Bell, Watson, Soft Iron, and the Insight That Commercialized the Magneto Telephone

By Ralph O. Meyer

Alexander Graham Bell's telephone of 1877 progressed from a noted idea to commercial success in 2 years, 4 months, and 11 days. It used the same instrument for a transmitter and a receiver, had a range of more than 100 mi, and used no batteries. In fact, Bell's original concept, a magneto telephone, is still used on ships around the world because these telephones are reliable and do not depend on external power. The story of this telephone's development is hidden behind the drama and controversy often reflected in historical accounts, and the fundamental technical complications are overlooked. In the following narrative, these technical threads are woven to reveal a story that is little known. This narrative does not focus on the legal priority of the telephone's inventor but instead focusses on the technological beauty and wonder of the world's first commercial telephones that are underappreciated because they are not widely understood.

This month's history article focuses on the story behind the technological breakthrough that led to the world's first commercial telephones.

Based on my reading, many historians provide a reasonable accounting of the telephone's development up to the time of the Centennial Exposition in Philadelphia in 1876, but, the last half-year of this development—which includes an essential breakthrough—is frequently glossed over.[1] We pick up the story just before the Exposition although it is necessary to discuss some concepts in order to understand the setting.

First, an electric current through a wire produces a magnetic field around the wire. This is the foundation of electromagnetism. This relationship, recognized since 1819, forms the basis for telegraphy of the period, relying on coils of wire wrapped around an iron core to attract an iron armature when current passes through the wire.

Second is the concept of magnetic induction, or magneto generation, whereby a changing magnetic field induces a current in a nearby wire circuit. Discovered in 1831, this forms the basis for magneto generators in which wires and magnets are moved relative to each other to induce a current in the wires. Siemens and Halske in Germany produced a sophisticated magneto generator as early as 1856.

Third is a matter of magnetic polarization. For example, if a nail is picked up with a magnet, the nail itself becomes a magnet that will pick up another nail. The nails have become polarized, as each now has a magnetic north pole and a south pole.

Finally, the magnetic properties of iron play an essential role. It was well known in the 19th century that pure soft iron was used to make the cores of coils in electromagnets, and it was also known that very hard steel was necessary to make good permanent magnets. However, the magnetic behavior of ferrous metals was not well understood by anyone in 1876.

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[1]For example, consider the historical accounts written by Herbert Casson, Frederick Rhodes, Robert Bruce, John Brooks, and David Hounshell.

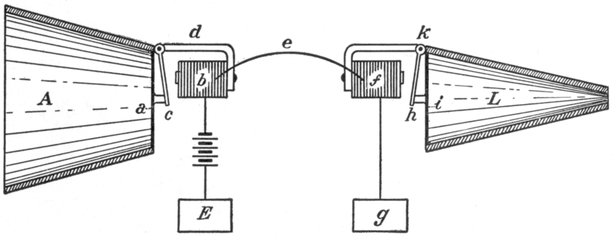

Fig. 1. ***Diagram of magneto transmitter (left) and receiver (right) from Bell's patent of 1876.***

I. MAGNETO TELEPHONE CONCEPT

Bell's famous patent of March 1876 was intended to protect his idea of generating a "magneto-electric current" by vibrating a magnet in front of a telegrapher's electromagnetic coil [7]. Fig. 1 shows a picture from this patent and offers a good starting point for our narrative [12]. In this figure, b and f are electromagnets (coils of insulated wire wrapped around short rods of soft iron). The hinged steel armatures possessing residual magnetism, c and h, are attached, respectively, to stretched membranes, a and i.[2] Metal brackets, d and k, hold the electromagnets, and A and L are sound funnels. The wire e is presumably an overhead line on telegraph poles, and the series of short and long dashes is the symbol for a battery. The earth is a conductor of electricity, and telegraphers would connect one wire to ground such that they needed only a single overhead wire. In the diagram, E and g should, thus, be considered to be connected together through the earth, completing the circuit through the battery, coils, and overhead wire.

In a confidential letter to his family ("Please keep this paper as a record") sent more than a year earlier, Bell documented the idea of vibrating a permanent magnet in front of an electromagnet to generate an oscillating current "without the use of a battery at all" [4]. Bell received financial support from Gardiner Hubbard, an American lawyer, financier, and community leader, to continue his work. Bell and his assistant Thomas Watson, on June 2, 1875, were testing telegraph sets in Charles Williams's shop where Watson was employed when they accidentally confirmed Bell's idea about vibrating magnets [5]. Watson later wrote that the vibrating spring-steel reed in their telegraph set, which had been "magnetized by its long use in connection with magnets, was functioning as a magneto-electric generator" [39, p. 1016]. This discovery confirmed their understanding, which prevailed in the spring of 1876 when Bell's patent was issued. Notably, it involved only electromagnetism and magneto generation but did not include the use of polarization and magnetic properties. According to Bell, he was navigating in a self-described mental fog, and it was very hard for him to find the shore [6].

[2]Membranes of parchment, gutta percha, and gold-beater's skin were used at different times [31, p. 92, 108].

In early April 1876, Bell started gluing a piece of steel clock spring (labeled S in Fig. 2, where A is again a sound funnel) to a stretched membrane, instead of using the hinged arrangement shown in Fig. 1 [8, p. 84]. This undoubtedly eliminated some free play and led to improved sound fidelity. Bell also started using a new receiver (labeled R in Fig. 2) [18, p. 102]. It was an iron cylinder that was closed off at the bottom, which supported the electromagnet's core, and a steel diaphragm S' rested on top of the cylinder.

On May 22, 1876, Bell tried using a double-pole electromagnet, as shown in Fig. 2 [9, p. 15]. Double-pole electromagnets were used almost universally in telegraphy of the period, so this was not an inventive change, although it probably improved performance. Later that day, Bell was testing this arrangement when his assistant for the day, Eddie Wilson, spoke into the transmitter A and said, "Mr. Bell, are you going to the Centennial?" Bell, listening at the receiver R, wrote "I heard the sentence ... with the utmost distinctiveness." These were the first clearly spoken words with Bell's magneto telephone, and Bell subsequently prepared to go to the Centennial Exposition in Philadelphia.[3]

Using Bell's then-current understanding, the clock-spring steel S, with its residual magnetism, was vibrating in front of an electromagnet, thus creating an oscillating current in the circuit by magneto generation. In the receiver, an electromagnet was pulling on, and then relaxing, a steel diaphragm in sync with the vibrations in the transmitter. This arrangement would work without a battery in the circuit, but the telephone worked better with a battery—a holdover from the telegraph circuit. Thus, a battery was left in the circuit for most of Bell's testing and demonstrations.

