

The Electromagnetic Telegraph^①

A technical history of the 19th-century electromagnetic telegraph, with special reference to the origin and variety of the alphabets, or codes, that were used.

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Preface

This paper began as an investigation into the circumstances of the origin of the International Morse Code, and how it was descended from the American, or Vail, Morse Code. This was satisfactorily done, showing that the usual Morse Code was the adaptation of the original code to the requirements of the German language around 1851. The scope was then broadened into the early history of the telegraph in continental Europe, which is not well-known to British and American technical historians, and has consisted mainly of isolated references, erroneous dates and partial understanding. This revealed the important role of K. A. Steinheil as a telegraph pioneer, and, later, as a proponent of the Morse system in Europe. This led to an investigation of the actual contributions of Morse and Vail to the telegraph, and its early days, which has been considerably obscured by the just reverence for Morse as a man. To make this clearer, I decided to include the technical background for the electromagnetic telegraph, and to show how the various elements work together, and were realized in practice. Finally, having done this, it seemed interesting to trace the history of the telegraph in the United States lightly to point out the relations with railway operation, military communications, and other classic applications. As a result, this paper has grown to unwieldy proportions, and the various twists and turns may still be traced at certain points. Nevertheless, the index above will allow you to jump to any part you wish to consult, and the only real disadvantage is the time required to load the file. Its size, however, is still less than that of many graphics that may be put in your way!

The References include the works I have consulted, with notes on them, and recommendations for reading. I have not covered business or traffic matters except as they influence the technical considerations, but there are a few lines on labor relations and woman operators, a fascinating subject. I have also made much clearer how telegraphs came to be used on railways in the United States, I believe. I would greatly appreciate any notice of errors or misapprehensions. The paper is currently in course of revision, and some of the rough spots and relics of earlier versions you may notice will, I hope, disappear.

Introduction

"Il arrache le sablier de la main du Temps, et efface les limites de l'espace" (duMoncel)

Alfred Vail watched as the register clicked out the first official message on the new government telegraph in the Pratt Street Station of the Baltimore and Ohio Railroad on the Baltimore waterfront, 24th May 1844. When it was complete, he stopped the tape drive, pulled the wedge out of his key, and tapped the message back to Samuel Morse in the Capitol Rotunda in Washington, 44 miles away, who was greatly pleased. This was not the first electric telegraph, not even the first electromagnetic telegraph, nor the first recording telegraph, but it was a momentous event for the Morse Patentees, and the opening act of a telegraph drama that would spread world-wide within a decade. The alphabet of dots and dashes that was used here would survive without change until the last train dispatching by Morse on American railways more than a hundred years later.

A few days later, on the 27th, the Democratic National Convention in Baltimore nominated Silas Wright for Vice President. The proceedings were being reported over the new telegraph, so when Wright heard this he immediately telegraphed back declining the nomination, which he did not desire. The Convention was incredulous, and did nothing until the telegram was confirmed by a messenger from Washington. Henry Clay's nomination by the Whig Convention in Baltimore on the 1st had been passed on to Washington over the yet incomplete line from Annapolis Junction by Vail. These events helped to introduce the new means of instantaneous communication to an astounded public.

The amateur radio operator still uses the Morse Code, and until recently it was current for marine communications, part of the International Code of Signals used worldwide at sea, and is still retained for emergencies. Everyone knows that SOS is ... --- ..., the conventional signal of distress, with things in threes. But Vail would be puzzled. He would send instead. The new code is similar to his, but somewhat different, with some signals reassigned, and some brand new, especially the numbers, which are totally different. How, where and why did this new code originate, and who was responsible for it? This article will explain all of this, as well as describing the early telegraph, which was different from its later and more familiar versions.

Vail's description of the new Morse system, which appeared within a year of the first trial, gives no hint of who was responsible for its various elements. He claims that Morse conceived the system on board the ship *Sully* in 1832, and that the system demonstrated in 1844 was the result of 13 years' development. In fact, there was a vast difference between Morse's first musings and the practical system of 1844, and it seems that Vail was, himself, responsible for nearly every detail, though he claims nothing. Morse did indeed fashion a code, but it apparently was nothing like the code of 1844, but involved wavy lines traced by pendulums, and a code book. I believe that the final code was devised by Alfred Vail (1807-1859), who described himself as "Assistant Superintendent, Electro Magnetic Telegraph for the United States." The word used for telegraph codes of this type was *telegraphic alphabet* at the time, so when I say *alphabet* I mean the telegraph signals for letters, numbers, punctuation and procedural signs. The word *code* strictly means a dictionary of messages identified by numbers or some such means. Vail's Morse alphabet was called by Shaffner in 1859 the American Morse, and the now-familiar system the European Morse. These are excellent terms, but, unfortunately, they were not generally adopted by later writers.

Most sources, such as encyclopedias, have no reason to make a distinction, since they are not aware of any alphabet but the one familiar to them, which is simply called the Morse Code. With few exceptions, all non-American sources give only the European Morse alphabet, called simply Morse. This alphabet has also been called Continental Morse, and more lately, International Morse. Vail's original alphabet is called just Morse in early American sources, and usually American Morse when a distinction has to be made. In this paper, I will usually call it the Vail Code or alphabet, and the other the Morse Code or alphabet, simply to make a clear distinction between the two.

Much of the history of the telegraph that is found in recent secondary non-technical sources is unreliable when it comes to the engineering and operational history of the subject. Many authors simply uncritically copy bits out of a technical source that they do not well understand, and nearly all have never operated a telegraph key or heard a sounder. (The sounder, the characteristic American telegraph receiver, is explained under Receiving By Ear.) For example, I noticed that an economic historian said the early telegraph used lead storage batteries. These weren't even invented at the time, and were later used only with dynamo power sources. It's no big point, but shows that otherwise reputable and well-researched accounts can fall short technically. The actual telegraph alphabets seem never to be mentioned

in later histories of technology, and are not common even in early references. Thompson, in his excellent business history of United States telegraphs, even reconstructs Morse's first message with the International Code, using dot dash instead of dot dot..dot [p. 24]. He also explains the sounder as a "buzzer" [p. 250], and some of his statements about British and European matters are simply wrong.

It is interesting that communication once again is becoming dominated by telegraphy. This page reached your browser by telegraphy, and soon the crass, mindless rubbish of television will also reach you the same way, instead of through the familiar analogue links. Except for local subscriber circuits, telephones are already digital. The internet uses packet switching, unlike the circuit switching that came in with telephones, which is much more efficient and economical than devoting a link exclusively to one user. The alphabets and means of modulation are very different, however, and computers assume the roles earlier played by humans. Nevertheless, many old ideas, such as communication over light beams, have been resurrected. In fact, your television remote communicates by on-off telegraphy in a very familiar way.

Electromagnetic Fundamentals of the Telegraph

The electromagnetic telegraph operates on a very straightforward and elegant principle. The transmitter opens and closes an electric circuit at one point. The receiver uses the electric current at any other point in the closed circuit to establish a magnetic field, the forces arising from which cause some observable mechanical effect. An electrochemical telegraph, such as the Bain telegraph, uses instead the chemical action of the electric current. Any other observable effect of the electric current could be used as well, provided it does not require an undue amount of current nor a too-high voltage. The heating effect has also been used.

Four scientific principles must be understood in order to create a useful electromagnetic telegraph. First, above all, is the production of galvanic currents by chemical action. This was demonstrated by Alessandro Volta in 1800, and the current was soon afterwards discovered to decompose water by electrolysis, and to heat fine wires. Chemical action in batteries was the only practical source of electricity for telegraphs until almost the end of the century, except for the occasional use of the magneto for intermittent currents. The second principle is the production of a magnetic field by a current, together with the means by which it can be intensified and caused to have a practical effect. G. D. Romagnesi of Trent seems to have been the first to observe, in 1802, that a current affected a magnetic needle, and a certain J. Majon observed that an unmagnetized needle near a current became magnetized. Such reports were little noticed until Oersted published his more detailed observations in 1820. Ampère then quickly worked out the magnetic action of a current, and Schweigger of Halle, in the same year, showed how to intensify its effect by winding the conductors in coils with the needle within, often called *multipliers*. The third principle is the temporary magnetization of soft iron. In 1825, Sturgeon wound the wire around an iron core and showed that this greatly increased the forces that could be exerted, showing the way to making strong electromagnets that would exert considerable forces on an iron armature. Finally, the requirements for designing an outdoor circuit of great length were established by Ohm (1827), Steinheil (1833) and Wheatstone (1836). This rested mainly on an appreciation of Ohm's Law, $V = IR$, and the meanings of electrical pressure and electrical current. Few of the earlier proposals for an electromagnetic telegraph got far enough to encounter the problems of a long outdoor circuit, which would generally have proved insurmountable. Indeed, the problem was not practically solved until after 1840, with the bare wire line supported by insulators on poles.

In 1845, few people had any idea of what an electric circuit was and how it functioned, and this included most of the telegraph pioneers, except for a few academics like Wheatstone and Steinheil. Ohm showed that the circuit was like the conduction of heat, with electrical pressure or voltage V , the driving force, electrical current I the flow or flux, and the resistance R the pressure needed for a unit flux, except that the analogue of heat had to flow in a closed path, like a fluid in a pipe with a pump. Hardly anybody believed him, but the analogy with a fluid was at least comprehensible, and is still used in explaining the electric circuit. Unfortunately, the analogy is a very poor one if carried any farther. Electricity was presumed to be an ethereal fluid like heat (also wrong) and this led to strange, useless conceptions.

Those who did understand Ohm took the pressure of the Daniell cell as the unit of pressure, the volt V , and a certain column of mercury the unit of resistance, the ohm Ω . The current forced through 1Ω by $1 V$ was the unit of current, the ampere, A . Then, the current I in amperes through any part of a circuit is equal to the voltage V applied across the part of the circuit, divided by the resistance R of the part. In a complete circuit, the pressure rise in the battery, E , equals the pressure drop V in the rest of the circuit, so $E = V = IR$, which is Ohm's Law. Four Daniell cells, each providing a pressure of $1 V$ and having a resistance of 2Ω will force a current I through 10 miles of #9 iron wire, with a resistance of 160Ω given by $I = 4 V / 168 \Omega = 0.0238 A$, or about 24 mA, milliamperes. The electrical current stays in the wire, unless the wire touches some other conductor of electricity. All of the early books on telegraphy take extreme pains to make these facts clear.

The electromagnet, which can attract a soft iron armature when energized, and release it quickly when the current stops, is the essential element of the electromagnetic telegraph. Arago noted that electric currents made nearby iron needles magnetic in 1820. In 1825, William Sturgeon carefully inserted a horseshoe-shaped iron core in a helix of bare copper wire. When he passed a current through the helix, the core became a magnet. He then insulated some wire with cotton thread, which enabled him to use a greater number of turns, and get a stronger magnet. Sturgeon's electromagnets soon became a popular demonstration, and an informal competition on who could make the strongest magnet soon arose. Moll made a magnet that supported 75 lb, and then one of 135 lb. In 1828, Joseph Henry's 1829 magnet had a 2 in square core and was 20 in long, wound with 540 feet of insulated wire. Henry later made magnets that could lift 2063 lb, and then 3500 lb.

Early electromagnets were not all the same. Sturgeon, looking for strength, wound his iron with a relatively few turns of large wire, so that he would get the greatest current, which would be limited mainly by the internal resistance of the battery. The magnetic effect depends on the product of the current and the number of turns, and Sturgeon tried to maximize this product, as did most others. He also found that the greatest forces were produced when the iron formed a closed loop with only the minimum air gap necessary, which is, in fact, a closed magnetic circuit of low magnetic resistance. Such a magnet was totally unsuited for a long telegraph line of relatively high resistance that would allow only a feeble current. Telegraphs made with one would work in a room, but would fail completely to work over only a short line, as many telegraph enthusiasts found to their disappointment.

Joseph Henry, among others, made magnets with many turns of fine wire as early as 1831, maximizing this quantity instead of the current. Now many cells of battery could be used in series, since the current would not be limited by their internal resistance, but by the resistance of the winding around the iron, and only a small current could exert strong forces. Such were called *intensity magnets*, working with high voltages, rather than the earlier *quantity magnets* that worked with high currents. The use of such magnets was the necessary and sufficient condition for a practical electromagnetic telegraph, not a mere 'detail' as Morse would have maintained in his state of electrical ignorance. Electromagnets and their properties were well-known in the United States only a few years after Sturgeon's invention.

The terms "earth" (British) and "ground" (American) in telegraphy usually refer to an actual conductive connection with the damp soil of the earth's surface or to the sea. This connection was generally made with a buried copper plate, or in some cases to a connection with a metallic pipe in contact with the ground. The resistance of the earth return was negligible, if a proper earth was made, with a buried plate in moist earth. Telegraph circuits were almost exclusively ground-return, as they were not affected by noise, since they depended on on-off operation. This insensitivity to noise is still an advantage of telegraphy. Telephony rapidly found that it could not use the cheap ground-return circuit.

Invention of the Telegraph

Telegraphs have a very ancient history. Polybius tells about letters displayed from towers, but visual telegraphs were quite impractical until the invention of the telescope in the early 17th century, and even then were not used for general messages until the remarkable Chappe telegraph of 1793, which gave us the name of telegraph. Before that, the world relied on messengers and beacons. Agamemnon sent information back to Mycenae of his victory at Troy by a chain of signal fires before 1000 BC, and beacons announced the arrival of the Spanish Armada in AD 1588. Romans used chains of watchtowers in the same way. American Indians used signal fires on hills as beacons, different numbers of columns of smoke indicating different messages. The messages had to be prearranged for this method to work. I do not know of evidence that Indians used smoke puffs with signal fires, but if they did, they certainly did not use the Morse Code for this purpose.

The electromagnetic telegraph spread with astonishing speed after its celebrated commercial introduction around 1845. By 1850 the United States and Britain had extensive networks, the telegraph was spreading to the European continent, having crossed under the Channel in that year, and by 1870 formed a world-wide telecommunications system. Indeed, it spread more rapidly than today's Internet. The optical telegraph was its only effective predecessor, and that mainly in France with the Chappe system, and a few lines for military and government messages in other countries. Chappe's optical telegraph dated only from 1794, and was for official messages only. Before that, there was no rapid communication at all, intelligence travelling no faster than a galloping horse. One reason for the success of the electromagnetic telegraph was its cheapness, speed and all-weather, all-day reliability (far superior to any messenger), but another was the radical change in society at the time, and the remarkable exploitation of the invention by private individuals and joint-stock companies in the United States and Britain, where it was enthusiastically accepted by commerce, newspapers, and the general public. Some of the earliest users were lottery men and stock brokers hoping to gain an advantage by timely, secret information.

Two systems of electric telegraphy achieved commercial success and fame, the needle telegraph of Cooke and Wheatstone in England (1839) and the recording telegraph of the Morse Patentees in the United States (1844). Both systems were the results of years of development, the efforts of predecessors, and the 'state of the art' in electromagnetics. The dates are those of the first commercial lines. These were by no means the first electromagnetic telegraphs, and neither system was a new invention, but simply the application of known principles to form a complete, useful system. Cooke and Wheatstone claimed only to have made an 'improvement' of the electric telegraph. The partisans of Morse claimed for him all originality and priority, quite ridiculously, and Morse, whose knowledge of technical subjects and electricity was negligible, soon firmly believed them himself. Even Alfred Vail, loyal associate of Morse, who actually invented the code and instruments that made Morse's ideas practical, was pushed into the shade as time passed. The unseemly and excessive pretense was carried on even by Morse's descendants. Let us, therefore, first look at the state of electrical telegraphy before Morse and Cooke.

Many inventors had tried to make telegraphs based on static electricity, but these were all impractical because of the difficulty of transmitting high voltages, and the weakness of the effects produced. Wood, in 1726, or Grey and Wheeler, in 1728, seem to have been the first to discharge a Leyden jar through long wires. In 1746, Winkler of Leipzig discharged a Leyden jar across a river. In 1748, Benjamin Franklin discharged a Leyden Jar through a wire across the Schuylkill River, igniting alcohol flares simultaneously on both banks, to the delight of the audience. He used only one wire, but this was not an anticipation of the ground return, since the concept of an electric circuit did not then exist. Dr Watson, bishop of Llandaff, constructed a static electricity telegraph on Shooter's Hill near London in 1747, 2 miles in length, after earlier experiments across the Thames at Westminster Bridge in London and at Stoke Newington. The mysterious C. M. (probably Charles Marshall of Paisley) suggested the speed of electrical communication in a letter of 1 February 1753. G. L. Lesage's static electric telegraph of 1774 in Geneva was one of the earliest actual devices to appear. It used one wire per letter, 24 in all, a pith-ball indicator, and only connected two neighbouring rooms (not shores of the lake). A similar demonstration is reported in France in 1784.

The Dyar telegraph of 1828 was an extraordinary episode. Harrison Gray Dyar proposed a telegraph between New York and Philadelphia using static electricity about 1826, and built a trial line around a race course on Long Island in 1828. He used bare iron wires on glass insulators with an earth return, producing the electricity by friction, and detecting it by its chemical effect on moist litmus paper, moved by hand. Fear of prosecution for "sending secret communications in advance of the mail" brought the project to an end. It would not have worked, because of leakage, but the attempt is remarkable in its

anticipation of many later developments. Dyar had an alphabet of symbols, based on numbers of "dots." His work, and early telegraphic alphabet, had no influence on later developments. He is, however, heard from again in the patent litigation over the telegraph in the 1850's.

A certain Reizen is reported to have made a telegraph using static electricity in 1794 that used 76 line wires. Betancourt experimented in 1798 with a line from Madrid to Aranjuez. This is the same as the Spanish experiment by De F. Silva that used sparks from Leyden jars on a 26-mile line. The best-known and practical static electricity telegraph was that of Sir Francis Ronalds (1788-1873) in 1816 or 1823 at Hammamsmith, London. The eight-mile line used synchronized clocks indicating letters, with a suspended pith ball as an indicator of what letter was meant. At least it did not have 76 wires. It is obvious that the idea of an electric telegraph was in the air throughout the 18th century, and there were many experiments, though no practical telegraph using static electricity was devised.

Schilling (1820)									
A	rl	K	rrrl	U	llr				
B	rrr	L	rrrr	V					
C	rlr	M	lrl	W	rrrl				
D	rrl	N	lr	X	llr				
E	r	O	rlr	Y	rrr				
F	rrrr	P	llrr	Z	rrrr				
G	lll	Q	llr	&	rrrl				
H	rrl	R	lrr	go on	lrrl				
I	rr	S	ll	stop	llr				
J	rrrl	T	l	finish	llrl				
1	rlrr	4	lrrrl	7	rrrl	0	lrrl		
2	rrrlr	5	lrrrl	8	rrrl				
3	rlrr	6	lrrrl	9	llrl				

Current electricity, discovered in 1800, offered new advantages, but at first the only effect of the current that could be used was electrolysis. S. T. von Sömmering's telegraph of 1809 had 26 wires, each corresponding to a letter of the alphabet. Signals were received by noting which wire was producing bubbles. Schweigger of Halle used an alphabet of groups of bubbles to reduce the number of wires. Baron P. L. Schilling von Canstedt, of the Russian Army, was very impressed by a demonstration, and thereafter collaborated with Sömmering on telegraphs. When the effect of currents on a magnetic needle became better known after 1819, Baron Schilling used suspended needles as a receiver. An early design had 36 needles and 72 line wires, but this was reduced later to a single needle. This was in 1820, and comprised the first electromagnetic telegraph. [A misunderstanding causes some authors to assume that this was in 1832, but the earlier date is correct. Reid gives 1836 for partisan reasons.] Dr. John R. Coxe of Philadelphia proposed a chemical telegraph with 72 wires in 1816, but never built one. Ampère experimented with a magnetic needle as a telegraph receiver in 1820, following a suggestion by Laplace. He clearly recognized the possibility of telegraphy by magnetic needles, as appears in his paper in *Annales de Chimie et de Physique*, v. 15, p. 72 (1821), suggesting one needle and wire for each letter. Ampère also was the first to use a key for breaking the circuit. In fact, he used many wires and a keyboard like a piano.

Gauss and Weber of Göttingen University became interested in the subject, and used the mirror galvanometer, which they had invented, as a receiver, employing polarized currents. That is, the direction of the current could be reversed, which gave an opposite deflection of the galvanometer. They constructed an alphabetic code using from one to four deflections to the right or left, which is shown in the Figure. Their circuit extended from the Physics Laboratory to the Observatory, a distance of 4500 ft, so the total length of the circuit was 9000 ft. This was in

Gauss and Weber (1833)									
r	a	rrr	cjk	lrl	m	lrr	w	llr	4
l	e	rrl	d	rrl	n	rrl	z	llr	5
rr	i	rrr	v,v	rrrr	p	rrl	0	llr	6
rl	o	lrr	g	rrrl	r	rrl	1	llr	7
lr	u	lll	h	rrr	s	lrrl	2	rrl	8
ll	b	llr	l	rlr	t	lrr	3	llr	9

1833. They had little time to spend on the project, so they enlisted the help of Professor K. A. Steinheil (1801-1870) of Munich University, with the principal aim of making a recording telegraph.

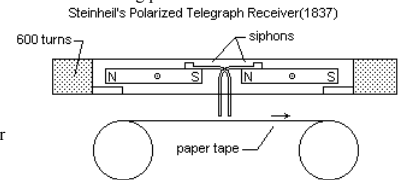
Steinheil, born in Elsass (Alsace), had come to Göttingen in 1823 as a student, and followed Gauss to Königsberg, where he received his doctorate in 1825. His specialty was instrumental astronomy. On the death of his father, he moved to Munich in 1830. He effortlessly became Professor of Mathematics and Physics in the University, and Conservator of the Mathematical and Physical Collections of Bavaria, in 1832, so capable was he. At the time of consulting with Gauss and Weber, in 1835, Steinheil was making a scientific journey through Vienna, Berlin and Göttingen. Professor Steinheil devised a receiver consisting of two bar magnets in a large, 600-turn coil. The magnets were pivoted so that one or the other moved when the current was in one direction or the other. Fine ink siphons were connected to the magnets, so that dots could be printed on a moving strip of paper, and a suitable alphabetic code was devised, shown in the figure. A bell alarm was included in the system, which could work at 6 words per minute (33 characters a minute). The main circuit was from the Royal Academy to the Bogenhausen Observatory (30,500 ft), but there were shorter lines from the Academy to the Physics Laboratory, and from Steinheil's residence to the Physics Laboratory. He also devised a magneto transmitter, which supplied currents by motive induction, not by chemical action. Any of these telegraphs would have been commercially viable, but Gauss, Weber and Steinheil were philosophers, not businessmen. Steinheil's telegraph was the first recording telegraph, clearly anticipating Morse on all counts. Steinheil's name should be added to those of Morse, Vail, Cooke and Wheatstone as an originator of the practical electromagnetic telegraph, something that even Morse later admitted.

Steinheil (1837)									
a	..	i,j	h	...	3	...			
b	...	l	sch	...	4	...			
c,k	...	m	t	...	5	...			
ch	...	n	u,v	...	6	...			
d	...	o	w	...	7	...			
e	...	p	z	...	8	...			
f	...	r	1	...	9	...			
g	...	s	2	...	0	...			

Gauss had suggested that the two rails of a railway might serve as telegraph conductors. Steinheil followed up this suggestion on the Nürnberg-Fürth Railway, but finding that the rails were not sufficiently insulated from each other and the earth, even when felt insulators were used in the rail chairs. Through this, he serendipitously discovered the earth

return, a great advantage for all telegraphy, which he declined to patent, dedicating it to the public. He constructed a line 4-1/2 miles long, connected to a buried copper plate at one end, and to a buried zinc plate at the other, evidently hoping for the galvanic action to also supply the current. This hope was impractical, but the earth return proved a very important invention. Not only did it make lines half as expensive to build, but also reduced their resistance and leakage to half. All this happened in 1837-8. Steinheil was the inventor of the lightning protector, in the form of a shunt around the apparatus, *die Blitzplatte*, in 1846. He also invented a *Translator* [thus in German] to replace relaying by retransmission at intermediate offices. Steinheil devised a rheostat, wound with fine brass wire, for adjusting the current in a telegraph circuit, which varied with the weather. Steinheil also invented an electric clock (a master-slate clock arrangement), and in 1838 established an experimental train control telegraph on the Munich-Naunhof railway, that reported the progress of trains along the line. Steinheil also made the first Daguerrotype in Germany in 1839, developed electroplating and alcoholometry, besides working in the standardization of weights and measures for the Kingdom of Bavaria. Telegraph trials were also made on the Saxon State Railways between Leipzig and Dresden by Weber of Göttingen and Steinheil in 1838, applying the telegraph to train operation, says M. M. von Weber in 1867, who also claims (probably erroneously) that the earth return was discovered there. Nothing permanent came from all this activity, except additional knowledge, since telegraphs in Germany, as in all of Continental Europe, were a monopoly of the postal authorities.

Professor Muncke of Heidelberg set up a telegraph line of his own, based on Gauss and Weber's, between his residence and his lecture hall, which he demonstrated to students. One demonstration was seen by William Fothergill Cooke (1806-1879) in March 1836, and made a deep impression. Afterwards, Cooke worked only on telegraphs. He enquired of Faraday about how he could get technical assistance, and Faraday referred him to Professor Charles Wheatstone (1802-1875). He formed a partnership with Professor Wheatstone on 19 November 1837. Wheatstone provided the essential electrical knowledge, so the telegraph, patented in 1837, soon saw the light of day. Cooke's attention to its promotion as a railway adjunct, for the operation of single lines, soon saw it in commercial application in the same year, at Euston Station. Wheatstone was not only an extremely skilled inventor, but one of the few people at the time who understood Ohm's analysis of the electric circuit, a key factor in the later development of the telegraph. This is the chain of events leading to the Cooke and Wheatstone telegraph, which they described as 'an improvement to the electromagnetic telegraph,' not as a new invention. Though the two men later fell out, they were complementary to each other, and their cooperation was necessary for success.



The story of Morse's invention comes largely from claims exchanged by himself and Dr C. F. Jackson in a later battle over credit, so they must be taken with a grain of salt. Samuel F. B. Morse (1791-1872) was returning in Autumn 1832 from Havre on the *Sully* after a visit to France to copy paintings when he fell into conversation with Dr Jackson, who was enthused about Pouillet's powerful electromagnet that he had seen in Paris, and had a small electromagnet and battery with him (he said). Morse conceived that this could be the basis of a telegraph (thinking, he said, of Franklin and the kite—probably the only electrical thing he knew). Experiments in 1835 proved fruitless, so he applied for help to Dr Leonard D. Gale (1800-1883), who showed him how to build suitable electromagnets, on Henry's principles, and supplied him with wires and battery. Morse had been fumbling with Sturgeon 'quantity' electromagnets that had a winding of low resistance and used a single cell, and were totally unsuited to telegraphy. Gale introduced him to the 'intensity' electromagnets of Joseph Henry, which had high resistance windings made from many turns of fine wire, and were used with batteries of many cells. Such magnets were essential to telegraphy. Morse contrived a system in which magnets moved a suspended pendulum to which was attached a pen or pencil to make zig-zag lines on a paper tape in response to long and short impulses (the "pen lever"). The lines were interpreted as numbers, and the meanings of the numbers were looked up in an elaborate code book. The original Morse system was indeed a code, not an alphabet.

