"What Hath God Wrought?"

How the Telegraph and the Telephone Formed a Worldwide Wired Electromagnetic Environment

by Ian Baldwin

INTRODUCTION

Alessandro Volta's invention of the electro-chemical battery in 1800 launched new and revolutionary investigations of the phenomenon of electricity. Used almost exclusively in research laboratories for thirty years, early 19th century European and US scientists discovered that electricity and magnetism were somehow coupled and could be put to work. By 1825, scientists knew that a battery-powered electric current traveling in a wire wrapped tightly in a coil around an iron bar would magnetize the iron, enabling it to move pieces of metal and even lift heavy weights. By 1832, Michael Faraday and Joseph Henry had independently discovered that a magnet moving in a solenoid, or coil of wire, would *induce* a current in the wire and produce an electromotive force. With the discovery of induction, a new and technologically revolutionary era was born.

The electromagnetic telegraph was the first practical result of this new era. Its impact was perhaps comparable to Guttenberg's invention of the printing press four centuries earlier. In the mid-1840s the telegraph, followed a generation later by the telephone, started a long and still unfolding process of continuous creation of new forms of instant communication, a process we take for granted, but unprecedented when it began. Within scant decades, the first telecommunications industries had utilized millions of miles of electric wire that crossed all continents except Antarctica, as well as the world's oceans and sea floors, "belting" the world with electromagnetic "lines of force" and becoming ubiquitous wherever humans lived. As they penetrated society, telegraphy and telephony powerfully shaped a new and increasingly urgent value – speed. The telegraph and telephone not only profoundly altered human relations on a global scale, but also launched a long, ongoing process of altering Earth's natural electromagnetic environment. Starting in the late 1870s, the alteration of the electromagnetic environment was also significantly intensified by the emerging electric light and power industries whose lines, radiating even more powerful electromagnetic force, competed for space with the more established lines of existing 19th century telecommunications industries.

In part because electromagnetism is invisible, the pervasive environmental transformation it has brought about is little understood, even today.

How did these momentous developments begin?

INVENTING THE TELEGRAPH

Historian of telegraphy J B Calvert tells us, "Practical electromagnetic telegraphy arose in Germany, England and the United States at about the same time and more or less simultaneously" in the late 1830s and 40s and "rested on a common foundation of technical knowledge" [1]. Within a year of the publication of Faraday's first seminal paper on induction, two eminent German scientists, Karl Friedrich Gauss and Wilhelm Weber, had set up "the first operational telegraph line." The simple network ran a distance of a kilometer on the University of Göttingen campus. Instead of a battery, the two scientists relied on “a generator using the phenomenon of induction discovered in 1831 by Faraday” [2].

Too busy to develop their make-and-break-circuit-driven electromagnetic prototype commercially, in 1835 Gauss and Weber enlisted the help of a former student, Karl August Steinheil at the University of Munich, to make a practical telegraph. During his work on the project in 1837, Steinheil discovered the “earth return,” which made telegraph “lines half as expensive to build,” because they could use a wireless ground or earth return to complete long telegraphic circuits and thereby also “reduced their resistance and leakage by half.” The following year, in 1838, Steinheil “established an experimental train control telegraph on the Munich–Naunhof line, that reported progress of trains along the line” [3].

In 1836, a young English entrepreneur, William Fothergill Cooke, attended a demonstration of Gauss and Weber’s telegraph at a University of Heidelberg lecture. Cooke was “struck with the wonderful power of electricity and strongly impressed with its applicability to the practical transmission of telegraphic intelligence” and returned home determined to work on the invention [4]. He sought scientific help from one of Faraday’s colleagues, the physicist Charles Wheatstone. Wheatstone was well aware of the telegraphic potential of Joseph Henry’s electromagnets. (In fact, Henry visited Wheatstone in 1837 and shared his ideas for an electromagnetic relay that would make possible long-distance telegraphy.) Cooke and Wheatstone teamed up to create and patent the needle telegraph, based on the use of galvanometer needles that were in effect pointers, activated and deactivated by the making and breaking of the electromagnetic circuit to which they were attached, and arrayed in a diamond-shaped, five-needle telecommunications apparatus.

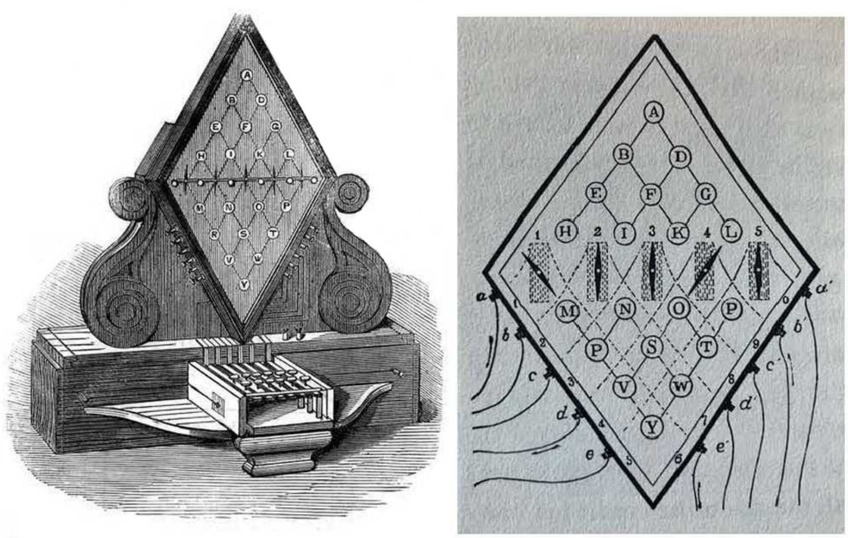

Figure 1: Cooke and Wheatstone’s five-needle telegraph (1839). Each needle could be shifted electromagnetically to the right or left. By moving two needles a letter could be pointed to, and letter-by-letter, words spelled out. Cooke and Wheatstone’s needle telegraph was constantly improved after its introduction in 1837 in London, where it found its first use in the British Railway system. By the early 1850s it was used throughout the British Empire. SOURCES: Left image: https://www.sciencephoto.com/media/997675/view/william-cooke-and-charles-wheatstone-s-five-

needle-telegraph; Right image: https://www.alamy.com/stock-photo-diagram-of-cooke-and-wheatstones-five-needle-telegraph-patented-1837-57309816.html

In 1832, a New York University art professor, Samuel Morse, returned from a museum tour of Europe inspired by a demonstration of electromagnets he had witnessed at a lecture in Paris. Morse "considered the possibility of using the clicking of an electromagnet to send numbers in the same way as a church bell" chimes to indicate time. He had "sketched out a way to record incoming signals on paper automatically, by marking a paper tape with the moving pencil controlled by an electromagnet" – a prototype of what became the Morse receiver [5]. When he bogged down with his scientifically uninformed attempts to create a long-distance telegraph, Morse turned for help to an NYU colleague, Leonard Gale, a chemistry professor and friend of Joseph Henry. Gale showed Morse how Henry's "intensity" and "quantity" magnets and batteries worked: the high-voltage, low-current intensity battery "pushed" the current along over long distances, and the low-voltage, high-current quantity battery operated the receiver's electromagnet.

By spring 1838, Morse, determined to create the world's first global telegraphic system, was on Henry's doorstep asking the master's advice, and for the next few years they communicated directly with each other.

Henry had, in fact, already invented the telegraph [6] and referred to it as "a philosophical toy," that is, an item solely of scientific curiosity. Before he had rung bells in his Princeton classroom in 1832, he had placed "something resembling a small clickable castanet, like a little metal tongue," next to an electromagnet. He turned on battery current and "powered up" the electromagnet which then "pulled the castanet toward itself," making a "click." "Turn off the battery and the electromagnet let go," making a weaker click – the equivalents of Morse and Vail's later dots and dashes, and eventually the "sounder," employed from the mid-1850s on when audible signals gradually all but replaced mechanically inscribed code. Henry understood "it would be easy to communicate just by agreeing that different arrangements of clicks would represent different letters" [7]. For Henry the scientific demonstration alone was sufficient.

Not for Morse. Driven by entrepreneurial ambition and vision, Morse was talking to the right man, even taking the precaution to surreptitiously patent some of Henry's ideas about telegraphy in 1838. Meantime Alfred Vail, a young inventor and Morse supporter, was helping him design both a code and a receiver or "register" that was "not a galvanometer or a magnetized needle, which European [British] telegraphs were employing, but a magnet operating a moveable armature which made rapid signaling and audible reception possible" [8].

