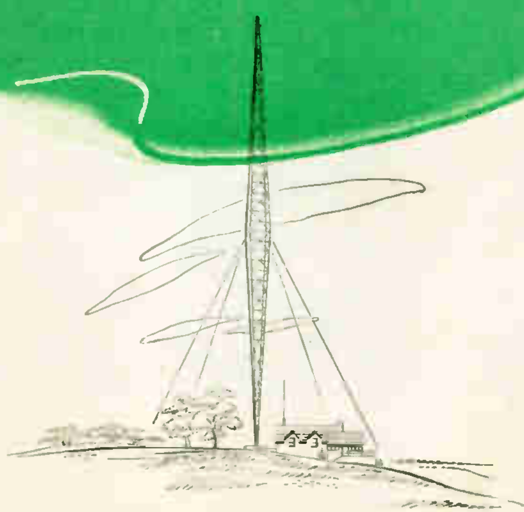
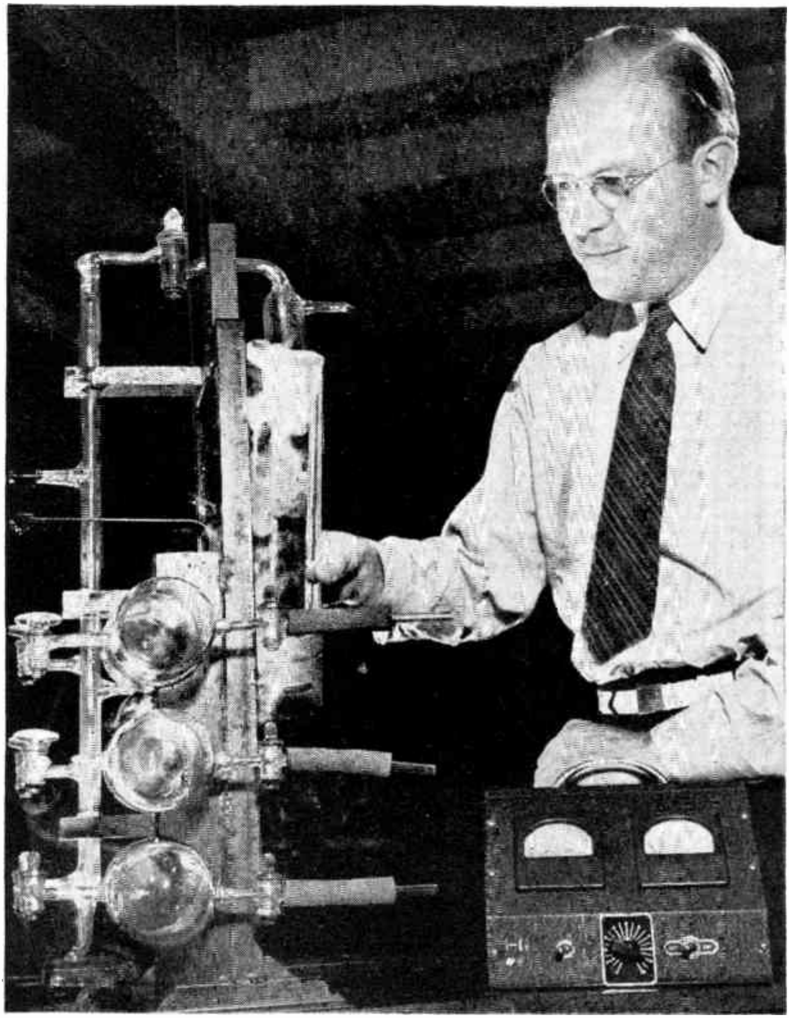
Eyes and Ears for the Millions

The story of
telegraph, telephone, radio,
and television



A WESTINGHOUSE LITTLE SCIENCE SERIES BOOKLET



Dr. J. A. Hutcheson, author of this booklet, caught the radio "bug" when he was a youngster and has been working with radio ever since. For the past 18 years, radio has been his specialty at Westinghouse. Now, as Associate Director of the Westinghouse Research Laboratories, he guides the work of research men in electronics and in ultra-high frequency, a new frontier in electrical communication.