Joseph Henry (1797-1878) had, like Muncke, set up a demonstration telegraph in his lecture hall in Albany by 1830, and Morse came to him for advice as well. Vail omitted to credit Henry in his 1845 book, and Morse likewise neglected to give any credit for the essential help he had received. Henry, Professor of Physics at Princeton from 1832, and first Director of the Smithsonian Institution in 1846, was deeply insulted by the inventor's arrogance. In 1831, he had invented the "intensity" electromagnet of high resistance, and rang an electric bell at a distance using a relay. All the electrical parts of the telegraph were common knowledge before Morse ever thought of it.

After the subsequent commercial success and fame of the Morse telegraph, Jackson thought he could claim some of the credit, and made an uproar in the newspapers. Jackson was notorious for engaging in such activity; Morse was not his only victim. The very thought that a mere conversation aboard ship could possibly be considered as marking anything significant, or for which credit was due, was absurd. Morse, for his part, was completely unaware of the decades of previous work on telegraphs, and even claimed that Steinheil had stolen his ideas, when an account of Steinheil's work in a translation from an article in the *Neue Würzburger Zeitung* was published in the United States in 1837. Later, the Morse family even attacked the contributions of Alfred Vail, who was responsible for the actual design of the system called the Morse telegraph, including the key, register, and code. Vail concurred with using Morse as a trade name for the complete system, of course, since he was a partner in the syndicate, and well knew Morse's insistence on using the name Morse for everything involved. The two men were never enemies or adversaries.

Relations were much more cordial twenty years later, on 17 August 1858, when the telegraph authorities of France, Austria, Belgium, Holland, Piedmont (Italy), Tuscany, the Vatican, Sweden, Russia and Turkey awarded Steinheil a prize of 400,000 francs in Paris for his invention of the earth return, and a similar prize to Morse for his system. In his acceptance speech, Morse acknowledged simultaneous invention in America, Britain and Germany in 1837, praising Steinheil as noble, unselfish, great-hearted and modest (which he was), and acknowledging the leading role he had played in spreading the Morse telegraph in Germany. Morse's speech was published in *Comptes Rendus de l'Acad. des Sciences*, v. 7, p. 595 (1858).

Arguments over priority of invention of the telegraph arose almost at once, and had become quite heated by 1850. Most early observers concluded that the electric telegraph had no single inventor, an idea that seems very well founded. Practical electromagnetic telegraphy arose simultaneously in Germany, England and the United States at about the same time and more or less independently, but resting on a common foundation of technical knowledge that we have outlined above. It should be very clear that even before Cooke and Morse began promoting their telegraphs, the idea was by no means new. Both enterprises would have failed without the scientific and engineering contributions of Wheatstone and Vail, as much as without the business and promotion abilities, and tenacity, of Cooke and Morse. This is a remarkable parallel.

Morse and Vail's Recording Telegraph

The fundamental Morse patent was granted 20 June 1840, extended 7 years in 1854, and expired 20 June 1861. An attempt to renew the patent again was rejected by Congress. The second patent expired 11 April 1860. The principles protected by these patents were well-known at the time, though not to American patent authorities or the courts. Only the details of the apparatus should have been protected, not the use of electricity and magnetism itself. Morse's patents were owned and promoted by a group called the Morse Patentees, which included S. F. B. Morse (inventor) 9/16 share, A. Vail (engineer) 2/16 share, L. D. Gale (scientist) 1/16 share, and F. O. J. Smith (1806-1876), a politician for legal and governmental liaison, 4/16 share. Amos Kendall (1789-1869), a lawyer and Postmaster in the Jackson administration, and Smith handled the business and patent affairs, Vail the technical side, Gale apparently did nothing whatever, taken on only to lend a scientific tint, while Morse took all the credit. Vail had received a

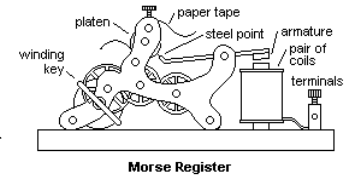
quarter share on 23 September 1837, later reduced to an eighth to add Smith to the syndicate. Morse bought out Gale for \$15,000 soon after. Shortly before the patents expired, the American Telegraph Company bought the remaining rights of Smith, Morse and Vail, and House and Bain to boot.

'Fog' Smith proved a difficult associate, but Amos Kendall became Morse's trusty business manager. Smith was a litigious, disloyal, unlikable Yankee who later persecuted Henry O'Reilly for absolute control of the Morse patents in the West, reneging on a contract concluded with Kendall. The contributions of Alfred Vail were not clearly distinguished and documented. Unlike other members of the syndicate, Vail did not become wealthy or successful, probably because he did not blow his own kazoo loudly enough. Vail, who was intending to become a minister and was studying at the University of the City of New York, saw an early demonstration of Morse's there on 2 September 1837, and was fascinated. He was active for the Morse cause in 1837-38, then again 1843-48. He described the Morse system in his book *The American Electro-Magnetic Telegraph* of 1845, which set off the unpleasantness with Joseph Henry over lack of acknowledging his assistance, which was significant. Later researchers have given Vail more of the credit that is undoubtedly his due. Morse and Smith were masters of no effective electrical or mechanical knowledge whatever. Alfred Vail did not "improve" Morse's invention; he created a very different and practical system with Morse only observing on the sidelines. Without Vail (and Henry), there would have been no Morse telegraph.

Morse Code		
1	.	6 ---
2	..	7 ---
3	...	8 ---
4	....	9 ---
5	.....	0 ---

Morse demonstrated his earliest device, with port rule and pen lever, on 2 September 1837 in New York, where it did not work, but Vail became interested, and offered to help. On the 4th it traced out the numbers 215 36 2 58 112 04 01837, which, translated by Morse's vocabulary, said "Successful experiment with telegraph September 04 1837." The impulses were sent by the so-called port rule, which had lead teeth like printer's type acting on switch levers that raised and lowered wires in or out of cups containing mercury as it was moved. The pulses were received by a pendulum deflecting to one side by the action of an electromagnet. The first code merely used from 1 to 10 pulses, each making a sidewise jerk of the pen. Later, the code shown at the left, devised by Morse, was used, which made short and long jerks. Vail was made a partner on the 23rd, and set to work improving the invention. An experiment over a half-mile of line was carried out on 2 October 1837, probably unsuccessfully. For the rest of the year, Vail worked to produce a different instrument, the register. On 6 January 1838, Vail's new register was tried over three miles of wire strung around the shop at Speedwell Iron Works in Morristown, New Jersey. Morse's memory later made this thirteen miles. The message sent was "A patient waiter is no loser." Soon after, the strange message "Attention the universe by kingdoms right wheel" [sic] was sent at a demonstration in New York City, probably on the 13th. On 8 February 1838, a demonstration was held before the Franklin Institute in Philadelphia, and finally on 21 February before the Congressional Committee on Commerce in the Capitol at Washington and President Van Buren. Reports of the Capitol demonstration were published in the *American Journal of Science and Arts*, v. xxiii, p. 168, and in the *London Mechanics' Magazine* for 10 February 1838. The chairman of this committee was F. O. J. (Fog) Smith, representative from Maine, who enthusiastically offered Morse his services, which were gladly accepted--provided he resign his government attachments to avoid conflict of interest.

By the time of the Capitol demonstration, Vail already had produced the new instrument, the *register*, that embossed dots and dashes on a moving paper tape by a stylus operated by an electromagnet, the circuit being opened and closed by a manual key. A later version is shown at the right. The key was used for winding up the weight (not shown) that drove it. The register worked much better than Morse's original pendulum contraptions. Morse could see no difference, but an idea is not an invention, and Vail had taken the essential step of reducing the invention to practice. The essential new element was the large electromagnets with many turns that required only a small line current. One of the greatest advantages of the Morse system over its competitors proved to be its production of a permanent record of a message, which other telegraphs (as far as Morse knew) did not do. Steinheil already had a recording telegraph, however, which operated like Morse's. This was the factor largely responsible for the spread of the Morse in Europe, where the Cooke needle telegraph was never widely used. Vail also devised the telegraph alphabet that came to be known as the Morse Code (with Vail's agreement) for use with the register. Part of an early form of the alphabet, superseded by 1844, is shown at the left below.



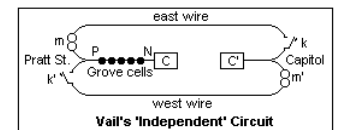
Early Morse		
E	.	W ---
O	..	M ---
A	...	N ---
H	....	S,Z ---
L	.....	K ---
X	..	T ---
I,Y	..	

F. O. J. Smith was taken into the partnership for his political knowledge and influence. He financed Morse's visit to England, and accompanied him there (where they found that their inventions had been anticipated) in 1838. The pair returned somewhat miffed if not chastened, but aware that their's was not the only telegraph in the world. Through Smith and persistence, Morse finally succeeded in getting a federal subsidy of \$30,000 by an Act of Congress in 1843, which made possible a 40-mile demonstration line between Washington, DC and Baltimore, over which the first public message was sent on 24 May 1844. This message ("What hath God wrought") was composed by Annie G. Ellsworth (or Elsworth), the daughter of Mr Ellsworth of the U. S. Patent office, a friend (and partisan) of Morse's. The tape was given to Governor Seymour of Connecticut, and is preserved in the Museum of the Historical Society of Hartford (Connecticut). It shows that the Vail alphabet was already in use. Morse was in the Capitol, Vail in Baltimore, and the message was sent and returned. The subsidy had reignited Vail's interest in the project, which had flagged after 1838, and he returned with enthusiasm. The US Post Office, to which Morse had offered the invention for a quite reasonable \$100,000, stupidly failed to take it up, and so this was the only telegraph line built with federal aid in the United States. Private investors, especially the new Magnetic

Telegraph Company, which licensed the Morse patents, eventually found the business lucrative.

Morse intended to bury the telegraph line, and Smith contracted to do this with a digging machine of his own invention. Smith soon enlisted the help of the technologically more capable Ezra Cornell (1807-1874) whom he had met earlier in Maine. Cornell devised a better digger, and began laying the wire in pipe (lead-sheathed cable) beside the Baltimore and Ohio from Pratt Street Station to Relay, intending to follow the Washington Branch thence to the capital. President Louis McLane of the B. & O. had given Morse permission to use the right-of-way as a personal favor. The cable had been laid as far as Relay when it was discovered that insulation failure had made the line useless, a disaster to the project's timetable. As an excuse for an extension of time to retain the subsidy, Cornell conveniently wrecked his digger, giving Morse the excuse he needed. It was decided to run the line on poles with Cornell's plate glass insulators (as Joseph Henry had suggested many years before), not Vail's cotton and beeswax. The conductors were #14 copper, wrapped with cotton thread and coated with a mixture of asphaltum, beeswax, rosin and linseed oil to keep the electricity in. The wire already insulated for the pipe was ready to hand. Two conductors were used for the circuit, instead of the earth return that had been introduced by Steinheil seven or eight years previously, and was already widely used elsewhere. This line clearly displayed the technological immaturity of the early Morse telegraph, but Vail and Cornell worked feverishly to refine it.

The first line had five Grove cells in Baltimore (keeping these evil things out of the Capitol and out of sight), and a key and register at both termini. Reid says there were 100 Grove cells in the battery, but this is probably incorrect, although large numbers of cells were soon used in attempts to drive unresponsive magnets. Before the public trial, Vail had made copper ground plates, 5 ft long by 2-1/2 ft wide, one of which was immersed in the sea at the Pratt Street docks, the other buried in the cellar of the Capitol. The ground return replaced the West wire for the duration of the trials. Afterwards, the keys and registers were rearranged so that transmission could simultaneously take place in both directions, using both wires. Vail was quite proud that only one set of batteries was required to operate both lines. The line was opened to the public on 1 April 1845, with Vail as operator in Washington, and H. J. Rogers in Baltimore, about a year after the first trial.

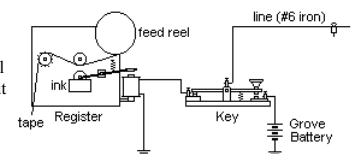


The register used for the trials embossed the paper tape with a steel point. Vail had first used a pencil, which required too much sharpening, then a pen, which kept clogging, then a method used for making manifold copies at the time (?), before deciding on the steel point. The paper factory made rolls 3' 6" wide on a wood core. These were marked off in 1-1/2" widths, and cut on a lathe with a knife, making 28 15" diameter rolls of tape from each large roll. The register was driven by a falling weight, which turned a clockwork regulated by a 'fly,' a primitive but effective means of controlling the speed. The first impulses received by the register would set the clockwork moving. The transmitting operator waited a short while until the register got up to speed, then transmitted his message. The receiving operator had to turn off the clockwork when the message had been received. The automatic nature of this is remarkable, and was very convenient.

The Morse inker was invented by Thomas John, an Austrian, in 1854, with the aim of making the register more sensitive. In this device, a rotating ink wheel dips in an ink reservoir. When lifted by marking current, it contacts the paper tape and leaves a mark. The most-used inker was manufactured by Siemens and Halske in Berlin, and was used throughout Europe. The paper tape was about 1 cm in width. Embossers remained standard in the United States.

The key used for transmitting was different from the later typical Morse key with front and back contacts, as well as from the modern key with a single contact pair and switch. It was a simple piece of spring brass with a 'hammer' and 'anvil' as the contacts were called at the free end. When it was desired to receive, a wedge had to be put between the contacts to close the circuit, allowing the operator at the other end to transmit with his key. This inconvenience was avoided by Vail's use of two wires, each used in one direction, so the key could be left open at all times. A new kind of key was soon designed, that would keep the circuit through the register closed, unless the battery was connected to the circuit by pressing the key.

When the Morse register was used, the circuit had to be normally open. To arrange for this, the key had both front and back contacts. When depressed, the key connected the battery to the line, at the same time disconnecting the local register. The figure at the right shows an elementary Morse-Vail telegraph station, such as would have been used in the United States in the 1860's. It shows an inking register, which replaced the embossing register. The register was usually operated by a relay, not directly from the line as shown in the Figure. Relays will be explained in detail below. They permit a feeble current to control a stronger one by opening or closing contacts. Morse independently had the idea of a relay, which he conceived as a repeater to operate very long circuits, but its practical use was for operating heavy-current devices like the register in a local circuit. Repeaters were not devised for many years, so messages were relayed at intermediate stations by retransmission. The noise of the register turning on served as an alarm to attract the attention of a receiving operator. A message could be sent, of course, without an operator being present to receive it, since the tape started automatically. The familiar later forms of the key, sounder and relay had been introduced by 1870.



Typical Morse (Vail) Telegraph Station (1860s)

The account I have just given of the beginnings of the Morse telegraph has been assembled from several sources, and seems to me to be relatively accurate. Nevertheless, the sources differ somewhat in dates, places, and names, even for the date of the 1844 event. May is probably correct, not March. A Dr Fisher is also said to have worked on the project, but no other reference to him can be found. However, there was a Dr Finley, Morse's uncle and the Charleston resident whose miniature portrait, painted by Morse, launched his painting career. Gale appears only to have shown Morse the Henry 'intensity' magnet he needed instead of the Sturgeon 'quantity' magnet, but this was a critical point that Morse never appreciated, and the change was made by Vail. Morse heard lectures on electricity by Jeremiah Day and Benjamin Silliman at Yale before he graduated in 1810, visited Silliman in New Haven in 1824, and heard James F. Dana's New York lectures where a Sturgeon-type electromagnet was demonstrated, in 1826 and 1827. Morse apparently never gained a useful knowledge of electricity, though he did not know significantly less than most of his contemporaries.

Companies were organized, funds raised, and construction begun in the latter half of 1845, with Philadelphia as a base. The Magnetic Telegraph Company was open to New York (Fort Lee, New Jersey) on 20 January 1846, and to Baltimore on 5 June. F. O. J. Smith's New York and Boston opened at Boston on 27 June. The New York, Albany and Buffalo reached Buffalo on 3 July, and the Atlantic, Lake and Mississippi Valley (later the Atlantic and Ohio) to Pittsburgh on 29 December. Except for Smith's Boston line, which aroused public scorn (Smith did not believe in insulation), these lines were in service more often than not. The original government line was purchased and went to the Magnetic. The winters of 45-46 and 46-47 taught many lessons in line construction. Copper soon disappeared, along with the

worst of the insulation methods. All these lines were Morse lines, and more or less affiliated through the Patentee's interests. They followed railways on a few routes, but mainly struck out along common roads. Funds were difficult to raise in the coastal cities, so Rochester, Utica and other small cities took the lead. Initial public traffic was less than anticipated, and business was slow to increase.

John Butterfield of Utica, a stagecoach operator, had glimpsed the possibilities of the telegraph when he observed the government line on a visit to Washington, and obtained patent rights in early 1845 for the New York, Albany and Buffalo Telegraph Company, which he and his associates formed. This turned out to be one of the best and most reliable lines in the country. In 1847 it was extended from Buffalo to Montreal by a Canadian company. Smith's Boston line was extended to Portland in that year, eventually reaching Halifax through a chain of companies for the European news. The Washington and New Orleans Telegraph Company, promoted by Amos Kendall, who as postmaster had established an extra-charge express mail to New Orleans, built the long line through Richmond, Wilmington, Charleston, Montgomery and Mobile to New Orleans, completed in 1848. Soon, the only states east of the Mississippi that did not have a telegraph line were Vermont, Tennessee and Florida. It should be remembered that in 1840, the population of Cincinnati was about 46,000, Pittsburgh 31,000, Louisville 21,000, Detroit 9100, Cleveland 6100 and Chicago 4470.

Henry O'Reilly (he spelled it thus; most references, including Reid, write O'Reilly) of Rochester contracted in June 1845 for the western rights to the Morse patents through the Pittsburgh gateway. He had met John Butterfield on the night boat to Albany on 7 January, and had become interested in the telegraph. His contract granted much of the territory also assigned to Smith when the Patentees divided their interests geographically. Smith tried, with only limited success, to declare the contract void the next year when he discovered what had been done. O'Reilly built the line from Lancaster to Harrisburg within the contractual time limit, but Smith claimed, unjustly, that it had to have been built through to Philadelphia within the time limit. The contract was not crystal-clear, but this was a very unfair accusation. Judge Kane of the U. S. District Court in Philadelphia ruled that he had not breached his contract. O'Reilly went on to build lines to Cincinnati, Louisville and St. Louis in the next few years, and even tried to extend his system beyond the limits set by his contract for the use of the Morse patents, with the People's Telegraph from Louisville to New Orleans. Smith, nevertheless, competed fiercely and relentlessly for more than a decade, building competing lines from the Buffalo gateway, which he controlled. O'Reilly was ruined in the end, though he had public support, and his lines were absorbed into Western Union together with Smith's in 1856.

As a contractor, in 1845-46, O'Reilly built the lines from Philadelphia to Baltimore and Pittsburgh. The Lancaster-Harrisburg line was opened in November 1845, the first commercial line (excluding the government line) to handle traffic. This company employed David Brooks, Anson Stager, C. T. Smith, and James D. Reid at the start of their telegraphic careers. The Pittsburgh line went from Philadelphia via Lancaster, Harrisburg, Carlisle, Chambersburg and Bedford to Pittsburgh, beside the railway from Philadelphia to Chambersburg, and beside the common road (now U.S. 30) beyond. When the Pennsylvania Railroad was complete, in 1853, the main line was moved to its right-of-way.

Messages were sent across the Hudson from Fort Lee by messenger or pigeon. Early attempts were made to cross this gap with cables, and by long aerial wires on masts, by various of the Morse associates, but with little luck. These people may have tried valiantly, but they certainly did not succeed, in underwater telegraphy. A successful cable was finally laid when gutta-percha insulated cables became available after 1847, the technology coming from Britain. This is discussed below in Underwater Telegraphs.

Amos Kendall became the business agent for Morse and Vail, while F. O. J. Smith exploited his quarter-interest separately. Kendall took the South, Smith the North. Competition ended with the formation of Western Union in 1855, in which the New York and Mississippi Valley Printing Telegraph Company of Rochester, New York, which was absorbing O'Reilly lines, merged with Smith's Erie and Michigan Telegraph Company. This company began eating up all the small, independent companies, and grew into a monopoly by the 1860's. Morse actually thought the telegraph should be operated by the Post Office, as it was everywhere except in the United States and Britain. British telegraphs, largely a monopoly, passed to the General Post Office in 1870, however, and the change was, in general, beneficial. In the U.S., the alternative of a regulated monopoly was chosen instead. It is curious that many of the American telegraph entrepreneurs were associated with Rochester, New York. Investors in the large coastal cities were not interested.

The year 1846 was the one in which many American telegraph pioneers entered the field, forsaking earlier occupations. Ezra Cornell manufactured telegraph instruments for Morse lines. In cooperation with F. O. J. Smith, Cornell, with his associate J. J. Speed, formed the Erie and Michigan Telegraph Co. to build lines from Albany north to Canada, and west to Milwaukee, which was reached in 1848 in the assault on O'Reilly's interests. In the same year, he organized the New York and Erie Telegraph Co., in effect competing with Morse and Vail, who had interests in the New York, Albany and Buffalo line. His empire entered financial difficulties, but an amalgamation of his interests with the New York and Mississippi Valley Printing Telegraph Company, a House line, created the Western Union Telegraph Company, as we have already noted, and rescued Cornell's fortune. After this, Cornell retired to found Cornell University in 1868.

By 1851, there were 67 Morse lines extending 20,000 miles, 8 House lines for 3000 miles, and 7 Bain lines for 2000 miles (see below for a description of the competing House and Bain telegraphs). The Mississippi River was crossed at St Louis by telegraph cables strung from high masts in 1852-3. The telegraph reached San Francisco in 1861. The speed at which the telegraph was extended in the United States was remarkable, but most of the lines were of execrable quality. By 1866, when the Atlantic Cable was put into service, most principal lines were in the hands of Western Union and the American Telegraph Company, who soon merged. The availability of money after the Civil War, and the low cost of telegraph construction, led to the mushroom growth of competitors, but there was little such competition after 1881, and Western Union dominated the market from then on. Some of the competing lines built after the Civil War were built solely for the purpose of being acquired by Western Union on advantageous terms.

The first telegraph customers were lottery sharps and stock brokers who obtained advance secret knowledge, of lottery numbers or the Philadelphia stock exchange, to gain advantage. However, news organizations were soon the best customers. Dispatches from the Mexican War were specially important, the earliest examples of instant news from the fronts. Newspapers formed associations to share intelligence, and obtained special volume telegraph rates. Six New York newspapers cooperated by forming the Associated Press for sharing the cost of news received by telegraph. It was much better than the postal service, which still used riders and saddlebags for most routes. Presidential annual messages were notable traffic: the first was President Polk's, in December 1848. It was attempted to send this message to many points by a single manipulation, and this almost succeeded, but a bitter storm made some relaying of the long message necessary. Soon merchants and businessmen found the wires essential for price reports, making deals and ordering. Private individuals began exchanging important messages, but did not use the service for chatting. A telegram was not cheap; a typical rate in 1846 was \$0.25 for 10 words for 100 miles, exclusive of address and signature. This was a fourth of a skilled man's daily pay. In fact, early telegraph traffic was unexpectedly light, because of the high charges. Private telegrams became associated with disasters and sad news. In 1866, Western Union charged \$2.05 for 10 words, New York to Chicago. In 1884, the charge was \$1.00 maximum between any two points on the continent. Occasionally, ruinous competition reduced rates to unremunerative amounts, while rates on the Pacific telegraph and similar monopoly circuits were extortionate. There was little rationality in the rate structure.

Telegraph charges were based on the number of words, exclusive of addresses and similar information, distance, and priority. The tariffs, however, were inconsistent and chaotic while there were competing companies, and no good system for the apportionment of revenues was devised. Air line distance between source and destination replaced wire distance. Rationality was finally introduced by Western Union when their territory was divided into zones, and rates set on a zone-to-zone basis (like some parcels rates are today). This was only possible because Western Union held a virtual monopoly. Words in a message were actual words, not the arbitrary 5-character words used to specify speeds of transmission. Some newspapers thought of packing as much as possible in a word, with things like "retackmentativeness" or "rehairoringed" that could be expanded into a paragraph by a code. This practice was forbidden, and code (cipher) messages charged in some fair way where they were allowed. Early operators occasionally guessed at words when the lines were bad, with sometimes comic results, so the redundancy of plain text was welcome.

The idea of a telegraphic alphabet was not new with Morse or Vail. However, most telegraphic systems, before the electromagnetic telegraph, used large vocabularies of prearranged messages identified by numbers or some similar means, called a *code*. For example, the Chappe visual telegraph showed 196 different positions or symbols (of which the operators at intermediate stations did not know the meaning). The prearranged messages could be complete sentences, phrases, individual words, or even letters and figures. Which dictionary was to be used was also expressed in the message. Morse's original system was like this, transmitting numbers that keyed into a vocabulary. These messages included the letters and numbers so that unusual words could be spelled out, but the bulk of the traffic was to be handled by means of the code book. Alphabetic codes were early used in nautical applications. The coloured naval signal flags now denote letters and numbers, and the Pasley semaphore telegraph of 1822 also used an alphabetic code. The idea of an alphabetic code was, therefore, not new in the 1830's. As we have seen, Gauss and Weber, Steinheil, and others, had used alphabetic codes. Even using an alphabetic code, one frequently employs certain prearranged messages, such as the radio Q signals (for example, QSL -- 'please acknowledge this contact in writing'). These standard international signals are used in Amateur Radio, for example.

Vail took the frequency with which the different letters were used in English text into account, making the more used characters shorter than the less frequent ones. One source says that his brother George, a newspaper editor, contributed the data, but I can find no evidence of such a brother. Another source, which gives Morse the credit, says a brother was involved as well. Morse indeed had a brother (at least two, in fact), one of which collaborated with him on various inventions, but his biography gives no hint of any contribution to a code. A look at a printer's type font would give a very good idea of the frequency with which letters are used, in any case. Vail's code involved not only dots and dashes, but spaced letters (such as O, .) and short, medium and long dashes. The T is a dash of the length of 2 dots, the L of 4 dots, and the 0 of 6 dots. These made sounds easily distinguishable on the sounder, which was ideal for receiving them, though the code preceded the sounder by some years. The Vail code turned out to be very well adapted to aural reception, though it was designed for the register. The use of the sounder in the United States ensured the continuation of the Vail code until its final use in railway train dispatching in the 1950's. There are many good reasons why it continued in this application even after the telephone was widely available, and was finally discontinued only because of a lack of Morse operators.

The European or Continental alphabet consists only of dots and dashes of one length, with no spaces in letters. O is -- -, for example. The International Morse O takes 11 unit times to send, the Vail O only 4. Vail tried to make the frequently-used letters as short as possible. The very common e is simply . . i is . . , t is -, c is . . , and so on. In Morse, some of these carefully designed codes are greatly lengthened, as we have seen with O. C is - . . , 11 dot times instead of 5. We will see that the changes were due to the adaptation of the alphabet to the German language, where, for example, C is much less used than in English. Numbers are much longer in Morse than in Vail. Indeed, abbreviated numbers are sometimes used in International Morse. It takes longer to send a given message in Morse than in Vail. Several dot-dash codes are shown in the section on Alphabetic Telegraph Codes to show the evolution of the Morse Code. Please consult this table when these codes are discussed in what follows.

