Lab 3a: Bell Telephone Laboratory

PURPOSE

To learn about Alexander Graham Bell's ideas concerning the harmonic telegraph and his method of speaking and listening at a distance.

LAB OVERVIEW

In this laboratory, you will (1) read about the original Bell Patent of 1876, (2) use harmonic telegraph transmitters, (3) use harmonic telegraph receivers, (4) learn how to connect two telephones, (5) design a telephone network, and (6) operate an early 20th century hotel switchboard.

The first half of the laboratory will give you the opportunity to learn about the harmonic telegraph transmitter and receiver developed by Bell. The second half of the laboratory will give you an opportunity to test a simple telephone network, and to design a more complex one. First you will connect a 1910-era "candlestick" telephone to a modern touch-tone desk phone. The 1910 telephone uses Bell's patented receiver and Edison's patented "carbon-granule" transmitter. The telephones are wired in series with a battery that allows current to flow in a large current loop. Later in the laboratory you will design a telephone network that connects 4 telephones together including with three phones on a party line.

INTRODUCTION

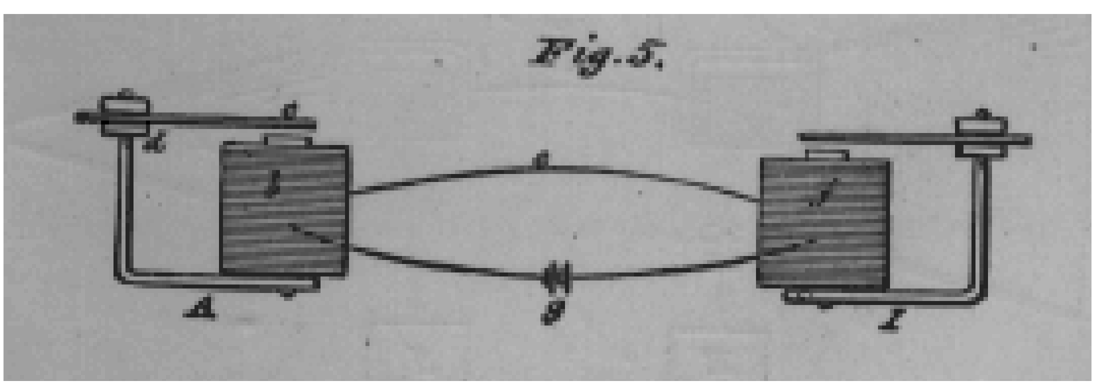
History

In 1876, America's centennial year, Bell demonstrated his new invention at the Philadelphia Exposition. Bell's telephone used a transmitter and a receiver connected in series with a battery. The transmitter and battery converted sound waves into an undulating current, and a receiver at the other end of the Exhibition Hall converted the undulating current back into sound. ("Undulating" is Bell's term for what today we refer to as oscillating.) Both the transmitter and receiver made use of a diaphragm. The telephone that he demonstrated in 1876 was based on earlier electromagnetic telegraph receivers and transmitters using tuned reeds to allow many messages to be sent over a single wire.

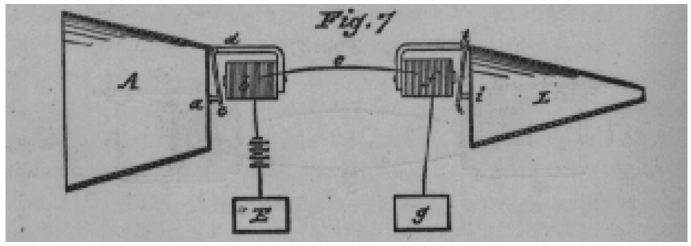
Alexander Graham Bell in 1875

Harmonic Telegraph

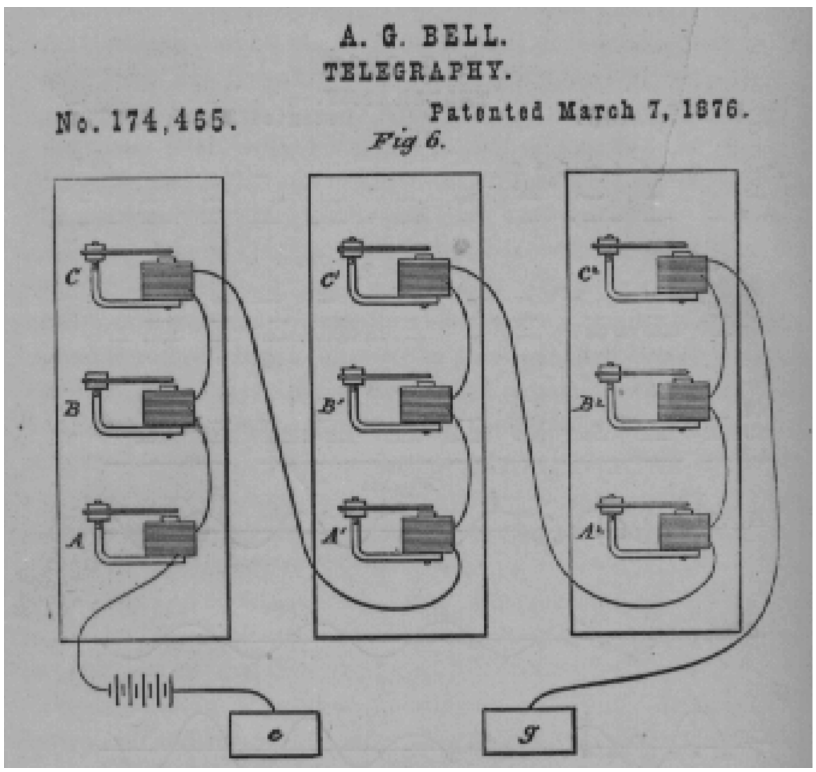
You begin the laboratory with an experiment involving the harmonic telegraph. Here you will explore tone and its relationship to frequency. You will make measurements of the undulating current produced when one or the other of two steel reeds is plucked and vibrates at a given frequency. The reeds can be tuned by means of adjusting their lengths from the clamped to the free end. The up-and-down vibration of each reed is transformed into an undulating current. The frequency (F) will be determined by measuring the duration of time to complete one period (T) of an undulation. The frequency is given by the reciprocal of the period. This is expressed by the formula, F = 1/T. You will observe also in subsequent experiment the transformation of the undulating current back into a sound. Here the undulating current is derived from a tunable function generator. When the frequency of the function generator is tuned to the frequency of the reed, it will "sing."