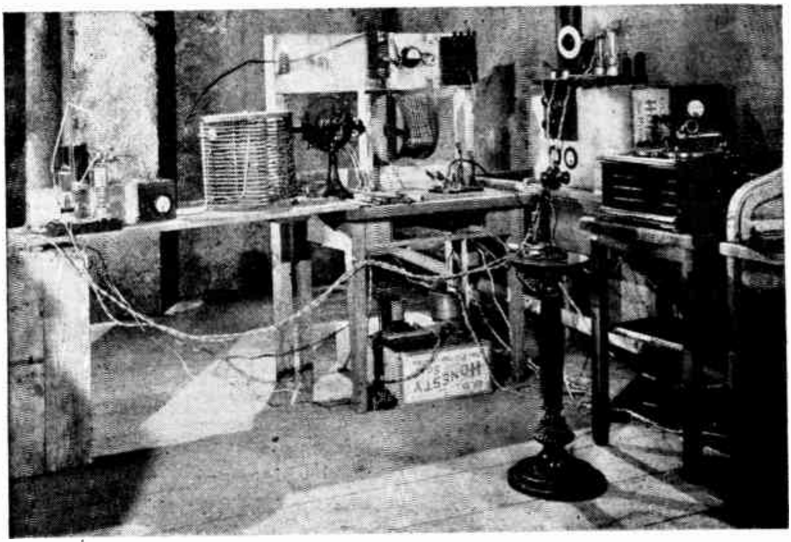
EYES AND EARS FOR THE MILLIONS

By J. A. Hutcheson, Ph.D.

On November 2, 1920, in a small frame laboratory on top of a factory building in East Pittsburgh, a half-dozen men worked anxiously over a maze of electrical equipment. It was Election Day, and the little room was the new-born radio station, KDKA, nursed into being by Dr. Frank Conrad, an engineer of the Westinghouse Electric Corporation. The men were broadcasting election returns in the contest between Warren G. Harding and James M. Cox. But to them and to the few hundred listeners, this was more than just a news report; it was the dawn of a new age of communication. It was the first scheduled radio broadcast in history.

Behind the triumph of that day lay a century of brilliant achievement. Men had always dreamed of using electricity to span space with words and messages, even before they knew what an electric cell or a generator looked like. Within the past 100 years, they had been making the dream a reality—learning what electricity could be made to do, harnessing its swift, invisible energy for communication.

It was late in October, 1832, when Samuel F. B. Morse, a well-known painter, returned to America after a few years of study abroad. On the home voyage, Morse had



Dr. Frank Conrad's early adventures in radio took place in a rough laboratory above his garage. From these humble beginnings grew the first regular broadcasting station, KDKA.

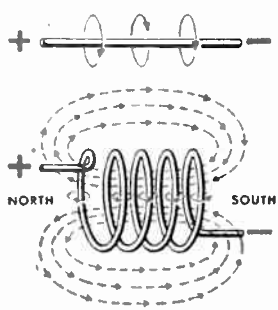
caught the "bug." A learned professor had told him some of the newly-discovered wonders of electricity, and Morse's eager imagination was busy devising ways of using this strange power for sending messages.

Morse had plans for his telegraph when he left the ship, but 12 years of hard work and disappointment were to follow before he could perfect his device and prove it to a doubting world. On May 24, 1844, Morse sat in the Supreme Court room of the nation's capital surrounded by the statesmen who had finally been persuaded to help him. In Baltimore, at the other end of the first real telegraph line, was Alfred Vail, the young man who had worked for years with Morse to help him develop his instrument. After a brief address, Morse sat down at the telegraph key and sent his message. He had scarcely finished when the receiver clicked. Vail had the message and was sending it back. The astonished statesmen listened, their doubts rapidly vanishing. Morse's message was being repeated word for word—the first great long-distance message sent by electricity:

"W-H-A-T H-A-T-H G-O-D W-R-O-U-G-H-T."