Cooke and Wheatstone's Needle Telegraph

Enthused by Muncke's demonstration, Cooke first tried to make a 'musical snuff box' telegraph, then one with an electrically-released escapement, both rather impractical. Wheatstone provided some new ideas, and Cooke thought of using electric currents to deflect pointers to right or left so that they would point to the letter to be transmitted. The already familiar magnetized needle in a coil of wire or multiplier was the means. This needle was connected by a shaft to the visible needle on the front of the instrument that was observed by the operator. The signals were sent by a commutator operated by a handle. When the handle was vertical, the circuit was open and the needle stood vertical. When the handle was moved to one side, a current was sent that deflected the receiving needle. When the handle was moved to the other side, the direction of the current was reversed, and so was the deflection of the needle. Five needles were placed in a row at the centre of a lozenge-shaped dial. Any pair of needles, when

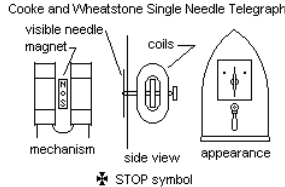
deflected, pointed to a single letter above or below the row of needles. This five-needle, or *hatchment* telegraph (from the shape of the face) instrument was to be connected with its mate at the other end of the line by five buried wires.

This telegraph was practical, and was actually brought into commercial service in 1838 beside the equally new Great Western Railway from Paddington to West Drayton, and eventually to Slough. The buried conductors, however, proved very expensive and troublesome. Although the early experimenters had used aerial lines with complete success, both the Cooke and the Morse telegraphs were introduced with buried conductors. The reason for this was not only to remove unsightly wires from public view, but also as an aid to security from physical damage or malicious interference. At Isambard Brunel's suggestion, the Cooke and Wheatstone line from Paddington to Slough was placed in iron pipe. However, the insulating materials of the day deteriorated rapidly under the conditions of burial, and lines soon became leaky and useless. Very soon, all telegraph lines were bare wire supported on insulators in pole lines. It was really not possible to make good buried cables until the introduction of gutta-percha insulation around 1847. Gutta-percha, a relative of rubber but not elastic, deteriorates rapidly when exposed to air and light.

As an example of the kind of misunderstandings that can arise in the history of the telegraph, Prescott says that the first electric telegraph was that of Wheatstone between London and Birmingham in 1835. He was using du Moncel as a source on telegraph history, and repeated an erroneous statement. Of course, the first Cooke and Wheatstone telegraph was between Euston Station and the Camden enginehouse on the London and Birmingham Railway in 1837, and was only an experiment, soon replaced by a pneumatic speaking tube.

Even with aerial lines, the five wires required for the hatchment telegraph were unnecessarily expensive. The number of needles was reduced to two or one, and the number of wires correspondingly. The simplified instrument case then acquired the familiar Gothic form (but sometimes was a plain rectangular box with writing desk), recalled in the Philco radios of the 1930's, as shown below. The needles and handles were electrically and mechanically separate in the two-needle instrument. Since the needles could no longer simply point to a letter, some code had to be created out of the elementary signals of right and left deflections. The single-needle code used from one to four deflections for each character. The deflections represented by long lines were done first, and those represented by short lines last. For example, d is left then right, while r is right then left. The symbol that looks like a Maltese cross was called STOP. It was sent at the end of each word. The receiving operator then replied with a single deflection to the right (M) if he understood the word, but with STOP if he did not. Special letters were used to shift in and shift out of numerical mode. The code was printed on the face of the instrument. Wheatstone provided an alarm bell for attracting the attention of the operator, in case the rattling of the needle was insufficient.

Single Needle (1846)															
✱	l	f	W	m	/	t	ll	1	/	6	^				
a	W	g	W	n	//	u	W	2	//	7	W				
b	W	h	W	o	///	v	W	3	///	8	W				
c	W	i	W	p	////	w	W	4	////	9	W				
d	W	k	W	r	W	x	W	5	W	0	W				
e	W	l	W	s	W	y	W								
✱ not understand, end of word E understand															
R wait W go on, decimal point H figures															



The two-needle telegraph was intended to speed up transmission by employing the additional signals that could be sent by two needles used individually, or simultaneously. The needles were used individually to send the letters printed above them to the right and left, using the appropriate number of repetitions. The code is shown on the right. The two-needle telegraph was the one mainly used for the commercial telegraphs, with trough batteries, in the 1850s and 1860s. The Electric Telegraph Company was formed in 1846, acquiring the Cooke and Wheatstone patents. By 1869, the needle telegraph was dying out as first the Bain electrochemical receiver, then the Morse register, then acoustic reception with the sounder, and finally the Wheatstone automatic telegraph took over. The single-needle telegraph remained as the normal 'speaking telegraph' on railways, where the demands made on it were not severe, and its cheapness and reliability were great advantages. It was still in use to an extremely limited extent as late as 1971. The single-needle telegraph was adapted as the three-position block indicator, and in this form survived into the 21st century. The block bell is a Morse key transmitter with a single-stroke bell receiver operated by a relay. Such instruments were used to a very limited extent in the United States in the

Double Needle (1843)															
	left		right		both										
+	l	H	r	R	ll										
A	ll	l	ll	S,Z,X	rr										
B	ll	K,Q	ll	T	ll										
C,1	lr	L,5	rl	U,9	rl										
D,2	rl	M,6	lr	V,0	lr										
E,3	r	N,7	r	W	r										
F	rr	O	rr	Y	rrr										
G,4	rrr	P	rrr												

late 19th century.

Needle telegraph receivers were essentially galvanoscopes to detect the presence and polarity of currents. The small permanent magnets not only became weaker with time, but strong earth currents in the coils could demagnetize them, or even reverse their magnetization, so they would give the opposite indication to the one desired. Every office had a large permanent magnet for remagnetizing the needles. This annoyance was relieved by the invention of the *induced needle* that used a sturdy permanent magnet to induce the proper polarity in a soft-iron armature connected to the indicating needle. Around 1866, C. V. Varley and C. E. Spagnoletti both devised induced needles.

Needle telegraphs were open-circuit in the sense that normally no current flowed in the line, and the needles were vertical (in the absence of earth currents). However, the circuit was closed through each instrument by contacts that opened when the transmitting handle was moved right or left, an action that put the local battery on the line with one polarity or the other. All needles on the line responded at the same time, and any operator could "break" by holding his handle to one side or the other. Exactly the same thing occurred when operating with a sounder, but the key had to have both front and back contacts, the back contacts keeping the line closed when not sending. In any case, there had to be a local battery for the line. Even when working a sounder, English circuits were operated open-circuit, and a needle was generally put in the line as a galvanometer. The usual line current was 15 mA.

By 1878 the Morse Code in its later form was used with the speaking telegraph on the Great Western Railway (and probably generally). Polarized currents were used with a single needle, as usual. Deflections to the left signified dots, those to the right, dashes. A full stop (period) was `llll`, 'I understand' was `T (/)`, and 'I do not understand' was `E (l)`. `T` was the response after the receiving operator took time to write down the word that had just been transmitted. It appears that the needle was watched until a word had been sent, and then there was a pause while the word was written down and acknowledged. Numerals were preceded by `FI` and followed by `IF`. The prefixes `SP` (important) and `DG` (danger message) were used to establish priority. When broken, the operator transmitting would send `WQ` ('I am in the middle of a message') and could proceed unless the operator breaking in sent `DG`. `TA` identified a train report, and `S` a public message. `RT` was the abbreviation for 'right.' The heading of this page shows a single needle sending the word "MORSE" with a left deflection for a dash, a right deflection for a dot [this is opposite to the usual convention; the graphic will be changed when time allows].

The Magnetic Telegraph Company, incorporated in 1852, operated lines from London to Ireland, over a submarine cable from Donaghadee to Portpatrick, and connected the major Irish cities, as far as Limerick, Killarney and Cork. The double-needle telegraph of Henley and Forster, with modifications by the Bright brothers, was used, which employed momentary currents generated by magnetos instead of batteries. The Brights were secretary and engineer of the company. Some of the lines of this company were underground. It also had lines to Glasgow and Edinburgh, as well as to Birmingham, Liverpool and Manchester.

Bain, House and Other Telegraphs

Du Moncel classifies telegraphs as: writing, needle, dial, printing and autographic. All types except the last, which was a curiosity, were commercially used at some time. An autographic telegraph reproduces the movements of a stylus remotely.

The success of the Morse telegraph in the United States, and of the Cooke and Wheatstone telegraph in Britain, caused many inventors to work on telegraphs that could evade the patents which were being used to create monopolies in both countries. An early and important example was Alexander Bain's chemical telegraph of 1846. This was an improvement on the original 1839 chemical telegraph of Edward Davy. The novelty was the receiver, consisting of a disc of paper moistened with a potassium ferrocyanide and ammonium nitrate solution and resting on an iron plate, on which a stylus traced a spiral as the iron plate was turned by clockwork. Whenever a current flowed, and only a very small current was required, electrolysis caused the formation of iron ferrocyanide, or Prussian blue, and a mark was made on the disc. It looked much like a disc record player of many years later. Bain even constructed a new code of dots and dashes which was purposely different from the Vail (Morse) Code. At least one Bain character found its way into the later Morse Code, as well as his numbers, and there is a logical reason for this. Unlike the Morse register, the Bain receiver was completely quiet, so Bain needed some kind of alarm, and he devised one as far from looking like anything Morse as could be. Later Bain telegraphs used a paper strip instead of the disc, and an iron stylus instead of the iron plate. Potassium iodide could also be used as the chemical, in which case electrolysis would free iodine, and make a brown stain instead of a blue one. Bain originated automatic sending with a perforated paper tape in 1846. Apertures in the form of dots and dashes were made in the tape, which was run between a conducting brush and roller. Electrolytic reception can be very fast, since there is no mechanical or electrical inertia. However, the inconvenience of maintaining a moist tape led to its disuse. The Bain system also included an electromagnetic "call" device, necessary to tell the operator when to start the receiver, since otherwise the system was silent. These appurtenances were attacked by the Morse Patentees quite vigorously.

The Bain telegraph was introduced to the United States by Henry O'Rielly when the "Columbian" telegraph of Zook and Barnes (1848) was struck down in the courts as an infringement on the Morse patents, and negotiations to use the House telegraph (which would not have worked on his bad line anyway) failed, as he struggled to bring the Louisville-New Orleans People's Telegraph into operation. O'Rielly could use the Morse patents only within the territory assigned in his original contract. For all further expansion, he needed another system. Bain's system with tape transmission and chemical reception, and indeed a new alphabet, was enough unlike Morse that it was ruled by the Kentucky courts as no infringement. This line was an operational and financial failure until sold to others. In 1850, the important routes from New York to Boston, Buffalo and Philadelphia all had competing Morse, House and Bain telegraph lines. In that year, of 22,000 miles of telegraph line in the United States, 12,000 were Morse, and the rest were Bain and House.

The Vermont and Boston Telegraph Company adopted the Bain system in preference to the Morse when it was founded in 1848. It used the Bain system until after it was acquired by Western Union in 1866, when Morse instruments were substituted. It was probably the last Bain line in service, and a rare one in that it did not parallel a Morse line. The Bain telegraph was quite practical, but it lacked acoustic reception, and this proved a worse defect than the dampness of the solutions. The V&B; used the English sand battery, #8 black Swedish iron wire, and the patent insulators of its engineer, Prof. Benedict, at least at the beginning.

The printing telegraph invented by Royal E. House of Vermont was patented in 1846, but was not usable until modified to eliminate interference with the Morse patents, and was repatented in 1852. It was the first printing telegraph, which recorded the message in ordinary letters on a strip of paper. The first U.S. patent application was attacked in court because of infringement of the Morse patents, after which House replaced electromagnets by pneumatic actuation. The operator worked a treadle to supply the air, and held down a key, like a piano key, that corresponded to the letter he desired to transmit. A commutator was rotated that sent pulses down the line, and the key operated a stop that stopped the commutator after the required number of pulses was sent, the number depending on the letter that had been sent last, so that a maximum of 28 pulses were required for each letter. There were 26 letter keys, and two more for "dot" and "dash." It is impossible to describe the mechanism adequately in the space available here, so the reader is referred to Jones or Prescott. At the other end, the type wheel or basket was rotated synchronously by pneumatic means as the pulses were received. When it stopped, the operator there took an action that pressed the receiving tape against the inked type, again using the air provided by a treadle. The first use was in 1847 between Cincinnati and Jeffersonville (Louisville). This was only a temporary expedient when Morse instruments were in tight supply. House circuits were established by Downing between New York and Philadelphia, and New York and Boston, in 1849, and set off the court suits. 30 Grove cells were required for the 100 miles to Philadelphia. The House telegraph required a much better circuit than the slower Morse register did. In Britain, the House telegraph was

known under the name of Jacob Brett, who was the representative there. The House was the fastest telegraph available at the time, twice as fast as Morse or Bain, but it required a good circuit and skilled operators. The air supplied by the treadles was later supplied by a crank turned by a man called the 'grinder.' Although the House telegraph saw much use along the Atlantic coast, it was generally adopted in the west when necessary to avoid the Morse patents. As soon as Morse patent rights were acquired, the House instruments were replaced by the much simpler Morse key and sounder.

The three significant early suits in U. S. District Courts were Morse vs O'Reilly, heard by Judge Monroe in the District of Kentucky, over the Zook and Barnes invention; Smith vs Downing, heard by Judges Levi Woodbury and Curtis in Boston over the House telegraph on the New York-Boston line in 1850; and French vs Rogers heard by Judge Kane in September 1851 in the Eastern District of Pennsylvania over the Bain telegraph on the New York-Washington line. Morse vs O'Reilly was decided in Morse's favor, but Smith vs Downing went against Morse, and no injunction was granted against the House telegraph. There was extensive expert evidence in especially the latter two cases, all of it in favor of the defense. The evidence presented in Smith vs Downing contains ample proof that Morse's claims were excessive and baseless. Joseph Henry said "I am not aware that Mr Morse has ever made a single original discovery in electricity, magnetism or electro-magnetism applicable to the invention of the telegraph." Every scientific witness said essentially the same thing. Dyar, the inventor of a static electricity telegraph in 1826 said: "The great fault of Morse and his friends has been, to claim the exclusive use of principles which he never discovered or invented." Prescott lists 62 inventors of telegraphs prior to Morse in 1838. Steinheil was recognized as the inventor of the practical recording telegraph, including the relay, by 1837.

In spite of the evidence, Judge Kane found for the plaintiffs, in a decision that was greeted with incredulity. Either the judge's mind had failed, or there was something else at work. Philadelphia, where the trial was held, was noted for corruption, and something like it may have penetrated here. Bain was Scottish, and that also may have been a factor. On appeal, Judge Cranch found for Bain, but the damage was largely done, and Kane's decision served the public and honest inventors very poorly. It was as if the inventor of the steam engine had patented steam in all its uses and could successfully sue the inventor of a steam hammer. It was said facetiously that the patent commissioner thought that "Mr Morse held exclusive right to electricity in any form in which it could be used for telegraphic purposes," and believed himself put at the head of the Patent Department solely to maintain Morse's rights.

Both Bain and House had quickly received British patents, but the U. S. Patent Office refused them. Both Bain and House appealed to the Supreme Court, which found in their favour, Judge Cranch for Bain, and Judge Woodbury for House. Nevertheless, Morse's patents on the recording and acoustic electromagnetic telegraphs were upheld until they finally lapsed, to the great disadvantage of the public. Curiously, the same competition between Morse, Bain and House (or Hughes; see below) systems existed in Continental Europe. Morse even patented a chemical telegraph, to head off the threat from Bain. Few inventors were ever less entitled to their patent rights than Morse.

The mechanical parts of the telegraph had every right to patent protection, by Vail as part of the Morse Group. These were good, useful inventions of great commercial value. Morse had achieved the federal subsidy by his persistence and devotion, and had seen the enterprise through. It was very unjust, however, to claim exclusive rights to things that others had discovered, and were well-known or had been given to the public by men like Faraday, Henry and Steinheil. The attempt to patent the transmitting key is one example, or the later attempt to patent chemical reception when Morse had been unsuccessful in realizing it earlier. Both things were merely the state of the art, and had already been published and used. In the same vein, Page patented the spring return of an electromagnetic armature! Such a device would have been obvious to anyone, and it is essentially patenting springs. Such greed and presumption, however, are still not rare.

Wheatstone's automatic telegraph (1855) used a punched paper tape to control the transmitter, and could send at speeds up to 130 wpm. Later equipment could send 300 to 400 wpm on a good circuit. The system consisted of a perforator, transmitter and receiver. Holes side by side sent a dot, and staggered holes sent a dash. Polarized pulses were used, two of opposite polarity for each dot or dash, received by a sensitive polarized relay. The receiver was essentially a sensitive Morse register that inked a tape, which was later transcribed in the usual fashion. Wheatstone's automatic transmitter was used on the busy lines of the Electric and International Telegraph Company between London and Manchester, Glasgow, Edinburgh and Newcastle. The Wheatstone was very convenient for sending the news, since only one tape had to be made for transmission of the same news to numerous offices. Edison also worked on automatic telegraphs, and invented a means of sharpening the pulses for higher speed. He achieved 1000 wpm on high-quality pole lines, using electrolytic receivers (like the Bain).

When T. T. Eckert and G. B. Prescott, General Manager and Electrician, respectively, of Western Union visited England in 1874, they brought back with them a pair of Wheatstone instruments as curiosities. When increasing traffic demanded some remedy, the Wheatstone was tried on a New York-Chicago circuit in 1881 and did quite well. The Wheatstone was brought into regular use in 1882 on duplexed circuits to Chicago, New Orleans and Kansas City. There were repeaters at Buffalo on the Chicago circuit, and at Lynchburg and Atlanta on the New Orleans circuit. These were duplex Wheatstone repeaters from England that could handle the necessary speed. 150 wpm was reached on the Chicago line, and about half this on the poorer New Orleans line. Perforating could be done at 30 wpm, and several perforators could feed one transmitter. Received messages were typewritten by female clerks. In 1886, there were 3 Wheatstone instruments and 10 perforators at the New York office, and the company owned 16 Wheatstones in all. This forebode the eventual replacement of manual operation by automatic telegraphs.

In spite of many attempts to design fast automatic telegraphs by many American inventors, notably Edison, only the Wheatstone, from England, ever saw significant practical use. The American Rapid Telegraph Company used some combination of automatic tape transmission and Bain reception with a two-line telegraph (like Steinheil's!) to offer service in 1879. Their secret weapon was the use of young girls as cheap labor. An 1884 lease to Western Union eliminated the competition. Elisha Gray's harmonic telegraph of 1874, Leggo's automatic transmitter, and Snow's compound wire were brought together in the Postal Telegraph Company of 1881 as a "high tech" wonder on the New York-Chicago route. Two compound wires on 43 chestnut or cedar poles per mile, beside the Erie and the Lake Shore and Michigan Southern roads offered 20 words for a quarter. The "postal" in the company name and the cheap rates were to encourage government interest as a possible post office adjunct. Western Union bought it out instead, putting an end to the nonsense. Gray's Harmonic Telegraph led to interest in the multiplex, sending several messages at the same time on one wire, which was finally practically accomplished in another way. The multiplex is explained below in the section on repeaters, duplex and quadruplex.

Cooke and Wheatstone both worked on electrically-released dial telegraphs on which a hand would point to the desired message or character, so that skilled operators (and their wages) would not be required, or that the telegraph could be operated by the general public. Wheatstone realized this principle in his ABC telegraph. After Wheatstone, many inventors came up with alphabetic dial telegraphs, which should be distinguished from alphabetic printing telegraphs. The dial telegraphs were not recording. They were usually called ABC telegraphs, after Wheatstone's instrument. In Wheatstone's instruments, pulses were generated by a hand-turned magneto, and needles on the transmitter and indicator moved synchronously to letter after letter in a message, returning to the zero position (Maltese cross) at the end. ABC instruments could be used by anyone, and were mainly used on private circuits. All the early visual and printing alphabetic telegraphs did not use a telegraphic alphabet, but relied on synchronism at the two ends of the circuit.

John Nott patented a dial telegraph on 20 January 1846 that was tried on a five-mile circuit between Northampton and Blisworth on the London and North Western Railway. The patent was purchased by the Electric Telegraph Company, but was never used to any extent. One may have been used for a while in Box Tunnel on the Great Western Railway around this time, since the company was their telegraph contractor.

The Hughes printing telegraph, invented by David Hughes, an obscure music teacher of Kentucky around 1855, patented in 1857, but developed in England and used chiefly on the continent, had a type wheel at the receiver synchronized with a wheel at the transmitter by means of tuning forks, with a pulse of current to print the letter at the proper phase, like a ticker. However, the type wheels were synchronized in a different way than in the ticker, and the printing used very little electrical power. It was much easier to use than the House telegraph, but more complex. A skilled mechanic had to be on hand with the Hughes teleprinter, since it was very delicate. By 1870, the House and Hughes teleprinters had been improved and combined by Phelps, whose American Printing Telegraph or Combination Printer helped the American Telegraph Co. and Western Union to dispense with skilled, and unionized, Morse operators on a few lines. The Hughes-Phelps teleprinter was used mainly in Europe, where it became relatively popular, but it was never used to any extent in the United States. It came too late to make any difference in the patent battles. Émile Baudot devised a printing telegraph using the 5-bit Baudot Code in 1874 that was the ancestor of ASCII, but printing telegraphs were really not easy to use until Kleinschmidt's introduction of the Teletype in 1928. These later developments are on the same principle as the Hughes, but with resynchronization for each character.

Stöhrer used a polarized relay to select when one stylus or the other would print dots and dashes on a moving paper tape. The use of four symbols rather than two made the characters more compact, increasing the speed of transmission. The system, an elaboration of the Morse register, was never widely used.

In England, Bright's Bell was an early acoustic telegraph receiver. Two single-stroke bells of different tones were rung by polarized pulses, a positive pulse ringing one and a negative pulse the other, signifying the dots and dashes of the International Code. A modification of this was the Double Plate Sounder, and another was Neale's Acoustic Dial, essentially a needle telegraph that gave acoustic output, so it could be used either visually or aurally.

Major Cardner, R.E. invented what he called a "vibrating sounder" in 1881 shortly after the arrival of the telephone. The receiver was a telephone receiver, but the sender was a vibrating buzzer coupled to the line through a transformer (like an induction coil), operated by a key in the usual way. The power supply was 4 Leclanché cells, so the apparatus was quite portable. At the time, telephones depended on the feeble energy supplied by the voice, and had a very limited range, but Cardner's telegraph was good for up to 300 miles. By using a capacitor and an inductor to separate the signals, the device could be used over a normal Morse wire. A similar device was Edison's *phonoplex* system used for through traffic over a normal circuit. The way-station relays were bypassed by capacitors, and the audio-frequency signal was separated from the Morse direct current by capacitors.

In 1849-1850, G. H. Horn invented an "igniting" telegraph receiver that used a loop of fine platinum wire to register on a paper tape by burning a brown spot. This receiver was used on a local circuit, so the obviously large current requirement was not a drawback. However, it was a solution for which there was no problem, and soon disappeared. A man named Johnson devised a telegraph in which electricity released certain amounts of lead shot, which was then pressed to make an indentation as a record. "Axial" telegraphs using solenoids were also proposed, by Daniel Davis of Boston, for example.

I believe I have mentioned most of the telegraphs that were used commercially to any extent, or which show the various techniques employed, but there was a very large number of proposals, patents and promotions which forms a study in itself. After about 1880, there was a flood of patents for automatic telegraphs, stock tickers, alarm and call systems, and other electrical inventions, few of which were ever exploited.

Continental Developments

In 1844 a government commission was formed in France to investigate the telegraph. The Cooke and Wheatstone needle telegraph was installed between Versailles and Orleans in that year. On 30 January 1845 construction began on the first permanent line, from Rouen to Paris, under the direction of Bréguet and Froment, the leading French telegraph engineers. Louis-François-Clément Bréguet (1804-1883)

was of the Huguenot family famous for clocks and instruments, the grandson of Abraham-Louis (1747-1823). A needle swinging between the two poles of a horseshoe electromagnet was the first receiver, but an instrument, based on electrically released clockwork, that simulated the signs of the Chappe optical telegraph was soon devised. Sending was by means of two handles that simulated the controls of the Chappe apparatus. This instrument, however, was used only to send alphabetical and numerical characters, not the Chappe symbols. The long regulator was horizontal, and only the two indicator arms rotated, each taking seven positions. It was essentially two telegraphs in one, and required two wires, in addition to the earth return. The first dispatch was sent from Rouen to Paris on 11 June 1845. The code is shown at the right.

Bréguet (1844)			
a	←	k	u
b	←	l	v
c	←	m	x
d	←	n	y
e	←	o	z
f	←	p	é
g	←	q	ment
h	←	r	sion
i	←	s	.
j	←	t	

This rather cumbersome system was superseded by the dial telegraph, which became the standard in France and Belgium. Both Bréguet and Froment developed such telegraphs in France, Siemens in Germany, and Lippens in Belgium. The idea is to rotate a pointer around a dial by sending a sequence of pulses, starting from some standard position. Bréguet's transmitter had a rotating handle, Froment's a piano-like keyboard. They were thought usable by untrained staff. Eventually, around 1854, Morse registers, and subsequently the Hughes printing telegraph, superseded the Bréguet instruments. Bréguet instruments were used on Italy's first line, from Pisa to Livorno, in 1847. Brussels-Antwerp followed before 1851, probably with Lippens instruments, and Stockholm-Uppsala in 1853, with instruments unknown to me, but probably Morse.

M. M. von Weber says the Cooke and Wheatstone double-needle instrument and bell were used for a railway block on the heavy gradient between Aachen and Ronheide in 1843. The first postal telegraph line in Germany connected Hamburg and Cuxhaven in 1847, using Morse instruments. Steinheil was sent from Bavaria to inspect and report on this development. Another source says Germany's first telegraph line opened in 1849, between Mainz and Frankfurt. The Morse register was generally adopted in Germany, in fact practically everywhere east of the Rhine, preferred to the Siemens dial telegraph and all other non-recording telegraphs. The Vail Code must have been used initially.

In Austria, a certain Baumgartner had introduced the Bain telegraph and was promoting its use. In 1849, Steinheil was appointed Chief of the Telegraph Department in Vienna, by the new Minister for Trade, von Bruck. He and von Bruck were not impressed by the Bain apparatus, and it was replaced by the Morse. Soon, Steinheil had provided Austria-Hungary with a 1000-mile Morse telegraph system connecting all the provincial capitals. It was a cross centred on Vienna, extending to Prague, Lemberg, Trieste and Bavaria, with a fifth line east to Hungary and Croatia. Since the Vail code had not been created with the German language in view, some new characters were desirable. It was also recognized that unless some uniformity was agreed upon, there would be chaos in telegraphing between the many different German-speaking states east of the Rhine. The Deutsch-Oesterreichischen Telegraphenverein was formed in 1850 for this purpose. At a conference in Vienna, Austria in October 1851, agreement was reached over the instruments to be used, and the code to be employed. The new code eliminated the spaced letters of the Vail Code, as well as the dashes of different lengths. A second conference in 1854 adopted a new code for numerals, as well as punctuation and operating signals. This conference was attended by T. P. Shaffner, who reports the code adopted there in his book. This code was what later was to become the International Morse Code, achieving its essential form at this early date. We see, then, that the greatest impetus for the change was the adaptation of the Vail Code to the German language, and this was probably done under the supervision of Steinheil. A Russian alphabet for Cyrillic letters was also created at an early date, and is shown on the right.

