not atypical. Emile Alexandre Cuche (1830-?), for instance, entered as an operator in 1851 and did not become an inspector until 1878, twenty-seven years later.[43]

With Cochery's changes, an individual aspiring to an ingénieur position in the Ministry of Posts and Telegraphs theoretically could successfully become a sous-ingénieur after only four years. First, the candidate took the general entrance examination taken by applicants for all positions whether in the postal or telegraph services plus the special exam for the technical service. Following successful completion of the tests, the aspirant spent six months in an operator training program in Paris, Brest, Bordeaux, or Montpellier. The examen du second degré provided access to higher positions. Upon passing that test and after two years of service, the would-be ingénieur took the competitive examinations to get into the Ecole supérieure de Télégraphie (or its preparatory school if necessary). Thus, with the proper education, someone could enter the telegraph service, attend the Ecole supérieure de Télégraphie after two years, and, after two more years at the Ecole, become a sous-ingénieur in the Direction technique.[44] An example of such rapid advancement is Albert Bazille (1859-?), who joined the telegraphs in 1879 as an operator trainee for one month, served in the military for four years, and returned to the telegraphs as a trainee in 1884. Bazille entered the Ecole supérieure de Télégraphie in 1887 and became a sous-ingénieur on 20 January 1890, after five years and ten months of service.[45]

Before the creation of these new career opportunities and the recruitment of _ingénieurs_ for the _Direction technique_ from within the Ministry of Posts and Telegraphs, the Ecole polytechnique, and other schools, private interest in electrical technology and industry grew and promised to provide the main thrust for the organization of electrical engineering institutions in France. The electrical lighting industry began to grow during the 1870s and the telephone arrived in 1879, providing a larger and larger number of engineering jobs outside the state and adding to those which already existed in the manufacture and installation of electric alarms and signals and other electrically-related fields. In 1875, Count Olivier Hallez d'Arros (n.d.)[46] started to promote an international electrical exhibition. His project marked the beginning of the organization of electrical industry and engineering outside the state.

Throughout 1875, Count Hallez d'Arros wrote to the Ministers of Public Works, of War, of the Navy, and of Public Instruction to obtain a site for his "_Exposition internationale des applications de l'électricité aux sciences, aux arts et à l'industrie_." The Minister of Public Works granted him use of the Palais de l'Industrie for the period 1 July through 30 November 1877.[47] By 1 January 1876, Count Hallez d'Arros had set up an organizational committee that consisted of an impressive array of government officials, Polytechnicians, inventors, and manufacturers of electrical apparatus, but included no one from the Telegraph Administration. Among the electrical manufacturers were several constructors of telegraph instruments: Louis and Antoine Breguet, Deschiens, Digney, Hardy, and Mors.[48] At a meeting of the organizational committee held at the Palais de l'Industrie on 14 October 1875, general operating rules were voted on and adopted. These rules stipulated that the exposition would be under the patronage of a private authority, composed of "scientific, artistic, industrial, administrative, military, and naval notables".[49]

The Count came very close to putting on his exposition. By the end of 1875, Count Hallez d'Arros also had organized committees to carry out the work of putting together the exhibition and established a program that divided all exhibitors into eighteen groups. One group was to be electric telegraphy, subdivided into four categories: wires and electric cables; alarms and signals; house telegraphs; and other telegraph apparatus.[50] Therefore, the exhibits of the Telegraph Administration, if it chose to participate, would be in the shadow of telegraphs from other countries, alongside electrical bells and signals and electrical wire and cable, all of which would be huddled in a corner of the Palais de l'Industrie, while seventeen other groups similarly vied for the public's attention. Worse, organization of the show was in private hands, not those of the Ministry. The proposed exhibition generated excitement in the scientific and general press[51] as well as within the Society of Civil Engineers of France. Presenting a plan for the exhibition at the 15 October 1875 meeting of the Society was Jules Armengaud (1842-1921), a graduate of the Ecole polytechnique, one of the Society's more prominent members, and one of the commissioners for the proposed exhibition.[52]

In addition to support from Armengaud and the Society of Civil Engineers, Count Olivier Hallez d'Arros sought support more generally and hoped to spread information about his planned exposition (and electrical science and technology in general) by founding a journal, _L'Electricité: Revue scientifique illustrée_.[53] _L'Electricité_ carried letters pledging support for the project, including those from Armengaud, Théodose Du Moncel (at the time no longer with the Telegraph Administration), various Polytechnicians, members of the Academy of Science, and the civilian and military government. The only published letter that came close to representing the telegraphs was that of E. E. Blavier. His letter expressed interest in the exposition, but, Blavier explained, "I am obligated to await the authorization of the Administration of the telegraph lines" before supporting the project.[54]

Despite what appeared to be widespread backing, the international electrical exposition never took place. In the

July-August 1876 issue of L'Electricité, Count Olivier Hallez d'Arros announced that he was abandoning the 1877 exhibtion because an international exposition was to take place in Paris in 1878. It seemed that the patriotic thing would be to abandon his personal project and to concentrate on the international exposition for the glory of France. His journal would continue to appear, he promised, but as "a special organ of electrical industry at the 1878 Exposition."[55]

The Paris International Exposition opened on 1 March 1878, the same date on which the postal and telegraph services were united.[56] One of the exhibition's attractions was the Pavillon des Electriciens, devoted not to electrical technology and industry in general, as one might expect, but exclusively to telegraphy and where the major exhibitor was the telegraph service.[57] After the triumph of the 1878 exposition, what better way was there to celebrate the merger of the post office and telegraphs - and to show off the newly created Ministry of Posts and Telegraphs - than an international electrical exposition sponsored by the Ministry? On 6 December 1880, Adolphe Cochery placed a bill before the Chamber of Deputies requesting an expenditure of 300,000 francs for an international exposition of electricity and a congress of electricians.[58] A week later, the Minister returned and demanded an immediate vote on the bill.[59] In the words of L'Electricité, "this law passed like a letter at the post office".[60] The Chamber approved it unanimously.[61]