Bell Transmitter/Bell Receiver



Bell's Telephone concept based on diaphragm



Three different frequencies (A, B, C) on one continuous circuit

Telephone Network

You will then turn your attention to a telephone network consisting of two telephones and a battery connected in series. The telephones form an intercom that operates without the assistance of a telephone company. When one speaks into either of the two telephone transmitters the current in the loop is changed in proportion to the pressure of the sound waves. The device that causes this action is the carbon-granule transmitter. The diaphragm in the transmitter vibrates in synchrony with the sound waves, pressing together or pulling apart a small volume of carbon granules. As the granules are compressed or released their resistance decreases or increases. The varying resistance is converted to varying current according to Ohm's Law ($I = V / R$). (The idea of using of carbon to convert sound into resistance was patented by Thomas Edison in 1877. The Bell Telephone Company later took ownership of the Edison patent.) The varying current is converted back into sound waves by each of the telephone receivers. The varying current produces a varying magnetic force on each of the receiver's metal diaphragms causing them to move back and forth producing sound.

BACKGROUND

The equation governing the relationship between current, voltage and resistance is:

$V = I R$

In the equation above the variables have the following meanings:

I is the current and is measured in Amperes, A

R is the resistance and is measured in Ohms, Ω

V is the voltage and is measured in Volts, V

The equation to determine the relationship between period and frequency is:

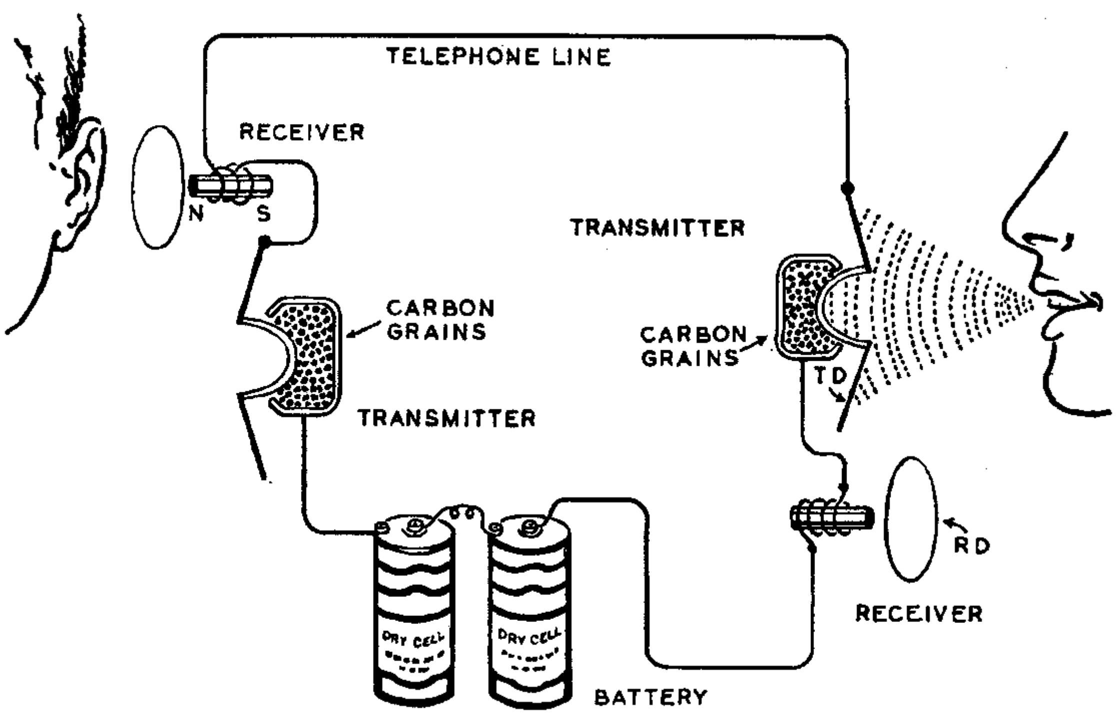
$F = 1 / T$

In the equation above the variables have the following meanings:

F is the frequency in cycles per second (also known as Hertz)

T is the period of one cycle or undulation in seconds

Below is a schematic diagram of a circuit that connects two telephones. The phone company provides the battery and the wire connections.



Important Equations

Variables

I = the current and is measured in Amperes, A

R = the resistance and is measured in Ohms, Ω

V = the voltage and is measured in Volts, V

F = the frequency in cycles per second (also known as Hertz)

T = the period of one cycle or undulation in seconds

Equations

Ohm's Law

$V = I R$

Relationship between frequency and period is:

$F = 1 / T$

Notes

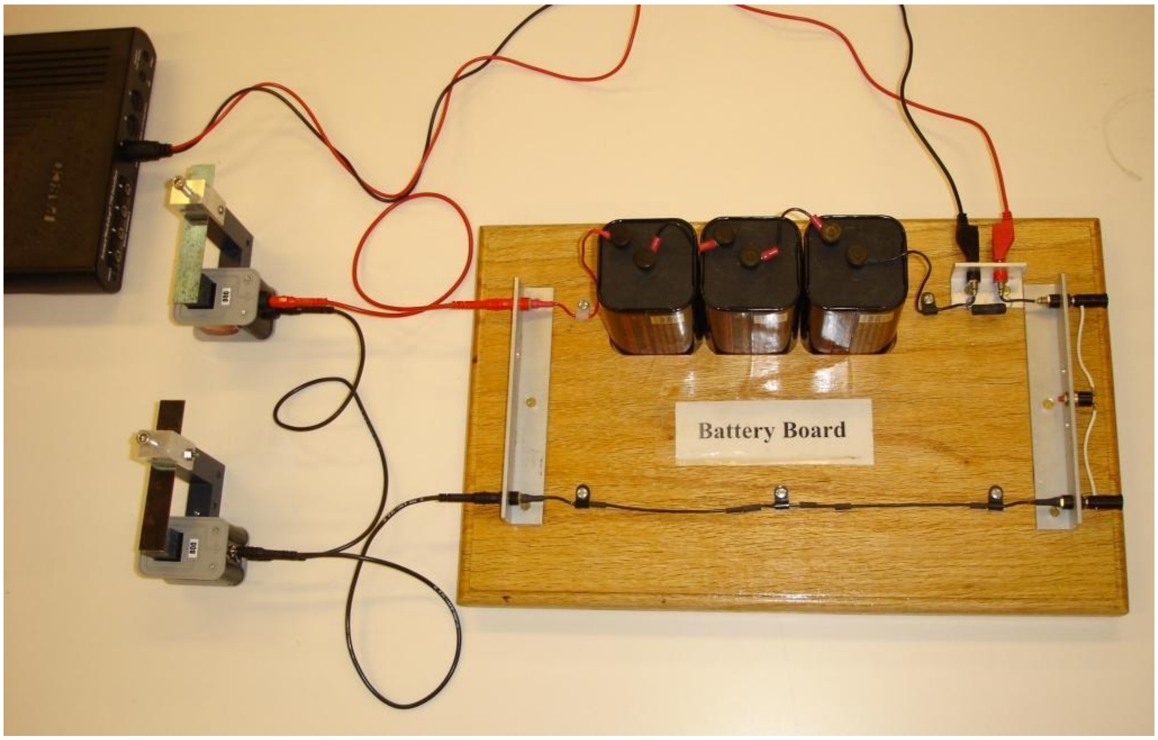
1. For most parts of the course, we use historical units, e.g. lbs and in
2. Use consistent units when adding and multiplying.
3. Percent error = *100% ** (*experimental - theoretical) /(theoretical)*