Russian Morse			
A	· · ·	K	· · · · ·
B	· · · · ·	L	· · · · ·
C	· · · · ·	M	· · · · ·
D	· · · · ·	N	· · · · ·
E	· · · · ·	O	· · · · ·
F	· · · · ·	P	· · · · ·
G	· · · · ·	Q	· · · · ·
H	· · · · ·	R	· · · · ·
I	· · · · ·	S	· · · · ·
J	· · · · ·	T	· · · · ·
K	· · · · ·	U	· · · · ·
L	· · · · ·	V	· · · · ·
M	· · · · ·	W	· · · · ·
N	· · · · ·	X	· · · · ·
O	· · · · ·	Y	· · · · ·
P	· · · · ·	Z	· · · · ·

When Baumgartner became Minister in 1857, Steinheil thought it best to depart from Vienna. In 1851 he had set up the Swiss telegraphs, 300 Swiss leagues long (says the source), with 40 stations and 80 telegraphers. The Morse register was later adapted to the use of ink instead of embossing, and was widely used in Europe, popularized largely by Steinheil, and using the new code. English Morse registers were made by Siemens, and continental ones by Digny of France. The fact that the new code was developed in Germany, on the 'Continent' in English terms, probably caused it to be called Continental Morse Code whenever a distinction was necessary. However, the distinction was not long required, since the Vail code probably vanished completely in Europe at an early date.

The Telegraph Line: Batteries

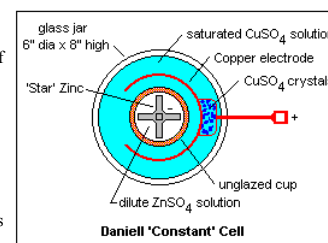
A telegraph system consisted of the wire line, the instruments, and the batteries used to supply the electricity. This type of line, bare wire suspended above the earth on insulators, was very well adapted to the purpose, with its low capacitance and inductance offering a bandwidth far in excess of what was required. Ground-return circuits were adequate, halving the cost and resistance of the line over those of a metallic circuit. Telegraphs used batteries as the power source from the beginning. Only small amounts of power are necessary, so that batteries are an economical choice. Until the development of efficient dynamos in the 1870's they were the only choice. Even then, until the arrival of mains power from central power stations after 1900, batteries remained the principal source of power, except in the large stations that could support the expense of a boiler and steam engine.

A chemical source of electricity consists of a spontaneous chemical reaction that involves the transfer of electrons from one species of atom to another, where the electrons are made to travel through the external circuit to accomplish the transfer. Half of the reaction occurs at one electrode, where the electrons are removed from an atom and sent through the wire. Chemically, this is called *oxidation*. This is the negative electrode, or *cathode*, as Faraday named it, by convention. The other half of the reaction occurs at the other electrode, where the electrons are received and supplied to the atoms that require them, which is called *reduction*. This is the positive electrode or *anode*. Any time the electrons do not pass through the external circuit the reaction takes place without useful effect, and is called *local action*. The solutions between the electrodes, called the *electrolyte*, must remain electrically neutral by the movement of charged atoms, or *ions*. Faraday named the electrodes from the movement of ions from (kata) the cathode, to (ana) the anode, which was true. People just assumed the current continued in the same direction through the external wire, but in fact the electrons are moving in the opposite direction. It makes no difference, as the motions are equivalent because the charges are opposite in sign. The U.S. Army decided current was in the direction of electron flow to simplify things for trainees in the Second World War, but this just adds confusion. In old accounts, the cathode, from which electrons came and which was the negative terminal, was called the positive electrode, and the anode, the positive terminal, was called the negative electrode. This was relative to the electrolyte, and the idea was that current flowed from positive to negative. This nomenclature should be avoided, and is mentioned only in case the reader encounters it.

The reaction that is almost always used is the dissolving (oxidation, in chemical jargon) of zinc from the solid metal to zinc ions in solution, releasing two electrons for each atom. Zinc has a strong tendency to do this, which supplies the power. This reaction, essentially 'burning zinc,' is still used in modern batteries. At the other electrode, the electrons must somehow get into the electrolyte to balance the charge of the zinc ions, and they cannot do this on their own. They can unite with water, however, to form hydrogen gas, leaving the negative part of the water, the OH⁻ in the solution. The electrolyte is made acid, so that water is formed again, and whatever negative ion the acid involves is left in the solution. This was Volta's original battery, or pile, and was the first telegraph battery. Strictly speaking, each individual zinc-copper pair formed a *cell*, and a number of cells connected in series, zinc to copper, is a *battery*.

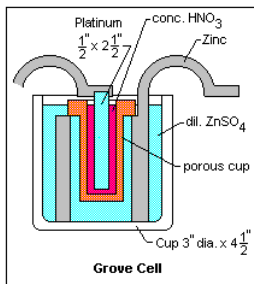
Cruikshanks' trough battery (about 1800), called the *pile anglaise* in France, consisted of a glazed earthenware trough with slate spacers dividing it into a number of chambers. Alternate copper and zinc plates (typically 112 mm x 87 mm) were held in a wooden top, and connected by wires. The battery was usually filled with sand (to prevent sloshing) saturated with acid water, usually dilute sulphuric acid, or even ammonium chloride solution. This battery supplied about 1 V per cell, but only when fresh. If current was continually drained from it, the plates became covered with bubbles of hydrogen and the internal resistance increased, while the terminal voltage decreased, a process inappropriately called polarization. Therefore, open-circuit telegraphs were the only possibility with this sort of battery. Smee invented a cell where the copper electrode was coated with finely-divided platinum. This caused the evolved hydrogen to form bubbles and detach themselves. However, this was only an imperfect solution.

The Daniell cell was invented at King's College, London by Professor of Chemistry J. F. Daniell in 1836, and was called a *constant battery* because it did not evolve gas, and therefore did not polarize, supplying a constant current. It furnished the unit of electric potential, the volt (1.079V in modern units), as a column of mercury did the unit of resistance, the ohm. The Daniell cell still used the familiar copper and zinc electrodes. The zinc electrode was put in a cup of unglazed earthenware and bathed in dilute sulphuric acid. The porous cup, which did not allow solutions to mix, but permitted ions to pass through, was Daniell's essential invention. The copper was surrounded by crystals of copper sulphate that maintained a saturated solution. Copper sulphate is sometimes called *bluestone*, so these batteries were often called bluestone batteries. Instead of releasing hydrogen, the electrons were furnished to the copper ions in the electrolyte, which plated out as copper metal on any nearby surface. The purpose of the cup was to keep the solutions separate while allowing electrical conduction by ion migration. If the solutions mixed, local action ruined the battery. When the cell furnished current, the zinc dissolved to form zinc sulphate solution, and copper from the copper sulphate plated out on the copper electrode. No gases were involved at all, so the cell did not polarize. The cell has a fairly large internal resistance, but this was not a serious defect in view of the small currents required, and actually proved an advantage in many applications. It also protected the cell against damage if shorted. The copper sulphate even kept algae under control. However, the porous cup, intended to keep the solutions separate, was rendered impervious after a time by deposition of copper on it as the cell operated.



The Daniell cell was widely used in France before the Leclanché cell was invented in 1866 by a man of that name who was with the Chemin de Fer de l'Est. This cell consisted of a zinc (negative) electrode in an electrolyte of ammonium chloride solution (sal ammoniac). The positive electrode was a carbon rod, packed with powdered carbon and manganese dioxide in a porous cup (positive). When current flowed, the zinc became zinc chloride, while the ammonium reacted with the manganese dioxide to form manganous oxide, ammonia and water. There was no production of hydrogen, and so no polarization. However, other reactions occur that do produce polarization, lowering the terminal voltage and increasing the internal resistance. These reactions are reversible if the cell stands inactive, so the cell is well-adapted to intermittent use. Its terminal voltage is between 1.6 and 1.4 V, usually taken as 1.5. The ammonia evolved by the cell sometimes attacked iron wires in the vicinity. The Leclanché cell is still in common use as the modern 'dry' cell, with a paste electrolyte and throw-away packaging. These dry cells weaken more rapidly than the wet cell, and have a higher internal resistance, but are very convenient.

The Daniell cell was rendered longer-lasting by a modification introduced by Callaud around the 1860s to eliminate the porous cup, which was just coming into service in 1870. It had been noticed that the copper sulphate solution was denser than the zinc sulphate solution, which floated on top of it if they were both poured into the same container. John Fuller in 1852, and C. F. Varley in 1854, had independently suggested gravity cells. Normally, diffusion would soon mix the two liquids, destroying the cell's efficacy, but if a current was drawn continuously, the natural migration of the ions kept the copper sulphate on the bottom and the zinc sulphate on the top, like oil and water. Callaud's cell (in the form used in the United States) consisted simply of the glass crock, a copper star for the bottom, and a zinc casting hung on the side of the crock. Crystals of copper sulphate were arranged around the copper, and distilled water was carefully poured in until the zinc was covered. Crystals were necessary, since powdered copper sulphate would form a crust and dissolve too slowly. A little acid was carefully poured in the top, and the cell placed under load. Soon you had a reliable cell as long as it remained undisturbed and did not freeze, and you could check its condition by looking at it. A little battery oil poured on the top prevented evaporation. The upper solution was clear, while the lower was a deep blue, and the boundary between them should be distinct. Concentrated zinc sulphate solution could carefully be dipped out and replaced by fresh acid, and more blue crystals could be dropped around the copper, until the zinc was consumed, at which time it was best to renew the cell completely. The supplies were easily stored, and the copper recovered was valuable. This was the familiar *gravity cell* that gave such good service until replaced by more modern cells in the 20th century. As many cells in series as required to supply the required current were used. Batteries, in general, cannot be paralleled for larger currents. Their physical size determines the current that they can safely supply.



In the United States, the usual telegraph line battery was the Grove cell, invented by (Sir) William Robert Grove in England, which was used on the first Morse telegraph in 1844. This consisted of a glass tumbler, in which a cast zinc cylinder was placed. An unglazed pottery cup was placed in the zinc cylinder. The zinc cylinder had an arm reaching to above the unglazed cup of the neighbouring cell, to which a strip of platinum foil was soldered, that entered the cup. The cup was filled with concentrated nitric acid, and the glass tumbler with dilute sulphuric acid solution. Wires were soldered onto the ends of the battery to make connections. The platinum was the positive terminal, the zinc the negative. When current was drawn, the acid decomposed, releasing noxious fumes, instead of polarizing the cell. The Grove cell had about twice the voltage of zinc-copper batteries, which was its principal advantage. When in use, the cell gave off nitric oxide, N_2O_4 , a poisonous gas. The expensive platinum electrode was replaced by a much cheaper one of carbon in the Bunsen or Carbon cell, where an acidic potassium dichromate electrolyte replaced the nitric acid. Grove also invented a fuel cell using hydrogen and oxygen, but it did not see practical use.

Vail's original Grove cell was in a tumbler 3" high and 2-3/4" in diameter. The zinc was 3" high and 2" in diameter, 3/8" thick, the unglazed cup 3" high under the rim, 1-1/4" in diameter, and 1/8" thick, with a 1/4" rim.

American telegraph circuits were very poor, suffering from high and variable leakage (as well as vandalism). Instead of improving the circuit, one simply piled on more batteries. It was not unusual to use 50 Grove jars on a long circuit. The usual ratio was one Grove cell per 20 miles of relay line (where local circuits had separate batteries). 50 jars could supply an 800-mile relay circuit, or a 50-mile register circuit. Half of the line batteries were placed at one terminus, the other half at the other terminus. With closed-circuit operation, intermediate stations needed only local batteries, usually two or three jars of gravity.

The Grove and Bunsen cells supplied about 2.14 V, and had an internal resistance of about 0.5 Ω for the usual 1-pint cell (3" dia by 4-1/2" high). The Daniell and Gravity cells supplied about 1 V, and had an internal resistance of about 2 Ω for the usual 1-gallon cell (6" dia by 8"-9" high).

Fuller's Patent cell, or Leffert's Patent, had a zinc cathode whose base was immersed in liquid mercury, in a porous container with a dilute sulphuric acid solution. The anode was carbon, surrounded by orange-red potassium dichromate ($K_2Cr_2O_7$) solution and crystals, again in sulphuric acid. When three zinc atoms lost two electrons each and went into solution, the six electrons passed through the external circuit, and were then supplied to two Cr atoms, changing them from valence 6 to 3 and producing Cr^{+++} ions. Sulphate ions diffused through the porous pot to complete the circuit. This cell had a terminal voltage of a little more than 2 V, and had the advantage of not producing any noxious gases. However, the dichromate was not cheap.

Impurities in zinc, such as iron or nickel, caused *local action*, which were minute short-circuited cells around each grain of impurity that would soon eat away the zinc. Pure zinc was far too expensive to be considered at that time, so the commercial metal had to be used. It was found (by William Sturgeon in 1835) that if the zinc electrodes were *amalgamated* with liquid mercury, the local action was eliminated. To do this, the electrode was first pickled in hydrochloric or sulphuric acid, then dipped in mercury, and then allowed to drain. This isolated the impurities from the electrolyte, while still permitting the passage of zinc ions and electrons, greatly extending the life of the zinc. Amalgamation had to be repeated as necessary. If the zinc is bathed in zinc sulphate solution, as it is in a gravity cell, local action is unimportant, and the zinc need not be amalgamated.

Several varieties of batteries were used in British railway telegraphs of the 1870s, among them the 'sulphate' battery, which was the common American gravity cell, described above. Each 4 miles of line with instruments, or 10 miles of plain line, called for one cell. Tyer's mercurial battery (silver and Hg-covered zinc in dilute sulphuric acid), Fuller's Patent mercury-bichromate battery, and the wet Leclanché battery were also used. It is remarkable how many batteries used elemental mercury at that time, usually for contacts or for preventing local action at the zinc. Batteries using nitric acid, or poisonous soluble mercury salts, were thankfully becoming infrequent by this time. Despite modern exaggeration of hazards, liquid mercury is relatively harmless, so long as the vapour does not hang around.

All the cells so far mentioned were *primary* cells, which meant that they produced electricity independently and irreversibly, consuming the materials of which they were made, usually zinc metal. The only other source of current electricity was the magneto, which produced only pulses or an alternating voltage. The magneto was rarely applied to telegraphy, and that mainly in Germany. The storage battery, made of *secondary* cells, was invented by Planté in 1859, using the reversible chemical change of the oxidation of lead in a dilute sulphuric acid solution. These cells were time-consuming to manufacture, since they had to be "formed" gradually. In 1880, Camille Faure discovered how to manufacture them ready to be charged, by stuffing the plates with ready-made lead peroxide. This was around the time that the first good direct-current dynamos were being designed, and the two worked together quite well. The chemical action in secondary cells is reversible, so they can serve to store electricity, as well as providing a constant-voltage source (each lead-acid cell supplies about 2 V). Later, in large offices telegraphs were operated from storage batteries charged from a small steam engine, or other prime mover, and later from the electricity mains, but this was long after our period. The storage batteries made the electricity supply to the telegraph uninterruptible, as it had been with primary cells.

Storage batteries were specially useful for common-battery operation. Several circuits requiring about the same voltage could be supplied from the same battery. This was satisfactory when the internal resistance of the battery was considerably lower than the parallel equivalent of the resistances of the separate circuits. Since lead-acid cells have very low internal resistances, they were ideal for this application, whereas gravity cells, for example, were not.

In the United States, the Grove cell was used from the beginning until after the Civil War for most telegraph lines, whether open or closed circuit. The Vermont and Boston Bain line, which was naturally open-circuit, used the primitive but cheap sand battery. The bichromate cell began to replace the Grove around the time of the Civil War, saving the batteryman's lungs. After the Civil War, the Callaud gravity cell replaced all other cells for static use. In 1886, Western Union used 12,500 jars of gravity in its New York offices. Every year, they consumed 35,000 lb of copper sulphate, 9000 lb of zinc, 3000 lb of copper (which was recovered) and 8 barrels of battery oil.

Dynamos used in large offices supplied nominally 60 V. If five were available, they could be connected to supply up to 300 V to a circuit, which was the highest voltage used, in steps of 60 V or 70 V. The current supplied to a circuit was adjusted by a rheostat. They had to be driven by a prime mover, a steam engine or perhaps an internal combustion engine of some type, which were becoming available at this time. Storage batteries could also be used, which gave the advantage of an uninterruptible supply, and a fine adjustment of the voltage. They could be charged by a dynamo, or by the local electricity supply, very conveniently if it was the three-wire Edison 220 V direct current available in the centers of large cities. Local circuits were 6 to 7 V.

The Telegraph Line: Wires

The telegraph wires of 1845-47 were #14 or #16 BWG (Birmingham wire gauge) unannealed copper. These weak, soft wires stretched and broke with the usual pole spacings of 20-35 to the mile, especially in the winter. For this reason, iron wire of the same conductivity was adopted, which was necessarily larger in diameter, since the resistance of iron is about seven times larger than that of copper. Reid tells that he used #14 iron tinner's wire to make a repair in Philadelphia in 1846 on the Magnetic when no copper wire happened to be available, and a local ironmonger happened to have some. This convinced the Magnetic to change from copper to iron soon afterwards.

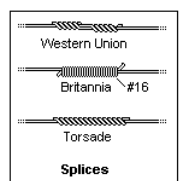
Hugh Downing of Philadelphia, who had interests in the first House lines, manufactured stranded iron cord, as it was called, and introduced it on his lines. There were from three to five strands of #14 or #16 iron wire, which would have had a conductivity somewhat less than that of the copper wire then in use. At the time, it was erroneously thought that conductivity depended on perimeter, not cross-sectional area, based on the fluid analogy of electric current. Nobody knew how to make accurate measurements, anyway. These cords, although made of the best Swedish iron, were ungalvanized and rusted rapidly, in spite of attempts to protect them with tar. The stranded construction tended to hold water. The first iron conductor seems to have been used by O'Reilly on the Philadelphia to Baltimore line for the Magnetic Telegraph Company in 1845. It was a four-stranded cord, tarred to prevent rust. Downing used 3 x #16 cord on the New York-Philadelphia line of the New Jersey Magnetic Telegraph Company, the House competitor of the Magnetic. Copper wire could usually be sold for enough to pay for the conversion to iron. When iron cord was broken, it tended to unravel and thrash around wildly and dangerously.

Marshall Lefferts, with interests in Bain telegraphs, imported galvanized solid wire from England, where its use was standard. Lefferts later manufactured this excellent wire himself in New York. H. J. Rogers used galvanized wire on the Baltimore-Harrisburg line in 1847, but it did not appear in any amount until Bains lines were built. Many Morse lines, acquiring the Bain lines that paralleled them, found them far superior to their own, and transferred their traffic to them. The best wire was about 1/6" in diameter, #8 BWG in England, and the thinner #9 in America (wire diameters are smaller as the gauge numbers become larger). Pope says the #9 wire had a resistance of about 16 Ω per mile, and a weight of 320 lb per mile. In 1870, it cost \$0.0775 per pound, or \$24.80 per mile. In America iron wire, other than this good, heavy wire, was not usually galvanized, as an economy (a false one).

Moses G. Farmer and G. F. Milliken developed the American Compound Wire in 1865-66, which was copper-sheathed steel, with the same conductance as #8 iron wire, but weighing only 80 lb per mile. The copper was apparently applied in the process of drawing. This wire suffered from electrolytic corrosion of the iron in contact with the copper, and was not successful. C. Snow's compound wire of around 1875 had the copper applied by electrolysis to produce a closer bond. Wire weighing 525 lb per mile, 3/5 copper, was manufactured at Ansonia, Connecticut. In 1883, the National Telegraph Company strung hard-drawn #12 copper wire on its new New York-Chicago line beside the West Shore and the Nickel Plate roads, up to 10,623 miles of it, but Western Union and most other companies stuck with iron. Hard-drawn copper was strong enough, and it slowly replaced iron, but galvanized iron did not disappear until 1900.

Splices, joints, or *joins*, as they were called in the early days, were very important. The Western Union splice was preferred in the United States, the Britannia in Britain. The French adopted a somewhat inferior splice, called a *torsade*, where the wires were simply twisted together in a dual helix. All wire splices had to be soldered; the neglect of this precaution was fatal. Some people assumed that galvanized wire did not have to be soldered, but this was a serious error. Oxidation always ruins a nonsoldered splice very rapidly. In the deprecated *hook joint*, the first attempt of the inexperienced, wires were bent around each other and the ends twisted, forming interlocking loops at the ends of the wires. These were sometimes found in the first American lines of the late 1840's, causing a great deal of grief.

Wire sizes were usually specified by a gauge number. The Birmingham Wire Gauge (BWG) was originally used, but different manufacturers had different ideas about what it was. It was also called the Stubs Iron Wire Gauge. In Britain, the Standard Wire Gauge (SWG) was eventually adopted to bring some order to the chaos. The Brown and Sharpe (B&S), or American (AWG), wire gauge was adopted in the United States in 1857, with a uniform series of sizes in geometric progression, in place of the arbitrary sizes of the BWG. The gauge numbers are about the same, but by no means equal. The #9 BWG (148 mils) is about a #7 AWG (144 mils). The AWG was used only with American-manufactured wire, of course, British copper remaining in BWG or SWG. Sometimes, the very logical course of specifying wire by the weight per mile was used in Britain. The usual iron wire varied from 800 to 200 pounds per



mile for line wire, with 400-pound wire (171 mils) the usual choice. The usual #6 AWG used in the United States was 162 mils in diameter, weighing 359 pounds per mile. The later, and now obsolete, U.S. Standard Gauge was used for steel products, including wire. The Steel Wire Gauge, or Washburn and Moen Gauge, is now used for steel wire.

The differences in the properties of commercially available iron and copper between the 1850s and the present day should be recognized. The copper used today as an electrical conductor is called OFHC (oxygen-free high conductivity) and is available in several hardnesses. Its conductivity (the reciprocal of the resistivity) is 97% of that of pure copper. Pure copper has a resistivity of $1.678 \mu\Omega\text{-cm}$ at room temperature, and is too soft to make a strong wire. Pure iron has a resistivity of $9.61 \mu\Omega\text{-cm}$, 5.7 times that of pure copper, and is also too soft for general use. At the time, resistivity was measured relative to mercury, which could be purified by distillation. The presence of impurities (such as dissolved oxygen) and alloying metals always raises the resistivity, sometimes sharply. Good commercial copper in 1870 had a conductivity of about 83% that of pure copper, and ordinary tough copper about 70%. Earlier, the copper available was considerably worse. An arsenic impurity greatly reduces its conductivity, and arsenic was a common impurity, sometimes even added to make the copper harder. Sometimes the copper would crystallize, making the wire easy to fracture. Copper is strengthened by work-hardening when it is drawn, and this also decreases its conductivity a little.

Iron wire was drawn wrought iron, made stronger by work-hardening. Wrought iron consisted of rather pure iron, which would have been a good conductor, and slag, which was an insulator. The best iron was supposed to be Swedish charcoal iron, which was very pure. The fibres of iron were aligned and lengthened when the wire was drawn, but the resistivity was higher than that of pure iron. If we use the common figure of 7 for the ratio of the resistivity of iron and copper wires (6.5 is an often-quoted value), the wrought iron wire would have had a conductivity of 57% that of pure iron. From this data, estimates of the resistivity of actual copper and iron in wires at this time would be $2.4 \mu\Omega\text{-cm}$ and $16.8 \mu\Omega\text{-cm}$, respectively. Pope's figures for #9 BWG wire given above suggest a smaller resistivity of about $12 \mu\Omega\text{-cm}$. The resistance of iron wire increases about 0.35% per °F, and that of copper wire by 0.21% per °F, according to Pope. Iron wire expands thermally 4.3" per mile, per 10°F change in temperature. Temperature changes would have far less effect on a circuit than moisture.

Western Union standards for iron wire in the 1880's specified that the resistance was to be no greater than 5500/W ohm, where W is the weight in pounds per mile. The elongation was to be no less than 15% before breaking, and the breaking stress was to be greater than 2.5W. The usual #8 wire was 388 lb per mile. These specifications are essentially those of the British Post Office.

An early belief was that the wires had to be strung taut and straight, or the messages would be retarded by the sags in the wire. This simply resulted in numerous fractures in the first cold weather. When more slack was allowed, the sagging wires were blown into contact, producing *crosses*. One couldn't seem to win!

The Telegraph Line: Insulators

When the key is pressed, the telegraph wire is connected to one pole of the battery, and charge flows into the line to bring it up to the potential of the battery. When this reaches the other end, current flows through the resistance of the receiving instrument according to Ohm's Law, $I = E / R$, and the relay clicks. The other pole of the battery and the other terminal of the relay are connected to a copper plate, or some such device, buried in the moist earth, which serves as a zero of potential, supplying or taking any amount of electrical charge to maintain this state. These principles, so clear to us now, and which I have stated in as precise a language as possible, were only a vague fog in the minds of early telegraphers.

On a typical 100-mile circuit, the wire was supported at from 2000 to 4000 points on poles embedded in the earth. At each point of support, there was the chance that some current would flow, driven by the potential of the wire through whatever resistance there was to earth. Each of these currents would add up to a considerable current in the whole line, producing a voltage drop in the resistance of the wire and the internal resistance of the battery, that might lower the potential at the receiving end of the wire enough that insufficient current flowed to operate the relay. This effect was called *escape* then, and is now called *leakage*.

It was necessary, therefore, to *insulate* the wire from the pole so that the leakage path was of high resistance. To do this was the duty of the *insulator*. The insulator also had to provide a firm mechanical support for the wire. Early views were complicated by a vague suspicion that electricity would leak out of an uninsulated wire like water oozing from a cracked hose. The government Morse line's wires were insulated with cotton impregnated with beeswax. Some early iron cord was also insulated. It was quickly recognized that plain wire did not result in escape, and on the Magnetic Telegraph Company's lines the wire was run around glass *bureau knob* insulators. Possibly, that very item of hardware was used. Tarring iron wires after they were strung was an attempt to reduce corrosion, not to keep the electricity in.

On O'Rielly's initial Lancaster-Harrisburg line, the copper wires were wound around the ends of arms resembling turned chair rungs, fitted into holes augered in the poles. Vail's cloth and beeswax was wrapped around the wires. This, of course, did not prove satisfactory. Another essay used iron hooks embedded in cast glass cylinders 2" in diameter. The cylinders were pressed into holes bored in the lower sides of the crossarms and held with wooden pegs driven in crossways. Lightning tended to shatter them, among other things.