II. CENTENNIAL DEMONSTRATION

Watson made a number of well-finished instruments for the Centennial Exposition, including the one shown in Fig. 2 [41, p. 18]. At the exposition, electrical exhibits were judged, and one of the judges was the revered British physicist, Sir. William Thomson (later known as Lord Kelvin). Upon returning home, Thomson gave a report to the British Association while holding up one of Bell's transmitters that had been given to him by Bell [33, p. 427]:

> All this my own ears heard, spoken to me with unmistaken distinctness by the thin circular disc armature of just such another electro-magnet as this which I hold in my hand. The words were shouted with a clear and loud voice by my colleague-judge, Prof. [James C.[4]] Watson,

[3]Bell spoke his famous "Mr. Watson – Come here" words on March 10. These are frequently recognized as the first words transmitted by telephone [8, pp. 40–41]. Those words, however, were articulated into a liquid-resistance transmitter that employed a wire dipped into an acid solution. A liquid transmitter was never used again, and its demonstration had no bearing on the first commercial telephones that were of Bell's magneto design.

[4]See [21, p. 191].

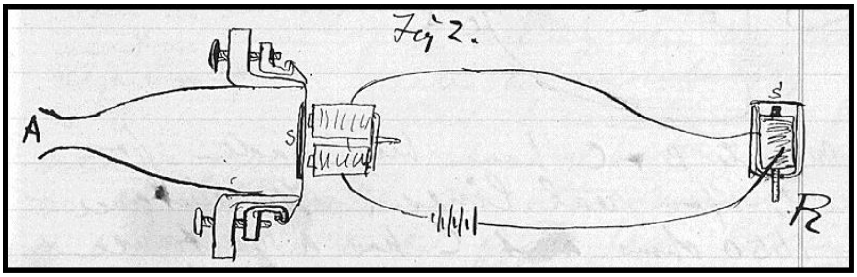

Fig. 2. *Drawing in Bell's notebook of May 22, 1876, of the first magneto telephone (left) that successfully transmitted speech.*

> at the far end of the telegraph wire, holding his mouth close to a stretched membrane, such as you see before you here, carrying a little piece of soft iron, which was thus made to perform in the neighborhood of an electro-magnet in circuit with the line motions proportional to the sonorific motions of the air.

Why did Thomson say it was a little piece of soft iron when Bell had been using a piece of hardened spring steel and had never mentioned soft iron? The following explanation is speculative, but the evidence is discussed below.

Thomson, who would have understood how Bell's device worked, probably told Bell that they were dealing primarily with induced (i.e., polarized) magnetism rather than retained magnetism, and therefore, they would be better off using soft iron than spring steel because of soft iron's magnetic properties. It is likely that Bell then substituted a piece of soft iron in his demonstration apparatus and it worked better. It is also likely that Bell did not fully understand this. A more detailed discussion is given in the following.

III. EXPERIMENTS FOLLOWING THE CENTENNIAL

When Bell returned to Boston, he had two electromagnets made for testing on real lines and a small piece of very thin sheet iron was attached to the membrane of the transmitter [9, p. 14]. As if to underscore the freshness of this feature, Bell noted that the sheet iron was Tagger's iron, which was imported from Russia and likely in stock at Williams's shop [18, p. 106, 142]. When he tested this magneto telephone on June 30, Bell thought it was "most extraordinary" that it worked well with only one battery cell, but he was disappointed that it did not work when the battery was disconnected.

Two days later, Bell wrote to Hubbard about his "startling discovery" that he could work his apparatus through a high resistance with just one battery cell [18, p. 107]. Bell appeared to understand that he needed some means of magnetizing the small piece of Tagger's iron, and he said that he was sure by substituting a permanent magnet for the pole of the electromagnet, and he could work his apparatus "without a battery at all." Bell then had Williams make an electromagnet with a permanently magnetized steel core, and Bell performed some tests with this electromagnet during July [18, p. 370]. He later testified, with considerable vagueness, that speech sounds were transmitted and received by such an apparatus, but he did not record these tests in his notebook [18, p. 373]. It is doubtful that they were successful because the magnetism of the steel was fixed and could not follow (i.e., be polarized by) the fluctuating magnetic field produced by the vibrating membrane and, hence, induce fluctuating current in the coil.

Less than two weeks later, Bell wrote down some thoughts on magnetic polarization in his notebook [9, p. 28]. Bell drew several sketches (not shown here) on July 12 showing armatures of Tagger's iron that were polarized by permanent magnets rather than a circuit with a battery. Nevertheless, Bell did not pursue such a permanent-magnet design at that time.

IV. TECHNICAL BREAKTHROUGH

Bell and Watson subsequently returned to testing with steel armatures, iron coil cores, and battery circuits. In October 1876, they obtained better results when a larger steel disc was glued to the stretched membrane. Subsequently, Watson eliminated the membrane altogether and substituted an even larger sheet steel (plate) diaphragm, which was about 4 in. in diameter, as indicated in Fig. 3. They were still testing this telephone with a battery when, on November 18, they noticed an unusual effect whenever the polarity of the battery was reversed. At first, the transmitter worked only feebly, but eventually, it returned to its normal volume and clarity [10, p. 35].

Watson soon realized what was wrong. Bell wrote that Watson said the result they were observing was "more likely due to the magnetism of the steel. The cores [of electromagnets] were made of the best soft iron and the reversal of current would instantly reverse their polarity—but the plates were of steel and they would require some time to be fully magnetized—or to be de-magnetized." Bell agreed, and this provided an important breakthrough. Thus, November 18, 1876, was a pivotal day in the development of the telephone. The subsequent progression and commercialization proceeded with lightning speed.