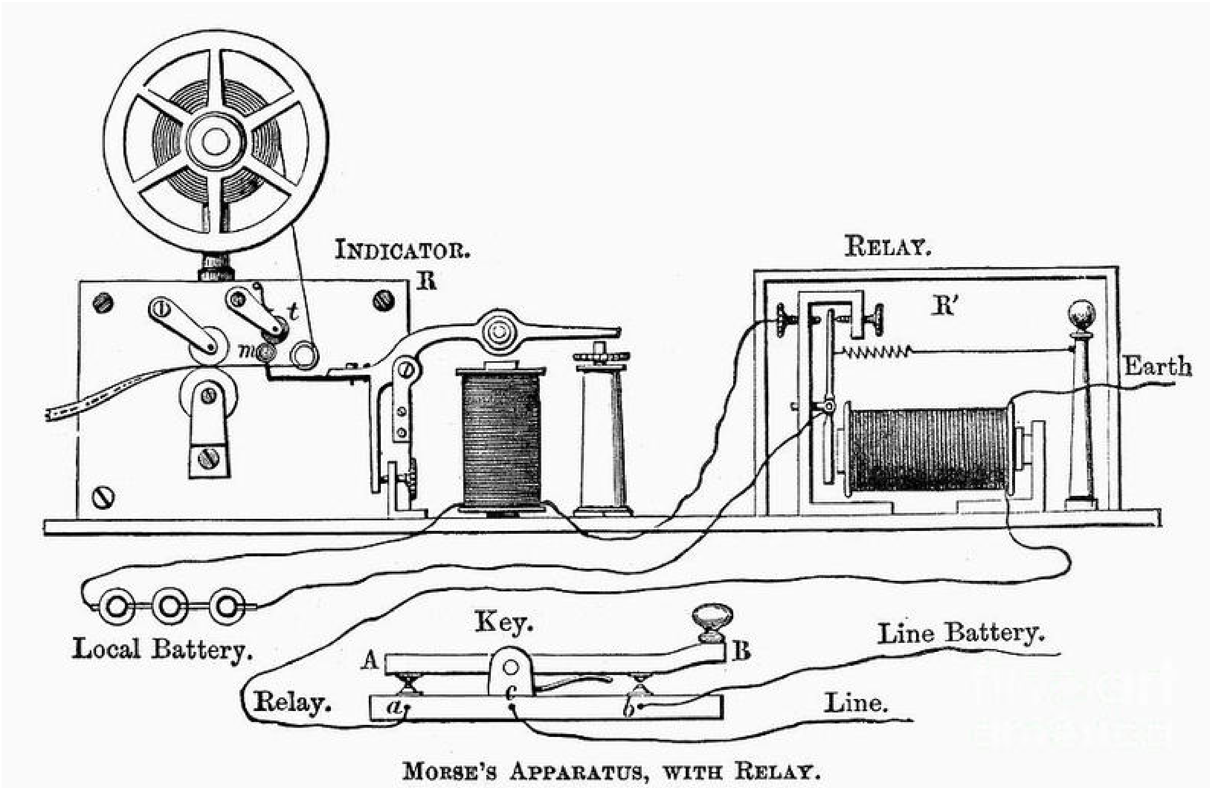

Figure 2: The Morse Telegraph System. The Key is the message transmitter that makes and breaks the circuit that sends the code signals via wire to the Relay, where the current is reinforced and retransmitted to the Indicator (the register, or receiver), activating an electromagnet that then attracts (draws down) the armature causing a mark to be made by a stylus that recorded the Morse code symbols – dots and dashes in various combinations comprising the letters of the alphabet – on the paper tape. The register was later replaced by the sounder. Not shown are the line and poles needed to connect the key to the relay, and the relay to the indicator or register, as well as the batteries needed to power the current's source at the key. SOURCE : https://kimon.hosting.nyu.edu/physical-electrical-digital/items/show/1096

In 1840, the year Morse patented his telegraph system in the US, the telegraph received a much-needed boost in publicity. It came from England, where the news of the birth of Queen Victoria's second son immediately reached the *Times*, enabling the paper to be "on the streets of London with the news within forty minutes" thanks to the Cooke-Wheatstone telegraph. The venerable paper declared itself "'indebted to the extraordinary power of the Electro-Magnetic Telegraph'" and the whole episode "enabled the fame of the telegraph" to take "a giant leap" forward [9].

After years of effort to gain Congressional funding for a demonstration, Morse and Vail were finally funded by Congress to run a 44-mile line between Baltimore and Washington, DC. On May 24, 1844, they successfully transmitted their legendary message: "WHAT HATH GOD WROUGHT."

The conflation of God and man was typical of the era.

THE WIRING OF THE WORLD BEGINS

The telegraph "spread with astonishing speed after its celebrated commercial introduction around 1845," taking off "more rapidly than today's Internet" [10]. Within a year of the Baltimore and Washington, DC, telegraph line's completion, lines were under construction connecting New York, Philadelphia, and Boston. From there, lines went north to Portland, Maine, and west to Buffalo. In 1847 Buffalo was connected to Toronto and Montreal, and from there, to Quebec City. That same year lines reached several Ohio cities, and by year's end, East St. Louis on the banks of the Mississippi. In 1848 the northern lines were connected southward to Charleston, South Carolina, and westward through Detroit to Chicago. By the end of the year Washington, DC, was connected to New Orleans. In 1852-3 telegraph lines strung on high poles crossed the Mississippi River to St. Louis. By the mid-1850s, California and Oregon were building their own systems and in 1859 work began to complete a national system that crossed the forbidding terrain of the Continental Divide and finally reached San Francisco at the outset of the US Civil War in 1861, eight years ahead of the transcontinental railroad.

In 1841 it took 110 days for the news of President Benjamin Harrison's death to reach Los Angeles. Twenty years later the news would cross 3,000 miles in seconds, and in hours be printed in newspapers for mass consumption.

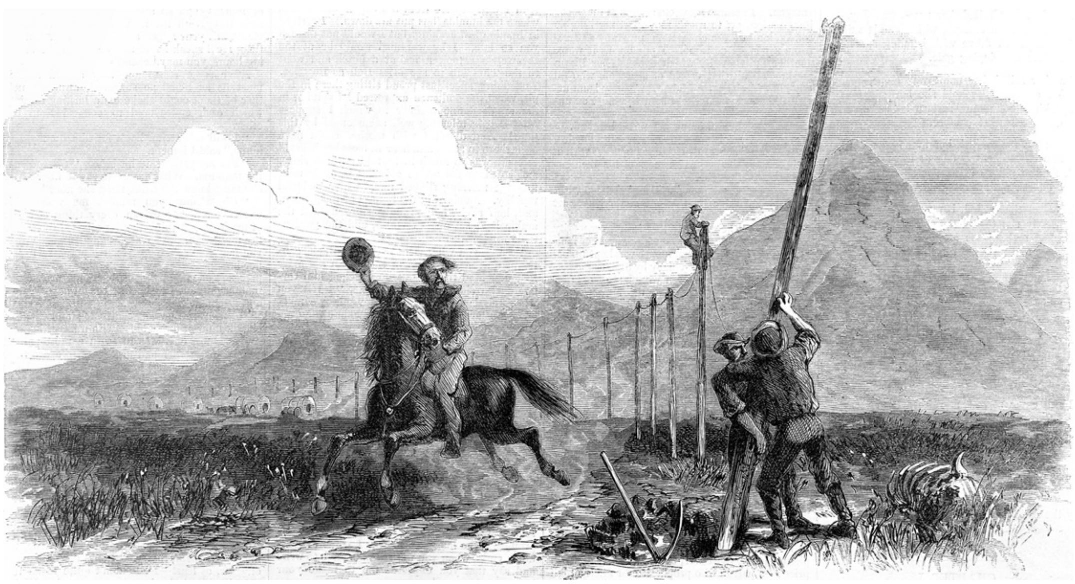

Figure 3: In April 1860, the Pony Express began operations from St. Joseph, Missouri, to carry the mail (and the news) as fast as possible westward to San Francisco. Construction of the western continental telegraphic lines – some 27,500 poles holding up 2,000 miles of single strand wire – was so rapid that by October 1861 the Pony Express closed its storied business, which lasted no more than a year and a half. The "two oceans were suddenly united," even as the American people were decidedly not. In October, California's Chief Justice sent the first transcontinental telegraph to President Lincoln, expressing loyalty to the Union. SOURCE: https://en.wikipedia.org/wiki/Timeline_of_North_American_telegraphy#/media/File:The_Overland_Pony_Express.jpg

In the early-to-mid-1840s, London was connected to the strategic naval port of Portsmouth, and soon thereafter to England's industrial heartland in Manchester, Birmingham, and Liverpool. By then the discovery of gutta percha, recognized as a natural waterproof insulator superior to rubber (which broke down when continuously submerged in water), enabled the first submarine cables to connect cities separated by bodies of water. In 1851 the world's first international submarine cable was laid from Dover to Calais, connecting London and Paris. That year the German-Austrian Telegraph Union adopted the Morse system, using Friedrich Clemens Gerke's international version of the Morse code, after which the Morse telegraph spread rapidly in continental Europe.

"By 1850, there were 2,215 miles of wire in Britain," [11] and on the eve of the new technology's take-off that year "telegraph lines were under construction on every continent except Antarctica" [12]. In the US 25,000 miles of wire were strung by 1851, and by 1855 "the telegraph network was ubiquitous in the east." By the 1870s the "telegraph and the railroad, working together created a single integrated market for the entire nation east of the Mississippi River" [13]. During the four-year US Civil War, the two opposed armies strung up an additional 15,000 miles of electric wire for command-and-control military communications.

Charles Dickens reported in 1859 that "the agents of the London District Telegraph Company persuaded nearly three thousand five hundred property owners to lend their rooftops as resting places for the two hundred and eighty miles of wires that were crisscrossing all of London, and that were shortly to drop into the shops of grocers, chemists [pharmacies], and tavern-keepers all over the city." Within a decade, an additional "two thousand five hundred miles of cable," each holding up to a hundred wires, had been strung "over the heads and under the feet of Londoners" [14].

POSITIVE FACT, OF COURSE.
A Message comes off on Mrs. Bluebag's Linen, which she is Hanging, as usual, on the Telegraph Wires.

Figure 4: 19th century Punch magazine cartoon depicting the arrival of telegraph lines over London rooftops. SOURCE : https://punch.photoshelter.com/gallery-image/John-Leech-Cartoons/G0000Cba0BhAM_Ks/I0000p3p2pw7HD7s

As London went, so went the world, and in cities everywhere “forests of overhead wires tangled their way between housetops, church steeples, and chimneys, to which they attached themselves like vines. And from those vines hung electric fields that blanketed the streets and byways” below [15]. The electric fields “beneath these earliest telegraph wires were,” researcher Arthur Firstenberg estimates, “up to 30,000 times stronger than the natural electric field of the earth at that frequency.” Firstenberg also calculates “that the magnetic field from a single early telegraph wire would have exceeded the earth’s natural magnetic field at that frequency for a distance of two to twelve miles on either side of the line” [16].

To the terrestrial land-line mazes was soon added the explosive growth of submarine cables. The abortive first transatlantic cable laid between Ireland and Newfoundland in 1858 had been celebrated by a contemporary source “‘as the greatest event in the present century … the whole earth will be belted with electric current, palpitating with human thoughts and emotions. It shows that nothing is impossible to man’” [17]. Due to scientific and technical misconceptions, the cable soon failed to function. Eight years later, in 1866, the first successful transoceanic cable was finally and dependably laid, thanks largely to the oversight of England’s foremost physicist, William Thomson.