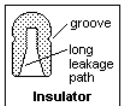
In 1846, George Little of England had designed a cylindrical glass insulator that had a groove around the top for attaching the wire, and a cup-shaped *petticoat* base, supported on a pin entering from below. This probably prompted Ezra Cornell to suggest the same thing in the United States. Since this is very much like the successful insulator that later became universal, one would suppose that the story was complete. Not a bit of it. Bureau knobs and Cornell thimbles were thought good only for weak copper wire, and when iron wire came in, something more robust was desired. In England, vitrified porcelain was soon selected as the insulator material instead of the cheaper glass, for reasons that will be presented below. On the continent, glass insulators of the Little pattern were the usual choice.



Nearly every telegraph contractor or electrician in America seems to have designed and used insulators of his own pattern. They included wooden blocks with wax or rubber to insulate the wires, and the cow horns used on the line from Natchitoches to Shreveport. There were glass plates and glass blocks, iron hooks, and slots sawn in the poles into which wires wrapped with fabric were stuffed. Cornell himself turned to cast-iron hats that were filled with molten sulphur, in which an iron hook was embedded. The sulphur developed fine cracks, that sucked up water by capillary action, destroying the insulation. These "brimstone insulators" were severely deprecated. Professor Benedict, engineer of the Vermont and Boston, used molten glass instead of sulphur, and produced a passable insulator. The House insulator, shown at the left, was similar, except that a core was used to provide a thread in the glass, and the insulator was screwed onto a wooden pin. It was a relatively serviceable insulator. These insulators encased in iron were probably intended to meet the ever-present threat of vandalism. Ebonite insulators were tried, which began looking pretty, but could not stand up to the weather (ebonite is rubber and sulphur heated under pressure until it forms a rigid solid). Porcelain-coated iron insulators were also useless, the slightest crack making them conductors. Van Choate used a wood/rubber/iron insulator for the short time that they survived, as late as 1865 on the Insulated Lines Telegraph Company, but soon switched to glass.

It seems that, extraordinarily, nearly every insulator inventor never tested his creation before applying it in great numbers. Usually, the next winter or rainy season brought enlightenment. F. O. J. Smith and J. J. Speed concluded that insulation was an unnecessary, sissy expense, and dispensed with it, stapling wire to poles or trees. These circuits did not work at all. Many circuits could be made to work over 50 miles in dry weather, perhaps 25 miles in wet weather, but no further. It was some time before it was realized that live trees do not make good telegraph poles, because of their high conductivity. Amos Kendall cut down every other pole between Philadelphia and Baltimore to reduce the leakage by half. On the New Orleans line, he demanded that there be only 20 poles per mile. Of course, crosses and ice breakages were encouraged by this. The early insulators, even when they used glass, had short leakage paths that rendered them less than satisfactory in wet weather.

The principal faults in patent insulators were not recognizing the importance of leakage paths, and construction or materials that allowed even microscopic cracks to provide a path when wet. The actual bulk insulating properties were always quite satisfactory.



Ordinary soda glass is hygroscopic, always covered by a film of moisture that permits leakage. Faraday noted in his researches on optical glasses that glass made without alkali was not as hygroscopic as ordinary soda glass, and there were attempts to follow up this hint to make better glass insulators, but it does not appear to have been accomplished. Glass was so subject to malicious damage that it was often protected by a wood sheathing (the Wade insulator). Shooting off insulators, or shying rocks at them, was a rural pastime. A New York law against telegraph vandalism was passed on 13 May 1845, and such laws became common. Some glass insulators were made with an iron covering, but this proved no protection at all from missiles. If glass cracked, capillary action drew water into the cracks. Glass knob insulators, with their relatively high leakage but low cost, became standard in America, except near sea water, after 1860, though they were used earlier on some lines, such as the Magnetic. A typical example, the Western Union insulator, is shown at the left.

In Britain, porcelain insulators were always used, which were much better, because they were not hygroscopic. By 1855, a superior ceramic insulator, the 'white flint' insulator of E. B. Elliott, was available in the United States. A glass insulator cost \$0.13 in 1860, \$0.25 with wood covering, but a white flint insulator only \$0.18.

It is important to leave insulators exposed to the weather so the rain washes away contamination. Glass has a resistivity of about $10^5 \Omega\text{-cm}$, which makes it a reasonable insulator, but porcelain's resistivity is around $10^{15} \Omega\text{-cm}$, very much better. Insulator porcelain has to be vitrified throughout, not just glazed, or a crack in the glaze would expose the porous interior. Glazed earthenware insulators, although tried, were useless because of this.

Insulators were originally cemented to their pegs, pins or spindles, but the much better idea of providing internal threads so they could be screwed on the pins later became universal. The pins fitted into holes in the crossarms, or into brackets that were screwed to the pole. Very many shapes of insulators were used, but were mostly similar in concept—to offer as long a path as possible for leakage. The double petticoat or double shed shape gave good results, since the inner parts remained dry in bad weather. However, American insulators were usually quite simple, of the single-petticoat form shown by the Western Union insulator in the diagram above.

To attach a line wire, it is placed in the groove around the insulator, and bound to it by a short piece of wire passing on the other side of the insulator and wound around the line wire on both sides. At intervals, provision has to be made for adjusting the tension in the wires.

The Telegraph Line: Poles

The best poles were cedar, white oak or chestnut, 5"-6" diameter at the top, 10"-12" at the base, 25' to 30' long, with the bottom 5' or 6' charred and tarred, and set 4-1/2' to 5' deep in soft ground. The wood should be winter cut, and seasoned for six months. Sap left in the wood when the poles are set causes rapid decay. Such poles cost \$0.80, or \$1.50, in 1860. In America, poles were usually purchased from

farmers along the route, like railway fuel and cross-ties, and the quality of such poles was low. The wood was usually unseasoned, and the bark was not removed. The sappy poles soon rotted, or caused considerable leakage. Some early contractors simply cut poles from what was available to be poached in the vicinity.

Hardwood poles, winter-cut and thoroughly seasoned, had a satisfactory life, especially if charred and tarred to above the ground level, where most decay occurred. Less durable wood had a short life unless protected against decay. This could be done by Burnetizing (impregnating with zinc chloride solution), Kyanizing (impregnating with mercurous chloride solution), Boucherizing (impregnating with copper sulphate solution), or, best of all, by creosoting. In creosoting, the sap is drawn out by heat and vacuum, and is replaced by creosote, a product of coal distillation. Boucherizing could be done with green wood, since the solution directly replaced the sap in the tree by pushing it out the far end. Nevertheless, creosote was the best process, and replaced all the others. The modern process that produces a greenish wood is impregnation with chromated copper arsenate (CCA), related to Boucherizing.

In cities, pole lines were erected along streets, and some carried prodigious numbers of wires. This was not permitted in England, where city telegraph wires at first crept stealthily over rooftops, the wayleaves given by the property owners, but later were buried beneath the streets, like the electricity mains. There was already agitation in New York and other cities to bury all electric and telegraph wires in the 1880's.

The distance between poles was quite variable, a compromise between cost, leakage and sag. The practical minimum was 20 or 25 poles per mile, especially for lines of one wire where crosses were not a danger. 30 poles per mile was considered better practice, giving a span of 176 ft. Later, 40 poles per mile was considered a strong line. This became the standard pole spacing in later years. The tension in the wire is approximately equal to one-eighth the weight of wire in the span, times the ratio of the span to the sag. For a span of 176 ft, a sag of 2 ft, and iron wire, the tension is about 117 lb, and the stress in the usual #9 BWG wire 11 400 psi. Wires were generally tensioned to one-quarter their breaking strength, which was about 300 pounds for the usual line wire.

Poles carried a single wire on top, two to three wires on brackets screwed to the pole. A crossarm was used for two or more wires, bolted to the pole and braced with iron struts. In America, poles carrying single arms with eight or more wires were common in later years. This put the outer wires out of reach of a lineman who had climbed the pole, so they had to be accessed with a ladder. In Britain, arms carried only two or four wires, so they were within reach of a lineman on the pole. Where arms carried only two wires, they were usually staggered in position. The arms, curiously, were conventionally on the side of the pole facing London, the "up" side of the pole. A single wire was sometimes carried on a saddle bracket at the top of the pole. The tops of poles were protected against the weather by a small "roof" of galvanized iron. On poles with several arms, a ground wire was sometimes used that ran down the pole, perhaps from a lightning rod on top, to a secure earth at the bottom. Leakage from the circuits could use this path to earth instead of leaking into other circuits and causing crosstalk. If the ground was poor, the ground wire just encouraged crosstalk. Ground wires do not appear to have been used in the United States.

The Telegraph Line: Miscellaneous Fittings and Weather

To make a temporary connection with a telegraph circuit, it is necessary to cut the wire. A special fitting was made for this purpose, that was clamped to the wire with clamps a short distance apart. The wire was then sawed or cut. An instrument such as a pocket relay could then be connected to binding posts on the fitting. When the shorting clip was removed, the relay and key were now in the circuit and could be used. When the temporary connection was no longer required, the shorting clip was replaced, and the fitting left in the line until the lineman could splice the wire at that point.

A new and strange kind of weather also affected telegraph lines very significantly. This was the electrical and magnetic weather caused by thunderstorms and solar particles incident on the ionosphere. The hazard of lightning was obvious. An actual lightning strike was catastrophic, but lesser activity was much more common, and was very troublesome and dangerous. Steinheil invented a lightning protector very early on, which merely bypassed the station equipment, and would have been of little use in an actual lightning strike. The protector that provides an easy path to ground for voltages high enough to break down a short air gap is much more effective. If this is put in the lead-in to the office, high voltages can be bypassed before they get inside. In the U. S. (but not in Britain) every residential telephone line first passes through a protector. Ground currents, induced by charged clouds or changing earth magnetism, can act like a battery in a telegraph circuit. Circuits have been operated on ground currents alone as a curiosity. When lightning strikes a telegraph pole, a surge is sent down the wires, but this is a different matter from an actual lightning bolt, since the lightning is looking for earth, not a high-wave-impedance telegraph line, and will get there as directly as possible.

Lightning protectors provided an air gap for high voltages to arc over, and sometimes some added inductance on the side towards the instruments to help convince the high voltage to arc over. The Siemens protector had brass plates with parallel ridges arranged so that the ridges on the top and bottom plates were at right angles, separated by a thin insulating sheet. Other protectors had points to help the discharge, or were kept apart by thin mica spacers provided with holes. The vacuum protector had two pointed electrodes close together in a glass envelope that was evacuated to a low vacuum to give the minimum breakdown potential. A simple protector was invented by David Brooks, which was a piece of paper around a water pipe. Wires were simply wound around this, and it worked quite well. The lightning protector is essential when wires run out-of-doors.

The Telegraph Line: Construction and Costs

The early telegraph promoters first organized a joint-stock company, and then hired a contractor to build and equip the line. They usually, in effect, hired themselves to carry out the construction, though under the name of a partner in the construction firm. Then the contractor endeavored to prepare the line for the minimum expense possible, leaving a handsome and immediate profit. It was not possible to pocket the stockholder's subscriptions directly, since the law frowned on that. The contractor may have previously been in the business of supplying wood to railways. Whatever his expertise, he, like everyone else, knew nothing about electricity, and learned by experience.

The cost of a telegraph line was only 1% or so of the cost of a railway line, so it was possible to raise sufficient funds even in the capital-poor United States to construct a line with local stock subscriptions. It was not necessary, as with a railway, to raise money in England through bonded indebtedness on the prospects for future profits. This makes the company and financial history of the telegraph industry very different from that of railways. The very fact that half the stock had to be furnished to the Morse Patentees put water in telegraph stock from the beginning, so that the stockholder's equity was negligible. On the other hand, earnings could be distributed as dividends without having to service the debt first. Reid and Thompson tell the tales of competition and absorption that led to the Western Union monopoly. It was well established that commercial telegraphs could only be efficiently operated as a single system. In 1886, there were 217 telegraph companies. Western Union had 14,184 offices, the Baltimore and Ohio Telegraph 1,143, and no other company in the United States more than 500.

The construction party for a new line could be large if rapid progress was necessary. The line was first located by a surveying party, and stakes were left where poles were to be erected. Easements were obtained from landowners, but this was avoided as far as possible by dealing with railroads or public authorities. Next, the heavy materials were distributed along the line, from a work train if the line followed a railroad, or by teams if it followed a common road. Although the poles had probably been furnished by local farmers, they had to be fetched from the seasoning piles. Telegraph lines seldom struck off cross-country, since then they would be hard to inspect and maintain. The cost of constructing a telegraph line was much less than the cost of a railroad, and even less than the cost of a good road. In addition, it could be completed much more rapidly, several miles a day being average progress.

The first American telegraph lines often followed common roads, or even struck out across country following "forest routes." The reason for this was that, in many cases, there were as yet no railroads. Even where railroads existed, the early promoters often could not come to a satisfactory agreement for erecting lines along the track. Railroad routes were greatly preferred, for not only did the presence of the railroad make construction and maintenance easier, they were much more secure. A forest route was subject to vandalism, theft of wire, and the depredations of those who considered the telegraph to be the devilish cause of drought or other rural catastrophes. It was also much easier to make a single agreement with a railroad company than multiple agreements with landowners and squatters. As railroads were built, telegraph lines were moved onto their rights-of-way as soon as convenient.

Holes for setting the poles were usually dug with pick and shovel, in the form of a stepped trench along the line of the wires. The Spanish Spoon might allow a shallow hole to be made with less work by digging from above and emptying out the waste. Augers could also be applied in easy soils. While the holes were being dug, the poles were fitted out while lying on the ground. The crossarms, brackets, insulator pins, and attachments for wire rope stays were put on at this time. Then the pole was put in the ground, and the earth tamped or "punned" firmly around it. Strength transverse to the line was highly important, if for no other reason than appearance.

Now stringing the wire began, which required the most skill and technique of any part of the construction. The insulators were screwed on the pins, and the wires, paid out from reels carried on barrows or frames on animals, were laid on the crossarms. The wire was then gripped by draw tongs, and stretched to the proper tension by using a spring scale. The wire was then bound to the insulators by #16 BWG iron wire or equivalent. The line wires passed through the groove in the insulator, but did not curve around the insulator. When the wire was bound to all the insulators in a section, the stay holding the previous section was removed, and the end of the new section similarly stayed. It was normal to provide longitudinal staying perhaps every quarter mile or 10 poles. The insulators and pins were not strong enough to support the whole tension in the wire. Poles were usually numbered for easy reference to any location. On a railroad, they generally were known by the milepost location, such as mile 240 plus 7 poles. Circuit wires were also individually numbered for reference.

Once a line had been constructed, a much smaller construction gang was enough to perform the necessary heavy repairs, such as replacing a pole or retensioning the wire, or even adding an additional wire. This gang probably was assigned to a central location, and might have several hundred miles of wire to look out for. A wire was said to be "cut in" when brought inside a building from the pole line.

In 1860, a Morse register cost \$30, a relay \$15, a key \$4, and a local battery \$3. A Grove jar cost \$1.50. \$150 per mile was the approximate cost of a good telegraph line, \$61.80 per mile the cost of a minimal line. The reported costs of lines may not be an accurate reflection of the actual costs, since often a \$150 per mile line meant \$75 to the contractor and a \$75 kickback to the promoters. Lines were capitalized at some four times their nominal cost, perhaps \$600 per mile. The Morse Patentees took 50% anyway, if they could. Typical costs in the 1845-1860 period, before wartime inflation, are given as \$150 to \$200 for a one-wire line, with \$75 more for a second wire. It is difficult to separate the amount that went into poles, insulators and wires and the amount that went into pockets.

Units and Measurements

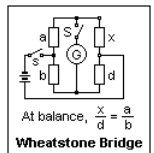
Telegraphy began long before there were agreed electrical units, and the early lines were constructed and operated without measurements or rational design of any kind, especially in the United States. Ohm's Law had been published in 1827, but was not understood. Wheatstone in England and Henry in the United States showed how it was useful--in fact, practically essential--to the proper design of telegraph circuits. Kirchhoff's Laws, facilitating the solution of complex circuits, were not available until 1845. Most early telegraph promoters understood very little about voltage, current, resistance, insulation and magnetism, and proceeded on purely empirical grounds. However, such knowledge was essential for success, as experience proved. A few electrical tests appear to have been introduced by Marshall Lefferts of the American Telegraph Company in 1864. It was the visit of C. F. Varley from England in 1868 that disclosed the sad state of most American circuits, and indicated what measurements could do to improve the situation.

The practical unit of electric potential was the Daniell cell, the unit of resistance was a column of mercury 1 meter long and 1 mm in diameter at 0°C and the unit of current was the current that one Daniell cell could pump through the unit of resistance. The unit of electrical charge was the net charge transferred per second by unit current. Gauss and Weber in Göttingen showed that electrical units could be defined in terms of the familiar centimeter, gram and second, using theoretical relations. These were the *absolute*, or electromagnetic units (emu). By an astounding coincidence, 10^8 emu of electric potential happened to be about equal to the practical unit, and 10^9 emu of resistance was also equal to the practical unit. This made the practical unit of current 1/10 emu of current. The practical units could be put on a rational basis with only small changes, of 10% or less!

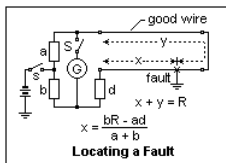
The International Electrical Congress in 1881 at Paris established the new standards by international agreement, and gave the units the names volt, ohm, ampere and coulomb for potential, resistance, current and charge, respectively. In 1889, 10^7 ergs, the emu of energy, was named the joule, and joules per second the watt, so that power in watts was volts times amperes. In 1893 the henry replaced the quadrat as the unit of inductance, and the names of the units that we now know were established. Before these agreements, they would not have been widely known and used.

Today we simply reach for the digital multimeter, and we can measure potential, current or resistance almost instantaneously and with good accuracy. The telegraph engineer of the 19th century, however, had only the tangent galvanometer and the Kelvin mirror galvanometer (1858) to detect or measure current, the Wheatstone bridge for resistance, and the potentiometer for voltage. Galvanometers had a magnetic needle moved by the magnetic field produced by coils carrying the current to be measured, and the earth's field had to be taken into consideration. These were all really laboratory instruments, especially the mirror galvanometer and the potentiometer. The tangent galvanometer and the Wheatstone bridge were most commonly used, and were portable. Voltage was usually not measured directly, but by comparison with standard cells of known voltage. Resistance substitution methods were popular, using the tangent galvanometer as an indicator of current. Most telegraph workers did not even have these instruments available, so troubleshooting was more of an exercise in guesswork.

The Wheatstone bridge compared unknown resistances with known resistances, and required only that a current be detected, not measured quantitatively. The circuit is shown at the right. Switch *s* is closed to apply the battery, then *a*, *b* and *d* are adjusted until galvanometer *G* does not move when *S* is closed. It was the most common and useful member of a family of bridge circuits. The Kelvin bridge (1861) was specially adapted for low resistances, for example. The term "bridge" is only a reference to the appearance of its circuit diagram. Christie invented the bridge, but named it after Wheatstone to honor him. The Wheatstone bridge was used to check the resistance of wire or instrument coils, and also to locate certain faults on the line.



Line faults could be opens, earths (grounds), or crosses. They were usually not ideal faults, but an open was an unusually high resistance and an earth or cross a small, but not zero, resistance. Sometimes, annoyingly, faults were intermittent. The first thing to do was to determine whether the fault was in the office, or on the line. If the fault was on the line, it was then found between which offices it was located. For an open, this was done by earthing the line at successive stations. The fault was then in the last section before the first station at which the circuit was open. Then, an inspection by the lineman usually found the fault in a short time. Meanwhile, the bad section could be bypassed by using another line between the stations on either side of it. Sometimes a spare wire was used for just this purpose.



An earth or a cross could be located with the Wheatstone bridge, perhaps with the help of a good wire, in terms of line resistance, which could easily be converted to distance. This could be done in such a way that the resistance of the fault had little effect. The method is shown at the left. *R* is the resistance of both wires in series. Wire resistances were often measured daily. With insulated cables, this was the only way of easily finding the location of a fault, which in cables is usually a loss of insulation. Today, time-domain reflectometry (a fancy name for measuring the travel time of a pulse to the fault and back) would be used for the same purpose. The bridge was also useful in measuring the resistance of a ground connection, which should have a resistance of less than 10 Ω, or as otherwise specified for good operation. A bad ground, incidentally, results in cross-talk between the separate circuits using it.

In 1881, W. E. Ayrton and J. Perry in London began the design and manufacture of switchboard and portable electrical instruments. They introduced the names *ammeter* and *voltmeter*. About 1885, M. Deprez and A. D'Arsonval in Paris entered the same field. D'Arsonval made the coil of a galvanometer movable and the magnet stationary, inverting the usual arrangement. This produced a portable, accurate instrument that was not affected by the earth's magnetic field. In 1888, E. Weston in the United States founded the Weston Electrical Instrument Co., which made portable ammeters and voltmeters on the D'Arsonval pattern that replaced all others for practical and switchboard use.

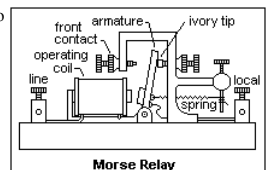
Relays, Repeaters, Duplexing and Quadruplexing

On the earliest Morse lines, the line current drove the register directly. Large coils were required to supply sufficient ampere-turns to operate the mechanical elements, as well as a battery of many Grove cells to supply the necessary current through the resistance of the line and the register coils, in addition to the wasted current through the line leakage. This severely limited the length of a single circuit. To cover a long distance, the message had to be received and retransmitted from intermediate stations, which was called *relaying* from the analogy with a relay race. This not only delayed the message, but also introduced errors in retransmission.

The situation was made worse by misapplying the only theoretical principle available, the Jacobi maximum power transfer theorem. Vail originally thought the resistance of the register should be about equal to the line resistance, so the early register magnets were wound with #16 wire, and had to be very massive to work.

The solution to this problem was to drive the register or sounder from a *local* battery that could supply the necessary power through a short local circuit without the resistance and leakage of the line. The local circuit was opened and closed in synchronism with the line currents by means of contacts operated by an electromagnet in series with the line. This electromagnet had only to operate the light armature bearing the contacts, and so could be made small and light. The line current could now be reduced to 15-25 mA, while the local current was about ten times higher. The arrangement of electromagnet and armature with contacts was called a *relay* by analogy with the relaying of a message, in this case from one circuit to another. A line relay typically had a resistance of 150 Ω, while a sounder to operate on a local circuit had a resistance of 4 Ω. The local battery was normally two jars of gravity, supplying 2 V with an internal resistance of 4 Ω, so the local current was $2 \text{ V} / 8 \Omega = 250 \text{ mA}$.

A typical (later) Morse relay is shown at the right. There are two terminals for the line, connecting to the pair of coils, and two terminals for the local circuit, connecting to the contact and the moving armature. It should be clear how the relay operates and is adjusted by the spring tension and the distance between the stops. Morse obtained a U.S. patent for the relay on 20 June 1840, intending to use it to extend the range of a telegraph circuit. That the patent was awarded is remarkable, because relays and local circuits had been used by others for years. In 1809, Sömmering invented a relay operated by gas bubbles collecting under a cup to serve as an alarm for his electrostatic telegraph. Joseph Henry made electromagnets in 1831, and by 1836 had applied them in a relay, where the motion of the armature closed electrical contacts. Wheatstone made an electromagnetic relay in 1837 where the contacts were made by wires dipping into small cups of mercury. Morse was fully anticipated by Edward Davy's British patent of 1838, which was well-known, and specified a local circuit controlled from the line. Morse's local circuit patent of 11 April 1846 was anticipated by Cooke and Wheatstone's British patent of 1837, as well as by Davy. So Morse's patent for a relay in 1840 was nothing very new or ingenious, and neither was the use of a local circuit. Both were "state of the art" and available for everyone to use. These patents were not upheld in court.



What the early telegraphers called "magnets" were the line relays. The early Vail magnets were massively built, weighing up to 75 pounds and delicate of adjustment. They had some 3000 turns of #16 copper wire, insulated with cotton and shellac. Ezra Cornell's first magnets had 8 coils, each weighing 10 lb, wound with #16 wire. His later "windmill" magnets had four coils, each 4" in diameter and including 2/3 of a mile of fine wire. At least some of Cornell's magnets had cores that were not soft enough, so after being energized remained permanent magnets and held the armature. Charles T. Smith made excellent magnets wound with silk-insulated #32 wire. Under Vail's supervision, James Clark and Son of Philadelphia made the first fine-wire magnets in February 1846. The Cornell and Smith magnets also appeared in 1846. Relays became much smaller and much more sensitive as their resistance increased. The usual fine-wire relay magnet had a resistance of 500 Ω. Incidentally, Morse's original magnets were only 2-1/2" in diameter and wound with #16 wire--they would never have worked.

Many different forms of relays were developed for specific applications. The relays used in railway signalling track circuits were arranged so that the armature was restored to its normal position by gravity, not by a spring that could break. The armature could carry a number of independent contacts. A contact that was normally open, and closed when a current passed through the coil was called a *front* contact. One that was normally closed, and opened when the relay was energized, was a *back* contact. A coil of many turns, and therefore high resistance, was used for line currents, while a coil of small resistance was used for local currents. The instrument called a *pocket relay* was actually a key and a main line (i.e., high resistance and sensitive) sounder in a very compact form, for the use of someone out on the line who would use it to communicate from the field. The coils might be wound with #30 wire, which was very fine, while a normal sounder would use #23 wire.

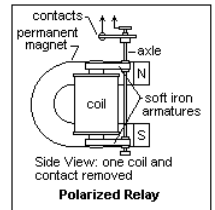
To cut into a circuit for transmission and reception, the line had to be cut. There was a special fixture for this purpose, which allowed the line to be closed when the temporary station was not in use. A pocket relay was the usual instrument employed. There was no need for batteries or an earth. Simply to eavesdrop on a line was fairly easy. An iron stake or something similar was driven into the ground for an earth, and a high resistance relay was connected between the line and the earth. This would act like extra leakage, and if not excessive was not apparent. At the time of the Civil War, accurate measurements were not made of line resistance, but such measurements would probably reveal the tap. One could receive only with this connection, not transmit.

The circuits controlled by relay contacts often contained the coils of other relays or sounders. When an *inductive* circuit like these is broken, the collapsing magnetic field causes a voltage of self-induction that attempts at all costs to keep the current flowing, and always succeeds, causing a spark at the opening contacts if necessary. These high voltages not only cause sparking, which is harmful to the contacts, but can also break down insulation. Sparks can be eliminated by connecting a capacitor across the contacts, or by connecting a resistance across the contacts that is much larger than the resistance of the

controlled circuit. In the latter case, the contacts switch between low and high resistance, not low and infinite, and this is often acceptable. These days, we would use a "catching diode" across the contacts, but such things were not available then. A capacitor in series with a properly-chosen resistance, called a *snubber*, gives the best spark suppression.

Relays were the vacuum tubes and transistors of 19th-century electrical technology. They were used as logic elements even into the era of computers. Many ingenious relay circuits were developed, sometimes involving time delays and other dynamic aspects. A very useful property of the relay is that the primary and secondary circuits are completely separated conductively, and also that they are electrically and mechanically rugged. These properties ensure that relays are still useful in modern technology.