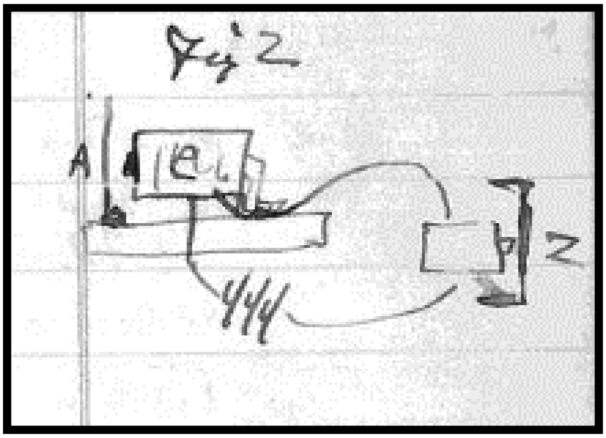

Fig. 3. ***Drawing in Bell's notebook of October 12, 1876, of magneto telephone (left) with a large steel diaphragm instead of a stretched membrane.***

This point had been difficult for Bell and Watson to understand. Thus, it is worth a digression in our review. Iron has many small atomic magnets, but the atomic magnets are normally arranged randomly with no net magnetic effect.[5] If a piece of iron is placed in a magnetic field, say from a coil of wire carrying a current, these atomic magnets can align themselves, thereby greatly enhancing the magnetic field. This enhancement (i.e., the ratio of the field strength with the iron present to that without) is the iron's permeability.

Iron, however, can be hardened by adding carbon (making steel), heating and quenching, and by other means. In glass-hard steel, the internal magnets are nearly frozen and require a very strong external magnetic field (coercive force) to align them or to realign them. The alignment persists after an external field is removed, and the hard steel will have residual magnetism (retentivity), thus creating a "permanent" magnet.

In pure soft iron, in contrast, the internal magnets can be aligned easily by an external magnetic field and will return to a near-random orientation once the external field is removed. In spring steel and mild steel, the result of applying an external magnetic field is intermediate; the internal magnets align themselves sluggishly, and when the external magnetic field is removed, they do not realign themselves automatically; there remains some residual magnetism in the steel.

Watson, who had spent days at the Boston Public Library reading about magnets, had just observed an effect of magnetic hysteresis in the mild steel that they were using for the vibrating diaphragm. Hysteresis was not well understood at that time [40, p. 100].

One more point is apparent. If a nail is picked up with a magnet, the nail itself becomes a magnet that will pick up another nail. The nails have become polarized, as each now has a magnetic north pole and a magnetic south pole. Thus, with reference to Figs. 2 and 3, the steady current through the electromagnet created a magnetic field that polarized (magnetized) the iron coil cores, which, in turn, polarized (magnetized) the mild steel diaphragm. The polarized diaphragm thus became the magnetized element that was vibrating in front of an electromagnet and producing a magneto-generated electric current.[6] In order to get the maximum amount of polarization in the diaphragm and, of course, in the coil cores, both should both be made from soft-iron rather than steel such that the atomic magnets can align themselves easily. This explains why Bell's experiment on June 30 with a Tagger's iron armature produced a result that was "most extraordinary."

Bell sought from the beginning to design an instrument that would work without a battery. He knew that the polarization could be provided by adding a permanent magnet to the design rather than using a battery circuit. He had sketched ideas for this in mid-July, but they did not result in a practical arrangement. For about a week after November 18, Bell seemed confused about how to utilize their new understanding, and he sketched additional transmitter geometries in his notebook.

V. PERMANENT-MAGNET DESIGN

On November 23, Watson wrote that he constructed iron membranes for their telephones instead of steel ones that they had been using [10, p. 43]. After November 23, however, there are no further entries in Bell's notebook for the year, or for 1877.[7] Bell and Watson must have realized that placing a horseshoe magnet behind a pair of telegrapher's electromagnets would complete the design. Their success may have been so astonishing so that they stopped keeping notes.

One of the revised instruments that Watson built for testing in late November is shown in Fig. 4. The diaphragm was soft iron, the soft iron coil cores are hidden from view, and polarization was provided by a large permanent magnet that can be seen clearly in the figure [31, p. 19]. This telephone's simplicity is stunning!

Starting on November 26 and continuing through mid-December, Bell and Watson conducted successful long-distance voice tests using two of these telephones over telegraph lines of the Eastern Railroad Company. The first test was from Boston to Salem, 18-mi distant, but a week later, the distance was extended to 143 mi [13], [14], [18, p. 136]. Bell's letter on December 6 to Gardner Hubbard's daughter, Mabel, to whom Bell was then engaged, captured the drama of that day.

[5] Atomic magnets are actually arranged in magnetic domains, but this oversimplification is adequate for now.

[6] Notice that when a battery is used, the electromagnet performs two separate functions: one is to polarize its core by virtue of the battery's current, and the other is to act as a pick-up coil for magneto generation. When the battery is eliminated, the electromagnet acts only as a pick-up coil.

[7] Bell does start a new notebook labeled Vol. IV in August 1877, but his notes are on different subjects [11].