Thomson was “one of the few thinkers then taking Faraday’s vision seriously,” meaning Faraday’s concept of “invisible force fields” that filled all of space, and when activated by a battery, mysteriously “pushed the current forward” in a wire. “The ‘sparks’ (the electrons) that tumbled along inside a wire didn’t move by their own power but were transported as though by an invisible flying carpet…the invisible force field” [18]. (Electrons were not discovered until 1897. Before then, some electricians believed indissoluble atoms were the smallest units that constituted an electric current, manifest as sparks.) Thomson believed a force field emerged from a battery and “would travel partly within but also alongside any wire stretching ahead of it” and – here is where he departed from conventional electrical knowledge – the field “would take up position along the whole length of the wire, very quickly [at the speed of light], and then it would reach in and pull forward any charged particles … it found near its path.” To Thomson, as to Faraday before him, the force field was “almost a living thing, constantly writhing and twisting” as it bore its “incredible pulling power” along the course of a conducting wire [19].

It was because of his respect for the invisible force field that Thomson succeeded in one of the most significant and difficult engineering projects of the century, a transatlantic cable that permitted instantaneous intercontinental communication. “Thomson didn’t know what exactly was inside the copper core [wire] … but he did know that whatever carried the electric current there was almost ineffably light in weight, so much so that the finest jeweler’s balance scales couldn’t detect it” [20]. And so, unlike the electrician Edward Whitehouse, his predecessor, who had used greater and greater voltages in the botched attempt to bridge the ocean span in 1858, shorting out the line, Thomson used relatively little power to send Morse’s coded messages 2000 miles beneath the sea.

Thomson’s method worked. The 1866 transatlantic cable “was hailed as ‘the most wonderful achievement of our civilization’” [21]. Two years later Malta was connected to Alexandria beneath the Mediterranean Sea and “[n]ew cables were being laid all over the world ... Cables reached India, Hong Kong, China, and Japan in 1870; Australia was connected in 1871, and South America in 1874” [22]. Within 30 years of Morse and Vail’s first long-distance telegraph between Baltimore and Washington, DC, “there were over 650,000 miles of wire, 30,000 miles of submarine cable, and 20,000 towns and villages were on line.” By 1880, “there were almost 100,000 miles of undersea telegraph cable” [23].

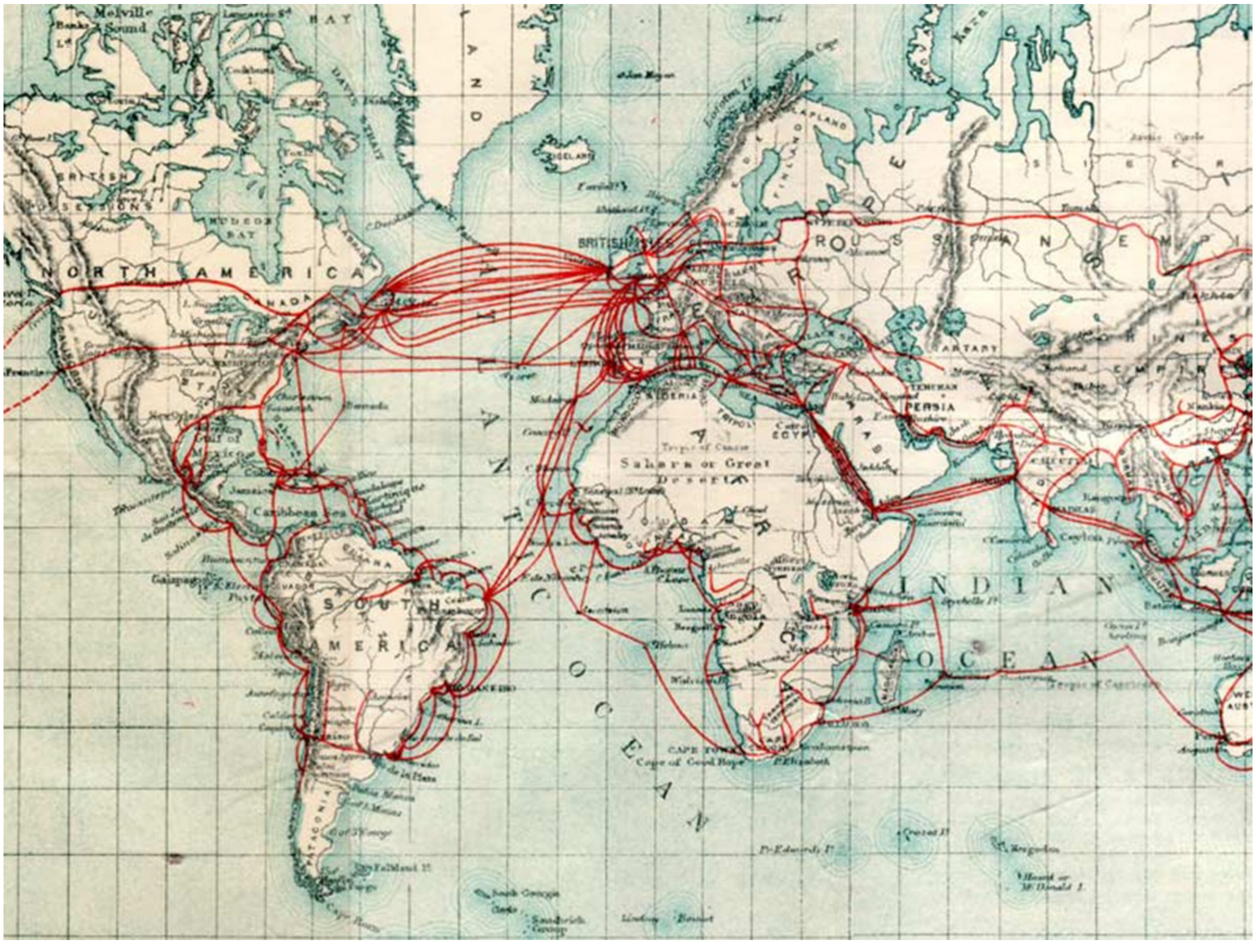

Figure 5: The Eastern Telegraph Company's submarine telegraph system, 1901. The British conglomerate's easternmost routes in Asia are not pictured here, nor are competing telegraph companies' lines. Transpacific ocean cables, laid first by the United States after the Spanish American War in 1898, were not completed until 1903, comprising 7,613 miles of cable to link San Francisco, Honolulu, Guam, and Manila. Manila was then linked to Shanghai and elsewhere in East Asia. SOURCE: https://www.wired.com/wp-content/uploads/2015/10/1901EasternTelegraph-crop-1024x768.jpg

By century's end, Earth had indeed been "belted with electric current."

At the outset of the telegraphy revolution the world was, as it had been for centuries prior to the mid-19th century, profoundly localized. Instantaneous communication, which inherently lessens the significance of local space, had begun to erode human identification with specific locales in favor of a purely cosmopolitan or more global outlook. Yet even such cosmopolitan centers as Paris, London, and New York were island societies at the start of the telegraphic revolution. Each city had its own time zone, according to its longitude. "Noon arrived a few minutes later in Baltimore than it did in New York," and each city "was a separate world." By the end of the 1870s "those [separate] worlds could be synchronized and, wherever you were, you knew where you fit in the tight, universal 'control' of clocked time" [24].

By the early 1870s, the telegraph's vast and expensive infrastructure was being challenged by mounting traffic demand. Charles Wheatstone's "electric Jacquard" or automatic telegraph used a perforated tape that reduced transcription errors and speeded up transmission. In the 1870s, the automation of the telegraph began to grow, having started with Wheatstone's invention; in 1871 the duplex doubled the traffic capacity of a line; in 1874 Thomas Edison's quadruplex doubled capacity again. These developments accelerated the growth of online traffic and "meant that current flowed at all times" so that electricity became a constant "presence in the average urban dweller's life" [25].

In this intensifying climate, merchants and bankers, statesmen and diplomats, generals and admirals, newspaper editors and reporters, among others, became effectively addicted to continuous information updates, updates that forced businessmen, in particular, to "be continually on the jump" [26].

Despite the growing societal addiction to telecommunication speed, no one was ready for the next wired-technology revolution, which not only allowed instantaneous two-way information exchanges but carried instant telecommunications beyond business, commercial, and governmental users into private residences.

This revolution arrived on what, in retrospect, seemed like gossamer wings.

BELL'S INVENTION OF THE TELEPHONE

Early proponents for the telephone assumed "that discrete electrical pulses, not a continuous current, should be used to transmit information," as was done by the dominant telecommunications technology, telegraphy [27]. But early prototypes, such as Johann Philip Reis's telephone (1861), could not capture the whole, complex sounds of human speech using the telegraph's make-and-break circuits. The electrical community of scientists and technicians – collectively called "electricians" during the 19th century – had "pronounced the telephone an impossible thing" [28]. This false pronouncement was made because electricians possessed only "a slight grasp … of magnetic action and the interrelation of the magnetic field and the electric current" [29]. As Bell himself later confessed: "'Had I known more about electricity, and less about sound, I would never have invented the telephone'" [30].

Trained and employed to teach the deaf to speak, Bell had a secure understanding of speech as vibrating sound waves that varied along an almost infinite range of pitch or frequency. Sound waves compressed the air, traveling along in energetic kinetic pulses: they could be felt, as well as heard. Bell used vibrations to sensitize his deaf students to the world around them: "By clutching" a toy balloon "tightly against their chests, deaf children could feel the vibrations of surrounding sounds," such as the rumbling noises made by potentially perilous horse-driven carriages on cobblestone streets [31].

Within a year of his arrival in Boston in 1871 to teach the deaf to speak, Bell read about the Western Union Company's offer to pay "a hefty sum" to the inventor of a telegraph system that could transmit more than one message simultaneously over a wire. Before leaving England in 1870 Bell had already learned that "a sound's pitch relies on its frequency – how quickly it vibrates – and that everything has its own natural frequency" [32]. In London a distinguished linguist had exposed Bell to the great German physicist Hermann von Helmholtz's "Sound Synthesizer," an instrument that used electromagnetism to keep tuning forks humming so that they "blended the tones…together to produce the complex quality of the human voice" with its undertones and overtones [33]. From Helmholtz Bell learned, early on, about electromagnetism's relationship to sound.