Cochery had not moved too quickly. The manufacturers of electrical equipment had started to organize. Hippolyte Fontaine (1833-1910), director of the Société des machines magnéto-électriques Gramme,[62] founded the Chambre syndicale de l'Electricité in 1879. The group concerned itself with such economic questions as tariffs and individual members gave talks on subjects relating to electrical technology and carried out various technical studies. The membership consisted of manufacturers of electrical lighting equipment, like Fontaine, Lemonnier, and Antoine Breguet, and telegraph instruments, such as Antoine Breguet, Carpentier, Mors, and Digney. Antoine Breguet, then Jules Armengaud, followed Fontaine as the Chambre syndicale's first presidents.[63]

Individually, the members of the Chambre syndicale de l'Electricité pledged 10,000 franc subscriptions to the exposition's capital guarantee fund, joining the Minister of Posts and Telegraphs and such banking firms as the Rothschilds. The need for private funding had arisen because the Ministry had begun organizaing the exhibition while the legislature was not in session. Although Louis Breguet and Cochery subscribed to the fund, electrical lighting manufacturers outnumbered telegraph people and included the Société génerale d'Electricité (Jablochkoff's company), Lemonnier, Armengaud, and Fontaine.[64] Many of the subscribers also joined the exposition's consultative commission, a 77-member commission named by the President of the Republic and officially responsible for deliberating all matters relating to the exposition.[65]

For the most part, though, the consultative commission consisted of appointees from the Senate and Chamber of Deputies (23), the Academy of Science (13), and the Corps des ponts et chaussées (7). The remaining 34 members represented banks, railroads, journals, and a variety of public institutions such as the Paris city council and the National Academy of Music. From the Ministry of Posts and Telegraphs came E. E. Blavier and two other _ingénieurs_. The head of military telegraphs, the director of the cabinet of the Ministry of Posts and Telegraphs, Louis Breguet, and a major French manufacturer of telegraph cables, but no electrical lighting equipment manufacturers, served on the consultative commission.[66]

The technical committee, the group charged with overseeing the installation and other technological aspects of the exhibits, also comprised a large number of individuals from the Senate and Chamber of Deputies, the Academy of Science, and the Corps des ponts et chaussées (12 out of 30). However, in comparison with these groups, and with representatives from the electrical lighting industry, the Ministry of Posts and Telegaphs contributed the largest number of members, including the committee's president (who was the Minister of Posts and Telegraphs). Antoine Breguet served as the committee's secretary and directly oversaw the setting up of all exhibits.[67] Furthermore, telegraph ingénieurs played a significant role as judges on the exposition's international juries. The secretary of the jury for telegraphs and telephones was E. E. Blavier and seven out of the seventeen Frenchmen judging telegraph entries were telegraph ingénieurs.[68]

The awarding of medals by the exposition's juries provided an opportunity to pay tribute to the Ministry of Posts and Telegraphs, its ingénieurs of the Direction technique, and the French telegraph manufacturing industry. In addition to an unspecified number of diplomas of honor, the juries were to award 50 gold, 200 silver, and 500 bronze medals.[69] Diplomas of honor not unexpectedly went to the Ministry of Posts and Telegraphs, the Ecole supérieure de Télégraphie, the Maison Breguet, and Emile Baudot. Fourteen gold medals went to French telegraph manufacturers, including Carpentier, Deschiens, Digney, Ducretet, Dumoulin-Froment, Hardy, Mors, and the inventor and telegraph agent Bernard Meyer. Other French telegraph employees, like Rouvier, won many silver medals, and only three bronze medals (the lowest honor bestowed) went to French telegraph service employees or manufacturers.[70]

Taking place at the same time as the International Electrical Exposition was the Congress of Electricians. The Minister of Posts and Telegraphs named the French delegation to the Congress. The president of the delegation was the Minister himself, with the ministers of public instruction, public works, and war serving as his vice-presidents. Although most of the 63 members of the French delegation taught science at the lycée level or higher or were members of the Academy of Science, seven were telegraph _ingénieurs_ (including Blavier and Raynaud) and one a manufacturer (Louis Breguet).[71] Thus the Ministry made a show of the Congress as well. The delegates to the Congress discussed a number of questions and the greatest concern was to reach an agreement on an international system of electrical units. Although the Congress of Electricians failed to establish such a system, it did agree to set up an international commission that would meet the next year and discuss the issue.[72]

By playing the chief role in the organization and running of the 1881 Paris International Electrical Exposition amd Congress of Electricians, the Ministry of Posts and Telegraphs and the _ingénieurs_ of its _Direction technique_ placed themselves in a position to direct the future organization of electrical engineering institutions in France for it was at the exhibition, according to A. P. Trotter, that "electrical engineering was born". Continuing its directive role, the Ministry used the exposition as a springboard for the organization of the country's chief electrical research and testing laboratory and the French electrical engineering society.

The French organization of electrical engineers, called the Société internationale des Electriciens, originated with a series of banquets started during the 1881 Electrical Exposition. As early as 6 November 1881, Antoine Breguet talked with Adolphe Cochery about the creation of a Société française d'Electricité and the nomination of Blavier as the Société's first president.[73] Those who attended the series of banquets were members of the Academy of Science, government officials, representatives of the scientific press (including Count Olivier Hallez d'Arros), electrical inventors and manufacturers, and telegraph ingénieurs. Adolphe Cochery hosted the first banquet. Presiding over the second banquet was Georges Berger (1834-1910), a graduate of the Ecole polytechnique, former engineer in the Corps des mines, member of the board of directors of the Maison Breguet, and an organizer of international expositions (including the 1878 Paris International and the 1881 Electrical Expositions) since 1867.[74] At the banquet of 21 June 1883, held in the building of the Ministry of Posts and Telegraphs, those in attendance discussed the formal creation of a society and named a committee to write statutes.[75]

With statutes written and approved, the society announced its formal organization at a meeting of 13 December 1883. The headquarters and meeting place of the Société internationale des Electriciens became the building of the Ministry of Posts and Telegraphs. The honorary president of the Société internationale des Electriciens was Adolphe Cochery. The membership was divided into six sections: electrical theory, electric motors and machines, electric light, telegraphy and telephony, railroad signals, and electrochemistry and electromedicine. The head of the telegraphy and telephony section was Blavier with another Ministry agent the section secretary. No one from the French telephone company held an equivalent position. Du Moncel became chief of the electrochemistry and electromedicine group, the section's secretary a member of the board of directors of the Maison Breguet.[76]

In addition to assuming the two leadership positions of the telegraphy and telephony section of the society, employees of the Ministry of Posts and Telegraphs made up a large portion of the society's founding members. As the name of the Société internationale des Electriciens implied, the organization comprised members from many countries. A list of founding members dated 15 January 1884[77] named 1,155 individuals, 310 of which were foreigners. Another 304 were French but did not provide any occupational title. Of the remaining 541 French members with identified occupations, 111 were employed with the Ministry of Posts and Telegraphs. In comparison, 56 were members of the Academy of Science or on a science faculty, 52 called themselves _électriciens_ or _ingénieur-électriciens_, 56 gave their occupation as simply _ingénieur_, and only 10 worked for the telephone company. In addition to the agents of the Ministry of Posts and Telegraphs, 11 telegraph instrument manufacturing firms were among the founding members, with 5 members alone from the Maison Breguet.