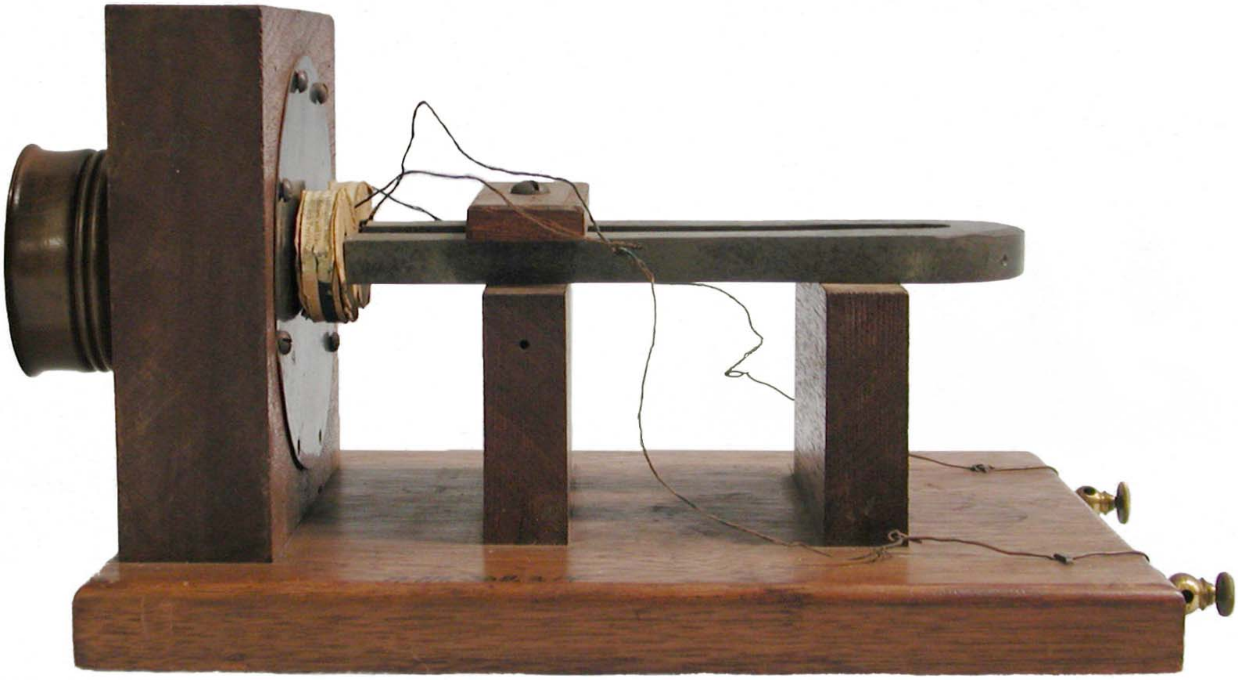

Fig. 4. *First fully developed magneto telephone, November 1876. Division of Work and Industry, National Museum of American History, Smithsonian Institution.*

> Our experiment last Sunday [December 3] was very nearly a failure. Mr. Watson was in North Conway [NH] and I in Boston—so that we were 143 miles apart. Unfortunately the wire had been injured the day before by the cold snap. It had been broken in no less than five places—and had been hurriedly mended. Some of the connections had been left in an imperfect state, and the result was that when I put the telephone to my ear a most extraordinary succession of noises made their appearance. It seemed as if a hurricane was going on for my express benefit—a roaring rushing sound like wind mingled with the crashing of branches and all the noises of a storm—utterly prevented us from hearing the faintest trace of Mr. Watson's voice a hundred and forty three miles away. It seemed as if a cyclone had been imported express by telegraph for the occasion. It was all the more mortifying—as quite a number of skeptical telegraphic people were present on the occasion. Mrs. Eustis Hubbard was there too. After trying all sorts of experiments for nearly an hour—at last the telephone triumphed—and Mr. Watson's voice was heard above the roaring of the storm—singing "The last rose of summer." I was glad that all present had the opportunity of hearing his voice even though the experiment was not as satisfactory as I had hoped. The power of the telephone was sufficiently demonstrated—and after the lapse of another half-hour Mr. Watson & I were able to hold conversation by word of mouth without much difficulty.

So far, we have focused on the operation of the magneto telephone as a transmitter, but its operation as a receiver is also easy to understand. When receiving, the alternating current generated by the transmitting telephone passes through the coils and generates an alternating magnetic field (electromagnetism) that causes the iron diaphragm to vibrate. The permanent magnet polarizes the coil cores that, in turn, pull in on the diaphragm. Thus, at rest (no voice current), the diaphragm is deflected inward because of the permanent magnet, and the voice current then alternately increases and decreases this deflection. Without the permanent magnet, there would be no deflection at rest, and each half cycle of the voice current would pull on the diaphragm (either pole of a magnet will pick up a nail). Thus, the permanent magnet avoids frequency doubling and increases the magnitude of the deflection twofold.

VI. FIRST COMMERCIAL TELEPHONES

On January 15, 1877, Bell applied for a patent based on the instrument, as shown in Fig. 4 [15]. A diagram from this 1877 patent is shown in Fig. 5, in which O is a permanent magnet, P and Q are soft iron cores of the coils R and S, respectively, and A is the soft iron diaphragm. Fig. 5 can be compared with a functional diagram shown in Fig. 6. In Fig. 6, north and south magnetic poles of the various parts are indicated by N and S, respectively; the red arrows show the direction of the magnetic flux; and CW and CCW indicate the clockwise and counterclockwise windings of the coils. Bell's patent diagram presents all details,

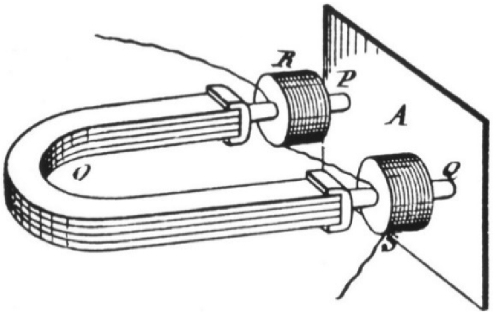

Fig. 5. ***Drawing of permanent-magnet magneto telephone from Bell's patent of 1877.***[8]

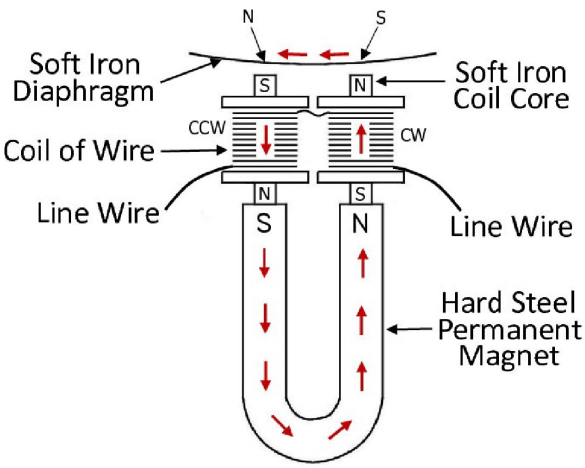

Fig. 6. ***Functional diagram of Bell's 1877 magneto telephone.***

including the opposite direction of the winding of the two coils. In retrospect, it is amazing that so much technical understanding is contained in this simple diagram, considering that Bell had been in a self-described mental fog [6].