Morse's invention was based on a principle almost every schoolboy knows today—the principle of *electromagnetism.* When an electric current flows through a wire, it creates a magnetic field around the wire. If the wire is wound around a soft iron bar, the magnetic field about the wire is concentrated in the iron, making the iron a strong magnet as long as the current continues to flow. As soon as the current stops, the iron loses its magnetism. Such a magnet is called an *electromagnet.*

Morse's telegraph key was nothing more than a switch which opened and closed an electric circuit at the touch

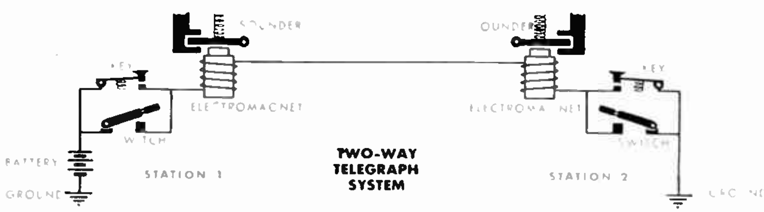


Every current-carrying conductor has circular magnetic lines of force around it. When the wire is wound in a spiral, or solenoid (below), the individual lines of force join together, making the solenoid as a whole very much like a bar magnet, with north and south poles. To find the north pole, hold fingers of the right hand in the direction of the current (from + to —), and stretch thumb out. Thumb points to north pole.

of a finger. At the receiving end, this current ran through the coils of an electromagnet whose force could be used in a number of ways to convey the message. It could draw down a pen so that the penpoint made a mark on a moving tape; or it could move the pen from side to side so that signals would be recorded on the moving tape something like this:

Or it could attract a bar of metal which clicked down when current flowed through the electromagnet and sprang back when the current stopped.

Morse and Vail worked out a code for representing letters and numbers by dots and dashes, so that it was a simple matter for a person receiving the message to interpret the clicks or the long and short lines on the moving tape. Morse's code is still in use today in modern telegraphy.



Here is a two-way telegraph system. When Station 1 wishes to receive, he closes his switch. Station 2 now uses his key to open and close the circuit and send signals. When the key is down, the electromagnets pull down a metal bar in the sounder. When the key is up, the bar springs back. After Station 2 has completed his message, he closes his switch, and is ready to receive. Station 1 opens his switch, and is ready to send.

A • —	K — • —	U • • —	1 • — — — —
B — • • •	L • — • •	V • • • —	2 • • — — —
C — • — •	M — —	W • — —	3 • • • — —
D — • •	N — •	X — • • —	4 • • • • —
E •	O — — —	Y — • — —	5 • • • • •
F • • — •	P • — — •	Z — — • •	6 — • • • •
G — — •	Q — — • —		7 — — • • •
H • • • •	R • — •	[.] • — • — • —	8 — — — • •
I • •	S • • •	[,] — — • • — —	9 — — — — •
J • — — —	T —	[?] • • — — • •	0 — — — — —

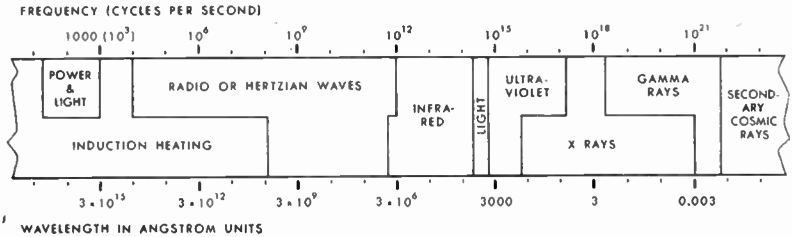
Continental Code, used in radio telegraphy, is a development of the code worked out by Morse and Vail.

About 20 years after Morse and Vail sent their epoch-making message, a British physicist and mathematician published an essay that caused some excitement in high scientific circles. James Clerk Maxwell had done a little mathematical figuring, and it seemed to him that there must exist electric impulses just like light waves but of a different length.

Light waves, as we know them today, are "electromagnetic radiations" which travel through space at a rate of 186,000 miles a second. The waves are very short, ranging in length from the tiny violet light waves, about 16 millionths of an inch long, to the somewhat longer waves of red light, 26 millionths of an inch long.

What Maxwell said was that there were probably other waves, longer than light waves, which could not be detected by the eyes. In every other respect, he declared, the waves were exactly the same as light waves.