The Ministry of Posts and Telegraphs, with the aid of the Société internationale des Electriciens, organized and built France's major electrical laboratory. The 1881 Electrical Exposition left the Ministry of Posts and Telegraphs with over 300,000 francs after paying off all bills.[78] The Ministry decided to use the money to set up a "_laboratoire central d'électricité_" to continue the electrical measurement work begun by the Congress of Electricians. Therefore, a decree of 24 February 1882 set aside 300,000 francs of the exhibition's profits for the creation of the Laboratoire. Nonetheless, the sum was insufficient to assure complete functioning of the laboratory and remained unused until, in 1885, the newly founded Société internationale des Electriciens approached the Minister of Posts and Telegraphs and suggested that the Société and

Ministry jointly participate in the running and financing of the project. Cochery agreed and, by a decree of 12 July 1888, provided the Société internationale des Electriciens with 30,000 francs toward the initial cost of setting up.[79]

On 30 September 1886, the remainder of the exposition money was turned into an annuity with E. E. Blavier in charge of the fund. The Minister of Posts and Telegraphs named a sous-ingénieur as head of the laboratory on 9 November 1886. The Ministry and the Société internationale des Electriciens jointly appointed a commission d'études, under the presidency of Blavier, to find additional money for the laboratory and asked industry to donate apparatus. The Société nominated a committee to run the laboratory and only two of the seven nominees were ingénieurs of the Posts and Telegraphs. This committee approved the installation project drawn up by the sous-ingénieur and began ordering apparatus in July 1887, the same month that donated equipment began to arrive. Finally, during a ceremony held the 9 and 10 February 1888, the Laboratoire centrale d'Electricité officially opened, with members of the Société internationale des Electriciens, the Ministry of Posts and Telegraphs, manufacturers, and members of the Academy of Science attending.[80]

The Laboratoire was to be (1) a board of standards for all electrical measurements; (2) a bureau to serve private industry by testing their measuring apparatus, primary materials (insulators, and so forth), machines, batteries, sources of light; and (3) a place for instructing students in the instruments of electrical measurement. In fulfilling this last goal during its first year, the laboratory admitted eight students, six French and two foreign. Three were graduates of the Ecole polytechnique, two from the Ecole centrale, one a licencié ès physique; the two foreigners were an officer in the Norwegian army and a Russian engineering student from the Saint Petersburg civil engineering school.[81]

The 1881 International Electrical Exposition indeed was the birthplace of French electrical engineering institutions. But it was the exhibition's sponsor, the Ministry of Posts and Telegraphs, that was largely responsible for the exposition and for pioneering in the founding of France's electrical engineering institutions: the Ecole supérieure de Télégraphie, the Société internationale des Electriciens, and the Laboratoire centrale d'Electricité. The creation of the Ministry was a consequence of the unification of the postal and telegraph hierarchies; the work of the Ministry of Posts and Telegraphs in organizing these early French electrical engineering institutions was the work of Adolphe Cochery. How long telegraphy could continue to play a dominant role in French electrical engineering would depend upon Cochery's ability to withstand changes of government and the dynamics of the rapidly growing French electrical lighting industry.

FOOTNOTES

[1]A. Michael McMahon, The Making of a Profession: A Century of Electrical Engineering in America (New York: I.E.E.E. Press, 1984), pp. 36-37.

[2]Annuaire du commerce, 1862, p. 298. I have found nothing to indicate Grenet's first name, dates, or other biographical information.

[3]Based upon a search of the lists of new members of the Society of Encouragement published annually in the Society's Bulletin. The other "ingénieur-électricien" joined in 1870.

[4]Patent no. 30,440, 8 January 1857; no. 38,811, 7 June 1858; no. 54,944, 22 July 1862; and Notice sur la pile électrique de M. Grenet dans les applications chirurgicales et sur les opérations que l'on peut faire avec cet instrument (Paris: Imprimerie de L. Martinet, 1859).

[5]Shinn, "Des Corps de l'Etat au secteur industriel: La genèse d'une nouvelle profession, 1750-1920," Revue française de la sociologie 19 (1978): 39-40, focuses on the shifting definition in French dictionaries of the term "ingénieur" from an employee of the state to a privately-employed individual. His work omits any discussion of the word as meaning an inventor. For my discussion of the word, I have relied upon the entry "ingénieur" in the following works: Institut de France, Dictionnaire de l'Académie française, 6th ed. (Paris: Firmin Didot frères, 1835), II:35-36; Supplément au dictionnaire de l'Académie française, 6th ed. (Paris: Gustave Barba, 1836), p. 457; Ch. Nodier and L. Barré, Dictionnaire universel de la langue française, 9th ed. (Paris: Firmin Didot frères, 1839), p. 397; Petit dictionnaire de l'Académie française (Paris: Firmin Didot frères, 1855), p. 346; Ch. Nodier and M. Ackermann, eds., Vocabulaire de la langue française extrait de la sixième et dernière edition du dictionnaire de l'Académie (Paris: Firmin Didot frères, 1849), p. 565; A. Beaujean, Dictionnaire de la langue française abrégé du dictionnaire de E. Littré, 7th ed. (Paris: Hachette et Cie, 1885), p. 593; E. Bouant, Dictionnaire-manuel-illustré des connaissances pratiques, 2d ed. (Paris: Armand Colin et Cie, 1897), p. 371; A. Beaujean, Dictionnaire de la langue française abrégé du dictionnaire de E. Littré, 11th ed. (Paris: Hachette et Cie, 1905), p. 594.

[6]Gerspach, pp. 68 & 231.