By 1874, Bell had developed his idea of a "harmonic telegraph" that could send multiple simultaneous messages of varying pitches over a single wire. Frequency or pitch in one object, such as a magnetized vibrating reed at the transmitting end, could induce a “sympathetic vibration” in another magnetized reed of the “same natural frequency” connected along the length of a wire to it at the receiving end [34].

Trained in music as well as acoustics, Bell understood the principle of “sympathetic vibration,” and had observed that by singing into a piano and varying his voice’s pitch he could make the piano’s corresponding strings vibrate in response. He explained to one of his two benefactors and future father-in-law, the well-known Boston attorney Gardiner Hubbard, “that if two pianos were connected by a wire, striking a note on one would cause the same note to answer back on the other” [35]. What, Hubbard asked, was the practical significance of that? Bell replied that one could telegraph messages, each with a different pitch, simultaneously along a wire to a receiver whose waiting “tuning forks would be tuned to [the] different frequencies” of the transmitted sounds [36].

Hubbard was captivated by Bell’s idea. With another Boston businessman, Thomas Sanders, also the father of a deaf child Bell was teaching, they backed Bell’s idea of a “harmonic telegraph,” and formed a partnership with him early in 1875. They also hired a talented 20-year-old machinist, Thomas Watson, to help him with his invention. Hubbard was eager, it turned out, to break the monopoly Western Union had on the telegraph.

But Bell himself had become “[e]nthralled by the elegance of the link between sound and electricity” [37] and by the elusive possibility of making a radically new use of magnetically induced current to carry a continuous, fluctuating sound wave that somehow mimicked the human voice: “‘theoretically you might, by magneto-electricity, create such a current’ Bell claimed, but he did not yet know how to do it” [38].

Aware of this impossibly impractical, competing interest of their young partner, the two businessmen persuaded him to keep his focus on the harmonic telegraph and sent him to Washington to file a patent for it. When Bell arrived in Washington, DC, on the first of March 1875 to file his patent, he visited America’s foremost physicist, Joseph Henry, then head of the Smithsonian Institution. As we have seen, Henry’s basic scientific insights had guided Morse’s commercial development of the telegraph, still the world’s reigning electromagnetic communications technology. Dutifully, Bell discussed his ideas for the harmonic telegraph. Numerous inventors, including Thomas Edison, were working on the idea of different ways to send several messages simultaneously on a single wire, however, and Henry seemed bored by Bell’s ideas for yet another form of the multiple telegraph.

Fortunately, Bell carried with him an apparatus consisting of “an electric wire stretching from a battery and connected to a single tuning fork. By switching the battery on and off he could make the tuning fork hum in various ways” [39]. This apparatus intrigued the old physicist, who invited Bell to return the following day, when they spent the afternoon playing with Bell’s primitive machine. Toward the end of the visit, they had a brief conversation Bell never forgot. “‘You are in possession of the germ of a great invention,’” the elder scientist told Bell, half a century younger, “‘and I would advise you to work at it until you have made it complete’. ‘But,’ replied Bell, ‘I have not got the electrical knowledge that is necessary.’” Henry’s laconic reply was, “‘Get it.’” [40].

The two imperative words were all Bell needed to persevere.

Bell’s path to discovering how an electric current could be made to carry the whole-sound complexity of the human voice, with all its subtly differentiated tonality or timbre, was critically aided by the gift of another scientist, Dr. Clarence Blake, who invited Bell to experiment with a Helmholtz Sound Synthesizer in a lab at MIT. When Bell soon complained the human ear was more sensitive than Helmholtz’s apparatus, Blake gave him the complete ear of a cadaver, including the ear drum and its associated bones. It turned out to be a momentous gift.

Bell took his skull fragment and “arranged it so that a straw touched the ear-drum at one end and a piece of moving smoked glass at the other,” so that when he “spoke loudly into the ear, the vibrations of the drum made tiny markings upon the glass” [41]. The ear’s drum, its tiny membrane, Bell noticed, was as thin as tissue paper, “and yet how effectively it could send thrills and vibrations through heavy bones” [42]. Bell wrote: ‘*…it occurred to me that if such a thin and delicate membrane could move bones that were, relatively to it, very massive indeed, why should not a larger and stouter membrane be able to move a piece of steel in the manner I desired? At once the conception of a membrane speaking telephone became complete in my mind*’ [43].

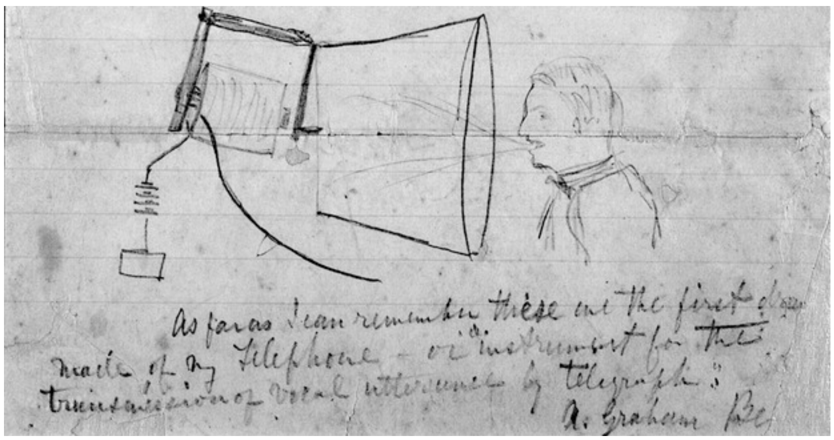

Figure 6: A glimpse into inventor Alexander Graham Bell’s “Aha” moment taken from his journal: *“As far as I can remember, these are the first drawings made of my telephone—or ‘instrument for the transmission of vocal utterance by telegraph*.’” At the lower left is pictured a battery feeding current to an electromagnet. The vibrations of the speaker’s voice activate the diaphragm which in turn vibrates and varies the current transmitted from the electromagnet along the transmission wire, shown stretching diagonally from the bottom of the magnet toward a receiver not pictured. SOURCE: https://techcrunch.com/2011/03/08/first-ever-sketch-of-alexander-graham-bells-telephone-concept/

Bell confided to Watson his idea of a “speaking telegraph”: ‘*Watson, if I can get a mechanism which will make a current of electricity vary in its intensity, as the air varies in density when a sound is passing through it, I can telegraph any sound, even the sound of speech’* [44]. Watson was thus fully aware of Bell’s dream as the two worked assiduously on the harmonic telegraph, using several reed relays as transmitters and receivers in different rooms of their garret-workshop, during the winter and spring of 1875, amid constant frustrations.

Then, on June 2, a serendipitous accident happened, causing a momentary work stoppage. Watson recounted the incident: ‘*One of the transmitter springs* [reeds] *I was attending to stopped vibrating and I plucked it to start it* [vibrating] *again. It didn’t start and I kept on plucking it, when suddenly I heard a shout from Bell in the next room, and then he came out with a rush, demanding, “What did you do then? Don’t do anything. Let me see!”’* [45]. In effect, Watson’s plucked reed’s vibratory motion had suddenly induced a current that traveled down 60 feet of wire to Bell’s corresponding receiver reed, which then vibrated at the same pitch or frequency as Watson’s transmitter reed, reproducing its exact same sound. A specific sound had been perfectly reproduced and transported by means of a magnetically induced electric current, without use of a battery.

The next day Watson built a membrane telephone based on electromagnetic induction. The transmitter's parchment diaphragm's vibrations caused the magnetic field of the permanent magnet adjacent to it to induce an "undulating current" in the wire that led to the receiver, where the undulating current's exact vibrations or frequencies would reproduce the spoken message at the receiver's diaphragm. The pair continued to experiment throughout the year, submitting a patent application by mid-February 1876. Three days after it was granted on March 7, 1876, they made their first successful unidirectional telephone call inside Bell's residence and workshop in Boston. Bell's famous utterance, "Mr. Watson, come here, I want to see you," was clearly heard by an amazed Watson – the first words ever heard over an electric wire.

By early June, Watson had built the "apparatus" that was then displayed in the Massachusetts section of the 1876 Centennial Philadelphia Exhibit.

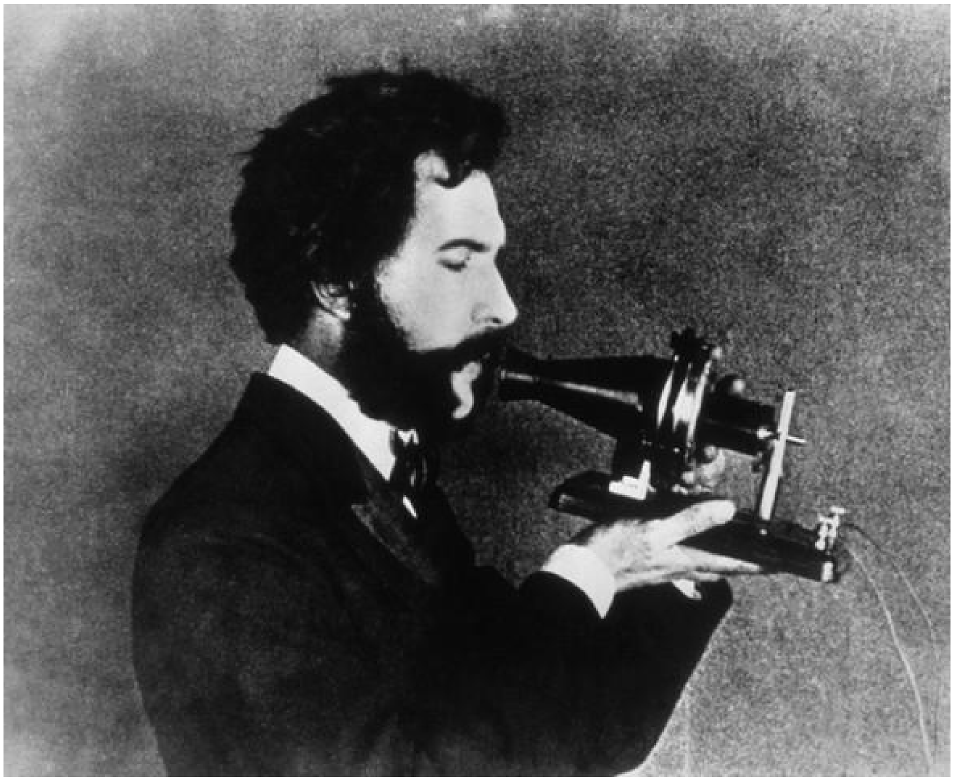

Figure 7: Alexander Graham Bell holding his 1876 Centennial Telephone. Bell's telephone patent was challenged and successfully defended over 600 times, starting with Western Union's lawsuit in 1878. In 1888 the Supreme Court upheld Bell's patent, putting an end to the ceaseless lawsuits. SOURCE: https://www.aim.org/wp-content/uploads/2013/04/alexander-graham-bell.jpg