LABORATORY PROCEDURE

Read the introduction and background to this lab before attempting to perform it.

Part 1 – Original Bell Patent of 1876

The original Bell patent of 1876 is at the end of this document. Read the portions that are in bold print. In the patent Bell describes the advantages of undulatory current over pulsatory current for sending messages. You need only read about the undulatory method that we explore in the following experiments.



Transmitter Apparatus

Part 2 – Harmonic Telegraph Transmitters

In this part you will use Bell-type transmitters to convert the tone of a vibrating reed into a time-varying current. The current is determined automatically by The Capstone data acquisition software with a computation using Ohm's law. The measured quantity is the voltage across a 10-Ohm resistor. The resistor is in series with two transmitters and the battery. You will determine how much DC current flows in the circuit when the battery is connected, and how much AC current is produced when each reed vibrates. You will also determine the period of each undulation and from that calculate the frequency of the undulation for each of the two transmitters.

1. Two harmonic telegraph transmitters are used in this experiment. Note that the two transmitters have reeds of different lengths. Pluck each one and hear that they are at different frequencies. The shorter reed will vibrate at a higher frequency than the longer reed. Connect the coils associated with each transmitter in series, and then connect the remaining coil leads to the red and black terminals of the "Battery Board" (see figure above). The terminals at the right-most end of the "Battery Board" are connected together using a wire and a push-button switch. The transmitters and wire/switch are all connected in series with the 18-volt battery.

2. Note that there are red and black leads connected to the "Battery Board" across the 10-Ohm resistor. This is where the Capstone program will measure voltage and compute current using Ohm's law. Open Capstone worksheet "Phone.cap" from the "cee102_262" folder on the desktop.

3. Before you begin taking data, press and hold the push-button switch while closely observing each of the reeds. You should note that the reeds deflect downward very slightly due to the current flowing in the circuit. Current flowing in the coil of wire turns the core into an electromagnet which attracts the steel reed.

4. Now start your measurement by selecting "Continuous Mode" from the pull down menu near the bottom left of the screen. Then click the "Record" button to the immediate left to record data. Press and hold the push-button on the "Battery Board" to complete the circuit. You should see the current increase in the graph window that records current versus time. While holding the push-button down, pluck a reed **forcefully** several times (you might send Morse code for SOS by plucking dot-dot-dot dash-dash-dash dot-dot-dot). Do this again with the other reed. Release the push-button on the "Battery Board" and end the recording by clicking the "Stop" button.

5. Examine the data closely by placing the cursor over the plot and zooming with the mouse wheel. There will be "bursts" of high amplitude undulations (oscillations) along the plateau of the plot. You can also place the cursor over the scaling of individual axis to rescale one axis at a time and make the data easier to interpret.

6. How large is the nearly steady current (dc)? How large is the current in the burst (ac)? Determine the strength of the dc or ac current by using the cross-hair feature that should be visible on the graph. Zoom out if it is not visible. Click and

drag the cross-hair to various parts of the plot, and it will display plot coordinates. Move the horizontal cross-hair to the steady portion of the graph and record the Y value that is displayed. The Y value is in given in Amps. **Check with an AI before continuing.** Next, drag the center of the cross hair into proximity of a burst, and zoom until full undulations are scaled to the graph. Move the cross-hair to the top of the ac burst and record its maximum value. Move to the bottom of the burst to determine the minimum value. The difference between maximum and minimum is the AC intensity or peak-to-peak amplitude of the burst. Make sure that you determine the AC intensity for a burst corresponding to each of the reeds. Typically the AC intensity for each reed will be about the same in magnitude even though the frequencies are quite different.

7. How long does each undulation (oscillation) last? Or in other words, what is the period of the undulation? To estimate the period of a single undulation, drag the center of the cross hair into proximity of a burst. Zoom in until individual undulations are discernible. **Check with an AI before moving on.** Rescale the axis and zoom as needed to clearly display about 15 distinct undulations. Drag the cross-hair to the top of an early undulation, and record the time setting. Count 10 peaks later, drag the cross-hair to the top of the later undulation, and record the time again. Figure out the time that it takes for 10 undulations to occur. Compute the frequency by dividing that total time by 10 and inverting it according to formula $F = 1 / T$, where F is the frequency and T is the period of 1 undulation. We use 10 periods here to improve the precision of the measurement. Make sure that you do this for bursts corresponding to each reed. The two frequencies are needed to test the same devices as telegraph receivers. **Check these values with an AI before moving on.**
8. If you want to save the Capstone worksheet, save it with a different name in the desktop folder 'CEE 102 Lab Group Data'.

Part 3 – Harmonic Telegraph Receivers

In this part you will use the same coil-core-reed units as in the previous part except that now they will be receivers which serve to convert the undulating current back into a tone. The current in this part is provided by a tunable signal-generator. As you tune the signal-generator to the characteristic frequency of each reed you should hear that reed "sing." When this happens the other reed, which is tuned to a different frequency, should be quiet. You should observe that the frequency that you measured in Part 2 is the same frequency displayed on the function generator that causes a reed to sound. Bell used these reed-based devices to both send and receive telegraph signals.

1. Get assistance from your lab instructor. Disconnect the leads going to the computer from the "Battery Board**." (It is essential that you disconnect the computer interface, otherwise you might fry the computer.)** Connect the red and black terminals of the function generator to the red and black leads of the 10-ohm resistor on the battery board.

2. Turn on the function generator with the amplitude knob to maximum. Set the range to 0.1-1.0 KHz. Turn the frequency knob so that the frequency is near the values that you computed in Part 2.