Bell and Hubbard placed the first manufacturing order for commercial telephones with surprising speed in March 1877 [34, p. 138]. These telephones were constructed, as shown in Fig. 5, and had a simple box built around them. In early April, Williams erected a telephone line from his shop to his home, 3 mi away in East Somerville, MA, USA [16]. Watson connected a box telephone at each end of the line, and what would become the Bell System went into operation on April 4, 1877 [40, p. 105].

Hubbard formed the Bell Telephone Company during the summer of 1877, and Bell's magneto telephone was used exclusively for almost two years [28]. Of course, there were minor design changes in the box telephone during this period, but the only significant change was the

[8]The U-shaped magnet in the diagram is shown as a stack of four-plate magnets. The only significance of this detail is that Watson was able to get a stronger magnet this way rather than magnetizing a single bar magnet with the equipment available to him in Williams's shop. This construction was later changed to a solid bar magnet.

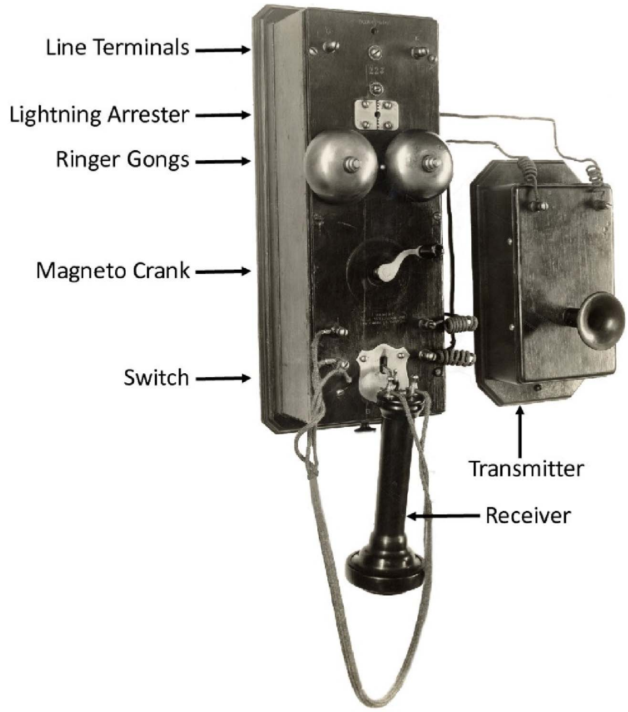

Fig. 7. ***Typical telephone set of late 1877–1878 (labels added). Courtesy of the AT&T Archives and History Center.***

practice of using two telephones at each station: a magneto box telephone for talking and a less efficient hand-held magneto telephone for listening (see Fig. 7). The hand-held telephone was designed in the spring of 1877 by William Channing and several colleagues associated with Brown University [23]. Approximately 6000 magneto box telephones (transmitters) were put in service during this period, along with a similar number of hand-held telephones (receivers) [25, p. 82].

VII. ELECTROMAGNETIC RECEIVERS

The magneto telephone did not survive long as a transmitter because it could not transmit over the longer distances envisioned for Bell's "grand system" of universal service [17]. Beginning in December 1878, the new Bell System began substituting a more powerful battery-powered resistance transmitter. At first, a new Blake single-contact transmitter was used, but multiple-contact transmitters followed, and they evolved into the common carbon-granule transmitter.

The magneto telephone did, however, survive as a receiver, and the cylindrical form persisted across manufacturers for almost 50 years. In Europe, during the late 1800s, a number of different shapes of magnets were used in attempts to improve the efficiency of the standard cylindrical receiver. These early receivers had names, such as the Phelps Crown receiver, the Goloubitzky telephone, the Gower receiver, and the Ader receiver. Because of the adequate sensitivity of the Bell-type instrument and increasing signal strength of newer transmitters, "few of

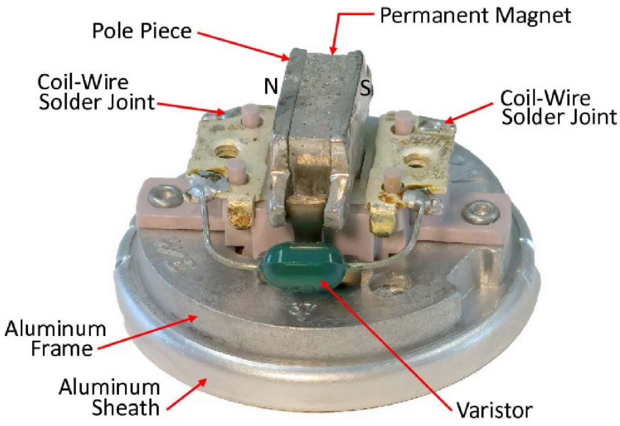

Fig. 8. ***Last receiver design (LA2) of the Bell System.***

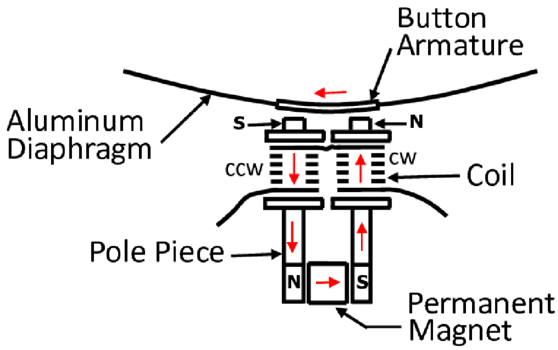

Fig. 9. ***Functional diagram of the LA2 receiver.***

these instruments offer any considerable advantage over the standard receiver" [42, p. 26]. There was an exception, however, that will be discussed in Section VIII.