As the end of the Centennial's judges' tour of the electrical displays was nearing late that June, one of the judges, Dom Pedro, the Emperor of Brazil, recognized Bell standing at his "small table in a narrow space 'between the stairway and the wall'" [46]. The emperor regaled Bell, whom he had met as a teacher of the deaf, months before in Boston, and volunteered to be the first to try out his novel invention. As Bell spoke at the transmitter, the emperor stood in a distant section in the hall where the receiver was, and "with a look of utter amazement" exclaimed, "'My God – it talks!'" Next to try was none other than Joseph Henry, Chairman of the judges' panel. Reportedly "no one could forget the look of awe that came into his face as he heard the iron disc speaking with a human voice." Third to try was the world's "foremost electrical scientist," Sir William Thomson, who "listened and learned … that all the countless varieties of vibrations produced by speech … could be carried along a wire and reproduced exactly" at a receiver. Thomson then rose from the receiver and "nodded his head solemnly," saying, "'It does speak'," adding, "'It is the most wonderful thing I have seen in America'" [47].

What amazed and even shocked two of the world's foremost physicists was that *electricity* could carry the whole complex integrity of human speech in one continuous current, on its face a radical, even outrageous scientific proposition, but one that henceforth could not be denied.

Both Thomson and Henry wrote published reports about the invention, with Thomson calling Bell's invention "of transcendent scientific interest." Though it employed a "homespun and rudimentary" apparatus, it was "perhaps the greatest marvel hitherto achieved by the electric telegraph." The eminent physicist informed his readers that in due course a "more powerful apparatus" will provide the means of a practical long-distance transmission of spoken words "through electric wire" [48]. With these two world-famous scientists' testimonials Bell's invention was all but assured eventual success.

In August 1876, Bell made the first one-way long-distance call from his parents' Canadian home in Brantford to Paris, Ontario, 13 kilometers away, using the telegraph line connecting the two towns. Soon thereafter Bell and Watson discovered "'that a piece of sheet iron was much quicker and more faithful in following the delicate changes required for speech than the most delicate membrane is'" [49]. They dispensed with the membrane and used "all-iron" disks that surprisingly "would vibrate under the slight influence of the spoken word" [50] and could efficiently send and receive the vibrations of speech via either electromagnetic induction or, using a battery current, variable resistance.

In October, Bell and Watson "borrowed the telegraph line between Boston and the Cambridge Observatory, and attached a telephone to each end," two and a half miles apart [51]. Relying on a "thin disk of steel in front of the electromagnet," their three-hour conversation was "carried on more easily than ever before" [52]. Their notes covering what they said to each other long distance were published in the Boston newspapers and "proved beyond question that the telephone was now a practical success." A subsequent call between Salem and Boston was covered by *The Boston Globe* which "caused the whole newspaper world to be agog with excitement." Bell was invited to demonstrate and proselytize his invention throughout New England [53].

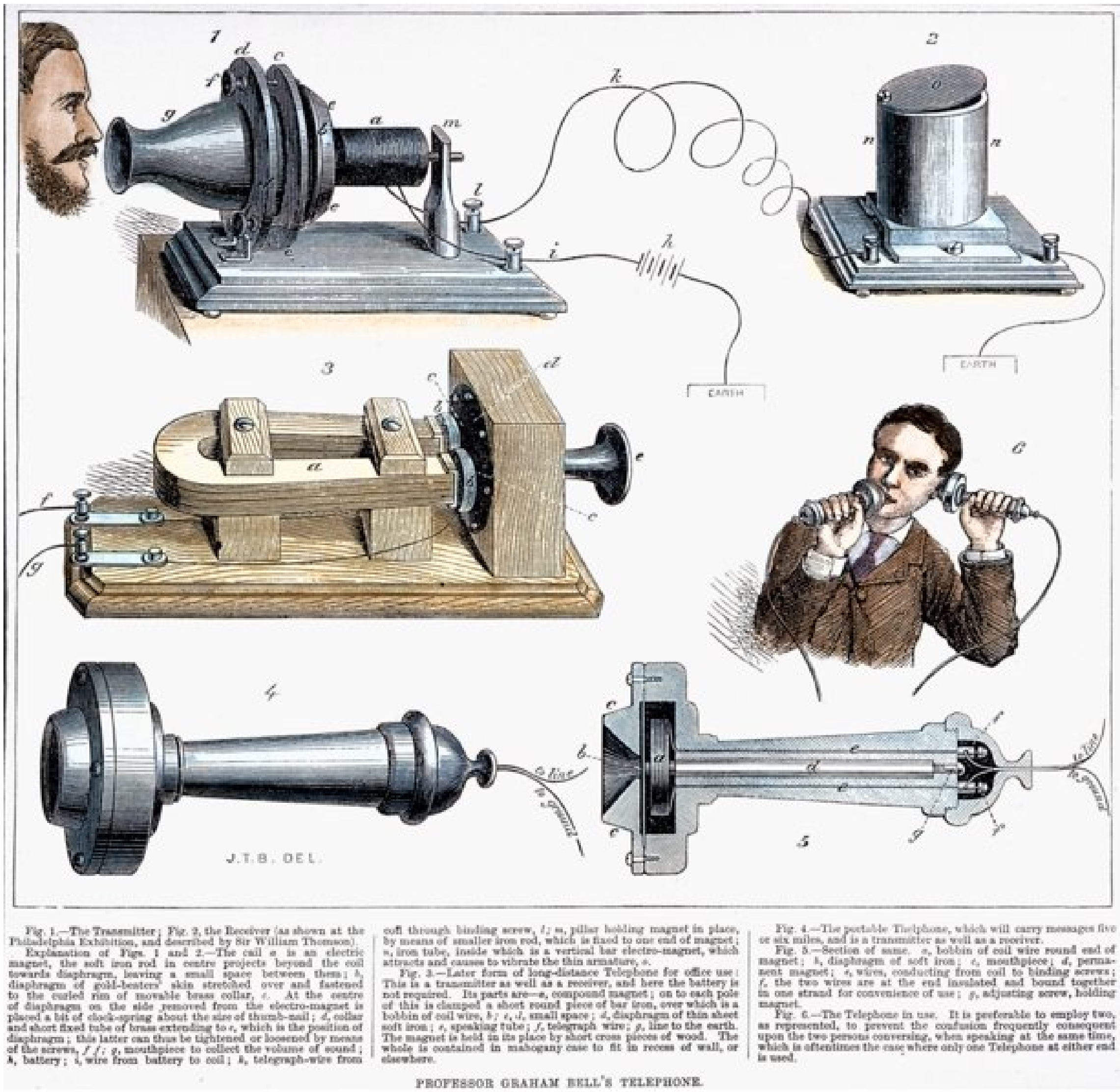

Figure 8: "Professor Graham Bell's Telephone" as it appeared in the *Illustrated London News* in 1882, showing the Centennial phone and its soon-to-follow elaborations. The illustration has six numbered figures: at the top, numbers 1 and 2 show a man speaking into a transmitter with wires leading to a receiver, whose vibrating diaphragm rests on its top. The listener had to bend down and place his ear next to the tabletop receiver to hear the speaker. Number 3 shows a business "form of long-distance Telephone for office use" that did not require a battery and served as both a transmitter and receiver. Numbers 4 and 5 show what the *News* captioned as "The portable telephone, which will carry messages five or six miles, and is a transmitter as well as a receiver," with Number 5 showing a cross section of the instrument. Number 6 is located on top of Number 5 and shows the early innovation of employing two telephones "to prevent the confusion frequently consequent upon the two persons conversing, when speaking at the same time, which is oftentimes the case where only one Telephone at either end is used." SOURCE: https://www.ebay.com/itm/PROFESSOR-ALEXANDER-GRAHAM-BELL-TELEPHONE-INVENTION-TRANSMITTER-RECEIVER-/400957642290

From the beginning, Bell's induction phone had a problem: to be heard people had to shout, as the strength of the weak induced current depended on how loudly one shouted, how much kinetic force one applied speaking at the transmitter's diaphragm. After the Centennial, publicity brought crowds to Bell's lectures and demonstrations of his and Watson's telephone. But people "felt foolish" and experienced "a sort of stage fright" when they had to yell at a transmitter to be heard at a receiver during these demonstrations. The press described the telephone as "weird and almost supernatural," and headline coverage of the Salem-Boston demonstration referred to the event as "Salem Witchcraft" [54]. However, Bell's on-the-road lectures during late 1876 and early 1877 slowly "pushed back the ridicule and incredulity" [55]. And in May 1877 a man from Charlestown, near Boston, unexpectedly showed up to place an order for two telephones, the first ever leased.

Three months later, 788 telephones were in use. Bell's primitive telephone "system" consisted of pairs of telephones sold to single users, often wired between home and office. But a telephone system had to consist of more than this. It needed a transmitter that allowed people to speak normally instead of shouting. It needed switchboards and exchanges. It needed its own wires and a circuit not subject to the strange noises carried by the telegraph's earth return, and much else.

In the summer of 1877, Hubbard, Sanders, and Bell incorporated the American Bell Telephone Company, and Hubbard adopted a leasing model that allowed scores of entrepreneurs in New England and beyond to participate in the rollout of the new technology. For their wire infrastructure, however, these first users depended on other already established wire-using businesses: "the fire-alarm, burglar-alarm, telegraph, and messenger-boy service" enterprises that "saw a glimmering chance of creating a telephone business" on the side [56].

Foremost among these businesses, of course, was the telegraph – dominated by one very large company.