[7]"Ordonnance du roi portant règlement sur le service de la télégraphie," _Lois et règlements_, 24 August 1833; "Décret qui règle le traitement et l'uniforme des fonctionnaires et agents des lignes télégraphiques," _ibid_., 4 June 1854; "Décret relatif à l'organisation administrative et à la règlementation du service extérieur des lignes télégraphiques," _ibid_., 29 November 1858; and, H. Blerzy, "Nouvelle organization du réseau télégraphique française," _Annales télégraphiques_ 2,6 (1863): 6-15.

[8]_Journal des télégraphes_ 2 (October 1867): 5-6: "Or, qu'ont à voir les mathématiques transcendantes dans la fabrication et l'achat des tabacs? dans l'établissement des lignes télégraphiques? . . . Aussi dans les télégraphes, par exemple, on remarque que parmi les nombreux fonctionnaires sortis de l'école, il ne s'est révélé aucun inventeur ni aucun électricien hors ligne. Les appareils en usage: le système Morse, le système Hughes, sont dus à des étrangers, et tous les perfectionnements introduits, à de simples employés de l'administration française."

[9]For a history of the Society of Civil Engineers of France, see _125 ans de progrès technique vus à travers la Société des Ingénieurs civils de France_ (Paris: Société des Ingénieurs civils de France, 1973).

[10]"Communication du comité sur le système de recrutement des ingénieurs de l'état," _Mémoires de la Société des Ingénieurs civils de France_ (1871): 507-512.

[11]_Annales industrielles_ 3 (1872): 324-325.

[12]_Mémoires de la Société des Ingénieurs civils de France_ (1872): 86.

[13]A record of the debate appears in the _Mémoires de la Société des Ingénieurs civils de France_ (1872): 78-89; 93-109; 123-139; 141-163; and 213-243.

[14]_Ibid_., pp. 100-102, 151, 215, & 220-221.

[15]_Ibid_., p. 87.

[16]François Noël Mellet, "Ingénieur," in A. Baudrimont et al, _Dictionnaire de l'industrie manufacturière, commerciale et agricole_ (Paris: J. B. Baillière, 1837), 16:513. The article gives a concise history of engineering in France.

[17]_Mémoires de la Société des Ingénieurs civils de France_

(1872): 87, 94-95, 100, 102, 216, 221, 223 & 235.

[18] Ibid., pp. 100 & 222.

[19] J. A. G. Amiot, Ecole des ponts et chaussées: Conférences sur la télégraphie électrique, session 1864-65 (Paris: n.p., 1865) and Amiot, Résumé des conférences sur la télégraphie électrique, session 1873-74 (Paris: n.p., 1874). d'Ocagne, p. 362, refers to this course.

[20] Annuaire de l'association amicale des anciens élèves de l'Ecole centrale des arts et manufactures (Paris: Association amicale des anciens élèves de l'Ecole Centrale des Arts et Manufactures, 1909), pp. 500-501 & 507.

[21] W. James King, "The Development of Electrical Technology in the 19th Century: The Early Arc Light and Generator," United States National Museum Bulletin 228 (1962): 334,339-340, 342, & 357-360.

[22] In the 1860s, the chief of lighthouses was Léonce Reynaud. For an example of the articles he wrote on electrical lighting, see his "Eclairage des phares par la lumière électrique," Annales télégraphique 2,6 (1863): 369-384. In 1884, the chief of lighthouses was Félix Lucas, whose membership in the International Society of Electricians is indicated in "Comité d'administration," Bulletin de la Société internationale des Electriciens 1 (1884): 23.

[23] While not attempting to delineate in detail the role of Polytechnicians in the development of electrical lighting in France, I hope that the examples given here serve to indicate at least the presence of Polytechnicians competing with Centraliens in the field of electrical lighting. For Lemonnier, see A. Brüll, "Notice nécrologique sur Paul Lemonnier, membre du conseil d'administration de la Société d'encouragement pour l'industrie nationale," Bulletin de la Société d'encouragement 93 (1894): 634-638 and "Paul Lemonnier," Bulletin de la Société internationale des Electriciens 1,11 (1894): 384.

[24] For Marcel Deprez, see H. Sebert, "Notice sur M. Marcel Deprez," Comptes rendus 167 (1918): 570-574.

[25] Personnel folder, "Lami de Nozan," F(90) 20,539, Archives Nationales, Paris. Information on the company's dealings with the Italian government and its eventual dissolution come from the Journal des chemins de fer 21 (1862): 646; 24 (1865): 101-102; 24 (1865): 595; and 25 (1866): 740.

[26]Marielle, pp. 151 & 205-206; Foy to the Director of the Compagnie du chemin de fer de Paris à Orléans, 31 March 1853, 60 AQ 334; de Vougy, "Rapport à Monsieur le Ministre de l'Intérieur, 8 March 1855, F(1a) 1986(4); and arrêté of the Minister of the Interior, 9 March 1855, F(1a) 1986(4), Archives Nationales, Paris.

[27]I have not found any biographical articles on Marqfoy to indicate what positions he held. However, according to Montoriol, p. 709 and Marqfoy, Notice élémentaire sur la télégraphie électrique (Paris: Victor Dalmont, 1858), title page, he worked for the Compagnie du chemin de fer du Midi as an engineer.

[28]Circular no. 162, Lois et règlements, 29 November 1858.

[29]For instance, see "Invitation de n'accorder des congés que dans les cas d'extrême urgence," Lois et règlements, 9 March 1861.

[30]"Décret portant réorganisation du service télégraphique," Lois et règlements, 20 January 1862.

[31]Emile Delfieu, Le monopole télégraphique et téléphonique (Nimes: P. Gellion et Bandini, 1918), pp. 14-17 and Annales télégraphiques 2,7 (1864): 319-320.

[32]Commission chargée d'examiner le projet de fusion des Postes et Télégraphes, Rapport du 7 avril 1865 (Paris: n.p., 1865), in discussing the duties of telegraph inspectors, "Ces fonctions exigent impérieusement une somme de notions scientifiques très-étendues, sans application dans le service des Postes."

[33]"Documents relatifs au projet de fusion des adminstrations des postes et des télégraphes," Annales télégraphiques 2,7 (1864): 613-663.

[34]Charles Rolland, "Rapport fait au nom de la commission des services administratifs (postes et télégraphes)," Journal officiel de la république française, 10 July 1872, p. 4700.