3. Depress and hold the push-button switch while you adjust the frequency of the function generator and listen closely – you should see a reed vibrate and hear it "sing" when you match its frequency. The other reed will be still. Use the push button to send a Morse code signal like dot-dot-dot. Verify that you can repeat this with the other reed.

Note: Bell conceived of using receiver/transmitter pairs tuned to the same frequency to send telegraph messages. Using many pairs of receiver/transmitters tuned to different frequencies would allow for multiple messages to be sent over a single telegraph wire. (The idea of using frequency-specific messages is the basis of the modern method known as frequency multiplexing which allows for channel selection in broadcast radio and television, and in some modern computer and information networks.) Bell also reasoned that it would be possible to combine all frequencies together so that the sound of voice could be sent instead. This was the idea that led to the telephone.

Part 4 – Connecting Two Telephones

1. **VERY IMPORTANT – MAKE SURE THAT YOU DISCONNECT THE FUNCTION GENERATOR AND THE RECEIVER/TRANSMITTERS FROM "BATTERY BOARD" BEFORE PROCEEDING.**

2. Using the antique candlestick telephone and the modern touch-tone telephone set up a simple point-to-point network. To do this the telephones are wired in series by connecting two wires from each phone to the terminals on the left and the right side of the "Battery Board." **None of the leads should be directly connected to the 10-ohm resistor.** Make sure that the modern phone is set to "LINE 1." Observe that the 18-volt battery is wired in series with the two telephones. In commercial

telephone networks the battery is located at the central station. The central station in Princeton is the brick building that is to the left of the E-Quad as you face the main entrance.

3. Pick up both telephone receivers. Have a group member speak into one of the transmitters. If the circuit is complete you should be able to have a telephone conversation, and you won't get a bill for service.

4. Disconnect the candlestick phone and connect the wall phone in its place. This time, before picking up the receivers, turn the crank on the wall phone to ring the modern phone. After it rings, pick up both receivers and verify that you can have a conversation. The crank adds a high-voltage low-frequency AC signal on the line. This AC signal is what drives the telephone ringer.

Part 5 – Designing a Telephone Network

For this part of the lab, you will experiment with different arrangements of modern telephones to accomplish your goals.

1. Wire up an intercom, using Line 1 on the modern black phone, connected to the modern white phone. (Line 1 is Red/Green, Line 2 is Black/Yellow). Use two 9-volt batteries in series as the power source for the current loop. As in Part 4, verify that the intercom works. **Show the intercom to your lab instructor and make a sketch of the circuit for your laboratory report. Check with an AI before moving on.**

2. Next wire up a party line involving three phones. Here the black phone is the host, which is connected to the white phone and the green phone. Verify that all three phones will work at the same time. Party lines were commonplace in rural America before the dial and switching relays were introduced in 1919. **Make a sketch of your circuit and show it to your AI.**

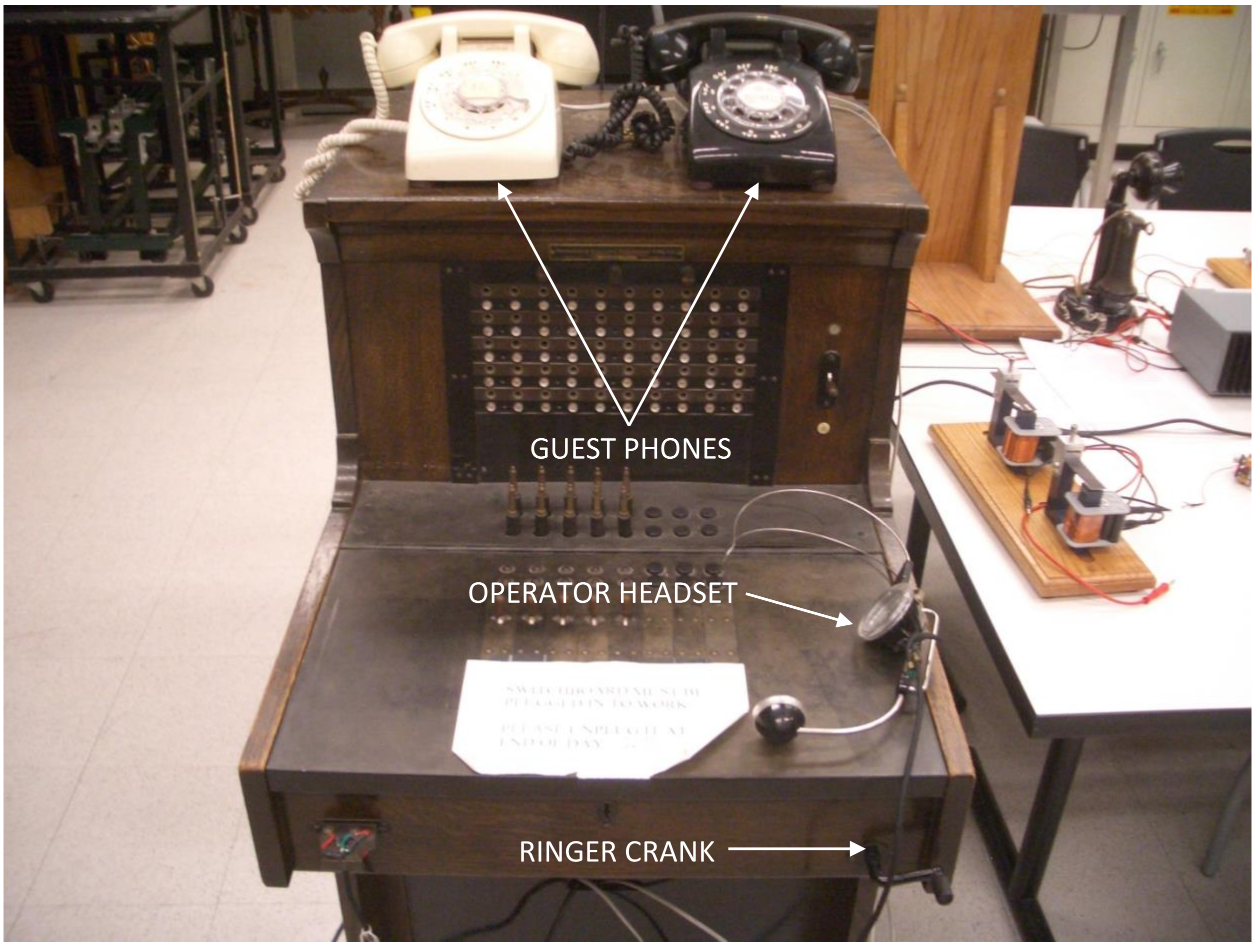
3. Finally, wire up a central station, using the black phone as the central station. Line 1 should connect to the white phone, which should connect to the green phone. Line 2 should connect to the blue phone. Make a sketch of your circuit.