The cylindrical hand-held receiver was eventually replaced by watch-case style receivers in handsets. These receivers operated on the same principle as the cylindrical receiver; the main difference being that the magnet was made in a small semicircular shape instead of a straight bar or horseshoe shape. As magnetic materials improved, even the semicircular form was replaced by small bars of powerful magnets. The last receiver designed by the Bell System, before its court-ordered divestiture, was so similar to the original Bell concept that it is worthy of a comparison. Fig. 8 shows this small LA2 receiver, which was designed for the *Trimline* telephone, and Fig. 9 shows a functional diagram of its working parts. The similarity between the functional diagram and Bell's original design (see Figs. 5 and 6) is striking.[9]

VIII. BALDWIN RECEIVER

One modification of the magneto telephone as a receiver was successful in increasing sensitivity, and its first patent was applied for in 1909 by Nathaniel Baldwin [1]. Two later patents describe improvements [2], [3]. Although Baldwin's instrument was never adopted by major telephone manufacturers, it found a niche market in headphones among early radio enthusiasts [44, various articles]. The novel feature of Baldwin's design was that it interchanged the location of the permanent magnet's pole pieces and the armature, putting the armature down the center of a single coil and the pole pieces outside of the coil. A diagram of this arrangement from Baldwin's first patent is shown in Fig. 10.

In the diagram, *18* is the coil, which has a flattened shape, and *25* is the wide-blade armature that goes down the center of the coil. The armature is pivoted in its center, and the pole pieces *19* and *20* provide polarization at both ends of the armature in a balanced manner. The pole pieces are attached to the ends of a U-shaped permanent magnet at *21* in the diagram. The armature is activated by a push rod attached to the sound membrane (diaphragm), and this arrangement is more clearly described for related designs in Section IX.

IX. SOUND-POWERED TELEPHONES

As with all the magneto telephones, the Baldwin instrument could be used both as a transmitter and a receiver. However, the balanced armature made the Baldwin design too fragile for rugged duty, such as military applications, where operation without an external power source would be very valuable. In 1933, Joseph Briggs applied for a patent on a transducer with a central armature that was clamped at one end and very rugged in construction. This patent was assigned to Radio Corporation of American (RCA) [19]. A sketch of the magnet and coil arrangement in the RCA transducer is shown in Fig. 11. In this design, two C-shaped permanent magnets of cobalt steel polarize upper and lower pole pieces of laminated silicon steel. These alloys have better hard-magnetic properties (high retentivity and high coercive force) and soft-magnetic properties (high permeability and low coercive force) than carbon steel and pure iron, respectively. With minor modifications, RCA produced sound-powered telephones with this transducer for the U.S. Army, U.S. Navy, and other services during World War II.

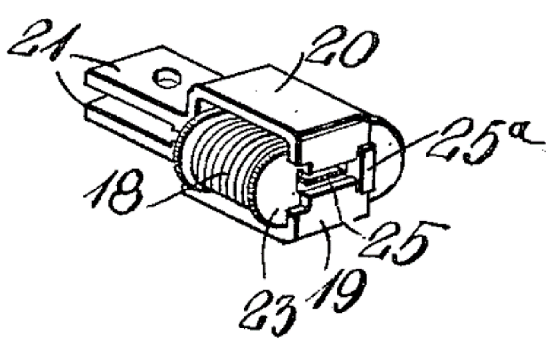

Fig. 10. ***Diagram from Baldwin's patent of central parts of his receiver design.***

[9]The varistor shunts high-voltage pulses around the receiver to eliminate switching noise (clicks), yet plays no role in the receiver's function.

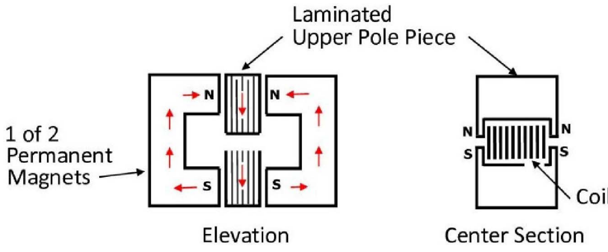

Fig. 11. ***Sketch of the magnet and coil arrangement in the RCA design.***

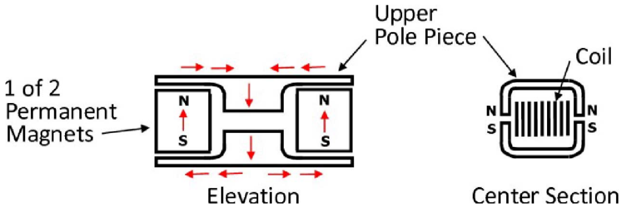

Fig. 12. ***Sketch of the magnet and coil arrangement in the USI design.***

Four years later, Arthur Turnbull and Herbert Warnke applied for a patent on a related clamped-armature transducer and assigned the patent to U.S. Instrument Corp. (USI) [35].[10] A sketch of the magnet and coil arrangement in the USI transducer is shown in Fig. 12. In this design, two bar-type permanent magnets of aluminum–nickel magnet alloy polarize upper and lower pole pieces that are formed from bent plates of silicon steel. The permanent magnets in the USI design are smaller than those in the RCA design, giving the USI design a lower profile. Smaller permanent magnets and bent-plate pole pieces made the USI design less expensive to fabricate than the RCA design.

A picture of the USI transducer is shown (face down) in Fig. 13 with labels being added. The armature is formed from a wide blade of silicon steel that is clamped between the pole pieces in the rear of this view and is not visible. The free end of the armature is connected to the aluminum diaphragm (also not visible) with a nonmagnetic bolt that acts as a push rod. A limit screw was provided to prevent the armature from being pushed down too far and sticking to the lower pole piece. This general layout for connecting the armature to the diaphragm is the same in all the sound-powered transducers, including the Baldwin receiver.

A functional diagram of the USI design is shown in Fig. 14. In transmitter operation, the high-pressure part of a sound wave pushes the free end of the armature close to the south pole of the lower pole piece such that the armature becomes magnetized with its north pole on this free end. Then, during the low-pressure part of the sound wave, the armature is pulled up near the north pole of the upper pole piece such that the armature becomes magnetized with its south pole on the free end. The changing magnetic field in the armature induces an electric current in the coil winding—magnetic induction—and the current carries the frequency and amplitude characteristics of the sound wave. A corrugated armature typically used in these transducers produces a broad resonance around 1200 Hz, in a useful range of the voice frequency spectrum, thus enhancing their sensitivity since both transmitter and receiver elements are the same.