A nice theory, but it was still only on paper! There seemed to be no way of proving it except by intricate mathematical calculations. Then in 1887 a youthful physics



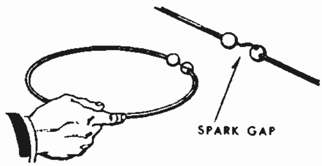
James Clerk Maxwell believed that there must exist electromagnetic waves just like light waves except for their wavelength and frequency. Modern science has proven him correct. The entire electromagnetic spectrum includes waves from power lines (usually 25, 50, and 60 cycles a second), induction heating waves for heating materials in manufacture, radio waves, infrared waves, light waves, ultraviolet waves, X rays, gamma rays (given off by radium), and secondary cosmic rays (believed to be given off from the impact of cosmic rays). Angstrom unit is the unit usually used for measuring wavelength of light. It equals 1/100,000,000 centimeter, or about 4 billionths of an inch.

—From Westinghouse educational chart, "*The Entire Electromagnetic Spectrum*"

professor at a high school in Karlsruhe, Germany, told the world of some amazing experiments that he had been performing for the past two years—experiments that showed beyond a shadow of a doubt that James Clerk Maxwell's figuring was correct.

This young man was Heinrich Rudolph Hertz. Hertz discovered that when he made a spark leap across a gap in an electrical circuit, he produced electromagnetic waves like the ones Maxwell had predicted. To detect the waves, Hertz used a small hoop of wire which held two balls of metal a short distance apart. The waves from the spark made another electric spark jump almost instantaneously between these metal balls.

With this simple apparatus, Hertz was able to prove everything that Maxwell said. He showed that the waves traveled through space with the same speed as light, and that they could be reflected or bent just like light. But more than that, he opened the door to the possibility of sending messages electrically without wire.



Heinrich Hertz discovered that waves from an electric spark made another spark leap between two metal balls held apart by a hoop of wire. With this simple apparatus, Hertz proved the theories of James Clerk Maxwell.

By 1895, many great men were hot in pursuit of capturing the waves that Hertz had described. One in particular was not very widely known, for he was only a young man of twenty-one, the son of a wealthy Italian banker. But in 1895, this young man, Guglielmo Marconi, was launching an experiment which was destined to grow into an enormous contribution to the world.

In his father's garden outside the city of Bologna, young Marconi had rigged up a spark gap similar to the one Heinrich Hertz had used in his experiments. But leading from this gap were two wires, one buried in the ground and the other carried high aloft in the air.

Marconi was experimenting with antennas and proving to himself that with the proper antenna a message could be sent over long distances. In 1895, Marconi succeeded in sending a message to his father a mile away. But he was not satisfied. He dreamed of sending a message across the ocean.

From his father's obscure garden in Italy, Marconi moved to England. Bit by bit he lengthened the stride of his messages, until finally, in December, 1901, he was ready for the great test.

In Poldhu, at the southwest tip of England, Marconi had set up a powerful sending station. Then he voyaged across the Atlantic and set up receiving equipment in an old watchtower overlooking the harbor of St. John's, Newfoundland. All was in readiness on December 12. Marconi sent up a kite which carried his receiving aerial 400 feet into the air. At the appointed time, he sat at his station with headphones over his ears waiting for the sound of the triple dots—the letter *S*—which Poldhu was about to send.

Marconi was not a man to get excited. When he thought he heard the faint triple buzz in his earphones, he handed the apparatus to his assistant and said, "Kemp, do you hear anything?"

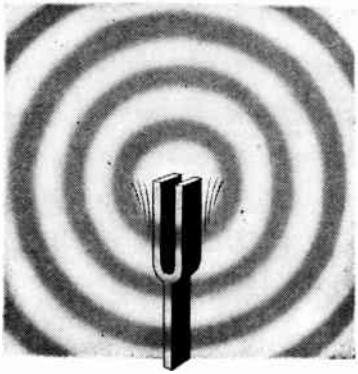
Unmistakably, the three dots of the letter *S* sounded in the headphones. From Poldhu to St. John's, electromagnetic waves leaped across the ocean with the speed of light—waves that Maxwell had predicted, that Hertz had experimented with, that Marconi had finally learned how to use for long-distance wireless telegraphy. Another great step had been taken in the taming of electrical energy.

Forty years had passed between the publication of James Clerk Maxwell's essay and that dramatic moment at St. John's, Newfoundland. Within those years, another invention had been born and grown up. The man responsible for this invention was a speech teacher, Alexander Graham Bell.

Professor Bell was not just an ordinary speech teacher. He had undertaken probably the most difficult job a speech teacher could possibly attempt—to teach deaf mutes how to talk. He knew all about sound and how it is produced, so that he was well prepared for his destiny when he stumbled on a discovery that led to the invention of the telephone.