   Important note: For this case, a battery must be in series with Line 1, and another battery is needed in series with Line 2.

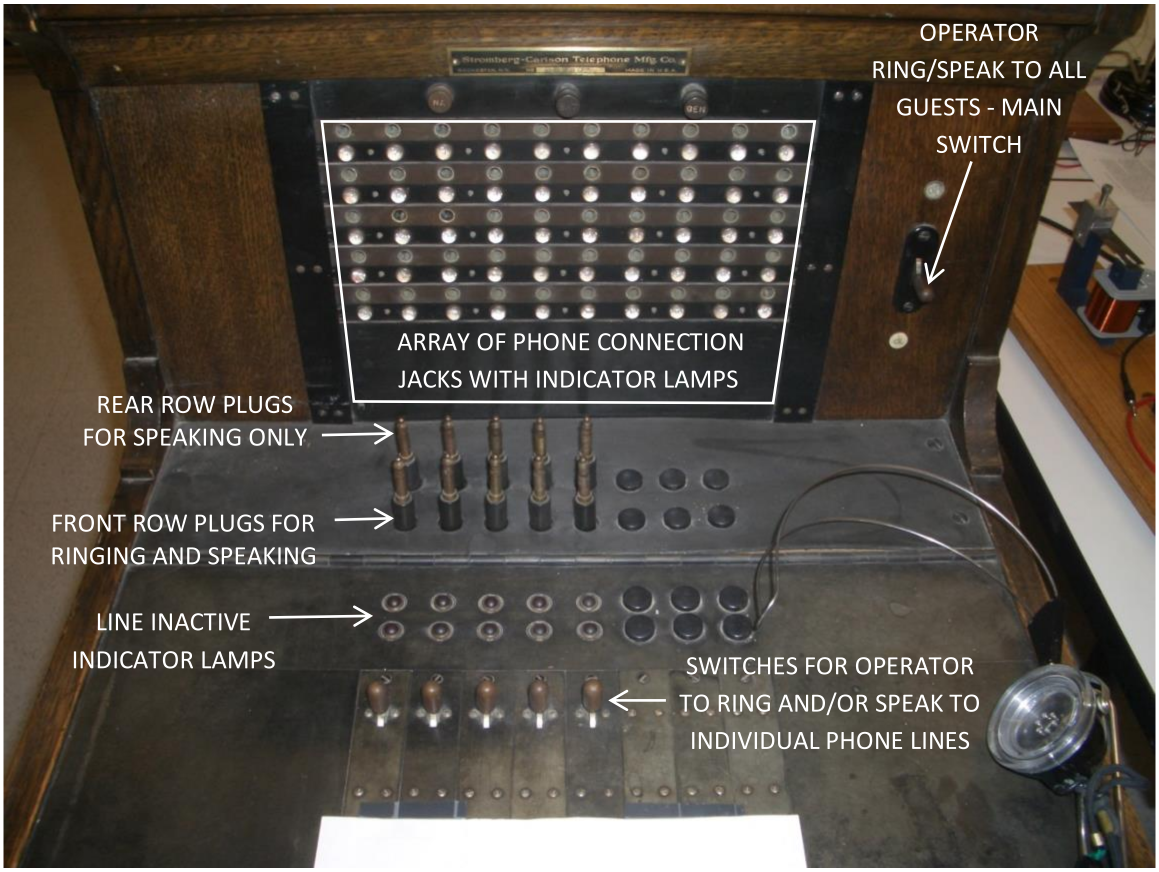
Part 6 – Operate an early 20th century hotel switchboard

For this final part of the lab, you will operate an early 20th century hotel switchboard to experience early switching technology.

The image below shows the switchboard with guest phones. **Note that these two phones represent only two of potentially many more**. **Also note that one of the phone lines in the array would be connected to a central station outside the hotel to place or receive outside calls, and the central station would have a switchboard as well.** Also shown are the operator's headset and ringer crank. To fully appreciate this antique, three people should participate; one each on the guest phones and one operator. Your instructor can participate if necessary.



In the next image, the detailed parts of the switchboard are labeled. **Note that the plugs and switches are arranged in columns of two plugs and one switch in each of five columns. The two plugs and single switch in an individual column only work in conjunction with one another. DO NOT USE THE FAR LEFT COLUMN AS IT DOES NOT WORK PROPERLY.**



THE SWITCHBOARD MUST BE PLUGGED INTO A POWER STRIP OR WALL RECEPTACLE TO OPERATE.

Before starting, all switches should be placed in the center neutral position. Note the row of three buttons above the array of phone connection jacks. Button "NA" should be pushed in, and buttons "BAT" and "GEN" should be pulled outward.

Reference the above images to carry out the operations detailed in the following instructions.

Operator calls all guests to make an announcement. For example, hotel fire!

First, both guests should pick up. Note that lamps 22 and 23 illuminate indicating the active phone lines. The guests should now hang up.

While wearing the operator's headset, the operator holds the main switch down while rapidly turning the ringer crank. The guest phones ring, and the operator releases the main switch. The guests pick up, and the guest phone indicator lamps illuminate. The operator pushes the main switch to the up position (no need to hold it). Operator and guests can now all speak with one another. Hang up and return the main switch to the center neutral position to finish.

Guest calls operator to place a call to the other guest. Note that either guest phone could be considered an outside line as well.

One of the guests should pick up to connect to the operator. The lamp for the active line illuminates (either line 22 or 23). The operator chooses one of the **rear row** plugs (but not from the far left column), pulls it up, and plugs it into the jack above the active lamp. The operator uses the switch **in the same column as the chosen plug** to connect to the guest by pushing the switch away to the rear position. The guest and operator can now speak with one another.

The guest asks to be connected to the other guest. The operator uses the **front row** plug **in the same column** and plugs it into the jack for the other guest's phone (jack 22 or 23 depending on which guest initiated the call). The operator now pulls the switch from the rear position and holds it fully forward while rapidly turning the ringer crank. The other guest's phone rings, and the operator releases the switch. The guest picks up, and the two guest phones are connected. The operator can join the guests' conversation by placing the switch back in the rear position, but must return the switch to the center neutral position to properly monitor line activity.

When the guests finish their conversation and hang up, the line inactive indicator lamps illuminate. This prompts the operator to remove the plugs from the jacks.