[35]Rolland, p. 4701: "Ils n'ont de charge, ce nous semble, que de faire des expériences pour hâter le développement de l'art télégraphique."

[36]Blavier, Considérations sur le service télégraphique et sur la fusion des administrations des postes et des

<u>télégraphes</u> (Nancy: Sordoillet et fils, 1872), p. 32.

[37] <u>Ibid</u>., pp. 46-47.

[38] Referred to in <u>ibid</u>., pp. 88-89.

[39] Delfieu, pp. 17-19.

[40] "Circulaire no. 17," dated 12 July 1878, <u>Bulletin Mensuel des Postes et Télégraphes</u> 1 (June 1878): 143: "<u>la science spéciale de l'ingénieur</u>" and <u>ibid</u>., p. 144: "l'enseignement technique . . . donnera à l'Etat des fonctionnaires non-seulement au courant de la science actuelle, mais prêts encore à en hâter les progrès."

[41] "Arrêté déterminant les attributions des différents services de l'Administration," <u>Bulletin mensuel des Postes et Télégraphes</u> 1 (1878): 5-15; "Circulaire sur la fusion des deux services des postes et des télégraphes," <u>ibid</u>., pp. 15-20; and "Instruction no. 30," <u>ibid</u>., pp. 289-306.

[42] "M. Léon Tamisier," <u>Annales télégraphiques</u> 3,3 (1876): 289.

[43] Personnel dossier, F(90) 20,536, Archives Nationales, Paris.

[44] "Arrêté déterminant les conditions d'admission," <u>Bulletin mensuel des postes et télégraphes</u> 2 (November 1879): 716 & 721 and Cochery, <u>Journal officiel de la République française</u>, 12 June 1884, p. 3164.

[45] Personnel dossier, F(90) 20,511, Archives Nationales, Paris.

[46] I have not been able to find any biographical information on Count Olivier Hallez d'Arros.

[47] "Lettres ministérielles," <u>L'Electricité: Revue scientifique illustrée</u> 1 (1876-1878): 17. Hereafter cited as <u>L'Electricité</u>.

[48] "Comité d'organisation," <u>L'Electricité</u> 1 (1876-1878): 18-19.

[49] "Règlement général," <u>L'Electricité</u> 1 (1876-1878): 19.

[50] "Programme générale," <u>L'Electricité</u> 1 (1876-1878): 22-23 and <u>Mémoires de la Société des ingénieurs civils de France</u> (1875): 732 & 734-736.

[51]"L'Exposition internationale d'électricité et la presse," L'Electricité 1 (1876-1878): 23-24.

[52]LePrieur, p. 1; Bulletin de la Société d'encouragement 120 (1921): 400-401; and Mémoires de la Société des ingénieurs civils de France (1875): 730.

[53]"A nos lecteurs," L'Electricité 1 (1876-1878): n.p.

[54]Letters written to Count Hallez d'Arros in support of the international electrical exhibition are in "extraits de lettres d'adhesion reçues par l'initiateur du projet," L'Electricité 1 (1876-1878): 61-64 & 80. Blavier's letter is in ibid., p. 64.

[55]"Avis aux lecteurs," L'Electricité 1 (1876-1878): 81: "organe spécial des industries électriques à l'Exposition de 1878."

[56]Alphonse Bertrand, L'Organisation française (Paris: A. Quantin, 1882), p. 308.

[57]Exposition universelle de 1878, Guide-itinéraire du visiteur (Paris: E. Dentu, 1878), p. 207.

[58]Journal officiel de la république française, 7 December 1880, p. 12,026.

[59]Ibid., pp. 12,282-12,283.

[60]"Exposition internationale d'électricité," L'Electricité 3 (1880): 370: "cette loi a passé comme une lettre à la poste". The implication is that the Chamber of Deputies voted the law with the same mechanical motion as that of a postal worker cancelling or sorting a letter.

[61]Journal officiel de la République française, 7 December 1880, p. 12,283.

[62]Maurice Magnien, "Un inventeur, un administrateur: Hippolyte Fontaine," Bulletin d'histoire de l'électricité 4 (1984): 5-29.

[63]Ministère du Commerce et de l'Industrie, Annuaire des syndicats professionnels, industriels, commerciaux et agricoles consitutés conformément à la loi du 21 mars 1884 en France et en Algérie (Paris & Nancy: Berger-Leurault et Cie., 1894), p. 289; "Chambre syndicale de l'Electricité," L'Electricité 3 (1880): 112; and L'Electricité 9 (1885): 59.

[64]Exposition internationale d'électricité, "Liste des souscripteurs au capital de garantie," F(12) 3171, Archives Nationales, Paris.

[65]Journal officiel de la république française, 24 December 1880, pp. 12,765-12,766.

[66]Ibid., pp. 12,765-12,766.

[67]Exposition internationale d'électricité, "Comité technique," F(12) 5016, Archives Nationales, Paris.

[68]Exposition internationale d'électricité, "Jury international des récompenses," F(12) 5016, Archives Nationales, Paris.

[69]Exposition internationale d'électricité, "Jury international des récompenses," F(12) 5016, Archives Nationales, Paris.

[70]"Exposition d'électricité: Distribution des récompenses," Annales télégraphiques 3,8 (1881): 471-503.

[71]"Exposition internationale d'électricité et Congrès d'électricité de 1881," Annales télégraphiques 3,8 (1881): 250-253.

[72]"Congrès internationale des électriciens," Annales télégraphiques 3,8 (1881): 444-470.

[73]"Antoine Breguet" folder, Collection Breguet, Paris.

[74]"Berger, Georges," in M. Prevost and Roman d'Amat, eds., Dictionnaire de biographie française (Paris: Letouzey et ané, 1951), 5:1515 and René Samuel and Georges Bonét-Maury, eds., Les parlementaires français, 1900-1914 (Paris: Georges Roustan, 1914), p. 33.

[75]"Projet de création d'une Société des électriciens," Annales télégraphiques 3,10 (1883): 260-262.

[76]"Société internationale des électriciens," Annales télégraphiques 3,10 (1883): 643-646.

[77]"Liste des membres fondateurs," Bulletin de la Société internationale des Electriciens 1 (1884): 33-63. The figures are from a count of the members given in this list.