The Morse relay was a *neutral* relay. That is, its armature moved when current passed through its coils, and was restored by a spring when the current ceased. A neutral relay responds equally well to currents in either direction. The armature, however, is relatively massive, and limits the sensitivity and operating speed. The search for a more sensitive relay led to the *polarized* relay, in which a soft iron armature moves one way or the other in the magnetic field produced by the operating coils. The direction depends on the direction of the current. A typical polarized relay is shown in the diagram at the right. The small, light soft iron tongues on the axle move to the side where the magnetic field is strongest, which depends on the current in the coil. The relay still has front and back contacts, and is *biased* to hold one or the other closed until current of the proper polarity is received. A polarized relay can be made very sensitive, and, of course, is necessary when the direction of the current is significant. Siemens was a well-known manufacturer of polarized relays. Their polarized relay had a resistance of 400 Ω and an operating current of 15-20 mA. The Post Office Standard Relay developed by the British postal telegraphs was used world-wide. These relays had coils of 200, 400 or 1200 Ω , and an operating current of 14-17 mA. Some relays were constructed with both neutral and polar contacts.

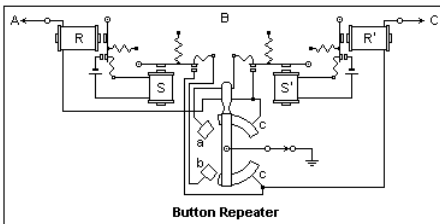
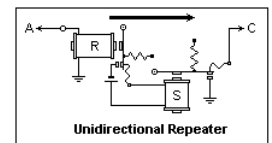


A device used to retransmit signals from one circuit to another is called a *repeater*, or *translator*. As a telegraph circuit becomes longer, two deleterious effects occur. First, leakage (at the line insulators) causes the voltage at the receiving end to become smaller, requiring more and more sensitive receivers and increased operating voltage. Second, the electrostatic *capacity* of the line increases. When the term "line capacity" is encountered, take care to interpret it in the proper sense, as electrostatic capacity, or else traffic capacity, two very different things. Electrostatic capacity means that electric charge must be supplied to the line to raise its voltage (charging), and removed to return it to its original potential (discharging). This charge must be supplied by the line battery, and must be discharged to earth after the signal is sent. The result is to slow the rate at which signals can be sent, because the signals become distorted as they travel. Both of the deleterious effects are small for a wire line on poles in a dry climate, where a distance of perhaps 600 miles is possible on a single circuit, using sounders and manual transmission. A more normal maximum distance for reliable communication is 300 miles in normal climates, down to perhaps 100 miles under bad (wet) conditions. All of these distances assume a good circuit with efficient insulators. Cables, whether underground or undersea, are always severely affected by line capacitance.

Examples of long circuits that were worked by repeaters by 1900 are New York - Galveston, 1800 miles, with three repeaters, and London - Teheran, 3800 miles, with two retransmissions and eight repeaters. The early Washington and New Orleans telegraph line used 10 Bulkeley "open circuit" repeaters. However, repeaters were never common for simply extending a circuit, since telegraph circuits are rather long-range by nature, and repeaters were added expense and bother. Frequent use of repeaters came with automatic telegraphs whose speed was limited by the quality of the circuit. Over a small distance, they were capable of perhaps 300-400 wpm, but were restricted to about 100 wpm on a normal telegraph circuit. High-speed repeaters became economically feasible in this case, where they overcame line capacitance.

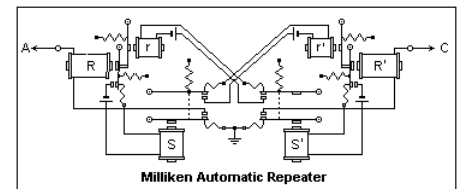
Another method of overcoming line capacitance was *double-current* working, much used in Britain but rare in the United States. In this method, the usual marking (current flowing) and spacing (no current) states were replaced by positive and negative currents. This polar working charged and discharged the line capacitance more quickly and definitely. Another method, called *curb sending*, transmitted a short pulse of opposite polarity after the key was lifted. Such methods were essential for ocean cables.

A simple repeater can be made by putting relay contacts on the sounder armature, and allowing these contacts to control the line in advance, as shown in the diagram at the right. The problem with this is that it only works in one direction, say from stations A to C through a repeater station at B. For communication in the reverse direction, another wire is needed. For this reason, the simple repeater was, apparently never used. A relay and sounder could be provided for each section, A - B and B - C, with a manually-operated switch to select the direction. This was first done by M. L. Wood at Auburn, New York, and was called a *button* repeater (the button being the direction switch). An operator was required at B to switch the direction when appropriate. The normal position of the switch made the two circuits independent. A popular button repeater was devised by David Brooks in 1847. The problem with a bidirectional repeater is that the repeated signal must not be fed back to the input. If it is, the result is what is now called a "flip-flop" with two states; the circuit simply locks up in one state or the other. Exactly the same problem occurs with a telephone repeater.

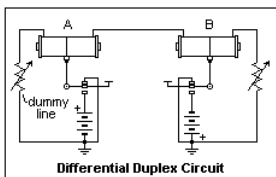


The circuit of a typical button repeater is shown at the left. It is assumed that the line batteries are at stations A and C for simplicity. When the handle is vertical, as shown, both circuits are returned to earth after passing through their respective relays, and each circuit can be used independently (the keys are not shown, but are placed in each line). When the handle is moved to the right, say, the line to C is keyed by sounder S, while sounder S' has no effect on the line to A. When the handle is to the left, the line to A is keyed by sounder S', while sounder S has no effect. An automatic repeater was devised by G. B. Hicks in 1858, and saw some use in the United States. Automatic repeaters were also devised by Farmer and Woodman, Bulkeley, Kendall and Tree, Clark, J. K. Knight, B. B. Toye, G. F. Milliken, Elisha Gray, C. H. Haskins, and Bunnell and Smith. Only those of Toye and Milliken were used to any extent. 10 Bulkeley open-circuit repeaters were used between Washington and New Orleans. Later, when this line was worked by the Wheatstone, only 2 were necessary.

An *automatic* repeater responds to signals from either direction, preventing signals from the output from affecting the input. With open-circuit operation, this can easily be done by making the sounder for one direction disconnect the line from the other direction by using front and back contacts. Such a simple arrangement does not work for closed-circuit operation, but circuits were devised that have the same effect. The Milliken Automatic Repeater, used in North America, has a special relay with an additional coil, which must be energized for the relay to work normally and control its sounder. It was designed by G. F. Milliken, superintendent of the Boston office of Western Union in 1868, when Edison began his career of invention. When a signal comes in from one direction, it de-energizes the additional coil on the relay for the opposite direction, so that it cannot affect the incoming circuit. The circuit is shown at the right. The sounders have two independent back and front contacts. One keys the line, while the other controls the coils r and r'. The springs on the armatures of r and r' are strong enough to hold the relay contacts closed. Only when they are energized can the relay control its sounder. The sounder contacts were arranged so that the contacts energizing the additional coils were completed before the outgoing line was keyed. Circuits for high-speed automatic repeaters, using polarized relays, are too complicated to explain here, but they did the same things, often for double-current working.



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Although the demand for repeaters was not great until fast automatic telegraphs came into service, the need for line capacity was continuous. One answer was *duplex* operation, in which a single line could be used simultaneously in both directions. Duplexing was first accomplished by Petrina and Gintl on the Austrian State Telegraphs in 1853 by using a relay with two windings, and had been suggested by Moses G. Farmer in 1852. In 1856, Hughes and Craig had worked a New York-Philadelphia line duplex with Hughes printers, 26 wpm in one direction and 28 in the other, simultaneously. J. B. Stearns of Boston made a practical duplex in 1868. Edison attacked the duplex problem when he was at Cincinnati, unaware of the previous work.

At each end of a duplex wire, there were two operators, one at the key and the other at the sounder. The key at each end only operated the distant sounder, not the local one, which seemed strange to the operators, used to hearing their own sounder. There are two ways to accomplish this, called *differential* duplex and *bridge* duplex. Differential duplex, the most commonly used system, used a relay with double windings, as shown in the diagram on the left. Current from the key went through one winding to the line, and through the other to a *dummy line* of the same resistance and capacitance. The two currents caused opposing ampere-turns, and so did not operate the relay. The line current, arriving at the distant relay, passed through only one of the relay coils and operated it. It was always necessary to adjust the dummy line with a rheostat to achieve a balance, at both ends of the circuit. Note that a battery is required at each end, and that the polarities are opposite. You may find it interesting to determine the current in the line with both keys up, one or the other key up, and both keys down. The key must have both front and back contacts. The differential duplex works equally well with polarized currents.

The bridge duplex, typically used with submarine cables, fed the line and earth through a pair of resistances, and a rheostat in series with the earth connection that could be adjusted to the line resistance. When the key at one end was closed, the potential between the ends of the pair of resistances was the same, so the receiving instrument was connected here. Therefore, the key did not affect the local receiver, but the current sent over the line operated the distant receiver. It was easy to accommodate the double-current method of working always used with cables with this system.

Duplexing was very often used, since the capacity of a busy line was practically doubled by the addition of operators and a little apparatus at the terminals only, with no change in the line. By 1872, it was quite common on Western Union. In 1874, Edison showed how to double the capacity of the line again, by *quadruplexing*. The key to this was a way to send two independent messages in the same direction at the same time, a method called *diplexing*. Diplexing was never used by itself, but always in connection with quadruplexing. Edison's idea was to send one message by varying the strength of the signal (as in off and on) and the other by polarity, positive and negative. There were two sounders or relays, one responding to strength, the other to polarity. The duplex circuit now only had to be duplexed by one of the existing methods, and two messages could be sent in each direction at the same time, or four in all. Soon, most important lines were quadruplexed. By 1878, Western Union had 13,000 miles of quadruplex. There were four operators at each end, two sending and two receiving, all at the same time. Edison made many contributions to telegraphy, of which quadruplexing and the stock ticker are the most famous. The principle of impressing two different kinds of signals at one end of a circuit and untangling them at the other was used in later inventions, such as the *Phonoplex* where audio frequency and direct current signals were superimposed.

A quite different method of transmitting more than one message at a time over a single wire was called *multiplexing*. This system used a commutator or distributor at each end of the line, running synchronously, so that each channel was connected for a fixed interval of time on each revolution of the distributor. Today, this is called *time-division multiplexing*, and is frequently encountered. It was suggested first in 1873 by Meyer, and improved by Baudot in 1881. Patrick Delany of New York developed a practical multiplex system in 1884, based on an earlier idea of La Cour of Copenhagen. La Cour drove the distributor wheel by current impulses generated by vibrating reeds, and corrected the position of the distributor on each revolution. The individual pulses, lasting about 2 milliseconds, are used to

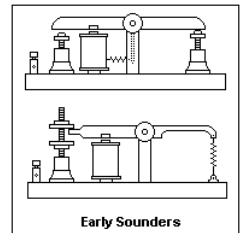
drive a polarized relay, the current being smoothed by a capacitor. Up to about twelve messages could be sent over one wire simultaneously by multiplexing, but six was more common. Like the fast automatic telegraph, multiplexing required a very good circuit with low capacitance.

Receiving by Ear

The Morse register made quite a clatter when it was pounding out a message, and the relay clicked in unison. Hearing this day after day, operators began to recognize characters by the sound they made, and the brighter ones were soon writing down the message as it came in. Station calls, in fact, were recognized by sound from the start, and Vail could read by sound. By the time the tape was torn off, copyists were handing copy to the clerk for disposition before the reader deciphered the tape. Morse strongly condemned this unorthodoxy, insisting that messages be decoded from the tape, which he thought was less subject to error. After all, the making of a permanent record was one of the selling points of the Morse telegraph. On all telegraphs in service so far, the operator either had to watch the instrument and receive messages in small bites, words or individual characters, or he had to decode the tape. Receiving by ear, or acoustically, was as natural as listening to speech, and quite accurate.

Every electrical telegraph presents its message as a time series, so it is natural that it can best be received by the sense best adapted to the reception of time series, the auditory sense. We have seen that no sooner was the Morse telegraph introduced, but the incidental noise produced in the course of its operation was used to interpret it, instead of the apparatus that had been provided for that purpose. There are many anecdotes of operators and others being able to read the register or relay by sound, notably Alfred Vail himself. J. J. Speed introduced reading by ear on his Buffalo and Cleveland line in 1847. Reid says that acoustic reception was used on the Pittsburgh-Louisville and New York, Albany and Buffalo lines in 1849. A young Anson Stager was reported to have copied a message by ear when the register was broken, to the astonishment of his colleagues. G. G. Ward was the first to read by sound in England, and A. M. MacKay first in Canada. It was originally deprecated by several companies, notably the Magnetic Telegraph Company, and by Reid himself. By 1854, reception by ear was acknowledged as the superior mode, and the sounder replaced the register for skilled operators. Only one person was required, not a reader and a copyist. In 1886, Western Union had 31,910 sounders in use, but only 1086 registers remained. Railroads used sounders exclusively.

The fact that an operator receiving by ear was about twice as productive as one who did not soon made an impression on telegraph officials, including Alfred Vail, who without doubt had learned the practice very early. Not only was it allowed when the register was in use, the tape being consulted only in cases of uncertainty, and saved as a record, but soon the register was dispensed with and replaced by the *sounder*, sometimes called a *pony sounder*, which was no more than an electromagnet with a hinged armature working between stops. The first sounder was apparently devised by S. W. Chubbuck of Utica, New York, a small manufacturer of telegraph apparatus who also made a fine-wire relay. The clicks could be heard well enough, but if amplification was required, the sounder could be put in a sounding box. The use of an empty metal tobacco can was traditional for the purpose. For those who have never received Morse, it is necessary to say that the individual dots and dashes are not separately perceived, only the overall sound of the character. It requires some months of practice to recognize the characters. Transmitting the code is very easy and quickly learned, once the usual beginner's errors are corrected and a good rhythm is acquired. The Vail code is very well suited to reading by ear, as if it had been expressly designed for the purpose. My American website contains an example of the sound made by a Vail sounder.



In radiotelegraph operation, the code is received with an earphone as an interrupted tone, not as clicks. This is true of the earlier spark-gap transmitters as well as later beat-frequency reception, which produces a clean tone. When a coherer was used to drive a relay and a register, of course there were clicks. A radiotelegraph operator will not understand sounder clicks, and an operator used to the sounder will not be able to read tone code. The sounds are too far different for this, and each must be separately learned. Of course, in America there was also the difference in codes, which is more important. When Morse code was used on land telegraphs in America, the code was always the Vail Code. On railways, the sounder was always the receiver, not the Morse register. However, some railway stations from which telegrams could be sent and received but did not have a skilled Morse operator used the register. The necessity of having a skilled operator was the cause of many interesting problems of labour relations. Western Union did its utmost to eliminate well-paid operators by introducing women, and automatic equipment as soon as it became available, so by 1900 Morse operators were limited to railways. Many of these, incidentally, were women, and they did an excellent job.

The Vail Code is not suitable for telegraphs received by eye alone, such as needle telegraphs, signal flags, and flashing lights. The eye cannot recognize the characters presented in a time sequence as a whole, and is not sensitive to timing, as is the ear. This would have been a very good reason for the elimination of spaced letters and dashes of several lengths in the Prussian telegraph code, while the code was being modified to include German letters in 1851.

The British Post Office Telegraphs used the Vail sounder on its main lines until automatic telegraphs became widespread. The double needle had been quickly superseded by the Bain, which was superseded by the Morse register. Some less-busy lines used the single needle or the ABC telegraphs. Eventually, the needle telegraph was also read by sound. Mr Neale of the North Staffordshire railway modified the instrument so that an iron strip struck either an iron point or a wooden peg, making different sounds. This allowed the message to be written down as it was received, without pauses for transcription. The "tin sounder" was an attachment to a single-needle telegraph arranged to give different tones when the needle struck a metallic sounding plate made of thin tinplate on one side or the other. Sometimes the users improvised their own sounding devices. Culley mentions that this was quite fast, and allowed the message to be written down as it was transmitted.

The introduction of the sounder after 1850 brought about a change in telegraph circuits in the United States. This was *closed-circuit* operation, where the signalling current passed continuously through the keys and relays of a telegraph circuit in series. This permitted several stations on the same circuit to receive simultaneously, a kind of 'party line.' When the circuit was broken at any point, either by a fault or deliberately to call attention, all the sounders in the circuit clicked. There was no need for a bell to call the attention of the operator, as in silent telegraphs. The modern key had a switch to close the circuit through the key. This was ideal for railway operation, since any one or more stations could be called at one time, and each station would receive exactly the same message at exactly the same time, which contributed greatly to accuracy of transmission. Each operator could listen to what was going on, and check the others. This was the reason that Morse telegraphy lasted so long on railways. It is superior to all other means of communication on this account. With closed-circuit operation, no key was necessary to send an emergency message. One simply cut the wire and tapped out the code with the loose ends.

Anson Stager is credited with introducing closed-circuit operation about 1850 at Louisville, replacing the Vail open circuit that had line batteries at each office. The key was now equipped with a circuit closer, conveniently to the right of the knob. Closed-circuit operation became practically universal, in North America, Australia, India, and on the continent of Europe. Only in England did the Post Office stubbornly hold to open-circuit operation. Indian telegraphs were very much like American telegraphs, using the Minotto version of the gravity cell, the sounder, and closed circuit.

In 1852, the Morse register was universal in the United States. The paper tape was transcribed by a reader and a copyist, taking two people as usual for visual reception. However, by 1860, says Prescott, "There is scarcely an office of any importance in the U. S. where the paper is used to receive the record." Only one Bain line survived then. By 1870, there were no more Bain lines, Morse having replaced them all, and the House and Hughes teleprinters had been replaced by the Phelps American Printing Telegraph teleprinter. An average operator with a sounder and key could send and receive at 25 to 30 words per minute (wpm, a word is 5 or 5-1/2 characters). A "plug" could probably handle 10-15 wpm. Numbers were spelled out, then sent as a figure. In fractions, a dot was used for the solidus. There were contests to see how fast expert operators could send. In 1860, James Fisher at Nashville was received by James Leonard at Louisville at a rate of 55 wpm, which gives a good idea of the maximum speed for the manual telegraph (the limit is set mainly by the rate of reception, not sending).

In an Atlantic Magazine article in 1858, Reverend Hale explains how "dots and lines" are used for communication, describing many ways of sending and receiving them. James Swain of Philadelphia had described what he called a Mural Diagraph in 1829, using knocks and scratches to communicate through walls (obviously not brick walls), that were like dots and dashes. The reverend says his friend Langenzunge (a joke?) cut the wires beside the Baltimore and Ohio during a delay in a trip on a freight train, put them in his mouth, and *tasted* the sad message that his friend Old Rough and Ready (President Taylor) had died. A blind girl had *smelled* a message received on the Bain electrochemical telegraph, and another blind person had read the message recorded by a Morse embossing register (a predecessor of the Braille code?). He says the dots and line have been seen, heard, smelled, tasted, and felt (using all five senses). You can believe as much of this as you want.

Perhaps better founded was the unusual trick of Anson Stager, a founder of the Western Union Telegraph Company. One night on the Pittsburgh, Fort Wayne and Chicago he cut a wire to tap out a request for a relief engine to rescue his disabled train, by tapping the line wire against a wire pushed into the ground. To receive, he then held one wire in his hand, and applied the other to his tongue. Marking current would cause the tongue to protrude, and Stager was unusual in that he could see his own tongue. It appears that he demonstrated this for the amusement of his friends in later years. During the incident, Stager received a considerable shock from the earth currents set up by a nearby lighting stroke. Reid also relates that Sam Zook received an unpleasant shock when he tried to read the telegraph with his tongue when out repairing the line near Norristown late in 1845.

The speed of transmission of a telegram depends on many things. One estimate, assuming a typical telegram of 17 words, with each word five characters long, was that 60 messages per hour could be transmitted with the sounder, 45 with the Morse register, 30 with the needle telegraph, and 15 with the ABC telegraph. Another estimate gives the rate of transmission with a sounder as at most 53 wpm, a good operator 40 wpm, and a normal operator 25-30 wpm. The House printing telegraph was good for 30-40 wpm. Bain once demonstrated reception at 1000 wpm with a special chemical receiver.

Telegraphic Personnel and Procedures

The telegraph operator was the most romantic figure on the telegraph scene, but this section will mention some of the other people who were necessary to provide the service, while not neglecting the operator. Like the locomotive engineer and steamboat pilot, the telegraph operator, communicating instantaneously with distant points using a private language, fascinated boys. They hung about the local telegraph office, usually at the railroad station in small towns everywhere, listening to the clicks of the sounder. The operator might notice their interest and adulation, and introduce them to the Morse. Edison, Carnegie, Short and many others learned telegraphy before the age of 14, and it introduced them to electricity and the technical world. Later, radio had the same effect on boys, but now they learned the International Morse and listened to the crackles and buzzes of the ether instead of the clicks of the sounder. Alas, few girls are recorded to have had the same interests, though women became excellent telegraphers, and this was the first skilled employment for women where they were the equals of men. These days, both boys and girls have no such inclinations, perhaps because the romance has been relentlessly squeezed out of such things. There was a similar interest among British boys, but it was never as strong as in North America, and there was no counterpart of the railroad telegraph operator.

The first American woman operator was Sarah G. Bagley in 1846, at Lowell, Massachusetts. Other early women operators were Emma A. Hunter at West Chester, Pennsylvania in 1851, for the Atlantic and Ohio, and Ellen A. Laughton, who became operator at Dover, N.H. in March 1852 on the Boston and Portland line. There was much prejudice against women operators, as could be expected, but they were excellent operators, and would work for lower wages. In 1886, approximately a third of the Western Union operators at New York were female. By this time, female operators were by no means a rarity.

The principal skill of the operator was sending and receiving Morse code by hand and ear. Receiving is difficult to learn, requiring extended practice. Once one can receive, sending is quite easy. The sound of each character is what is learnt, not the individual dots and dashes. A beginner will almost invariably make the International letter C, - . - ., sound like NN, - . - ., until shown how it should sound. The Vail alphabet, with its spaced letters, is even more tricky. A railroad operator was usually allowed to take on a small number of students, since this was the usual way operators were trained. There were regular telegraph schools in large cities, where the demand for operators was greatest. Individual operators sometimes affected certain syncopations that gave them a recognizable "fist," but this was bad practice, though irresistible to a certain type of person. The best code was perfect code, since it could be universally understood, like good pronunciation in speech. A beginning operator was called a "plug" by analogy with horseflesh.

The railroad operator's main job was as a signalman and handler of train orders; telegraphy was only a tool he used. Each office had call letters to identify it, usually two letters. When he recognized his call in the traffic taking place on his sounder, he would break (open his key) and reply at the first opportunity. Only in an emergency would he break in the middle of traffic. To listen on two wires, the sounders would be made to give different sounds. It took considerable skill to listen to one with the other in the background. Since he was usually isolated in an office by himself, he knew how to adjust his relay and sounder, and to maintain the wet batteries for his local circuit. In case of any problem with the wires, he would call for the lineman or line repairer. On some of the rickety early commercial lines, the operator might have to double as lineman, hanging the sign "Gone to Mend a Break" on the office door.

Railroad offices gave Western Union a universal presence at a low cost. Of 8203 offices in the Central Division, 7187 were railroad offices, or 88%. The expense of these offices, if devoted wholly to Western Union, would have been prohibitive. Railroad operators also handled Western Union traffic, while they did other things like selling tickets and handling packages, which supplemented their income. Boys interested in telegraphy delivered messages for the tips they received, or in return for telegraph instruction. Commercial messengers were paid, in large cities by the message, and even then relied on tips to eke out their small wages. Salaried messengers were happier, and more loyal to the company. Service as a messenger was usually the entry position into the industry.

A Chief Operator at each major commercial station was usually appointed to preserve order on the wires, if there were no Wire Chief, and to ensure that traffic was handled expeditiously. A Night Chief Operator did the same on the night shift. Sometimes the Chief Operator handled the technical aspects of the line when there was no Superintendent, or the Super had no technical knowledge. In large offices, there might be a batteryman to tend the noxious Grove cells, and wire chiefs to distribute the traffic over the available circuits. Shifts were usually 12 hours long before the Civil War, and shortened only very gradually, especially in railway service.

The telegraph operator was a new kind of employee. A few month's training produced a plug operator, but several years' practice was required to develop a first-rate operator who could send and receive at 20 or 25 words per minute. There were also electrical matters to deal with, which were new and technical. The operator worked in a clean, bright office and no strenuous manual effort was required. This made it possible for women to be operators, in no way less capable than men. This was a new phenomenon in the world of work, and the proper status of the operator was not easy to work out. On a railroad, the operator was among the most skilled of non-management employees, but was often paid less than trainmen because his job was not out in the rain and snow. In commercial telegraphy, the operator was not of management rank, and there were few opportunities for promotion except in the ranks of operators. This problem was almost exclusively North American, where the skill of reading by sound was necessary. In the rest of the world, it was soon a matter of simply serving machines (as it is today).

There were notable operator's strikes in 1870 and 1883, which illustrate more than anything else the sadly missed chances for both capital and labor. The operators desired to assert themselves as free men, while the managers jealously guarded their absolute authority. The issues were secondary. The January 1870 strike was organized by the Telegrapher's Protective League, which had been formed in 1866 at the same time as many other labor organizations. Arbitrary adjustments of salaries in San Francisco was the trigger, and the strike spread as far as New York in the bitter cold winter weather. The Brotherhood of Telegraphers of the United States and Canada called a strike in July 1883 with demands for no compulsory Sunday work, the 8-hour day, equality of the sexes, and a 15% general increase in wages. The Brotherhood was District Assembly #45 of the Knights of Labor, and had been urged not to strike. However, Master Workman John Campbell went ahead without a sufficient strike fund, and the strike failed. In such a business, it was easy for management to get along in an emergency by extraordinary measures. Operators were skilled men in a clean, warm job, but there was no place for "white collars" at the time.

The lineman's or repairman's job was routine maintenance of the circuits, both the outdoor lines and the indoor apparatus. He had a horse, with everything he needed in the saddlebags. His most important function was inspecting the line and catching trouble before it occurred, so he made regular rounds, mounted or on foot. He could replace insulators, straighten arms, retension stays and such other things as can be done by one man. In case of a break, or failure of a pole, he could make temporary repairs, but called for the construction gang to put things right. He could probably wire a new office, installing the lead-in and ground plate, and make it ready for use. However, construction men would do any digging and heavy lifting that was necessary. The length of line assigned to a lineman was extremely various. If he was expected to inspect the line daily, this could hardly be more than 20 miles, and would be justified only for a very busy and important line. The pole climber, spurs attached to the boots, called "irons," was invented by C. T. Smith of the Magnetic Telegraph Company around 1846, and not patented.

Finally we come to the telegraph engineer, or "electrician," who designed and surveyed a new line, specified all the materials and apparatus necessary, and tested procured materials to make sure that they were of the necessary quality, especially wire and insulators. On the first American lines, these men were the superintendents. Such men who were knowledgeable and capable were always educated, but often self-educated, since the field was a completely new one. Telegraphy was the first commercial use of electricity. The nature and properties of electricity were very poorly known, even after practical telegraphy had made some progress. Even Ohm's Law was not widely understood until the 1840's. Every early manual on telegraphy took pains to explain electricity from the ground up, sometimes comprehensively, sometimes obscurely. In the United States, it was quite a long time until telegraph engineers generally knew what they were doing, and some had very strange ideas about the subject.