On a day in June, 1875, Bell was busy with his assistant, Thomas A. Watson, in their workshop. He was working on what he hoped would be a "harmonic telegraph" —a system for sending several telegraph messages at once through a single wire by making metal reeds at the receiving end of the line vibrate in harmony with reeds on the sending end. One of the reeds had stuck, so that for a moment current flowed steadily through it. Watson plucked at the reed trying to free it, when suddenly Bell's alert, trained ear caught a genuine sound. In his tinkering, Watson had unwittingly fallen upon the principle of the telephone.

The two men abandoned their "harmonic telegraph" and went to work perfecting a method of transmitting voice by wire. Bell knew that sound is carried by waves. These waves originate with a vibrating object, like a tuning fork or vocal cords, and spread out from the object in much the same way as ripples on a pond. The vibrating object packs the molecules of air densely together when it moves in one direction and pulls them apart, or *rarifies* the air, as it moves in the opposite direction. The sound waves which spread out from it are ripples of dense and rare air.



A vibrating object sends out ripples of dense and rare air. These are sound waves. The pitch of the sound we hear when the waves strike our ear depends on the frequency of the waves—the number that strike our ear in one second. The ear responds to waves with a frequency lower than 10 cycles a second (very low notes) and as high as about 20,000 cycles a second (very high notes.)

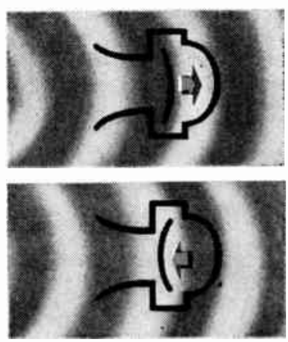
Many men before Bell had sought to invent the telephone. Bell was successful because he combined his knowledge of sound with his knowledge of electricity and therefore began with exactly the right idea of what he was trying to do. He was trying to take the *varying densities of sound waves* and change them into *varying intensities of electric current*, then send this current through wires to a receiver and change it back into sound waves.

On March 10, 1876, Bell and Watson were trying out some new apparatus in the attic of their lodgings in Boston. Watson had just set up the apparatus and hurried to Bell's bedroom where the receiver was located. Suddenly he heard Bell's voice: "Mr. Watson, come here! I need you." But the voice did not come from the attic; it came from the telephone receiver. It was the first time a voice had ever been transmitted by wire.

Telephones today are vast improvements over Bell's first awkward instruments, but they are based on the same principles. When we speak, our vocal cords vibrate and send out a complicated series of dense and rare air-ripples. These ripples strike a thin disc or diaphragm in the telephone transmitter, making it vibrate in the same way as our vocal cords. Each ripple of dense air pushes the diaphragm in; each ripple of rare air allows the diaphragm to spring back.

Behind the diaphragm is a chamber full of tiny particles of carbon. When the diaphragm moves against them, they are packed close together, and when the diaphragm moves away, they loosen apart. Electric current passing through the carbon particles varies each time this happens, for when the particles are closely packed they allow more current to flow than when they are loose.

In other words, dense and rare air waves are changed into varying intensities of electric current. A dense ripple of air pushes the diaphragm in; this packs the carbon particles, and more current flows. A ripple of rare air allows the diaphragm to spring back; this loosens the particles, and the flow of current is reduced.



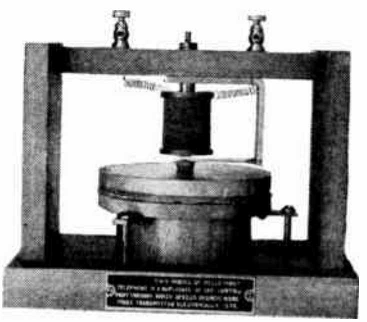
When sound waves strike the diaphragm in a telephone transmitter, they make the diaphragm vibrate. The vibrations of the diaphragm have the same frequency as the sound waves.

The varying current is next sent through a transformer, which changes it into a back-and-forth or *alternating* current. Each alternation of direction is an electrical counterpart of the original impacts of dense and rare air on the diaphragm of the transmitter.