This concludes the switchboard activity. **Please unplug the switchboard from line power.**

UNITED STATES PATENT OFFICE.

ALEXANDER GRAHAM BELL, OF SALEM, MASSACHUSETTS.

IMPROVEMENT IN TELEGRAPHY.

Specification forming part of Letters Patent No. 174,465, dated March 7, 1876; application filed February 14, 1876.

To all whom it may concern:

(1) Be it known that I, ALEXANDER GRAHAM BELL , of Salem, Massachusetts, have invented certain new and useful Improvements in Telegraphy, of which the following is a specification:--

In Letters Patent granted to me April 6, 1875, No. 161,739, I have described a method of, and apparatus for, transmitting two or more telegraphic signals simultaneously along a single wire by the employment of transmitting instruments, each of which occasions a succession of electrical impulses differing in rate from the others; and of receiving instruments, each tuned to a pitch at which it will be put in vibration to produce its fundamental note by one only of the transmitting instruments; and of vibratory circuit-breakers operating to convert the vibratory movement of the receiving instrument into a permanent make or break (as the case may be) of a local circuit, in which is placed a Morse sounder, register, or other telegraphic apparatus. I have also therein described a form of autograph-telegraph based upon the action of the above-mentioned instruments.

In illustration of my method of multiple telegraphy I have shown in the patent aforesaid, as one form of transmitting instrument, an electro-magnet having a steel-spring armature, which is kept in vibration by the action of a local battery. This armature in vibrating makes and breaks the main circuit, producing an intermittent current upon the line wire. I have found, however, that upon this plan the limit to the number of signals that can be sent simultaneously over the same wire is very speedily reached; for, when a number of transmitting instruments, having different rates of vibration, (2) are simultaneously making and breaking the same circuit, the effect upon the main line is practically equivalent to one continuous current.

In a pending application for Letters Patent, filed in the United States Patent Office February 25, 1875, I have described two ways of producing the intermittent current -- the one by actual make and break of contact, the other by alternately increasing and diminishing the intensity of the current without actually breaking the circuit. The current produced by the latter method I shall term, for distinction sake, a pulsatory current.

My present invention consists in the employment of a vibratory or undulatory current of electricity in contradistinction to a merely intermittent or pulsatory current, and of a method of, and apparatus for, producing electrical undulations upon the line-wire.

The distinction between an undulatory and a pulsatory current will be understood by considering that electrical pulsations are caused by sudden or instantaneous changes of intensity, and that electrical undulations result from gradual changes of intensity exactly analogous to the changes in the density of air occasioned by simple pendulous vibrations. The electrical movement, like the aerial motion, can be represented by a sinusoidal curve or by the resultant of several sinusoidal curves.

Intermittent or pulsatory and undulatory currents may be of two kinds, accordingly as the successive impulses have all the same polarity or are alternately positive and negative.

The advantages I claim to derive from the use of an undulatory current in place of merely intermittent one are, first, that a very much larger number of signals can he transmitted simultaneously on the same circuit; second, that a closed circuit and single main battery may be used; third, that communication in both directions is established without the necessity of special induction-coils; fourth, that cable despatches may be transmitted more rapidly than by means of intermittent current or by the methods at present in use; for, as it is unnecessary to discharge the cable before a new signal can he made, the lagging of cable signals is prevented; fifth, and that as the circuit is never broken a spark-arrester becomes unnecessary.

(3) It has long been known that when a permanent magnet is caused to approach the pole of an electro-magnet a current of electricity is induced in the coils of the latter, and that when it is made to recede a current of opposite polarity to the first appears upon the wire. When, therefore, a permanent magnet is caused to vibrate in front of the pole of an electro-magnet an undulatory current of electricity is induced in the coils of the electro-magnet, the undulations of which correspond, in rapidity of succession, to the vibrations of the magnet, in polarity to the direction of its motion, and in intensity to the amplitude of its vibration.

That the difference between an undulatory and an intermittent current may be more clearly understood I shall describe the condition of the electrical current when the attempt is made to transmit two musical notes simulataneously -- first upon the one plan and then upon the other. Let the interval between the two sounds be a major third; then their rates of vibration are in the ratio of 4 to 5. Now, when the intermittent current is used the circuit is made and broken four times by one transmitting-intsrument in the same time that five makes and breaks are caused by the other. A and B, Figs. 1, 2, and 3, represent the intermittent currents produced, four impulses of B being made in the same time as five impulses of A. c c c, &c., show where and for how long time the circuit is made, and d d d, &c., indicate the duration of the breaks of the circuit. The line A and B shows the total effect upon the current when the transmitting-instruments for A and B are caused simultaneously to make and break the same circuit. The resultant effect depends very much upon the duration of the make relatively to the break. Fig. 1 the ratio is as 1 to 4; in Fig. 2, as 1 to 2; and in Fig. 3 the makes and breaks are of equal duration. The combined effect A and B, Fig. 3, is very nearly equivelent to a continuous current.

When many transmitting instruments of different rates of vibration are simultaneously making and breaking the same circuit the current upon the main line becomes for all practical purposes continuous.

Next, consider the effect when an undulatory current is employed. Electrical undulations, induced by the vibration of a body capable of inductive action, can be represented graphicvally, without error, (4) by the same sinusoidal curve which expresses the vibration of the inducing body itself, and the effect of its vibration upon the air; for, as above stated, the rate of oscillation in the electrical body -- that is, to the pitch of the sound produced. The intensity of the current varies with the amplitude of the vibration -- that is, with the loudness of the sound; and the polarity of the current corresponds to the direction of the vibrating body -- that is, to the condensations and rarefactions of air produced by the vibration. Hence, the sinusoidal curve A or B, Fig. 4, represents, graphically, the electrical undulations induced in a circuit by the vibration of a body capable of inductive action.

The horizontal line *a d e f,* &c., represents the zero of current. The elevation *b b b,* &c., indicate impulses of positive electricity. The depressions *c c c,* &c., show impulses of negative electricity. The vertical distance *b d* or *c f* of any portion of the curve from the zero line expresses the intensity of the positive or negative impulse at the part observed, and the horizontal distance *a a* indicates the duration of the electrical oscillation. The vibrations represented by the sinusoidal curves B and A, Fig. 4, are in the ratio aforesaid, of 4 to 5 -- that is, four oscillations of B are made in the same time as five oscillations of A.