WESTERN UNION, THOMAS EDISON, AND THE CARBON TRANSMITTER

Western Union was the world's most powerful electric company and the only US company to operate on a national scale. "It owned rights-of-way along roads and on house-tops. It had a monopoly of hotels and railroad offices. No matter in what direction the Bell Company turned, the live wires of the Western Union lay across its path" [57]. And Western Union was in the process of "reaching out to monopolize all methods of communication by wire." In early fall 1876 it rejected an offer by the Bell group to sell its patents for $100,000. Western Union's CEO asked demeaningly, "What use could this company make of electrical toy?" [58]

The corporate behemoth's nonchalance suddenly changed, however, when it discovered that one of its subsidiaries, the Gold and Stock Company, had bought and wired up several telephones to supplement its printing and dial telegraph machines. In response, Western Union formed another subsidiary, the American Speaking-Telephone Company, and turned to Thomas Edison for help. For years Western Union had underwritten the work of Edison, one of its most important independent contractors, who had set up a business dedicated to constantly improving and producing telegraphic equipment and stock tickers for the big company. In 1875 William Orton, the company's CEO, had asked Edison to investigate the Reis telephone, which was, after all, based on telegraphic on-off technology, and therefore familiar.

Later that year, Orton also provided Edison with enough money to set up the world's first industrial research and development laboratory at Meno Park in rural Raritan, New Jersey. Orton understood that a well-financed laboratory would enable Edison "to make invention a more regular and predictable process” and that Edison could “significantly” increase “the rate at which he could develop new inventions” [59]. Though Edison eventually held over 1000 patents for his inventions, many agree “his most important invention was one that couldn’t be patented: the process of modern invention itself.” Menlo Park started operations in the spring of 1876, when Bell was filing his telephone patent. “Edison created a process in which skilled scientists, machinists, designers, and others collaborated at a single facility to research, develop, and manufacture new technologies” [60].

The newly funded Menlo Park “inventory factory” soon “enabled Edison to make invention a more regular and predictable process.” This in turn “helped to demonstrate the value of invention to industry and showed that invention itself could become an industrial process” [61]. Edison’s collaborative enterprise tackled several projects at a time. During the 1880s its engineers and technicians “produced the generators and streetcars and motors and lighting systems that created … great metropolises around the world” [62].

Figure 9: Located on the crest of a hill “high enough to command a view of New York,” the Menlo Park research and development complex was dominated by a building with a front office and library, and a machine shop behind them on the ground floor. The laboratory occupied the entire second floor and “was lighted by windows on every side.” Its “walls were covered,” according to a *Popular Science Monthly* reporter writing in 1878, “with shelves full of bottles containing all sorts of chemicals.” In the center of the room was “a rack full of galvanic batteries.” Tables everywhere “were covered with electrical instruments” as well as “microscopes, spectroscopes, etc.” Elsewhere on the campus were a glass-making house, carpenter and blacksmith shops, a carbon shed, and later a separate machinist shop, library, and office for Edison. Edison and his family lived in a comfortable house within the complex. SOURCE: https://www.thoughtco.com/what-was-menlo-park-1992136

By the time Bell had patented the telephone and was beginning to earn fame for his invention, Edison's own research had convinced him "that a successful telephone would be based on variable resistance not electromagnetic induction" [63]. In January 1877 Edison learned that Western Union was not going to purchase Bell's patents, so he ramped up his search for the right material to make a continuous but variable current capable of carrying the human voice not only faithfully but fully audibly. To avoid the weak signal-carrying capacity of induction current, "Edison decided instead to employ a battery current on the line" and rely on spoken words "to vary the current's strength by varying the resistance of the current." To do that, "Edison decided to use carbon" [64].

Edison knew that carbon "had a high resistance when placed under mechanical pressure" and therefore he "needed a carbon compound that was very sensitive to physical force," that is, to the kinetic energy of the human voice. "Ideally, a small change in the pressure on the carbon should produce a large change in the resistance, thus amplifying the signal" [65]. After conducting hundreds of experiments testing materials in 1877, Edison and his researchers discovered lampblack – carbon residue deposited on the glass of kerosene lamps – was an ideal resistor. Out of lampblack they then made "buttons" of carbon in the Menlo Park complex's carbon shed.

After more experiments, the Edison team next fastened their new carbon button "directly to a thick iron diaphragm" and in April 1878 conducted field tests on Western Union's lines between New York and Philadelphia. The tests demonstrated Edison's new battery-powered device "was capable of transmitting even whispers loudly and distinctly" [66]. The company immediately installed Edison's variable resistance carbon telephone in several US cities, purchasing all Edison's telephone patents for, ironically, $100,000. "Armed with Edison's patents," in September 1878 "Western Union attacked the American Bell Telephone Company through patent litigation" [67].

Edison "had made an instrument of marvelous alertness" and it soon caused Bell's lessees to clamor for "'a transmitter as good as Edison's'" [68]. The Bell Company, a mere David facing Goliath, survived the challenge because in August 1878 a young Bostonian named Francis Blake had given the cash-strapped company his patented transmitter in exchange for stock. Blake's transmitter was "as satisfactory as Edison's" and "instantly put the Bell Company on an even footing with the Western Union," and thus simultaneously encouraged both old and new investors to provide the fledgling company with the capital to both fund its expansion and cover the costs of its litigation [69].

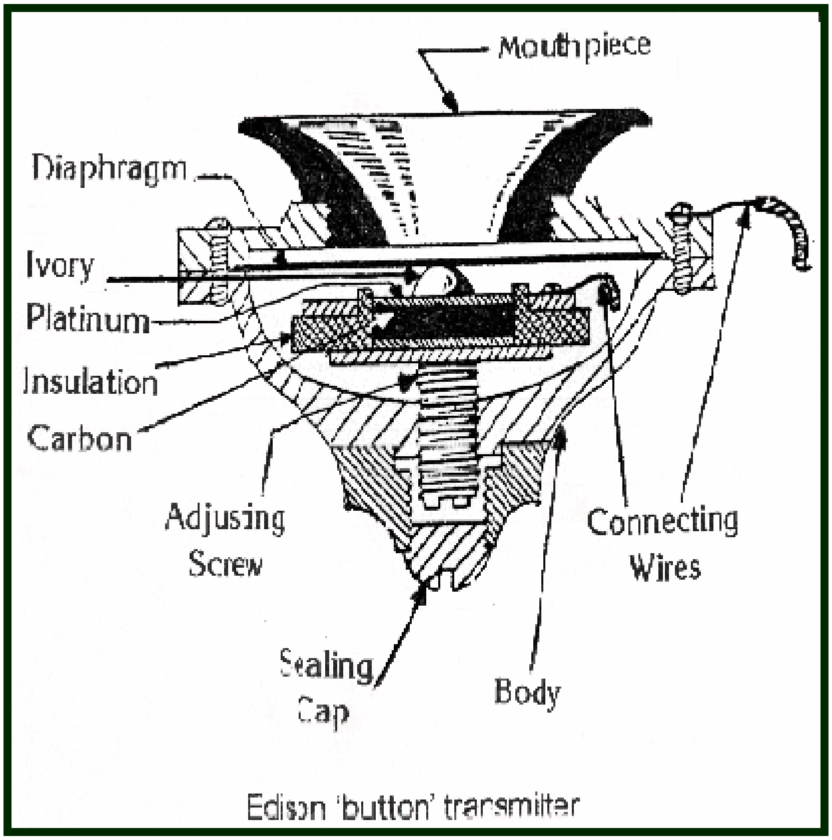

Figure 10: During 1877, Edison experimented with a great variety of materials before settling on kerosene lamp black, a soot, or soft powder that could be compressed into cakes and reground before being molded into more rigid carbon "buttons" that provided the myriad contact points needed to successfully transmit the human voice by variable electric current. Shown above is a drawing of an early version of Edison's carbon transmitter, in which the carbon "button" is replaced by an ivory contact affixed to a platinum plate (electrode) making contact with the diaphragm above. Below the platinum electrode is a disk of carbon held in place by an insulating ring that also serves as the bottom plate (electrode). The adjusting screw was used to increase or decrease the pressure on the carbon and diaphragm. At the end of 1878, all Edison's telephone patents were acquired by The Bell Telephone Company in its settlement with Western Union. Bell mothballed Edison's transmitter in the US in favor of its own Blake transmitter. During the 1880s Edison's carbon button technology underwent many changes, including Edison's 1885 improvement of the Hunnings carbon granules transmitter. Englishman Henry Hunnings' 1880 "improved Edison design" utilized carbon granules (hard coal dust) in lieu of soft carbon. Edison sold his 1885 improvement to Bell, which had also acquired the Hunnings patent. In the early 1890s a Bell engineer named Anthony White further adapted the Hunnings-Edison granule transmitters, which then dominated telephone transmitter technology well into the 20th century.
SOURCE: http://diclib.com/Telephone,%20Carbon/show/en/en_st_electrical/T/144/0/0/1/2268

In due course, Western Union's own attorneys persuaded management that Bell's original patent was fundamentally beyond challenge and that the company should pursue a settlement. When Western Union finally acknowledged Bell's status as the original inventor and recognized his patent, the companies settled terms in November 1879. Western Union agreed to transfer ownership of its telephone patents, including Edison's transmitters, and sell its telephone subsidiary to the Bell group.

Meantime Bell would stay out of the telegraph business and pay Western Union royalties for seventeen years for its leased phones. Effectively Western Union was compelled to abandon a technology whose revolutionary potential eluded its corporate imagination, and it left the Bell group to bear the substantial risks and costs of developing a wholly new industry, almost from scratch.

In early 1880, the Bell Company acquired 56,000 telephones in 55 cities from Western Union. By the following year, Bell had added 1,200 towns and cities to its system. It was on the cusp of astonishing decades-long growth. In 1882 the American Bell Company had "a boom year," as it doubled its gross revenues. The telephone system, however, was primitive and faced several major challenges, the most "stupendous" of which was "how to link together three telephones, or three hundred, or three thousand, or three million, so that any two of them could be joined at a moment's notice" [70].