The alternating current is sent

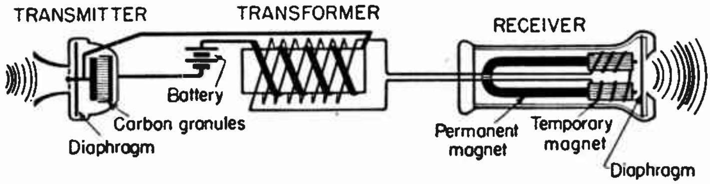
to the telephone receiver. Here it passes through an electromagnet attached to the end of a more powerful permanent magnet. Each time the current changes direction, the north and south poles of the electromagnet change ends. At one instant the electromagnet is pulling in the same direction as the permanent magnet, and the strength of the two magnets is added together; but the next instant the poles of the electromagnet are reversed and its strength acts to weaken the strength of the permanent magnet. In this way, the alternating current is changed into a magnetic force which varies in strength with each change in the current.

The varying magnetic force tugs and releases a diaphragm in the receiver and makes it vibrate in just the same way as the diaphragm in the transmitter vibrates when sound waves strike it. The diaphragm, in turn, pushes and pulls the air, creating sound waves similar to those entering the transmitter at the other end of the line.



Bell's first telephone was a far cry from the streamlined models of today, but it was based on the same scientific principles.

Bell's invention got off to a slow start, but by the time Marconi proved to the world the power of wireless telegraphy, there were more than a million telephones in use in the United States alone. All that was needed for the birth of radio was a combination of wireless and tele-



The essentials of a telephone circuit: Sound waves, entering the mouthpiece, vibrate the diaphragm, which in turn packs and loosens the carbon granules, varying the amount of current going through. The varying current goes to the transformer where it is changed to alternating current and sent to the receiver. Here the alternating current, each time it changes direction, changes the direction of pull of the temporary magnets, so that at one instant they add to the pull of the permanent magnet and at the next they subtract from it. This varies the pull on the diaphragm in the receiver, making it vibrate in harmony with the diaphragm in the mouthpiece and send out sound waves similar to those which entered the mouthpiece.

phone—some way of attaching "voice" waves electrically to the speedy electromagnetic waves of wireless telegraphy.

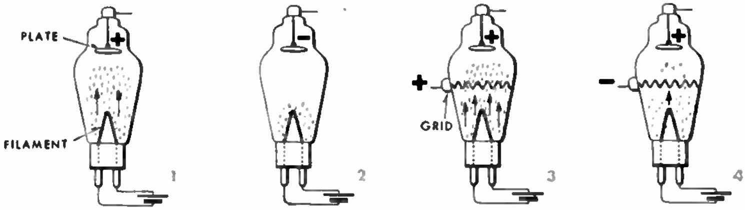
The man who first succeeded in doing this was Reginald Fessenden. For his electromagnetic, or "carrier," waves Fessenden used a special generator which sent out 50,000 waves a second. These were caught by receivers, but made no sound, for the vibrations they caused were too rapid for human ears. To these silent couriers were attached "voice" waves from a special microphone. They were a current of varying intensities which made the carrier waves weaker and stronger.

Fessenden's hardest job was to generate the carrier waves, but after years of work a machine was finally developed to do this. On Christmas Eve, 1906, wireless operators were startled to attention by a CQ signal—a call to all operators. A moment later, their attention changed to surprise, for they heard a woman singing—a violin playing—a man speaking! Fessenden was broadcasting from his station at Brant Rock, Massachusetts. He had proved the possibility of radio—just one week before the discovery that completely revolutionized the science of electrical communication.

Seven days after Fessenden's broadcast, a man by the name of Lee DeForest was doing some experiments with a strange-looking tube. This tube was the "Fleming valve," an ingenious electrical traffic cop which let current flow in only one direction. At one end of the tube was a filament of fine wire which became hot when electric current flowed through it. When it was heated, electrons—tiny particles of negative electricity, which are the actual stuff of an electric current—boiled out of it.

At the other end of the tube was a metal plate. When this plate was attached to the positive pole of an electric cell, it became positively charged and attracted the electrons which boiled off the filament. Thus a current flowed through the tube. But when the plate was attached to the negative pole of the battery, its own negative charge forced back the electrons from the filament, so that no current flowed. In other words, current flowed only when the plate was positive, and electrons could travel in only one direction—from the hot filament to the plate.