USI was a small company and, by 1960, had only 15 employees [30, p. 3849]. During World War II, large manufacturing companies, such as Western Electric,

[10]There is an interesting connection between the RCA and USI designs. If Warnke was employed by the company to which he assigned his patents, then he worked for RCA during the period 1932–1934 and for USI from 1937 to at least 1960; at that time, he was the President of USI [30, p. 3849], [37], [38]. Thus, Warnke would have been employed at RCA working on sound-related devices during the time when Briggs developed the RCA design. This knowledge may have been in Warnke's possession when he applied for the USI design patent. Turnbull has no other related patents, and he described himself as an executive for a telephone parts manufacturer [36]. Thus, the USI design work may have been performed by Warnke.

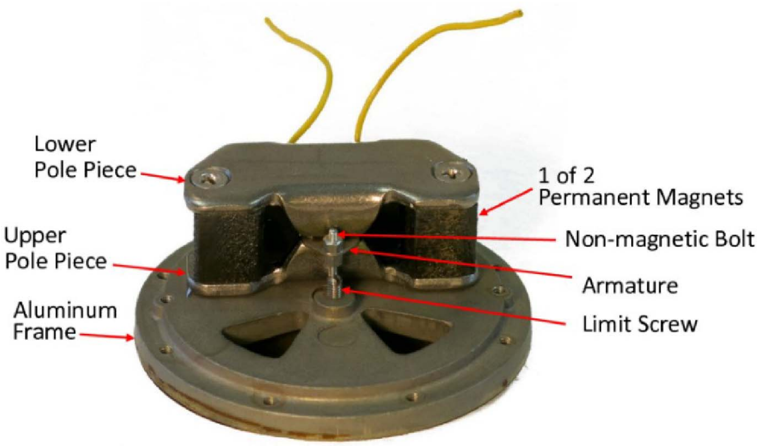

Fig. 13. ***USI transducer shown face down.***

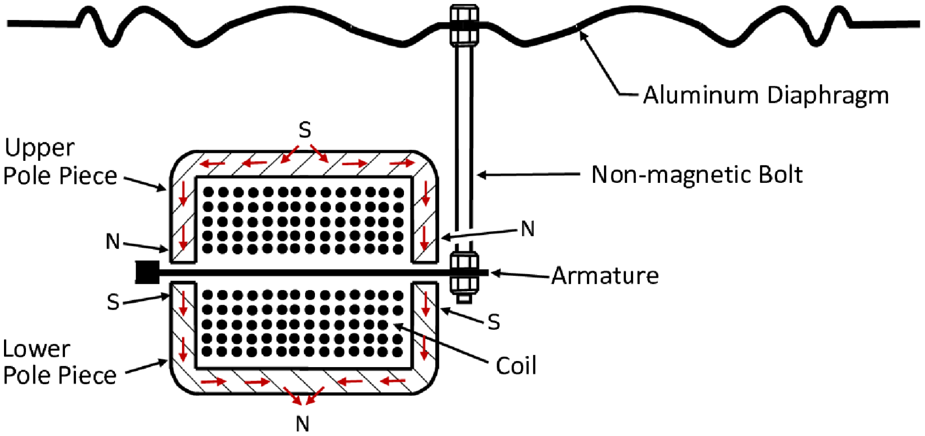

Fig. 14. ***Functional diagram of USI transducer.***

American Electric, and Stromberg-Carlson, produced variations of USI's design for military applications. The scale of this manufacturing was large, and on a battleship such as the USS Wisconsin, for example, there were more than 2000 of these instruments on a single ship connecting all of its battle stations [43].

Two current companies, Dynalec Corporation and Hose-McCann Communications, continue to manufacture USI's design for the U.S. Navy's H-203/U handset (see Fig. 15), which performs without any batteries or external power and has a useful range of over 30 mi [24], [26], [29]. The transducer element in these handsets is used as both a transmitter and a receiver—just like Bell's early magneto telephones—and sailors are known to have talked into either end of the handset successfully.[11] These two companies and many other manufacturers around the world make similar sound-power telephones for various industrial applications.

Fig. 15. ***U.S. Navy sound-powered H-203/U handset.***

X. RETROSPECTIVE

Looking back, prominent telephone historians have only provided cursory explanations of how the magneto telephone works. They overlooked that pivotal day of November 18, 1876, when Watson solved the magnetic mystery and ushered the telephone onto a fast track for commercialization [20, p. 52], [21, p. 206], [22, p. 44], [27, p. 161], [32, p. 37].

Casson, the earliest of these authors, insightfully forewarned contemporary observers of the new invention: "No one, literally, could understand how it worked." Consequently, many historians failed to make the subsequent connections between Bell's telephone and the later sound-powered telephones.

Bell's magneto telephone was a wonderful application of science, which took the energy in sound waves, converted it into electrical currents in a wire, and reversed the process at the other end—reproducing both pitch (frequency) and volume (amplitude) of the original sound. No battery or external source of power was needed. Magneto telephones were soon replaced as transmitters in commercial phones by more powerful battery-powered devices to operate over the longer distances needed for universal service. However, the electromagnetic principles proved to be so invariant to environmental conditions that such sound-powered telephones are still used today in critical applications, such as in ships, in mines, on ski slopes, and for other sites where outside power may fail or explosion-proof designs (utilizing no power source to produce a spark) might be required. Thus, Bell's magneto telephone provided the beginning of voice communications, and it did so without the use of outside power sources; this magneto method has proved to be a vital source of communications to this day. ■

[11] Like radio enthusiasts of the 1920s who used Baldwin receivers, today's crystal radio enthusiasts often use vintage sound-powered transducers as sensitive receivers (https://crystalradio.net/soundpowered/).