Another problem was caused by the use of the earth return, a boon to telegraphy but a curse to telephony. The earth was the source of many strange noises that made themselves heard during the telephone's first years of use: "… sputtering and bubbling, jerking and rasping, whistling and screaming … the rustling of leaves, the croaking of frogs, the hissing of steam, and the flapping of bird's wings" as well as the "clicks from telegraph wires" and "scraps of talk from other telephones" all infused themselves into the telephone's low-voltage, undulating current [71]. In 1883 a Bell engineer named J J Carty decided to try running a full "metallic circuit" between Boston and Providence: "The effect was magical. *'At last … we have a perfectly quiet line'*," the engineer celebrated [72]. The repercussions included a doubling of the lines required as the telephone industry grew, service mile by service mile.

In 1884, J J Carty oversaw the construction of a 10,000-pole line, made not with iron wire but "glistening red copper," connecting Boston and New York. By doubling the wire, he not only made a metallic circuit for intermediate local users, but also created the first dedicated long-distance telephone service. The new line "was the salvation of the business" and "swept away the prejudice that telephone service could become nothing more than a neighborhood affair. It marked a turning point … when the day of small things was ended the day of great things was begun" [73].

Writing in 1910, H N Casson reminded his readers that the "crowning glory of the telephone system to-day is not … the simple telephone itself, nor the maze and mileage of its cables, but rather the wonderful mechanism of the Switchboard … the part that will always remain mysterious to the public" for it "defies all metaphors and comparisons." A single telephone switchboard was "a pyramid of inventions" that may have had as many as two million parts and be "nerved with as much wire as would reach from New York to Berlin." Without a "switchboard, there would still be telephones, but not a telephone system. To connect five thousand people by telephone requires five thousand wires when the wires run to a switchboard; but without a switchboard there would have to be 12,497,500 wires – 4,999 to every telephone," a technologically preposterous proposition [74].

Though the first commercial switchboard exchange was created in 1878 in New Haven, Connecticut, it took another decade before for the invention was improved by the prodigious engineer Charles E Scribner to handle hundreds or more users. Scribner created a "multiple switchboard" to handle the volume of traffic posed by 10,000 users, the technology's practical limit. More users required another switchboard, and banks of switchboards soon made up the great exchanges lodged unobtrusively inside the burgeoning metropolises of the late 19th and early 20th centuries.

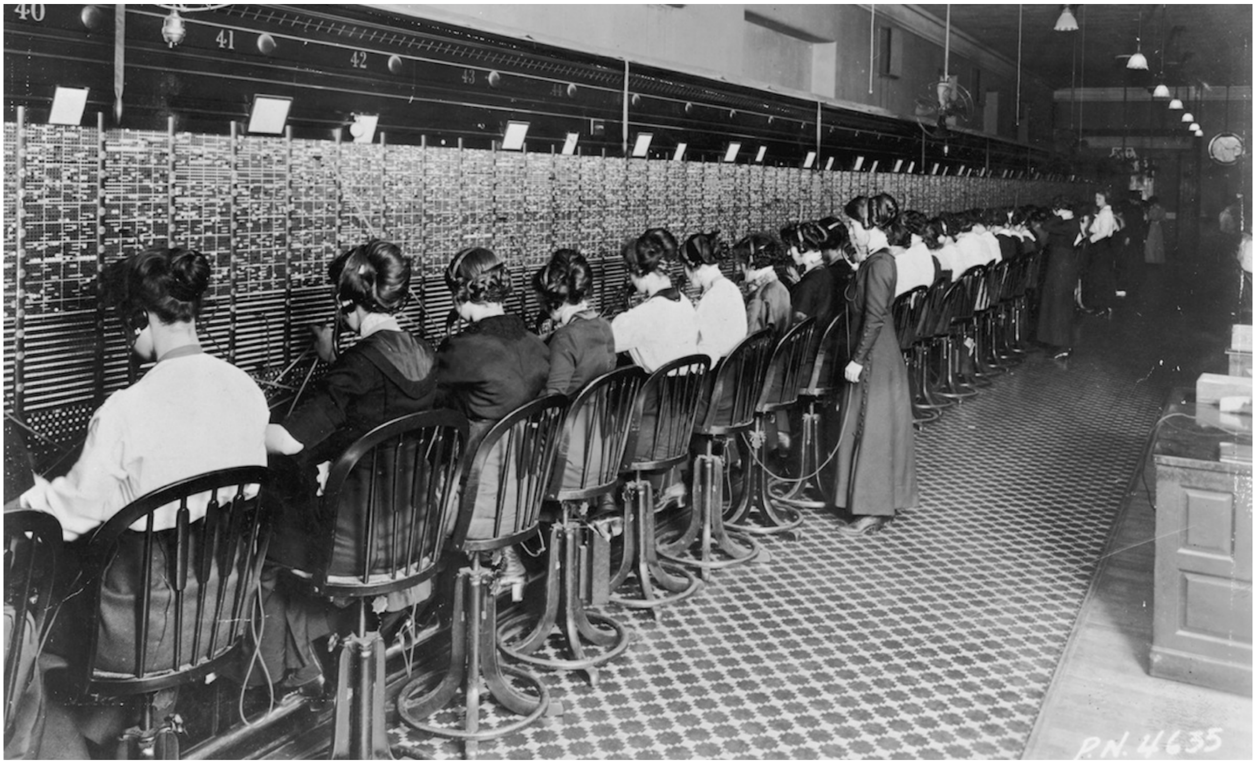

Figure 11: US female "long switchboard" operators on New York City's Cortlandt Exchange, turn of the century, depicting the telephonic labor force in action. SOURCE: https://time.com/4011936/emma-nutt/

"By the late 1880s, the telephone was booming," with more than 250,000 phones in worldwide use [75]. "[P]eople were making a million calls a day," with "Boston and New York … talking to Chicago, Milwaukee, Pittsburgh, and Washington." By 1892 "half the people of the United States were in talking distance of each other" [76]. And, "by the turn of the century there were nearly 2 million phones in use" [77]. In the first decade of the 20th century two-thirds of the world's telephone infrastructure was concentrated in the US alone, "strung out over fifty thousand cities and communities" that required 10 million poles and 11 million miles of wire that enabled US citizens to have 7 billion conversations a year across any distance [78].

WIRES, WIRES EVERYWHERE

The growing demand for telephone service coincided almost exactly with a burst in demand for electric light. In 1877 Paris streets, train stations, and emporia began to be lit with Russian émigré Pavel Yablochkov's "candles," or arc lamps. Yablochkov candles soon lit up the streets and parks of Berlin and London. In 1879 Charles Brush's improved high-voltage arc lamp technology began to light up US city streets and public spaces. Three years later, in late 1882, Edison's incandescent light began to be installed in households and business establishments in lower Manhattan, and soon traveled to smaller cities in New Jersey, Pennsylvania and elsewhere to compete with already established arc-lighting along streets and in public spaces.

The electric companies strung their "high-tension wires along streets already thick with wires for telephone, telegraph, fire and police alarms, and stock tickets. In dense urban intersections a pole might carry as many as two hundred different wires," that however unsightly, used "a moderate current that posed no danger" to pedestrians [79]. City dwellers now encountered a new hazard as "the sky overhead became increasingly ominous, thick with wires that might pour down" lightning bolts without warning. The new single-wire power lines "were poorly insulated and frequently broke loose," creating "fireworks." As one Chicago newspaper reported, "'The old wires just tingled, but the new ones killed'" [80].

During the 1880s "[e]very week the papers ran stories of this very modern form of sudden death" [81]. Hazard only seemed to sharpen the appetite of Americans, in particular, for the miraculous new powers and products of electricity. "Some streets in the larger cities had become black with wires" by the late 1880s. "Poles had risen to fifty feet in height, then sixty – seventy – eighty," and on New York's West Street the poles rose a towering ninety feet, each "carrying thirty cross-arms and three hundred wires" [82]. In London "wires carrying two thousand volts were trailing across rooftops" and "along streets already thick with wires" [83].

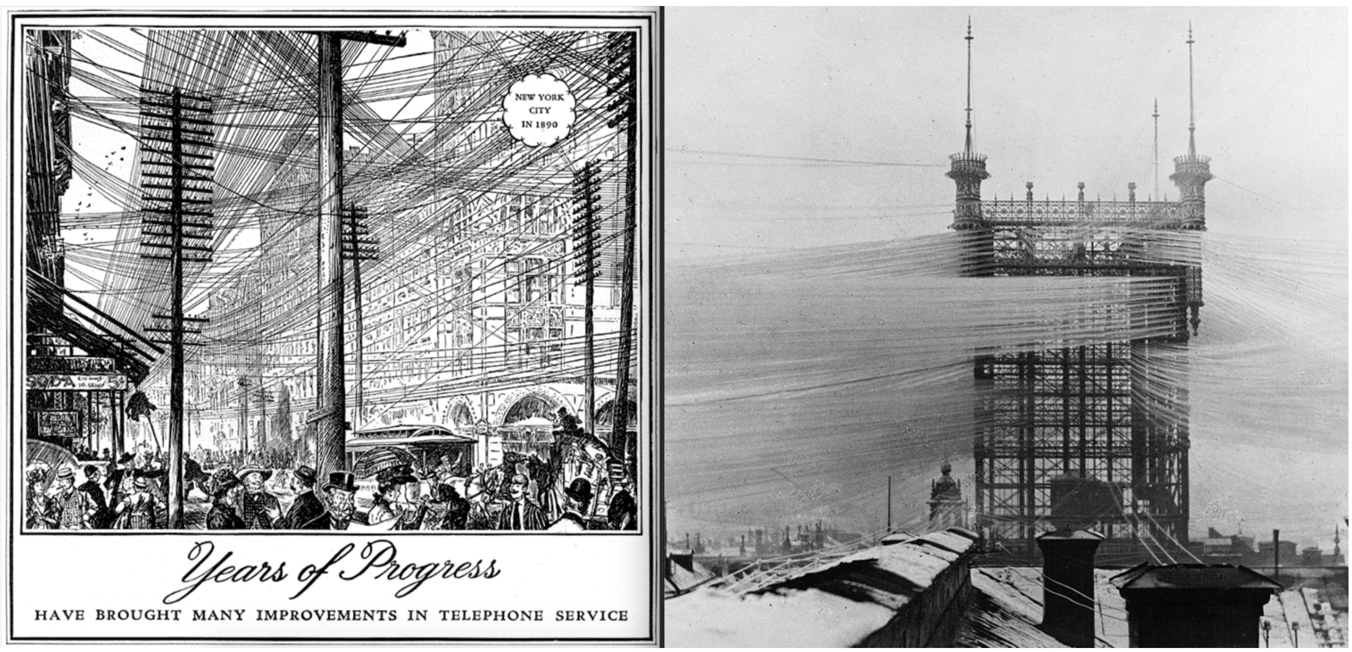

Figure 12: Though dated 1890, this "Years of Progress" poster (left image) advertising the telephone could represent the state of overhead wires in New York City at any time during the late 1880s. During the 1890s New York City (and other US cities) buried all its overhead wires. Stockholm's famous 80-meter-tall telephone tower (right image) carried 5,000 lines and was in service from 1887 to 1913, by which time all telephone cables were buried beneath the city's streets. SOURCES: Left image: https://www.glassian.org/Bell/yearsofprog.gif, and right image: https://www.reddit.com/r/interestingasfuck/comments/jynpb7/this_is_how_the_system_of_5_000_telephone_lines/