The early American lines did not have telegraph engineers, because none were available. The job was generally assumed by the Superintendent, who delegated various functions as convenient. The lack of any electrical knowledge was something of a hindrance, leading to the extreme unreliability of early American lines. Insulation was the main lack, and wide spacing of poles to counteract this meant many crosses and grounds. Copper wire, used in the early days, broke frequently. Sometimes it was simply wound around turned arms like chair legs attached to unbarked log poles, with cotton and beeswax as insulation. Such lines worked only fitfully. In 1869, the firm of Edison, Pope and Co. was founded, and they called themselves "electrical engineers." The American Institution of Electrical Engineers was organized in 1884.

There was usually a switchboard in every office for interconnecting the line, instruments and batteries, and for making line tests. Connections were usually made by inserting brass plugs that made contact between the contact bars. These switchboards could be extensive in offices with a number of operators, but were quite simple in the one-man office. Operators at individual desks normally worked the same lines, and messengers circulated between the operators with messages to be relayed. Later, in the commercial telegraphs of large cities, there were switchboards developed from those for telephone service, where operators answered calls and made connections with patch cords in the same way, connecting city offices with one another directly so that messages did not have to be relayed.

Railway Telegraphs

Cooke promoted his telegraph for the operation of single-track railways as early as 1842, and it was used for this purpose from 1844 and for many years thereafter. It was also used for isolated blocks through long tunnels, steep gradients, and other local dangers, but not generally for controlling trains on double track until the telegraph block system was gradually and generally introduced in Britain after about 1865. The Morse telegraph was used similarly in the United States, but not originally for the operation of single-track railways, for which the time table was the sole authority. It should be understood that the railways already had operating procedures independent of the telegraph that were satisfactory under the conditions of the time, both in the United States and Britain.

It is said that the pioneer Baltimore-Washington line was used by the Baltimore and Ohio to arrange for the movement of a special train in 1844. The value of the telegraph for this purpose was certainly suspected at that time, but the unreliability of telegraph lines precluded regular use, and certainly there was no idea of a block system. Not until the telegraph lines were under the control of the railroad company and properly maintained was the regular use of the telegraph in train movements practicable.

The usual discussions of the relations of railroads and telegraphs, such as the chapter in Thompson, miss the important points entirely. The telegraph wire, although built on railroad property, was operated by telegraph employees for public traffic. The offices were open only by day, and accepted railroad traffic on the same basis as commercial traffic. The lines were unreliable and often down. Under these conditions, the telegraph could not be relied upon for train movements, only for the occasional message. The railroad was hindered from establishing its own telegraph service, since this would mean payments to the Patentees and competition with the commercial telegraph. Change could only come when the railroad owned its wires, operators were railroad employees, and the wires worked day and night. For most companies, the telegraph represented a novel and considerable expense. The later development of the train order system was only possible when the railways controlled their own lines and employed their own operators.

When the first telegraph lines were being built just after 1845, there was a limited railway network in the East, but the great era of construction in the West (Ohio to Illinois) had not yet begun. In 1841, there was less than 200 miles of railway in all of Ohio, Indiana, Illinois and Michigan. In fact, only the New York Central route was complete to the Lakes by 1846, the Pennsylvania Railroad was yet to be organized, the Erie was stalled somewhere near Port Jervis, and the Baltimore and Ohio was creeping west from Cumberland, having reached that point only in 1842, and was not to arrive in Wheeling until 1853. Therefore, most telegraph lines had to follow common roads when the early "grapevine" wires were strung, except along the seaboard.

The celebrated refusal of the New Jersey railroads to provide accommodation for the Magnetic Telegraph Company's line in 1845 was not for any contempt of the telegraph, but vengeance on Amos Kendall, who earlier was Postmaster, and had been unpleasant over mail contracts then. Another cause of friction in telegraph-railroad relations was caused by careless maintenance of the telegraph line, which might fall on trains where it crossed from one side to the other of the track, or cause other mischief.

Judge J. D. Caton of Illinois, president of the Illinois and Mississippi Telegraph Company, took advantage of his legal expertise to devise contracts for putting telegraph lines beside railways that were advantageous to both parties. Railways already had means of operation that did not require telecommunications. However, the great advantages of using the telegraph to facilitate the operation of trains was soon recognized. The telegraph handled delayed and extra trains expeditiously, which were a great annoyance under the old system. Judge Caton made his first agreement in 1855, and after that telegraphs and railways became symbiotic. He recognized that night service was essential, and that train control messages had to have top priority. Anson Stager of Western Union also encouraged agreements with railway companies.

Railroad companies, such as the Pennsylvania and the Erie, had already independently acquired or constructed telegraph lines, arranging patent rights as necessary. That patent rights hindered these developments is shown by an early incident, when Governor John Brough, president of the Madison and Indianapolis Railroad, desired a telegraph along his line in 1850. Reid built and equipped the line on

the quiet, without patent rights. The Morse patentees made a strenuous objection, so Reid had to purchase the necessary rights from Tal. P. Shaffner, who was a Morse patent trustee.

An agreement with a telegraph company brought with it the necessary Morse patent rights, which was the principal benefit of the agreement to the railway company. No other technology was applicable to railway use. The railway company usually did most of the construction, and also paid a certain amount per mile, perhaps \$30, to defray the cost of its wire and instruments. Of course, the railway company moved telegraph supplies and personnel free. Railway operators handled public messages when it did not interfere with railway business and turned over all the proceeds to the telegraph company, receiving a commission for their services. This was the way most railway telegraph lines were built, normally at the time of construction of the railway, when telegraph lines along common roads were moved to the new railway. Very few, if any, railway companies did not use the telegraph if it existed along their lines. After 1860, the connection between railroads and telegraphs was intimate. Reid calls the Pennsylvania Railroad the "mother of telegraphs" [p. 488].

The folklore of how the telegraph came to be used in railway operation in the U. S. is usually in the form of a fable concerning Superintendent Charles Minot of the Erie. He is supposed to have thought it up on the spot one day when his train was delayed, and he wanted to get to Port Jervis in the face of the delayed Western Mail. Reid and Prescott tell how it was actually done.

In one of his devious plots, F. O. J. Smith had Ezra Cornell and J. J. Speed build a telegraph line along common roads from New York to Dunkirk to compete with the existing line via Albany to Buffalo. This New York and Erie Telegraph Co. began construction in 1847, with 40 poles per mile and #9 iron wire. The Erie built its own telegraph line along its track, with the help of Cornell, when it came along, on a different route, in 1851. Mr L. G. Tillotson was given control of the eastern end of the line, and Mr Chapin the western. Charles Minot, the General Superintendent, convinced the Superintendent of the Susquehanna Division to experiment with controlling train movements by telegraphic messages sent to the train crews. There was some opposition by other officers of the company, but the good results won them over, and the use of the telegraph spread system-wide.

The intention from the first was to use the telegraph to facilitate the operation of trains. Minot made an offer to purchase the Morse patent for the line, but Smith refused and made unacceptable counter-proposals, so there was some wrangling. Smith's line proved unprofitable, and was transferred to the Erie right-of-way in 1852-3, where it gradually fizzled out. In 1864, a Western Union line replaced it. Tillotson resigned in 1866 to look after his business of manufacturing telegraph apparatus in New York, and was replaced by W. J. Holmes as Telegraph Superintendent. The Report to the Stockholders of 1855 describes the progress with the telegraph. There were two wires over the 469 miles of the line. One wire was a through circuit, the other was divided by operating divisions. The conductor and engineman of a train receiving an order to proceed or stop had to receipt for it before it was acted upon. The Erie then had 68 telegraph offices, 17 open continuously, staffed by 100 operators, 7 repairmen, and 12 messengers. Minot was succeeded as Superintendent by D. C. McCallum, also a strong supporter of the telegraph for railway operation. McCallum was later General Manager of the U. S. Military Railroads in the Civil War, and this helped to spread the railroad use of the telegraph. Caton, Stager and McCallum are largely to be thanked for the rapid introduction of the telegraph on American railroads.

The Atlantic and Ohio Telegraph Company opened a line from Philadelphia to Pittsburgh, via Chambersburg and Bedford, in 1846. The first segment of this line, from Lancaster to Harrisburg, was probably the first commercial telegraph in the country. In 1850, Andrew Carnegie hired on as messenger and later operator at Pittsburgh. The first train of the Pennsylvania Railroad arrived in 1852, and the tunnel at Gallitzin was opened in 1854. The Pennsylvania acquired legal powers to construct its own line, having purchased the necessary patent rights. David Brooks was the first Superintendent of Telegraphs, appointed in 1852. The impetus may have come from J. Edgar Thomson, the engineer who became president of the company in that year. It is clear that the Pennsylvania had a telegraph for its own use before its construction was complete. Later, the A. & O. built a line alongside the Pennsylvania.

The Pennsylvania employed its own operators, which were used for moving trains and other company business. The Divisional Superintendent was the only officer authorized to issue train orders, and signed them with his signature. Night train dispatchers relieved the Superintendent, but still issued orders under his initials. This was a departure from the general practice of having officers of the company issuing orders independently at terminals and points along the line. Single authority remained a basic feature of the train order system, along with written messages to all those who were to execute them in the same words, and rigorous measures for transmission accuracy. The efforts of the Pennsylvania and the Erie marked the beginning of the American train order system, which required a further thirty years to perfect. The basic principles appeared in the 1874 Rule Book of the Pennsylvania. The train order system was finally established as the Standard Code of Train Rules in 1889. The Standard Code was broadly based on the practice of the Pennsylvania and the Chicago, Burlington and Quincy companies, and was practically perfect when introduced, reflecting the lessons of over twenty years.

The first use of the telegraph block system in the United States was between Philadelphia (Kensington) and Jersey City on the United Railroads of New Jersey, in 1867, by Ashbel Welch. By this time, railroad telegraphs were well-established. This system was further developed by the Pennsylvania Railroad after acquiring this company in 1871, and extended over its double-track main line from Philadelphia to Pittsburgh by the summer of 1876. The Pennsylvania soon used the telegraph block system on all of its principal lines east of Pittsburgh, but was the only major company to adopt the block system generally for many years. The Morse telegraph with sounder was the only telegraph employed.

In Britain, the needle telegraph was adapted around 1855 by Edwin Clark of the London and North Western Railway as a *block indicator* to show the state of the line, whether occupied by a train or not, depending on the direction of deflection of the needle, which was constantly maintained by a current. The signalmen were also given a bell and a single-needle telegraph to exchange the necessary messages. The Tyer system originated with a patent in 1852 for a treadle-worked automatic signal that would be set when a train entered a block, and cleared when it exited, by the use of momentary currents. In 1854 the system was changed to be worked by signalmen instead of by treadles, and in this form came into wide use, in spite of the faulty system of using momentary currents. Tyer claimed that this gave immunity from lightning, which it perhaps did after a fashion, but the main advantage was the use of a single wire, instead of the three required with Clark's system. Tyer instruments were well-made and reliable. The development of the Telegraph Block is a separate extensive study, with nothing to do with telegraph codes, and so will not be further mentioned here.

In Germany, electrically-released weight-driven single-stroke bells were used to announce the departure and arrival of trains between stations, the circuits extending from station to station, and operated by the stationmasters, who directed trains to start or wait. This system was used on some single-track lines in France.

In France, the Bréguet dial telegraph was used by stationmasters to regulate the traffic between their stations. Regnault, of the Chemins de fer de l'Ouest, invented an instrument with two needles and two buttons, much like an English block instrument, but differently used. One instrument was located at each end of a section of line. The D button was pressed when a train departed, and the A button when one arrived. An indicator needle showed when a train was on the line, and a repeater needle showed that a transmitted signal had arrived properly. The rigorous British block system with its chain of signal boxes was far too much trouble.

Military Telegraphs

The telegraph was used for communications between the headquarters of the allies in the Crimean War, 1854-55, but not as a field telegraph. The British army in India used the telegraph in 1857. The United States Army was the first to use field telegraphs extensively, in the American Civil War, 1861-65. Andrew Carnegie brought telegraphers from the Pennsylvania Railroad to initiate this service in 1861. The Secretary of War named Anson Stager of Western Union Superintendent of the United States Military Telegraph. His assistant, Thomas T. Eckert handled most of the work in organizing and deploying the new organization. The telegraphers were civilians, not military, and besides telegraphing handled all cryptographic work. The Caton pocket instrument was used with the Vail code. #14 wire and batteries were carried on mules, the wire insulated by small glass screw insulators and lifted as far as possible above the constant traffic of the battlefield. The wet batteries must have been a trial, and were probably still Grove cells. Gravity cells are wholly unsuited to the wandering life. The telegraph followed commanders without being ordered, and provided an excellent service, to which Grant and other officers witnessed. The Confederacy made little use of field telegraphy, employing only the commercial lines in most cases. Eckert became Assistant Secretary of War under Stanton, and later president of Western Union. Both Stager and Eckert became generals, and were later distinguished with that rank.

The Signal Corps was organized in June 1860. Major Albert J. Myer, then Assistant Surgeon General, was named Chief Signal Officer. Around 1855, in Texas, Myer had noticed the Indian fire signals. Remembering his past as a telegraph operator, he devised a method of semaphore signalling with one flag. The flag was moved to one side for a dot, to the other for a dash. At the outbreak of war, a school for signal officers was established at Fortress Monroe, later moved to Georgetown, D. C. In 1862 there were 198 officers and 594 men in the corps, the men doing most of the real work. Myer decided the Signal Corps could handle field telegraphs better than the USMT with the aid of a new patent telegraph of G. W. Beardslee of New York. This was a magneto-electric alphabetic dial telegraph suspiciously similar to instruments by Werner Siemens, so perhaps Beardslee had been perusing the German patents for ideas to steal. This telegraph did not need the batteries that were such an encumbrance with the Morse, and the higher voltages could use finer, lighter wire. The army bought 40 of these machines for Myers's mobile field telegraph, and competition with the USMT began. Each of Myers's wagons carried 5 miles of vulcanized-rubber-insulated wire, which could be laid quickly on the ground. Myer was promoted Colonel in March 1863, and the Corps was expanded, but on 10 November 1863, Myer was relieved of duty with the Signal Corps, due to conflict with Secretary of War Stanton, and all telegraphs were handed over to the USMT. The magneto telegraph had not done a good job, and no more was ever heard of it.

In 1866, the Signal Corps had one chief, 6 officers and 100 noncommissioned officers. With this reduced staff, the Military Weather Service was formed in 1870 to make use of the telegraph capabilities of the Corps for synoptic weather reporting. Its duties were storm warnings for the Gulf, Atlantic and Great Lakes. There were 24 reporting stations in 1870, and 55 by the next year. For meteorological expertise, of which the Corps had none whatsoever, civilian experts, usually from universities, were attached. The service demonstrated its worth very quickly, so in a reorganization of 10 June 1872 its services were extended throughout the United States. In 1871, the only offices in the west were at Omaha, Cheyenne, Corinne UT, and San Francisco, and there was a severe lack of telegraphic facilities that hindered collection of weather data. There were no local forecasts until 1881, and even then only for a few places, such as New York. By June 1890 there were 26 first order stations, 118 second order and 34 third order, reporting the usual surface meteorological data. From these origins the United States Weather Service was formed in 1891.

The Prussian army seems to have been the first with a regular telegraph department. The telegraph was used in the 1864 war with Denmark, and was said to have been decisive at the battle of Sadowa in 1866, where it was used to coordinate the movement of two separate columns. By the time of the Franco-Prussian War, 1870, military telegraphs were an established service.

District Telegraphs

Just as one delivered a parcel to the railway company at a station, and it was delivered to the addressee when it reached its destination, one handed a message to the clerk at the telegraph office, and it was delivered by messenger at its destination. However, in distinction to a railway, the construction of a telegraph line was cheap and easy, so it was, in principle, possible to bring a line to the individual user. The greatest obstacle was the necessity of a skilled operator if the Morse system was used. Professor Morse had a private line put in, but this was very exceptional. I will call local telegraphs in a restricted, usually urban, area *district telegraphs*. This will include reporting, messenger, fire, police and individual subscriber services.

The earliest private lines served the traders and brokers in restricted areas of large cities, of which New York is the prime example. These were one-way lines that reported prices and sales on an exchange instantaneously to the subscribers, replacing the scurrying messengers previously used for this purpose. The earliest appears to be the reporting of the price of gold on the Gold Exchange in New York just after the Civil War. The price of gold then determined the prices of commodities and the rates of settlement of financial instruments, since the currency then floated. The service was later extended to stock prices on the New York Stock Exchange, becoming famous as the "stock ticker."

The stock ticker originated with the "gold indicator" of Dr S. S. Laws, invented in 1866, with the help of F. L. Pope, that repeated the price of gold at several locations by means of electrically-moved wheels. E. A. Callahan introduced two type wheels and printing in his stock price indicator, or ticker, of 1867. The letters identifying the stock were on one line, the figures on another, a format that became standard. The central office at 18 New St., New York sent quotes to 25 satellite stations. The "ticking" was the ratcheting of the print wheel caused by brief pulses in the line, which either drove the wheel directly, or released weight-driven clockwork. The inked print wheels of the transmitter and all receivers connected to it rotated synchronously. When the desired letter was in the proper place, a pulse in a different circuit operated the print magnet, whose armature raised the tape to press against the print wheel, and then advanced the tape one space. Callahan's ticker used three wires, and sometimes the wheels got out of correspondence. The ticker was a small but very important field of application of the telegraph.

Edison improved the stock ticker in 1869, the first of his inventions after the vote register for which there was no demand. If no printing pulse was received after a certain number of revolutions of the print wheel, it was stopped at a reference location until the next printing pulse (which printed a space). This "unison device" kept the printing wheels in step. The necessary pulses could be sent over one wire, differentiated by length. A short pulse moved the type wheel, while a long pulse operated the printing solenoid as well. The two functions could also be carried out by polarized pulses. It was also necessary to shift between the letters and numbers print wheels. However, later Edison tickers seem to have used two wires. The transmitting instrument had a keyboard for selecting the letters and numbers sent. This telegraph was best adapted to sending the same information to a number of subscribers in a limited area. It required a good line and considerable power. Unlike the ABC, tickers do not appear to have been used for regular commercial telegraphs. The Edison "Universal" ticker under its glass dome was used worldwide, but not in New York, where the Callahan ticker was supreme.

The American District Telegraph Company was organized in 1872 to provide call-box services to its subscribers in New York City. The call box could send four different messages: 1-messenger desired; 2-fire; 3-police; 4-physician. A bell rang to show that the request had been received. It was essentially a 911 service, supplied for \$2.50 per month. Its messengers were uniformed boys of 14 and over, who worked on a salary. There were 2000 subscribers by 1874, 4500 by 1878, and 11,897 by 1885, when 1200 messengers were employed. Boxes in private houses were later phased out in favor of public boxes in the streets.

The Mutual District Messenger Service, organized in 1881, supported 10,000 boxes and 500 messengers. The Manhattan District Telegraph Company, from 1883, had 6000 boxes and 350 messengers. These services were obviously quite popular, and spread to other cities. Fire alarms and police call boxes were introduced after the Civil War, as well as annunciators and calls in hotels and other establishments. These were fertile fields for inventors in the latter half of the 19th century. They all used standard telegraph technology, which was the basis for the electrical industry when it began to supply light and power in the 1880's.

Large business houses could employ a skilled telegrapher, so private lines were opened to them, in Philadelphia, New York and other places. The Manhattan Quotation Telegraph Company, organized in 1872 and using the Pope and Edison patent tickers employing polarized pulses and an automatic unison stop, was later absorbed by the Gold and Stock Telegraph Company of 1867, a direct descendant of the Gold Reporting Telegraph Company of 1866, which it absorbed in 1869. Even the Western Union's Commercial Reporting Service was sold to the G&S; in 1871.

Private lines to individual subscribers in their homes or businesses depended on instruments that could be worked by unskilled operators. In Britain, the Wheatstone ABC was used for this purpose (and even in the long-line service for small post offices). In the United States, the Gray teleprinter, with a button keyboard and a tape printer like a ticker was similarly used. A polarized relay was displayed under glass between the keyboard and the ticker dome as an elegant functional decoration. These services never developed fully, since they were overtaken by the telephone which really requires no skill to operate. The short range of the first telephones restricted them to district use, but they originated the technology of the switchboard. Until the 1890's, the telegraph had the monopoly of long-distance communication. The telephone was considered a useful adjunct, for receiving and delivering telegrams, not a threat.

Underwater and Long Distance Telegraphs

Lardner says Dr O'Shaughnessy laid the first telegraph submarine cable across the Hooghly in India, in 1839. It was attached to a chain, so perhaps it was slung above the river, not laid on its bed. At any rate, this is very early, and one wonders what kind of instruments were used for this apocryphal feat. In 1852, Alexander Jones thought an Atlantic Cable an impossibility, but a line to Europe via Bering Straits quite feasible. Samuel Morse, however, was sanguine about an Atlantic Cable at an early date. These things were thought about as soon as the telegraph arrived. Wheatstone had experimented with circuits under water in the early 1830's. Morse (and others) tried cables across rivers and lakes, but all these attempts met with only limited success. Either the insulation failed, or the cable was snagged by boat anchors and such.

The earliest American river crossings were made with the aid of high masts, not submarine cables. These were troublesome crossings. At St. Louis, there was a 160' mast on the Illinois shore, a 185' mast on Bloody Island, and a shot tower of equal height on the St. Louis side. The spans were 2700' and 2200', respectively. The crossing of the Hudson River by the telegraph was not easy. Ezra Cornell put wires with cotton and rubber insulation in a lead pipe across the Hudson at Fort Lee, near New York, on 20 November 1845. Ice ripped out the cable that winter. Then, the 2700' crossing was made by a long wire supported on high masts on the banks near West Point. When a ship came along, the wire was lowered beneath the surface, which was obviously not a permanent solution.

In 1847 a cable insulated with the new material gutta-percha was put across the river at Cortlandt Street, but it was soon torn out by an anchor. Two gutta-percha insulated cables were laid at Ft. Lee in 1850, and they survived. Soon, most river crossings were made by submarine cable rather than by masts, for example at St. Louis in 1852-3, Cape Girardeau, 3700 ft (1853), and across the Ohio at Paducah, 4200 ft, and Henderson, 3200 ft (1854) by Shaffner. The 3000 ft cable at New Orleans was made by Newall of London, and laid in 1854. In fact, the manufacture of submarine cables became a British specialty. The quality of these cables could not be imitated. Lardner gives a comprehensive list of early submarine cables in all parts of the world.

Gutta-percha is an insulating plastic compound chemically similar to rubber, but not elastic. It became famous when used to insulate the first submarine cables. It must be kept away from air and weather, which oxidizes and hardens it, causing it to crack and lose its continuity, but survives indefinitely under water. Creosote rapidly attacks gutta-percha. Rats were said to eat it when they burrowed into underground cables. Its great benefit was that it could be applied to wires in a continuous coating, giving an air-tight insulation that would not crack and admit moisture. Rubber was a competing material, especially for insulating wires used in the air, but gutta-percha was only completely replaced by thermoplastic insulation much later, which has similar characteristics but is stable and durable.

In 1850 a great event in telecommunications history took place. The first long submarine cable was laid between Dover and Cape Grisnez under the English Channel, 30 miles. This cable, promoted by John Watkins Brett and his brother, operated for only a few hours, but in 1851 a gutta-percha insulated cable with four conductors was laid between Dover and Calais, and this cable continued to function. This cable provided two double-needle links, with the usual earth return. Longer submarine cables, like the Atlantic Cable, had high capacitance, unlike the pole lines on land, and were very sluggish to charge and discharge. To overcome this, they were operated by polarized currents, and sensitive galvanometers were used as receivers. This made them very slow, and highly unsuitable for the Vail code. Submarine wires were no novelty in 1850, since Schilling had used them to explode mines as early as 1812, and the Hudson River was crossed by the telegraph in 1845, but the Channel crossing was a much more ambitious undertaking.

The first Atlantic cable, from Ireland to Newfoundland, was laid in 1858 by HMS Agamemnon and USS Niagara, but soon failed. High potentials produced by a Ruhmkorff induction coil were mistakenly used to try to overcome the distance, but they destroyed the insulation. A battery of 400 Daniell cells was later used, but the cable soon failed anyway. The operators were attempting to drive a Morse register with the cable. Success was finally achieved after the American Civil War when the huge P. S. Great Eastern (then known as Leviathan) was used to lay the cable, in 1865-66. William Thomson had invented the mirror galvanometer as a sensitive current detector, and it was used for testing as well as for 'speaking' -- that is, for sending messages. Apparently the instrument used for testing the cable was more sensitive, while the speaking instrument was faster, with less damping. Signalling was by current reversals, the only way a highly capacitive line can be successfully worked. The initial speed was about 8 words per minute (wpm, a word being five, or five and a half, characters). An excellent contemporary reference, the book by Russell published in 1865, gives minute details of the cable and its laying, but never once mentions the code used for messages. It was probably International Morse, with dots and dashes represented by opposite polarities. The siphon recorder, introduced in 1870, made a permanent record of the signal, and permitted an increase of speed to 15-17 wpm, which was quite good.

When I first considered the origin of the International Code, I neglected the underwater cables, and thought, erroneously, that it was devised shortly after 1900 to overcome the difficulties with radiotelegraphy. Then, I realized that the Atlantic Cable would have presented similar difficulties. It now appears that neither the difficulties of signalling underwater or in the air had anything to do with the change. To review the radio developments, we recall that Guglielmo Marconi succeeded in the Mission: Impossible to telegraph without wires, using Hertzian waves. The high-frequency oscillatory decay of currents in a circuit with a spark gap was used to create the waves, and a coherer, a device containing a conducting powder that oscillatory currents made conducting by causing the particles to cohere to one another, as a receiver. The coherer was in the circuit of a relay which drove a Morse register. It is doubtful if the Vail code could be used with this system, and I originally thought that this must have been the stimulus for the new code. Of course, we have seen that a Morse Code was already at hand and had been used for some years. It was already available for the cable and the radio.

Kelvin's experience with the Atlantic Cable led him to work out the theory of the propagation of signals on a transmission line, taking into account the electrostatic capacity and the inductance of the line. Edison and others working on the problem of transmitting rapid pulses were baffled by the distortion of the pulses by line capacity, which showed up at high speeds on land lines as it did on long submarine cables at much lower frequencies. The lack of theoretical knowledge made any real understanding or progress impossible. Later, Pupin found that adding inductance (coils) in series with the line, called *loading* solved the problem well enough to allow long-distance transmission of speech. Edison would have thought adding coils in series with the line ridiculous, since inductance slowed down signals just like capacitance. What he did not realize was that the effects cancelled each other out as far as signal distortion was concerned.

Elisha Gray showed that different frequencies propagated separately on a line and could be separately controlled. This was just an expression of Fourier's Theorem, now so well known, that any signal can be expressed as a superposition of signals of definite frequency. By equalizing a line, the speed of propagation of each frequency is made the same, so the different components remain in step, and the shape of the pulse does not change. The cost of this is that the attenuation, the rate of decrease of intensity, is increased, but the exchange is well worth it.