[78]"Projet de création d'un laboratoire central

d'électricité à Paris," Annales télégraphiques 3,9 (1882): 66.

79 F. G. de Nerville, "Le laboratoire central d'électricité," Annales télégraphiques 3,15 (1888): 206.

80 Ibid., pp. 206-208.

81 Ibid., pp. 208-209 & 221-222.

CONCLUSION

In at least one sense, A. P. Trotter was correct: with the exception of the Ecole supérieure de Télégraphie, French electrical engineering institutions did begin with the 1881 Paris International Electrical Exposition. Nonetheless, the French telegraph service and industry laid the groundwork for the emergence of electrical engineering long before 1881, as this thesis has argued throughout. The training of telegraph instrument manufacturers and employees of the telegraph service; the technologies, techniques, and organization of the network; the institutions founded for the advancement of science, technology, and industry that concerned themselves with telegraphy; the solution of the day-to-day problems of managing the telegraph system; and the construction of telegraph apparatus all, in one way or another, reflected the close relationship between telegraphy and science in France.

The highly scientific nature of French telegraphy led the telegraphs to create instructional programs in telegraphy that culminated in the founding of France's first program in electrical engineering in 1878. The merger of the postal and telegraph authorities into a new ministry and that ministry's hosting of the International Electrical Exposition and Congress of Electricians in 1881 permitted the Ministry of Posts and Telegraphs and its <u>Direction technique</u> to play a commanding role in the formation of France's earliest electrical engineering institutions: the Société internationale des Electriciens and the Laboratoire central d'Electricité.

Thus, the marriage of science and telegraphy had a third partner: the state. This "<u>ménage à trois</u>" of telegraphy, science, and the state had significant implications for the development of French electrical industry and electrical engineering institutions both before and after 1881. In tension and in cooperation with French electrical industry, Adolphe Cochery and the Ministry of Posts and Telegraphs founded the country's earliest electrical engineering institutions. This relationship between the state and industry was the leitmotif for the emergence of electrical engineering and industry during the 1870s, as this thesis has pointed out, as well as into the present century.

Despite Cochery's ability to withstand seven changes of government, he was replaced on 6 April 1885. On 30 May 1887, the Ministry of Posts and Telegraphs ceased to exist. Until its reconstruction as the Ministry of Posts, Telegraphs, and Telephones in 1929, the telegraphs assumed lesser bureaucratic and political importance as an adjunct to other ministries: those of Finance; Commerce, Industry, and Colonies; and Public Works.[1]

While governmental reorganizations eclipsed the bureaucratic and political position of the telegraphs, the star of French electrical lighting and power shone brilliantly. Although the electrical lighting and power industry fared poorly in "the city of lights,"[2] it performed remarkably well outside Paris, particularly in the Alps, Pyrenees, and Massif Central where water power was cheap and plentiful.[3] As the need for engineers in the industry grew, electrical lighting and power industrialists founded a school for advanced electrical engineering instruction through the Société française (formerly internationale) des Electriciens. Created in 1894 and initially occupying a building next to the Laboratoire central d'Electricité, the Ecole supérieure d'Electricité taught 2,804 students between 1894 and 1925, many of whom came from outside France. The administration of the school was in the hands of a committee of the Société française des Electriciens composed of the society's members and officers, members of the committee in charge of the Laboratoire central d'Electricité, the school's director, the Rector of the University of Paris, and the Director of the Ecole centrale. Telegraph *ingénieurs* were notably absent from the school's faculty and administration.[4]

Programs in electrical engineering also became available at various French universities during the 1890s through the efforts of university science teachers and local industrialists without the intermediary of the telegraphs.[5]

While the creation of these programs represented a triumph of private industry, the growth of the electrical lighting and power industry did not take place without at least some intervention from the telegraph service, especially while Cochery was minister. For example, before industry could undertake the installation of electrical power lines on a large scale, the state determined the installation conditions of those lines.

After receiving a report on the subject from Cochery, on 15 September 1884, the President of the Republic established a commission to set forth the requirements that entrepreneurs would have to fulfill when installing electric power lines. In addition to the usual group of government officials and scientists, individuals from the _Direction technique_ of the Ministry of Posts and Telegraphs made up five of the commission's sixteen members. Representatives of the lighting and power industry were not included. While the reason for creating the commission was ostensibly to guarantee the public's safety, the legal basis for the state's action was a telegraph law of 27 December 1851. That law updated the law of 1837 that had made the semaphores the monopoly of the state and, essentially, had defined all electrical "transmissions" as the monopoly of the state. Since the power lines were to transmit electricity from one point to another, they too fell under the authority of the state - and the _Direction technique_ was there to provide its special expertise.[6]

For the most part, however, the French electrical lighting and power industry matured without extensive intervention from the telegraph service. The growth of the telecommunications industry, on the other hand, illustrates more clearly how the combination of telegraphy, science, and the state affected the emergence of electrical industry and engineering after 1881. On 29 October 1877, Antoine Breguet demonstrated the Bell telephone before the Paris Academy of Science.[7] During 1878, three telephone companies formed to build telephone networks, each armed with its own set of patents. The desire to provide interconnecting service between the companies' systems in 1880 led to the merger of the three into a single company, the Société générale des Téléphones.[8] Initially, then, France had a rapidly forming and growing telephone industry.

The same law that had placed electrical power transmission lines under the authority of the state and had called forth the expertise of the telegraph _ingénieurs_ claimed the telephone as the provenance of the state. However, convinced that the telephone would not become a commercial success and not wishing to spend the money to develop it, Cochery conceded the telephones to the entrepreneurs of the telephone company.[9] The conditions under which the Société générale des Téléphones operated were almost guaranteed to bring about the failure or at least the retarded growth of the industry.

A ministerial order of 26 June 1879 established those conditions. The telegraph service would install and maintain all outside lines. The telephone company paid the state for these services as well as 10% of its gross receipts each year. The company was responsible for all inside lines connecting an individual's apparatus with the state-installed lines. The company's rate schedule and all apparatus used had to be approved by the Ministry of Posts and Telegraphs. Though the Société générale des Téléphones could not offer businesses lower rates, all municipal and state agencies paid less for their telephone service. The telegraph service supervised the operation of the system, with the right to enter switching stations and any other company building at any time.[10]

While the <u>Direction technique</u> supervised the telephone company and installed and maintained all outside lines, starting in 1882, the state began to set up its own telephone lines and reserved all intraurban and long-distance service for itself. In addition to certain designated cities, the telephone company could install lines only where the telegraph service charged extra to deliver telegrams because of the distance from the nearest office. In general, the telephones were not to compete with the telegraph service.[11] But that did not mean that the telegraph could not compete against the telephone.