The combined effect of A and B, when induced simultaneously on the same circuit, is expressed by the curve A+B, Fig. 4, which is the algebraic sum of the sinusiodal curves A and B. This curve A+B also indicates the actual motion of the air when the two musical notes considered are sounded simultaneously. Thus, when electrical undulations of different rates are simultaneously induced in the same circuit, an effect is produced exactly analogous to that occaisioned in the air by the vibration of the inducing bodies. Hence, the co-existence upon a telegraphic circuit of electrical vibrations to different pitch is manifested, not by the peculiarities in the shapes of the electrical undulations, or, in other words, by the peculiarities in the shapes of the curves which represent those undulations.

There are many ways of producing undulatory currents of electricity, dependent for effect upon the vibrations or motions of bodies (5) capable of inductive action. A few of the methods that may be employed I shall here specify. When a wire, through which a continuous current of electricity is passing, is caused to vibrate in the neighborhood of another wire, an undulatory current of electricity is induced in the latter. When a cylinder, upon which are arranged bar-magnets, is made to rotate in front of the pole of an electro-magnet, an undulatory current is induced in the coils of the electro-magnet.

Undulations are caused in a continuous voltaic current by the vibration of motion of bodies capable of inductive action ; or by the vibration of the conducing-wire itself in the neighborhood of such bodies. Electrical undulations may also be caused by alternately increasing and diminishing the resistance of the circuit, or by alternately increasing and diminishing the power of the battery. The internal resistance of a battery is diminished by bringing the voltaic elements nearer together, and increased by placing them further apart. The reciprocal vibration of the elements of a battery, therefore, occasions an undulatory action in the voltaic current. The external resistance may also be varied. For instance, let mercury or some other liquid form part of a voltaic current, the the more deeply the conducting-wire is immersed in the mercury or other liquid, the less resistance does the liquid offer to the passage of the current. The vertical vibration of the elements of a battery in the liquid in which they are immersed produces an undulatory action in the current by alternately increasing and diminishing the power of the battery.

In illustration of the method of creating electrical undulations, I shall show and describe one form of apparatus for producing the effect. I prefer to employ for this prupose an electro-magnet A, Fig. 5, having a coil upon only one of its legs *b*. A steel-spring armature, *c*, is firmly clamped by one extremity to the uncovered leg *d* of the magnet, and its free end is allowed to project above the pole of the uncovered leg.

The armature *c* can be set in vibration in a variety of ways, one of which is by wind, and, in vibrating, it produces a musical note of a certain definite pitch.

(6) When the instrument A is placed in a voltaic circuit, *g b e f g*, the armature *c* becomes magnetic, and the polarity of its free end is opposed to that of the magnet underneath. So long as the armature *c* remains at rest, no effect is produced upon the voltaic current, but the moment it is set in vibration to produce its musical note a powerful induction action takes place, and electrical endulations tranverse the circuit *g b e f g*. The vibratory current passing through the coil of the electro-magnet *f* causes vibration in its armature *h* when the armature *c h* of the two instruments A I are normally in unison with one another; but the armature *h* is unaffected by the passage of the undulatory current when the pitches of the two instruments are different.

A number of instruments may be placed upon a telegraphic circuit, instruments is set in vibration all the other instruments upon the circuit which are in unison wiht it respond, but those which have normally a different rate of vibration remain silent. Thus, if A, Fig. 6, is set in vibration, the armatures of A1 and A2 will vibrate also, but all the others will remain still. So, if B1 is caused to emit its musical note the instruments B B2 respond. They continue sounding so long as the mechanical vibration of B1 is continued, but become silent with the cessation of its motion. The duration of the sounds may be used to indicate the dot or dash of the Morse alphabet, and thus a telegraphic despatch may be indicated by alternately interrupting and renewing the sound. When two or more instruments of different pitch are simultaneously caused to vibrate, all the instruments of corresponding pitches upon the circuit are set in vibration, each responding to that one only of the transmitting instruments with which it is in unison. Thus the signals of A, Fig. 6, are repeated by A1 and A2, but by no other instrument upon the circuit; the signals of B2 by B and B1; and the signals of C1 by C and C2 -- whether A, B2, and C1 are successively or simultaneously caused to vibrate. Hence by these instruments two or more telegraphic signals or messages may be sent simulatneously over the smae circuit without intefering with one another.

I desire here to remark that there are many other uses to which these instruments may be put, such as the simultaneous transmission (7) of musical notes, differing in loudness as well as in pitch, and the telegraphic transmission of noises or sounds of any kind.

When the armature *c*, Fig. 5, is set in motion the armature *h* responds not only in pitch, but in loudness. Thus, when *c* vibrates with little amplitude, a very soft musical note proceeds from *h*; and when *c* vibrates forcibly the amplitude of the vibration of *h* is considerably increased, and the resulting sound becomes louder. So, if A and B, Fig.

6, are sounded simultaneously (A loudly and B softly), the instruments A1 and A2 repeat loudly the signals of A, and B1 B2 repeat softly those of B.

One of the ways in which the armature *c*, Fig. 5, may be set in motion has been stated above to by by wind. Another mode is shown in Fig. 7, whereby motions can be imparted to the armature by the human voice or by means of a musical instrument.

The armature *c*, Fig. 7, is fastened loosely by one extremity to the uncovered leg *d* of the electro-magnet *b*, and its other extremity is attached to the centre of a stretched membrane, *a*. A cone, A, is used to converge sound-vibrations upon the membrane. When a sound is uttered in the cone the membrane *a* is set in vibration, the armature *c* is forced to partake of the motion, and thus electrical undulations are created upon the circuit E *b e f g*. These undulations are similar in sound to the air vibrations caused by the sound -- that is, they are represented graphically by similar curves. The undulatory current passing through the electro-magnet *f* influences its armature *h* to copy the motions of the armature *c*. A similar sound to that uttered into A is the heard to proceed from L.

In this specification the three words "oscillation," "vibration," and "undulation," are used synonymously, and in contradistinction to the terms "intermittent" and "pulsatory." By the term "body capable of inductive action," I mean a body which, when in motioin, produces dynamical electricity. I include in the category of bodies capable of inductive action -- brass, copper, and other metals, as well as iron and steel.

Having described my invention, what I claim, and desire to secure by Letters Patent, is as follows:

1. **A system of telegraphy in which the receiver is set in vibration (8) by the employment of undulatory currents of electricity, substantially as set forth.**
2. **The combination, substantially as set forth, of a permanent magnet or other body capable of inductive action, with a closed circuit, so that the vibration of the one shall occasion electrical undulations in the other, or in itself, and this I claim, whether the permanent magnet be set in vibration in the neighborhood of the conducting-wire forming the circuit, or whether the conducting-wire be set in vibration in the neighborhood of the permanent magnet, or whether the conducting wire and the permanent magnet both simultaneously be set in vibration in each other's neighborhood.**
3. **The method of producing undulations in a continuous voltaic current by the vibration of motion of bodies capable of inductive action, or by the vibration or**

motion of the conducting-wire itself, in the neighborhood of such bodies, as set forth.