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REFERENCES

[1] N. Baldwin, "Telephone receiver," U.S.Patent 957 403, May 10, 1910; Application filed Jul. 1, 1909.
[2] N. Baldwin, "Telephone receiver," U.S. Patent 1 153 593, Sep. 14, 1915; Application filed Mar. 27, 1913.
[3] N. Baldwin, "Sound-producing device of the telephone-receiver type," U.S. Patent 1 581 155, Apr. 20, 1926; Application filed Jun. 14, 1922.
[4] A. G. Bell, *Letter to Family*. Library of Congress loc.gov, Alexander Graham Bell Family Papers, Nov. 23, 1874.
[5] A. G. Bell, *Letter to Gardner Hubbard*. Library of Congress loc.gov, Alexander Graham Bell Family Papers, Jun. 2, 1875.
[6] A. G. Bell, *Letter to Family*. Library of Congress loc.gov, Alexander Graham Bell Family Papers, Jun. 30, 1875.
[7] A. G. Bell, *Letter to Gardner Hubbard*. Library of Congress loc.gov, Alexander Graham Bell Family Papers, Aug. 14, 1875.
[8] A. G. Bell, *Experiments*, Notebook vol. I. Library of Congress loc.gov, Alexander Graham Bell Family Papers, 1875.
[9] A. G. Bell, *Electrical Experiments*, Notebook vol. II. Library of Congress loc.gov, Alexander Graham Bell Family Papers, 1876.
[10] A. G. Bell, *Electrical Experiments*, Notebook vol. III. Library of Congress loc.gov, Alexander Graham Bell Family Papers, 1876.
[11] A. G. Bell, *Experimental Note Book*, Notebook vol. IV. Library of Congress loc.gov, Alexander Graham Bell Family Papers, 1876.
[12] A. G. Bell, "Improvement in telegraphy," U.S. Patent 174 465, Mar. 7, 1876; Application filed Feb. 14, 1876.
[13] A. G. Bell, *Letter to Family*. Library of Congress loc.gov, Alexander Graham Bell Family Papers, Nov. 26, 1876.
[14] A. G. Bell, *Letter to Mabel Hubbard*. Library of Congress loc.gov, Alexander Graham Bell Family Papers, Dec. 6, 1876.
[15] A. G. Bell, "Improvement in electric telegraphy," U.S. Patent 186 787, Jan. 30, 1877; Application filed Jan. 15, 1877.
[16] A. G. Bell, *Letter to Mabel Hubbard*. Library of Congress loc.gov, Alexander Graham Bell Family Papers, Apr. 6, 1877.
[17] A. G. Bell, *To the Capitalists of the Electric Telephone Company*. Courtesy of the AT&T Archives and History Center, Mar. 25, 1878.
[18] A. G. Bell, *Deposition of Alexander Graham Bell*. Apr. 4, 1892. Circuit Court of the United States, District of Massachusetts (Printed by the American Bell Telephone Company, Boston, MA, USA, 1908).
[19] J. Briggs, "Telephone," U.S. Patent 2 060 607, Nov. 10, 1936; Application filed Oct. 4, 1933.
[20] J. Brooks, *Telephone: The First Hundred Years*. New York, NY, USA: Harper & Row, 1975.
[21] V. Bruce, *Bell: Alexander Graham Bell and the Conquest of Solitude*. Boston, MA, USA: Little, Brown & Co., 1973. Reprinted by Cornell Univ. Press, Ithaca, NY, USA.
[22] H. N. Casson, *The History of the Telephone*. Chicago, IL, USA: A. C. McClurg & Co., 1910.
[23] W. F. Channing, *Letter to Bell*. Library of Congress loc.gov, Alexander Graham Bell Family Papers, Jul. 16, 1877.
[24] *Sound Powered Handset H-203/U*, Dynalec Corp., Sodus, NY, USA, 2011, a dated brochure.
[25] M. D. Fagen, Ed. *A History of Engineering and Science in the Bell System: The Early Years (1875–1925)*. Indianapolis, IN, USA: Bell Telephone Laboratories, 1975.
[26] *Hose-McCann Communications*. [Online]. Available: https://www.hose-mccann.com/
[27] D. A. Hounshell, *Two Paths to the Telephone*, vol. 244. Scientific American, Jan. 1981.
[28] G. G. Hubbard, *Declaration of Trust* (U.S. Patent Office on Jul. 28, 1877) (Courtesy of the AT&T Archives and History Center), 1877.
[29] MIL-DTL-15514G(SH). 20016. *Detail Specification, Telephone Equipment, Sound Powered Telephone*. Washington, DC, USA: Department of the Navy, Jan. 19, 2016.
[30] National Academy of Sciences. *Industrial Research Laboratories of the United States*, 11th ed. National Research Council, Publication 844, 1960.
[31] G. B. Prescott, *Bell's Electric Speaking Telephone: Its Invention, Construction, Application, Modification and History*. New York, NY, USA: D. Appleton & Co., 1884.
[32] F. L. Rhodes, *Beginnings of Telephony*. New York, NY, USA: Harper. Reprinted by Ayer Co., Salem, NH, USA, 1929.
[33] W. Thomson, *Opening Address*, Nature vol. 14, Sep. 14, 1876.
[34] R. J. Tosiello, "The birth and early years of the bell telephone system, 1876–1880," Ph.D. dissertation, Boston Univ., Boston, MA, USA, 1971.
[35] A. Turnbull, Jr., and H. R. Warnke, "Telephone instrument," U.S. Patent 2.245 511, Jun. 10, 1941; Application filed Dec. 4, 1937.
[36] A. Turnbull, Jr., *Sixteenth Census of the United States for Far Hills*. Somerset County, NJ, USA: U.S. Census, 1940.
[37] H. Warnke, "Sound translating device," U.S. Patent 2 085 721, Jun. 29, 1937; Application filed Oct. 29, 1932.
[38] H. Warnke, "Sound translating device," U.S. Patent 2 123 640, Jul. 12, 1938; Application filed Apr. 28, 1934.
[39] T. A. Watson, "How Bell invented the telephone," *Trans. Amer. Inst. Elect. Eng.*, vol. 34, no. 1, 1915.
[40] T. A. Watson, *Exploring Life: The Autobiography of Thomas A. Watson*. New York, NY, USA: D. Appleton & Co., 1926.
[41] T. A. Watson, *The Birth and Babyhood of the Telephone*. New York, NY, USA: American Telephone and Telegraph, Information Department, 1940.
[42] H. L. Webb, *The Telephone Hand-Book*, New Edition. Chicago, IL, USA: Electrician Publishing Co., 1902.
[43] Western Electric, "Nerve system for battlewagons," advertisement in Life Magazine, Sep. 1944.
[44] J. A. White, Ed., *The Wireless Age*. New York, NY, USA: Wireless Press, Nov. 1922–Jan. 1923

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