Short submarine cables can be worked with the usual telegraph instruments. An example were the 1865 cables from Punta Rasa on the Florida mainland to Key West, 133 miles, and from Key West to Moro in Cuba, 102 miles. The maximum depth of this cable was 845 fathoms. A heavier cable, 1-1/4 ton/mi with 2 ton/mi shore section, was used on the Gulf cable than on the interior waters cable, which was 3/4

ton/mile. The cables, as was typical, had copper cores surrounded by gutta-percha, heavily armored by steel wires, with fibre used as necessary between the layers. Cables were relatively maintenance-free and the rights-of-way easy to obtain, so they came to be used where one would expect a land line. Communication with Mexico, opened in 1851, was via a cable from Galveston to Vera Cruz, calling at Tampico, then a land line to Mexico City and Acapulco. The telegraph down the Pacific coast of South America travelled over cables along the coastal waters calling at the important cities. Cables also ringed the Caribbean. A cable was laid from Pernambuco in Brazil to Portugal, with connection to the cable links on the Atlantic coast of South America. By 1870, telecommunication was worldwide.

From the first, the telegraph was recognized as an instantaneous, long-distance means of communication. Though relaying was necessary, it could soon be performed automatically. A message tapped out at one point was received at once at a point a thousand miles away or more, without intervention, and over any route, however convoluted. The building of long telegraph lines soon became routine. A line from the States to California had been mooted since the early 1850's, but sectional rivalries retarded the realization. The Pacific Telegraph Act was passed 16 June 1860, and construction began 4 July 1861, Western Union undertaking the subsidized project. Two years had been allotted for construction. The line was complete from St. Joseph to Sacramento 15 November, only 4 months and 11 days later. There was no railroad, so the line went up the North Platte along the wagon trail, and through South Pass to the Salt Lake.

Perry McD. Collins had agitated for a line to Europe via the Bering Straits from late in 1861. In 1863, he submitted his proposals to Western Union, who accepted them, emboldened by the success of the Pacific Telegraph. The Russians were very interested in the project. They had completed the Moscow-Irkutsk portion of the 7000-mile line from Moscow to the mouth of the Amur River at Nikolayevsk, near the Chinese border. It was 2800 miles from New Westminster, B.C. to the Amur, with only a 178 mile cable across Bering Straits, as well as a 209 mile cable across the Gulf of Anadyr to make the route more direct. A fleet of 24 steam vessels was assembled, and completion was scheduled for 1867.

The route of the Russian Extension of the Intercontinental Pacific Telegraph Company (the subsidiary created by Western Union for the project) led up the Fraser, then to the Skeena via Lake Babine. From there, along the Stikine, Pelly and Yukon, and westward to Bering Straits. This was all well inland, away from the difficult fjords of the coast. On the Asian side, the line leaped the Gulf of Anadyr by cable, then directly southwestward over very thinly populated country via Okhotsk and Yamsk.

The line was completed to the Skeena, 850 miles from New Westminster, but then the news that the Atlantic Cable had been successfully laid. The long overland route could not compete with a relatively short, underwater cable, so the \$3,000,000 project was abruptly abandoned. It was an heroic effort, now almost completely forgotten.

Miscellaneous Uses of the Morse Code

Applications of the telegraph are already enumerated by du Moncel: railways, military, weather (Fitzroy's amazing network in Britain), determination of longitude, coast semaphore, fire alarm, flood warning, herring fishing, and private or domestic uses, all in addition to the obvious one of the transmission of messages.

The most familiar modern use of Morse Code is in signalling at sea, so we ought to consider how it came to be used in this application. Ship-to-ship and ship-to-shore communication was remarkably primitive until recently, shouting no doubt being the commonest method. Battle fleets were controlled by raising flags or firing cannon to express a few prearranged signals. In the 18th century, navies used their individual codes of signals expressed by flags of different designs and arrangements, some quite elaborate with hundreds of messages. By night, arrangements of up to four lanterns were used, and in fogs, groups of cannon discharges, indicated a smaller number of possible messages.

Capt. Frederick Maryatt devised an alphabetic flag code in 1817, and it was more formally promulgated by the Board of Trade in 1857 for civil as well as military use. The need for some means of communication between ships of different countries, especially in emergencies, was so obvious that an international committee was formed in 1856 to work out a single common code. It would not be surprising if the Morse Code was adopted at that time (it had already been approved by the German-Austrian Telegraph Union), but perhaps only flag signals were considered. There was a general international agreement to adopt a standard code of flag signals in 1897. This was the basis for the International Code of Signals, revised in 1900 and in use by 1902, that is still valid, with modifications. The Morse Code was included, and this is probably the origin of the term International Morse Code. I would like to know the earliest date at which Morse Code formed part of the International Code of Signals. Hand flags are now used to display Morse Code. A dot is both over the head, a dash is both held out to the sides, a word separator is flags held pointing to the ground on either side, and the separation between successive dots or dashes is flags in front of the chest, as shown here: . The arms alone can be used if flags are not available. It is clear that the Vail Code would not be suitable for this application, and in general for visual reception.

In addition to flags, the British Admiralty finally adopted Pasley's semaphore for general sea service in 1866 (though such semaphores had been in use since Popham's semaphore of 1807). The code was alphabetic, but not Morse, relying on a set of about 30 signs made by two arms with a common pivot. It was easy to write down each signal as a two-digit number and look up the letter later, if one did not know the code. Pasley's semaphore was later emulated by a signalman holding two flags that took the same positions as the semaphore arms. This code even appeared in the Boy Scout Handbook as late as the 1950's, and used square flags with a contrasting square patch in their centres. The Morse Code using two flags (as shown at the top of this website) and simple positions seems to have replaced this earlier semaphore code, though it takes much longer to send a given message. Flag signalling, or the *wig-wag*, was much used in the Civil War, since it has many advantages for quick signalling over limited distances.

By day, in sunny climates, the sun can be reflected by a mirror to a distant observer by the *heliostat*. 's Graveande is said to have used this method around 1730. In 1861, the United States Coast and Geodetic Survey communicated over 90 miles on Lake Superior by heliostat, and it was often used in the western surveys. The mirror was about 3 or 4 inches in diameter, and a telescope was used to help in directing it. The heliostat later became very popular with the French in North Africa, and with the British in Africa and India. International Morse was probably used with this as with all visible telegraphs, for which spaced letters are inappropriate.

Captain Philip Colomb devised a means of signalling by night using a shuttered lantern in 1867. An arc lamp or limelight was used. The Morse Code was not used at first, but an alphabet specially created. Later, the Morse Code was used. Marine references are completely unaware of the Vail Code. Electric searchlights greatly increased the range of night signalling with lights, and in 1897 the slatted shutter on a searchlight was introduced in the Royal Navy by Capt. Percy Scott. It was known earlier in France. Searchlights were found useful even by day when well-aimed, and were used for secure communications in both world wars. The American Navy used the Ardois system with colored lights on a mast head. Red and white lights signified dots and dashes, respectively. Messages have been sent by reflecting a searchlight from a cloud, whose illumination by the searchlight beam is observed. In fact, this was the original intention of Captain Scott. Morse code was sent over light beams using a selenium photocell in the 1880's. It is notable that communication by interrupted light signals using an alphabet was introduced in emulation of telegraphic signals, not the reverse.

The first overwater radio communication took place in May 1897 between Lavernock in South Wales and Flat Holm island in the Bristol Channel. Marconi sent the famous "S" across the Atlantic from Poldhu in Cornwall to Newfoundland in 1901, using a frequency of about 330 kHz. By 1906 some Atlantic liners had radiotelegraph, and it had become rather common by 1912. The radiotelegraph was recognized as a great help to safety at sea when it saved many lives in the wreck of the liner *Republic* in 1903, and in a fire at sea in 1909, as well as in the well-known Titanic disaster of April 1912. CQ is an invitation for any station to respond, and CQD was a call for help from any source. CQD was used in 1909, and the Titanic sent both CQD and the new SOS, which was easier to remember and more distinctive. The first use of SOS seems to have been by S.S. Arapahoe in 1909, off Cape Hatteras. In the present International Code, C means 'yes,' and N means 'no.' K means 'over, go ahead, transmit' and J means 'I am on fire, and have dangerous cargo on board' (for example). The special groups AR. -.-., meaning 'out, end of message' and AS. -.-., meaning 'wait' are example of procedural signals, as is K itself. Each category of telegraphers developed its own abbreviations and procedural signals.

Comparison of Alphabetic Telegraph Codes

The table below allows easy comparison between the original Vail alphabet (after 1840, surely by 1844), the Austro-Germanic ("Prussian") alphabet for Morse instruments (1851), the present Continental Morse alphabet, and the Bain alphabet (1846). There were several revisions of the Bain alphabet, affecting as many as 19 of the characters. The Continental Morse code shown was in use by 1854, and is the same as the modern International Morse Code. The Prussian code is probably that agreed upon at the Vienna Conference of 1851, and was put together by Steinheil. Punctuation, operating signs, and special letters for German (umlauts, ch) are not shown. In the Morse code, the dash is 3 dots in length, the space between dots or dashes in a letter is one dot, the letter spacing is 3 dots, and the word spacing is 6 dots. In the Vail code, a space in a letter has the same duration as one dot (some say two dots), and the T,L and O are 2, 4 and 6 dots long, respectively. All of these codes were used with recording instruments, as well as with acoustic receivers.

It is quite clear that the Prussian and eventual Continental Morse Codes are based on the Vail Code, and the Prussian Code is an intermediate step. In this revision, the spaced letters C, O, Y, Z and R were eliminated. R received the previous code for F, C, less frequent in German than in English, received J's old code, and J, not necessary in German, was omitted. Y, an infrequent letter, received a new code including three dashes. Z received a strange new code, as did O, a popular letter. F received the Vail code for Q, and the less frequent letter Q was given a somewhat longer one. X's code went to the more common L, and X received Bain's code for it. P retained its five dots, since this was not yet used for the numeral 5. In fact, the numbers were the same as in Vail. Vail's numbers all consisted of 11 basic (dot) intervals, including --- for 5 and for 6. Codes for the umlaut vowels (ä -.-, ö ---, ü ---), as well as the common combination ch (---), also entered the code at this time.

The next step was to take over the numerals from the Bain code (which might have been suggested by Baumgartner). Numerals now consumed up to 19 dot times, considerably longer than in the Vail code. This meant that P had to have a new code, and the Vail for the numeral 1, now free, was used. The five-element code for O was probably replaced by the Bain code for H at that time. The old numeral 7 went to Z. This was, coincidentally, Steinheil's old code for the letter. The three dashes for O make it the longest of all the vowels. For use with French, Spanish and English, a J was necessary, and a rather long code was chosen. There are also codes for accented letters, such as é (-.-), as well as for ñ (-.-). Already by 1869 there was a long list of special codes for punctuation and procedural signals. The joined AS (-.-) was used for 'wait' even at this early date. The process just described seems plausible, but it would be good if it could be confirmed by documented evidence.

At the American Telegraph Convention of 1854, there was some talk of altering the Morse alphabet, to eliminate the spaced letters C O R Y Z. The Bain alphabet was proposed for adoption by the New York, Albany and Buffalo company for the Morse services, but rank-and-file opposition arose. No change appears to have been made. The characters for punctuation added to the American Morse Code are shown at the right.

.....	&	
....	0	....
....	italics	....
....	¶	
?		

Some procedural signals used in America by 1860 are the following: OK, all correct (Oil Korrekt, 1840); GA go ahead; GM good morning; GN good night; R repeat, please; SSS finished; 1 wait; 13 do you understand?; 31 I do not understand; 23 message for all, usually announcing accident or death, 73 good wishes or compliments. The large numbers of

special signals used in various places were becoming reduced and standardized by 1860. A message was said to be "bulled" if it was received incorrectly, as by a sticky sounder. Some United Press reports included characters giving formatting information.

Letter	Vail	Prussian	Morse	Bain	Letter	Vail	Prussian	Morse	Bain
A	.-	.-	.-	.-	S	...	...	...	..
B	...-	...-	...-	..-	T	-	-	-	..-
C	..	..-	..-	..	U	..-	..-	..-	....
D	..	..	..	...-	V	...-	...-	...-	...-
E	.	.	.	..	W	..-	..-	..-	...-
F	.-	..-	..-	..-	X	.-	..-	..-	..-
G	..	..	..	..-	Y	..	..-	..-	..-
H				---	Z	...-	...-	...-	...-
I	..	..	..	...	1	..-	..-	..-	..-
J	..-	absent	..-	..-	2	..-	..-	..-	..-
K	.-	.-	.-	..-	3	...-	...-	...-	...-
L	---	..-	..-	..	4	-	-	-	-
M	--	--	--	..-	5	----	----	----	----
N	..	..	..	..-	6	.....	.....	.....	.....
O	...	...	---	...	7	----	----	----	----
P			..-	..-	8	-	-	-	-
Q	..-	..-	..-	..-	9	..-	..-	..-	..-
R	..	.-	.-	-	0	---	---	---	---

Outstanding Questions

Suggested answers are in square brackets, where there is any hint.

- 1. What code was used on the Atlantic telegraph with the galvanometer receivers? [the Continental Morse with opposite deflections]
- 2. When was the Morse Code adopted for the single-needle telegraph in Britain? [between 1864 and 1878, closer to the latter]
- 3. When was the Morse Code adopted for maritime purposes, in the International Code of Signals? [as late as 1900, with the introduction of radiotelegraphy]
- 4. Are there some good early descriptions of the telegraph in German?

American Manufacturers of Telegraph Equipment in 1870

From advertisements in the D. Van Nostrand edition of Frank Pope's book. There were, of course, others. Western Union had a manufacturing site, originally Phelps and Dickerman in Troy, later moved to New York, of which G. M. Phelps was long the manager.

- 1. Charles T. and J. N. Chester, 104 Centre St., New York
- 2. Chester, Partrick & Co., 37 S. Fourth St., Philadelphia
- 3. L. G. Tillotson & Co., 8 Dey St., New York
- 4. Bliss, Tillotson & Co., 171 S. Clark St., Chicago
- 5. Charles Williams, Jr., 109 Court St., Boston
- 6. Dr L. Bradley, 7 Exchange Place, Jersey City

The Chester firms also supplied a portable nitroglycerin-making apparatus.

Telegraph Relics in the Science Museum, London

A few interesting relics are on public display here, so a brief list of them might be useful because of the accessibility of this museum. The Science Museum is in transition from a place of learning and wonder to a place of fun, so one wonders how much longer even these items will remain. The Synopsis display on the ground floor mezzanine should not be missed; it is fairly well organized and tells a story, unlike most exhibits. A Post Office sounder, clearly identified as P.O. 2062, is beside a strange two-needle telegraph with an uncommon code. It is not the usual two-needle instrument. Its name and source are not given, which is characteristic (it could be a Henley and Forster from the Magnetic Telegraph Company). There is a Baudot keyboard and distributor (multiplexer). The other relics are in the Telecommunications section on the first floor. At the entrance to this section is a Wheatstone automatic transmitter, and a presentation relating to the Atlantic Cable. The ship picture labelled "Great Eastern" is certainly not this ship; it appears to be the stern of a first- or second-rater sailing warship. It cannot even be the U.S.S. Niagara, which helped lay the first cable. It could possibly be H.M.S. Agamemnon.

Most of the exhibits are way in the back of the area, around to the right in a corner. Here are a Hughes printing telegraph, a Wheatstone ABC, a Bain receiver with a paper tape, a Wheatstone perforator, transmitter and receiver, and a Vibroplex key. There are photographs of Morse and Vail. Vail is described as an art student of Morse's, which, of course, he was not. A great deal of ignorance may be suspected in the preparer of this exhibit. There is a machine labeled a Morse telegraph of 1835, which is indeed a pendulum device, but it is certainly not an original (among other things, the date is too early). There is a register of 1846, which is also probably a replica (but an accurate one). Replicas are created in all good faith, but after the passage of years they become confused with true relics. The Morse Code in the later form is displayed, not the original Vail code, and the ridiculous "transmitting plate" is shown as well. There is an excellent two-needle telegraph from the Electric Telegraph Company, said to be from 1846 because of the date printed on the dial. The date is the date of foundation of the company, not the date of manufacture of the instrument. There is a two-needle instrument from 1843 (it is claimed). There is no explanation of the small box on top of the instrument, which was where the alarm bell was located, or even the slightest indication of how it was used. A Cooke and Wheatstone single-needle instrument, also in excellent condition, has the date 1837 on the dial, which, of course, is the date of the Patent.

Among the things absent from the exhibits, which are all static ones, is any appreciation of the earth return, or of the electromagnet, or power supply, or any description of how any of the instruments worked. All speeds of transmission are given as "30 words per minute" in several different contexts, when it would have been easy to compare the hand key, the Vibroplex, and the Wheatstone automatic, for example, or give the capacities of operators of different degrees of skill. There was no capsule history of the Electric Telegraph Company or the Post Office Telegraphs, and no appreciation of historical time. There was no motion or sound in any part. The application of the telegraph to railways was nearly totally absent, except for mentioning that the Admiralty used the telegraph beside the London and South Western Railway from London to Gosport, and a few largely erroneous comments here and there. It was stated, for example, that unskilled operators could send "stop" and "go on" with the two-needle telegraph. These messages were not on the dial, and the two-needle was never used in this way.

My general impression was that someone has gone through the museum eliminating any reference to electricity and magnetism, or to Faraday and Maxwell (their portraits are there, but little else). Mathematics receives equally short shrift. There is a Chemical Industry section (but no Chemistry section) where the young visitors get the most pleasure from banging their feet on the metal floors. In fact, this is a most curious museum in which most of the visitors seem to regard the exhibits not at all!

Acknowledgements

I wish to thank Mr Paul Bock, whose comments led me to make the initial investigation, which has corrected my earlier wrong and fuzzy ideas.

Most of the references were generously made available to me by the British Library, St. Pancras, London, to whom I am deeply grateful. I am also indebted to the Exeter University Library, the Devon Library Services, especially the Railway Collection in Newton Abbot, the University of Illinois library at Urbana, and the University of Denver Penrose Library.

References

For a good course in the American telegraph, I recommend reading Vail (1845), Shaffner (1859), J. D. Reid (1886), and Thompson (1947), as well as Pope (1870) for technical matters. Reid is perhaps the most important of these sources.

The references in this list have been seen by me in their original editions, or else as quoted in full elsewhere (except as noted). Many include excellent cuts and line drawings, that I am not able to include here, unfortunately. This list includes all references made in the works I have seen. It is not intended to be an exhaustive bibliography of telegraph engineering, but is becoming moderately complete, concentrating on early sources and technical matters, omitting later secondary works. Additional references scattered through the text were taken from quotations in the original sources, and mostly have not yet been consulted. The references are given in chronological order. If the date is unknown, a reference precedes works in which it is referenced. I would appreciate knowing where to find works listed as "not yet located," which are mainly in German or French.

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2. A. Vail, *Description of the American Electro Magnetic Telegraph: now in operation between the cities of Washington and Baltimore* (Washington: J. & G. S. Gideon, 1845). The alphabet is presented on pp. 19-24.
3. C. V. Walker, *Electric Telegraph Manipulation* (London: Knight and Sons, 1850). The best reference for the way the double-needle was used.
4. D. Davis, Jr *Book of the Telegraph* (Boston: Daniel Davis, 1851). History and description of instruments, with cuts. The history shows that people already realized the Morse claims were excessive.
5. E. Highton, *The Electric Telegraph, Its History and Progress* (London: John Weale, 1852).
6. A. Jones, *The Electric Telegraph* (New York: G. P. Putnam, 1852). Excellent coverage of the legal maneuverings of the Morse Patentees. Morse, Bain and House systems explained. Unusually, quotes sources whenever possible. Lardner's source for American information. Uses the spelling O'Reilly.
7. L.-F.-C. Bréguet, *Manuel de Télégraphie Électrique* (Paris: 1852). Not yet located.
8. K. A. Steinheil, *Instruction für die Telegraphisten der Schweiz, u.s.w.* (Bern, 1852). Not yet located.
9. Schellen, *Das electro-magnetische Telegraph* (?) Not yet located.
10. E. E. Blavier, *Cours Théorique et Pratique de Télégraphie Électrique* (Paris: Lacroix et Baudry, ?). Not yet located.
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13. D. Lardner, *The Museum of Science and Art* (London: Walton & Maberley, 1854). Volumes III and IV. The Vail Morse Code is given on p. 42 of Chap. VII in Vol. IV. This encyclopedic popularization of technology may include the same information as the following reference.
14. D. Lardner, *The Electric Telegraph Popularised* (London: Walton & Maberley, 1855). Part of "Lardner's Museum of Science."
15. Rev. E. E. Hale, *The Dot and Line Alphabet*, Atlantic Monthly, October 1858.
16. T. P. Shaffner, *The Telegraph Manual, a Complete History and Description of the Semaphoric, Electric and Magnetic Telegraphs of Europe, Asia, Africa and America* (New York: Putney and Russell, 1859). Shaffner constructed the line between Louisville and New Orleans, and promoted a telegraph to Europe via the Bering Straits. He travelled widely in Europe, meeting Steinheil among others, whose contributions he mentions at length. The "American Morse" alphabet is on p. 469, the "Austro-Germanic" alphabet of 1854 is on p. 472, and the "European Morse" as of 1859 on p. 474. Shaffner also gives the Steinheil, Chappe, Bain, English one- and two-needle, and Russian alphabets. Biographical information on American telegraph pioneers, most still living at the time, is included.
17. J. von Hamel, *Historical Account of the Introduction of the Galvanic and Electro-Magnetic Telegraphs* (1859).
18. G. B. Prescott, *History, Theory and Practice of the Electric Telegraph* (Boston: Ticknor and Fields, 1860)
19. J. Gavarret, *Télégraphie Électrique* (Paris: Masson et Fils, 1861)
20. R. S. Culley, *A Handbook of Practical Telegraphy*, 1st ed. (London: Longmans, et. al., 1863). There are 8 editions of this work, the last in 1885. Culley was Engineer-in-Chief to the British Post Office. Telegraph alphabets are not shown, but in 1871 he says that the new Morse code was then used in Europe, Asia and Australia, and the acoustic telegraph in America and India.
21. W. H. Preece, "On Railway Telegraphs" in Min. Proc. Inst. Civ. Eng. (London) 13 January 1863.
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23. W. H. Russell, *The Atlantic Cable* (London: 1865)
24. M. Max Freiherr von Weber, *Das Telegraphen- und Signalwesen der Eisenbahnen* (Weimar: 1867)
25. R. Sabine, *The History and Progress of the Electric Telegraph*, 2nd ed. (London: Virtue & Co., 1869)
26. F. L. Pope, *Modern Practice of the Electric Telegraph*, 3rd ed. (New York: D. Van Nostrand and Co., 1870). Excellent technical book, well illustrated and teaching how to send and receive, but with little history. The best reference for American practice.
27. *Rules and Regulations*, Great Western Railway Telegraph Department, November 1878.
28. J. D. Reid, *The Telegraph in America and Morse Memorial* (New York: Derby Bros., 1879 and John Polhemus, 1886). The Morse part is unadulterated hagiography. The company histories are better, since Reid was a witness to most of the events and knew the men. Reid was a Rochester man who started with O'Reilly and ended up with Western Union. There is considerable technical information scattered through the book, which is not often mentioned by later authors. It should be remembered that "Prof. Morse's account of his invention" was written 30 years after the fact, and the other historical information is selectively taken from trial evidence. Vail is mentioned as a financial supporter, but the admission that "Mr Alfred Vail took charge of the machinery" says a lot. On p. 88 it is definitely stated that the register of 1838 and thereafter is due to Vail. Vail is belittled by Morse with faint praise: "...Mr Vail had invented an ingenious machine for receiving and distributing type, which, however, proved of no practical use. Dr Gale claims that Mr Vail was the first to read messages by sound." [p. 65] "Mr Vail had designed a plan, not stated, which Professor Morse at first approved, but which, on consultation with Prof. Henry, he rejected." [p. 103] There is, however, information on Morse's port-rule and pen-lever device, never reduced to practice, which is interesting. Reid uses the spelling O'Reilly. There is no index, which is very unfortunate considering the company-by-company method of presentation. This is an indispensable reference for American telegraphs.
29. W. R. Plum, *The Military Telegraph During the Civil War in the United States* (Chicago: Jansen, McClurg & Co., 1882). A theatre-by-theatre account of operations, with rather little technical information, but an extremely interesting account of how the telegraph was used at this time. The history isn't bad, but he repeats the Wheatstone-Cooke London to Birmingham error, and never mentions Vail.
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38. W. K. Towers, *Masters of Space* (New York: Harper & Bros., 1917). A well-written and generally accurate popular account, but completely without bibliography or references. Neglects European developments almost completely, making telecommunications an Anglo-American, and mostly American at that, affair (Marconi was half-Irish, so this explains him). Mentions many now-obscure technologies, such as conductive, inductive and light-wave experiments of the 1880's. Good account of radiotelegraphy and radiotelephony, but without technical details. His assessment of Alfred Vail is similar to mine, perhaps even more favorable.
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40. R. Appleyard, *Pioneers of Electrical Communication* (London: Macmillan, 1930).
41. A. F. Harlow, *Old Wires and New Waves* (New York: Appleton-Century, 1936).
42. *Dictionary of American Biography* (New York: Scribner's, 1936), v. 19, art. Alfred Vail, and vol. 13, art. Samuel Finley Breese Morse.
43. M. MacLaren, *The Rise of the Electrical Industry During the Nineteenth Century* (Princeton, NJ: Princeton University Press, 1943), Chapter II. A typical nontechnical short account, well-meaning but with often incorrect and misleading scraps of information. Alfred Vail is mentioned only as a financial contributor, Bain and House are not mentioned, but the Hughes telegraph, never used in the United States, is. The Morse register is said to have been devised for the benefit of those who could not read by sound. Steinheil is absent, and Wheatstone's needle telegraph is confused with his ABC telegraph.

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46. C. Singer, E. J. Holmyard, A. R. Hall and T. I. Williams, *A History of Technology* (Oxford: The Clarendon Press, 1958), Vol. IV, Sec. 22, pp. 645-662, article Telegraphy by G. R. M. Garratt. Plate 47 shows a Morse 1835 telegraph; this may be a reconstruction. An 1846 register is also shown.
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48. A. F. Harlow, *Brass Pounders* (Denver, CO: Sage Books, 1962). Excellent popular history of the United States Military Telegraph Corps. The story of Jackson's capture of B&O; equipment at Harper's Ferry is mainly a tall tale. He did capture equipment, but there was no elaborate plot.
49. E. A. Marland, *Early Electrical Communications* (London: Abelard-Schumann, 1964). Mainly British and American developments, with good accounts of the invention of the telegraph, including Edward Davy's telegraph of 1838.
50. Geoffrey Hubbard, *Cooke and Wheatstone and the Invention of the Electric Telegraph* (London: Routledge & Kegan Paul, 1965). Describes the early installations on the London & Birmingham, Blackwall, and Great Western. Notes: Christie, inventor of the Wheatstone Bridge for measuring resistance, himself asked that it be given that name to honour Wheatstone, at the Royal Society. Wheatstone was one of the first English-speaking people to understand Ohm's Law and resistance. Morse's middle name was Breese, not Breeze. The telegraph relics said to be on display at the Science Museum no longer are.
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