As an alternative to the telephone, the Ministry of Posts and Telegraphs offered the "ligne d'intérêt privé." These private line telegraphs often linked several buildings of the same business (such as a warehouse and an office). However, it was not uncommon for these private telegraph lines to connect with the state network or to provide communications to an isolated hamlet or farm. The telegraph service built and maintained these lines at the expense of their users, who also paid for the apparatus. In addition, the telegraphs charged an annual tax determined by the number of posts and kilometer length of the line. The number of these private lines increased slowly at first, only 167 being installed between 1857 and 1878. A substantial reduction of the annual tax stimulated demands for private telegraph lines; in 1883 alone, 704 new lines were installed. By 1 January 1884, France had 1,651 private line telegraphs comprising 6,513 km of wire. In contrast, at the same time, there were 5,079 telephone subscribers served by 7,055 km of wire.[12] While there were (only) three times as many telephone subscribers as users of private telegraphs, the private telegraph lines constituted a network of wires equal to 92% of that of the telephones.

More importantly for French electrical engineering, Cochery had stipulated that the telegraph service would oversee the telephone system. Consequently, the *ingénieurs* of the *Direction technique* became interested in the telephone and contributed significantly to its evolution in France. Marius Cailho (1857-?), for example, graduated from the Ecole polytechnique and, in 1880, entered the Ecole supérieure de Télégraphie, where telephony was part of the course in *physique appliquée à la télégraphie*. As an *ingénieur*, he oversaw the construction of the first two telephone circuits between Paris and London and studied the German telephone system. In 1890, he invented a procedure for simultaneous telegraph and telephone transmission along the same conductor.[13]

French electrical engineering's long preparation period before 1881 was based upon an intimate joining of science and telegraph technology as well as a legal tradition that made telegraphy a state monopoly. The understanding of industry's role in this conjunction of science, telegraphy, and the state was that of a supplier of apparatus. Private cultivation of the telegraph would not take place save by grace of the state. With the rise of electrical lighting in the 1870s essentially outside the pale of the state, a rivalry emerged between the state-run telegraphs and private industry. The Paris 1878 International and 1881 Electrical

Expositions were clear victories for the newly-formed Ministry of Posts and Telegraphs. The rivalry between state _ingénieurs_ and privately-employed electrical engineers and industrialists also provided the leitmotif for the growth of French electrical industry and engineering after the 1881 Electrical Exposition. The case of the telephone and its retarded development was yet another triumph for the telegraph service (and loss for France), but the creation of the Ecole supérieure d'Electricité in 1894 indicated the strength of French electrical industry. With the invention and spread of wireless telegraphy, radio, then television, new opportunities arose for rivalry between the electrical industry and the telegraph service and the shaping of French electrical engineering institutions.

FOOTNOTES

[1]Michel de Cheveigné and Pierre Lajarrige, "Le téléphone de 1881-1889," in _Chroniques téléphoniques et télégraphiques_, p. 93.

[2]Charles Malégarie, _L'Electricité à Paris_ (Paris and Liège: Librairie Polytechnique Charles Béranger, 1947), pp. 9-60.

[3]Soubrier, pp. 1-8.

[4]Société française des Electriciens, _L'Ecole supérieure d'Electricité, 1894-1925_ (n.p., n.d.).

[5]Paul, pp. 143-163, and Shinn, "Des Corps de l'Etat," pp. 61-65.

[6]_Journal officiel de la République française_, 18 November 1884, 6057-6058; "Décret sur les lignes télégraphiques," _Lois et règlements_, 27 December 1851; and Ministère des Postes et Télégraphes, _Projet de règlement concernant les conditions d'établissement et d'exploitation des conducteurs électriques destinés à la transmission de l'éclairage ou au transport de la force_ (Paris: Imprimerie nationale, 1887).

[7]C. Breguet, "Antoine Breguet, du téléphone de Bell au photophone (1880-1882)," _Diligence d'Alsace_ no. 30 (1984): 2-4.

[8]De Cheveigné and Michel Jacquet, "Les débuts en France, 1877-1881," in _Chroniques téléphoniques et télégraphiques_, pp. 77-80, and Jacquet and Lajarrige, "Dates importantes du téléphone," in _ibid_., p. 6.

[9]Bertho, pp. 195-196.

[10]Cochery, "Rapport au Président de la République," pp. 3174-3175, and "Décret et arrêté relatifs aux concessions de lignes télégraphiques d'intérêt privé," _Bulletin mensuel des postes et télégraphes_ 2 (1879): 371-376.

[11]_Ibid_, pp. 3175-3176.

[12]_Ibid_., pp. 3173-3175.

[13]Personnel dossier, F(90) 20,535, Archives Nationales,

Paris; Cailho, "Notes sur le service téléphonique en Allemagne," Annales télégraphiques 3,24 (1897): 5-33, 289-362, 385-423; and Montoriol, pp. 622-623.

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Archival Materials

The Archives Nationales, Paris, series F, furnished the lion's share of the manuscript materials examined in researching this thesis. The vast majority of those materials, moreover, were in the F(90) subseries, which encompasses documents pertaining to the Ministère des P.T.T.

Within the F(90) subseries, I looked at some of the many official telegrams that make up the collection: 1087*, telegrams emanating from Paris, 1845; and 1315*, official telegrams received in Paris, 1844-1845. The correspondance of the head of telegraphs with Paris and provincial local offices, inspectors and station directors, foreign telegraph services, and others, was a far richer source, consisting of dossiers 1440*-1441*, 1843-1848; 1451*, 1829-1849; 1452*, 1852-1854; 1455*, 1831-1854; 1456*, 1833-1853 & 1861; 1457, 1867; 1458-1459, 1833-1853; 1460, 1842-1851; 1461(A), 1853-1855; 1461(B), 1854-1856; 1466, 1851-1854; 1467-1468, 1849-1855, 1857-1860. Other dossiers consulted in the F(90) subseries consisted of 1453*-1454*, circulars, 1829-1854 & 1863; 1462-1464, notes and correspondance relating to personnel, 1814-1849; 1465, materiel and construction of lines, 1830-1853; 1469, documents dealing with code vocabularies, 1848; 1470, telegraph inventions, 1833-1855;

1471(A), materials relating to the use of the telegraph to gather election returns, 1842-1869; 1471(B), correspondance relating to personal messages being sent free, 1858-1869; 1472-1473(B), 9203-9211, the administrative correspondance of local bureaus, 1855-1889; 1474, a chronological recording of decrees, orders, and ministerial decisions relating to various facets of telegraphy, 1844-1857.