Thanks to "poorly insulated electric light wires, the telephone network had become 'full of electricity.'" In 1889 the leading citizens of St. Louis gathered with electric company officials on New Year's Eve to celebrate "the first lighting of a large section of the city." The celebrants' applause for the new light barely had died down when protests from telephone customers started to arrive, "complaining that all they could hear on their lines was a powerful hum, like a hive of bees" [84]. Casson claims that "had the telephone," whose real heyday was still decades away, "been born ten years later, it might not have been able to survive" the challenge posed by "the powerful currents of electricity that came into general use after 1886" [85], when the advent of high voltage alternating current first began its eventual domination of how electric power was delivered to industry, retail trade, and residences. The telephone's "tiny Genie of the Wire" was "perhaps the quickest, feeblest, and most elusive force in the world…so small that the electric current of a single incandescent lamp is greater [by] 500,000,000 times" [86].

In the meantime, a new, increasingly common – and puzzling – medical condition had been discovered.

NEURASTHENIA: A DISEASE OF ELECTRICITY OR A FREUDIAN "ANXIETY NEUROSIS"?

After the US Civil War, a young New York neurologist, George Miller Beard, wrote "the first clinical histories of a previously unknown disease," a disease he believed was related to new stresses that came with "modern civilization," a disease that signified "weak nerves." Characteristic symptoms were "headache and backache; irritability and insomnia; general malaise; excitation or increase of pain; over-excitation of the pulse; chills, as though the patient were catching a cold; soreness, stiffness, and dull aching; profuse perspiration; numbness; muscle spasms; light or sound sensitivity; metallic taste; and ringing in the ears" [87]. In 1869, Beard named the disease "neurasthenia."

In 1881 Beard co-authored an authoritative textbook, *Medical and Surgical Electricity*, which used the terms "electro-susceptibility" and "electro-sensibility" to describe those easily harmed by electricity and those who were extremely sensitive to its presence, respectively. When Beard died two years later, neurasthenia's cause, "to everyone's frustration, had still not been identified" [88].

In France the term "*mal télégraphique*" (telegraphic sickness) entered the national lexicon in the 1870s. It referred to a medical condition that presented itself with multiple clinical characteristics. As reported by patients, and in particular, telegraph operators, these symptoms included "heart palpitations, dizziness, insomnia, weakened eyesight, and a feeling 'as though a vice were gripping the back of their head.'" These patients "suffered from exhaustion, depression, and memory loss, and after years of work, a few descended into insanity." In 1905, a disconsolate German telegrapher wrote: "'Hanging always between sickness and health, we are no longer whole … Has the release of electrical power from its slumber … created a danger for the human race?'" [89].

Mal télégraphique was known to also afflict telephone operators. Studied by German physicians in the late 19th and early 20th centuries, telephone operators "typically had headaches and dizziness, tinnitus and floaters in the eyes, racing pulse, pains in the region of the heart, and palpitations. They felt weak and exhausted and were unable to concentrate. They could not sleep. They were depressed and had anxiety attacks. They had tremors" [90]. Mysteriously, neurasthenia sufferers tended to be persons in the prime of life, between 20 and 50 years of age, and they paradoxically tended to live longer than average, albeit with a reduced sense of aliveness.

Sigmund Freud had been in practice as a specialist treating nervous diseases for eight years when he wrote his now-famous paper, "On the Grounds for Detaching a Particular Syndrome from Neurasthenia under the Description 'Anxiety Disorder'" (1894). It changed how Westerners – the first peoples to experience the electricity revolution – would come to view neurasthenia. Freud "ended the search for a physical [or environmental] cause of neurasthenia by reclassifying it as a mental disease," and "by designating almost all cases of it as 'anxiety neurosis'" [91]. Telegraphers and telephone operators were suffering from endogenous anxiety, in today's parlance, panic attacks, or perhaps, from a current clinical perspective, from chronic fatigue syndrome, a late 20th century form of physically untreatable "anxiety."

The electric telecommunications revolution was born in the West, and Freudian analysis did not follow it to Asia and other parts of the world, proselytizing the idea of anxiety neurosis. Outside the US and Western Europe, "neurasthenia is today … one of the most frequently diagnosed diseases in general medical practice" and electricity is recognized "as one of its causes" [92].

Approximately 30 percent of humans are weather-sensitive. They are therefore also likely to be "electrically sensitive." In 1980 Felix Gad Sulman, an Israeli medical researcher, led a 15-year interdisciplinary medical study of 935 weather-sensitive patients. The researchers learned that four out of five of these patients "could predict weather changes twelve to forty-eight hours before they happened." Sulman reported: "The 'prophetic' patients" – those that could make predictions in advance of actual changes – "were all sensitive to the electrical changes" that preceded the weather, reacting to "ions and atmospherics which naturally arrive with the speed of electricity – before the slow pace of the weather winds" [93].

A decade before Freud cast a pall on the discussion of neurasthenia as a medical condition with a physical basis, another German physician, Rudolf Arndt, proposed that neurasthenia and electrosensitivity were linked. Arndt also suggested that "people who were less sensitive to electricity," that is, a majority of the population, "did not take its effects seriously." Besides, almost all our ancestors were in love with the miraculous powers conferred on them by the electromagnetic force, and firmly believed nothing should slow down its progress. "[I]n the middle of an intense, unrelenting haste to wire the whole world," Arndt pleaded not to neglect electricity's physical effects on the electrosensitive, but to work to elucidate "phenomena that now seem puzzling and inexplicable," to do the painstaking scientific research [94].

Unsurprisingly, his plea was ignored.

CONCLUSIONS

In little more than half a century, Earth was fully "belted" with electric wires, from San Francisco across the Pacific Ocean to Manila and Tokyo, from Hong Kong, Delhi, and St. Petersburg to the capitals of Europe, from London across the Atlantic to New York, Chicago, and points west. Cities in Central and South America were linked to northern metropoles, as were many cities in Africa, Australia, and Southeast Asia, through millions of miles of wire and cable. Urban denizens were "bathed" in new electromagnetic fields. These anthropogenic "force fields," as Faraday termed them, are estimated to have been many orders of magnitude stronger than Earth's natural fields possessing the same frequencies. By the dawn of the 20th century the electromagnet-based communications technologies of telegraphy and telephony had also altered the speed and conduct of commerce, diplomacy, journalism, and private intercourse. In the process of developing the first electromagnetic telecommunications technologies, scientific and development became more directly tied to large-scale industry. Industry increasingly paid the cost of making inventions, and by the end of the century a new industry, that of invention itself, had been born. During this same momentous period, new diseases such as neurasthenia arose, diseases whose etiology is still little understood, but whose arrival coincided with the electrification of the world.

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[43] Pasachoff, Op. Cit., 39.

[44] *Ibid.*, 44.

[45] Gorman & Carlson, *Op. Cit*.

[46] DeLand, *Op. Cit*.

[47] Casson, *Op. Cit*., 21.

[48] DeLand, *Op. Cit*.

[49] *Ibid*.

[50] Casson, *Op. Cit*., 63.

[51] *Ibid.*, 27.

[52] DeLand, *Op. Cit*.

[53] Casson, *Op. Cit*., 27, 28.

[54] *Ibid.*, 24.

[55] *Ibid*., 29, 31.

[56] *Ibid*., 63.

[57] *Ibid*., 46.

[58] *Ibid*., 33.

[59] Israel, Paul, *Edison: A Life of Invention* (New York: Wiley, 1998), 119.

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[61] Israel, *Op. Cit*., 119.

[62] Bodanis, *Op. Cit*., 39.

[63] Gorman & Carlson, *Op. Cit*.

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[66] *Ibid*.

[67] *Ibid*.

[68] Casson, *Op. Cit*., 39.

[69] *Ibid*., 43.

[70] *Ibid*., 68.

[71] *Ibid*., 70-71.

[72] *Ibid*., 72.

[73] *Ibid*., 102.

[74] *Ibid*., 83-84.

[75] Standage, *Op. Cit*., 204.

[76] Casson, *Op. Cit*., 107-108.

[77] Standage, *Op. Cit*., 204.

[78] Casson, *Op. Cit*., 116.

[79] Freeberg, *Op. Cit*., 80.

[80] *Ibid.*, 81.

[81] Freeberg, Ernest, *The Age of Edison: Electric Light and the Invention of Modern America* (New York: Penguin, 2013), 81.

[82] Casson, *Op. Cit*., 74.

[83] Firstenberg, *Op. Cit*., 77.

[84] *Ibid.*, 183-184.

[85] Casson, *Op. Cit*., 75.

[86] *Ibid*., 67, 66.

[87] Firstenberg, *Op. Cit*., 51, 38.

[88] *Ibid*., 38, 51.

[89] *Ibid*., 58-59.

[90] *Ibid*., 60.

[91] *Ibid*., 63.

[92] *Ibid*., 64.

[93] *Ibid*., 40, 418.

[94] Ibid., 62.