4. **The method of producing undulations in a continuous voltaic circuit by gradually increasing and diminishing the resistance of the circuit, or by gradually increasing and diminishing the power of the battery, as set forth.**
5. **The method of, and apparatus for, transmitting vocal or other sounds telegraphically, as herein described, by causing electrical undulations, similar in form to the vibrations of the air accompanying the said vocal or other sounds, substantially as set forth.**

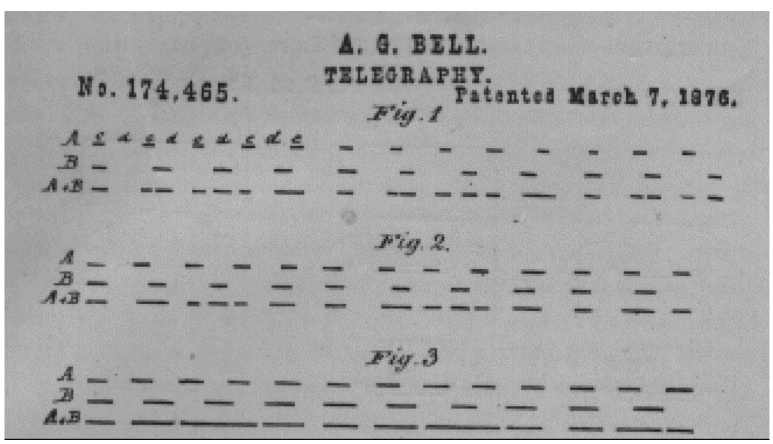
In testimony whereof I have hereunto signed my name this 20th day of January, A.D. 1876.

ALEX. GRAHAM BELL.

Witnesses :

Thomas E. Barry.

P. D. Richards.



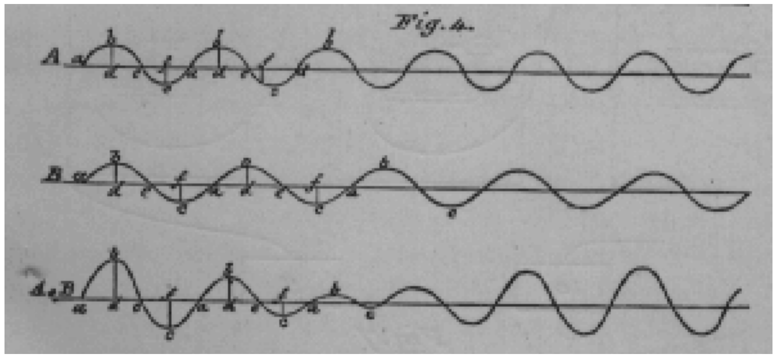


Fig. 4.

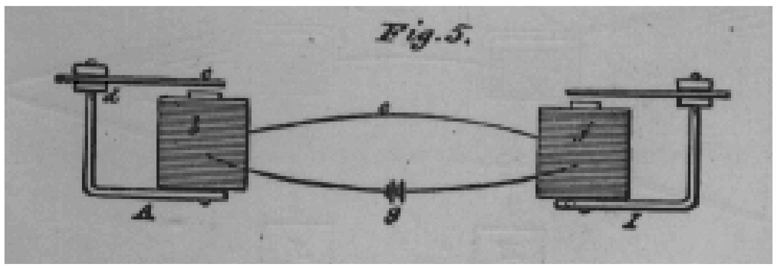
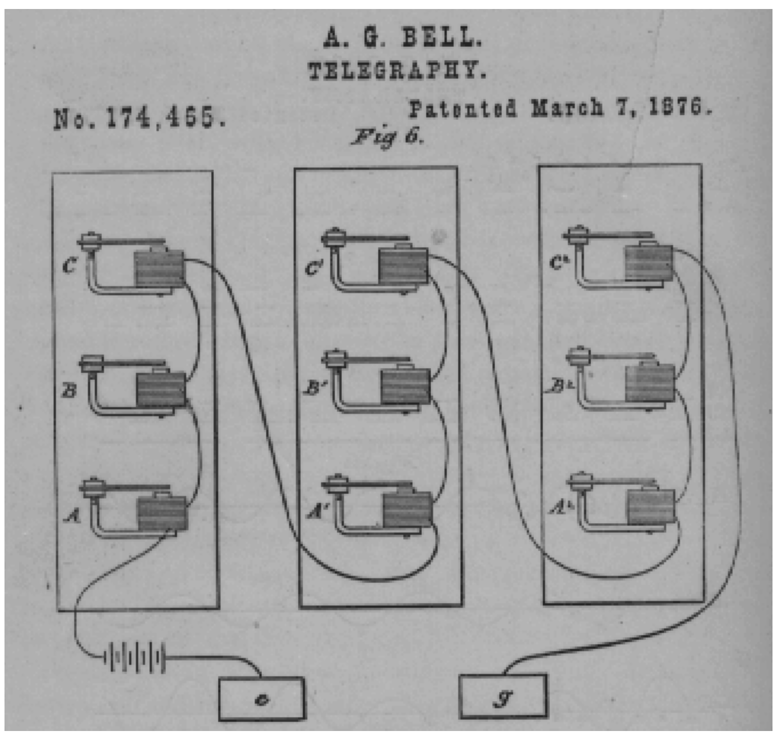


Fig. 5.


A. G. BELL.
TELEGRAPHY.
No. 174,465.
Patented March 7, 1876.
Fig 6.

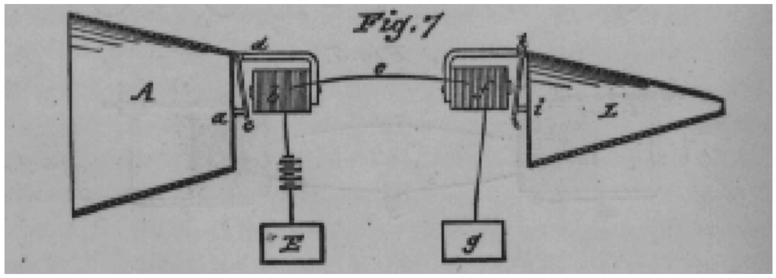


Fig. 7