The F(90) subseries also contains many papers relating to personnel of the postal and telegraph services. Unfortunately, in the great majority of cases, it is difficult to distinguish postal and telegraph employees and the only item remaining of what must have been thick personnel dossiers is the single-sheet _feuille de personnel_, which provides the employee's name, place and date of birth, positions held in the bureaucracy, and date of retirement, but not date of death or information on the individual's educational background. The organization of the personnel files is also a bit peculiar. Boxes 20,436-20,549 relate to those postal and telegraph employees who entered the service before 1881. Most of the remaining personnel materials are arranged by the employee's year of birth: 20,982-20,993 contain the _feuilles de personnel_ of those functionaries born between 1800 and 1870; 20,511-20,530 those born before 1865 (the oldest was born in 1836); and 20,994-21,037, those in the Central Administration and upper ranks born after 1881.

The most useful group that I encountered comprised boxes 20,531-20,549, the somewhat incomplete dossiers of those postal, telegraph, and telephone workers who achieved notariety in one field or another.

Another fertile subseries was that of the Minister of the Interior, F(1a). Boxes 1985(3)-1986(6) contain ministerial orders and decisions concerning personnel and money expenditures. Particularly useful were 1985(6) and 1986(1), which contain documents relating to the purchase of telegraph instruments and other materiel, 1854-1857. Agreements signed with railroad companies for the construction of telegraph lines are in 1985(3).

Several other subseries were useful in furnishing additional documentation. In the F(12) Ministry of Commerce and Industry subseries, I found dossiers dealing with the 1881 International Electrical Exposition, nos. 3171, 1015-1016, and 5016-5019. Of special interest were box 3171, with its floor plans for arranging exhibit materials, and 5016's posters for lectures given in association with the Congress of Electricians. Also in this subseries are materials on telegraph inventions, 6811 and 2213; and the Conservatoire national des arts et métiers, 4861-4863 (personnel folders and reports on the courses, 1850-1860). Box 3409 holds questionnaires filled out by French telegraph manufacturers for the 1878 Paris International Exposition. I looked at

Legion of Honor dossiers, particularly those of Baudot, Breguet, Dujardin, Froment, and Hardy; 5086, 5097, 5134, 5149, and 5166, respectively; however, these provided little useful information as a consequence of autograph hunters or others who have left most of these folders virtually empty. The F(14) subseries, that of the Ministry of Public Works, has two boxes, 11,049 and 3185, with documents relating to the Corps des ponts et chaussées and the semaphore network, 1810-1814. In the Ministry of Public Instruction subseries, F(17), I examined box 13,551, the minutes of the meetings of the faculty of the Collège de France, 1834-1848, for a reference to the Wheatstone telegraph demonstration, and boxes 3100-3104, which comprise materials relating to the Volta Prize competitions, 1852-1887. The printed documents subseries AD XVIII(F) furnished me with information on the telegraph budget between 1831 and 1881. Naturally, I examined other subseries and boxes, but they provided little additional documentation directly useful to the thesis.

In addition to the collections of the Archives Nationales, I utilized the archival holdings of the Academy of Science in Paris. Dossiers on Blavier, Du Moncel, Breguet, and others as well as the Academy's collection of sealed envelopes ("_plis cachetés_") proved very useful. Finally, I was extremely fortunate to have the benefit of the private collection of the Breguet family through the kind assistance and cooperation of M. Claude Breguet.

Journals and Serial Publications

Although I consulted articles in dozens of journals, I have listed only the most important ones here. This list also includes those serial publications utilized other than journals such as the Paris city directory.

Annalen der Physik

Annales de chimie et de physique

Annales de la propriété industrielle artistique et littéraire

Annales du Conservatoire des arts et métiers

Annales industrielles

Annales télégraphiques

Annals of Electricity

Annuaire général du commerce, de l'industrie, de la magistrature et de l'administration

Archiv für Deutsche Postgeschichte

Archives de l'électricité

Archives des sciences physiques et naturelles

Bulletin de la Société d'encouragement pour l'industrie nationale

Bulletin de la société des amis du musée de la poste

Bulletin de la Société internationale des Electriciens

Bulletin de l'Association amicale des anciens élèves de l'Ecole centrale

Bulletin d'histoire de l'électricité

Bulletin mensuel des postes et télégraphes

Comptes rendus des séances hebdomadaires de l'Académie des sciences

Le Cosmos

Diligence d'Alsace

The Electrical Engineer

Electrical Engineering

Electrical Review

The Electrician

L'Electricité: Revue scientifique illustrée

Journal de physique

Journal des chemins de fer

Journal des télégraphes

Journal of the Society of Telegraph Engineers

Journal télégraphique

Journal officiel de la République française

La Lumière électrique

Mechanics' Magazine

Mémoires de l'Académie de Stanislas

Mémoires de la Société des Ingénieurs civils de France

Moniteur universel

Polytechnisches Journal

Revue d'histoire des sciences et de leurs applications

Revue des P.T.T. de France

Revue générale des sciences pures et appliquées

Revue scientifique

Séances de la Société française de physique

The Telegrapher

The Telegraphic Journal and Electrical Review

Van Nostrand's Engineering Magazine

Works on French Telegraphy

This section comprises works dealing exclusively with telegraphy in France. Those treating telegraphy in France as well as other countries will be found in the following section. A listing of relevant articles in the _Journal des télégraphes_, the _Annales télégraphiques_, the _Journal télégraphique_, the _Moniteur universel_, the _Lois et règlements_, the _Bulletin de la Société d'encouragement pour l'industrie nationale_, and _L'Electricité: Revue scientifique illustrée_ would be too lengthy for inclusion here or in the following section and so has been omitted.

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