Lee DeForest, in his experiments, slipped a screen, or grid, of wire between the filament and the plate. He discovered that when he gave the grid a slight positive charge, he could make more current flow through the tube; for the positively-charged grid attracted the nega-



The Fleming valve, or diode, as it is called today, is a one-way street for electrons. When the filament is hot and the plate is positively charged (1), electrons flow through the tube. When the plate is negatively charged, no electrons flow (2). DeForest discovered that a grid placed between the filament and plate could control the flow of electrons. A small positive charge on the grid (3) increased the flow, a small negative charge (4) decreased the flow. This three-element tube is called a triode.

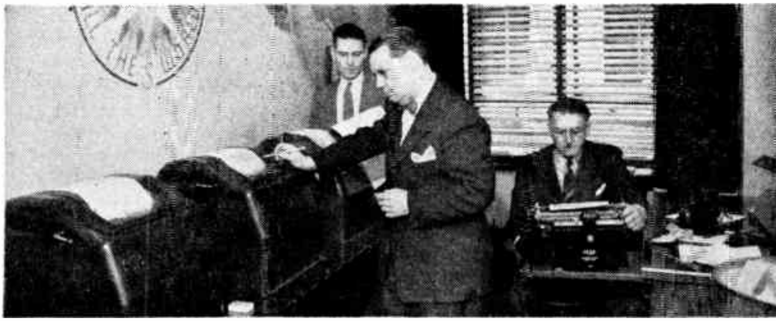
tively-charged electrons from the filament and gave them a swift start in their journey to the plate. When he charged the grid negatively, he could reduce the flow of current through the tube. The grid acted like a lever. Small changes in its electrical charge brought about big changes in the flow of electrons through the tube.

The discovery of this three-part, or *triode*, tube cleared the way for rapid progress in the development of radio. Though simple in principle, the triode can perform jobs that even the most complex machinery cannot perform. It can take weak electrical signals and amplify or strengthen them to tremendous power. It can take an alternating current and change it to a direct or one-way current. Or it can do the reverse and generate an electric current which changes direction back and forth millions of times a second. A tube which does this is called an *oscillator*, and it is used in every radio station today to generate the carrier waves for radio broadcasting.

The triode and its many relatives in the family of electronic tubes are the backbone of modern communication. Their exact and delicate control of the movements of tiny electrons has made possible almost miraculous developments in radio, telephone, and telegraph.

You would scarcely recognize Station KDKA today as a direct descendent of the pioneer station which broadcast the first scheduled radio program. From its quarters on top of a factory, KDKA has moved to a modern building in downtown Pittsburgh where it occupies an entire spacious floor with its studios, control rooms and offices. About 100 experienced men keep it operating smoothly. Here in one office is the Program Director whose job it is to supervise all the programs that go on the air and to build new and better ones. Near him is the Production Department, where all the necessary arrangements for broadcasts are made. A Continuity Department is busy writing the thousands of words spoken each week into the microphone, building new shows, writing special programs for special events. A Music Department shapes into final form all the music that will be needed, often searching through the files of the large Music Library for selections. A staff of thoroughly trained announcers read over the lines they will have to speak.

News editors are always in the newsroom studying the latest reports as they are automatically typed out direct from the "wires." Here in the newsroom, modern telegraphy is playing its role. The large news-reporting agencies, like Associated Press, United Press, and International News Service, send their messages direct by telegraph.



In the newsroom of Westinghouse Station KDKA, a news editor studies late reports typed out on the teletype machines.

But instead of tapping the message out on a key, they tap it out on a typewriter. On the receiving end, a machine automatically re-types the message, so that news flashes are ready to read over the air as soon as they are sent.

In one of the studios a show is on the air. The orchestra watches the music director as he waves his baton. The artists move up to the microphone to speak their lines and then move silently away. In one corner a sound-effects man, surrounded with a weird array of contraptions, prepares to rattle a large strip of sheet metal so that you will think you hear the boom of thunder. Off to one side, in a glass-enclosed soundproof control room, the director keeps a sharp eye on his stop-watch, signaling now and then to the performers. Beside him is a studio engineer, one of the corps of technical experts who keep KDKA broadcasting 20 solid hours a day without a hitch. His fingers are on the dials, and beneath the dials is a newborn radio program.

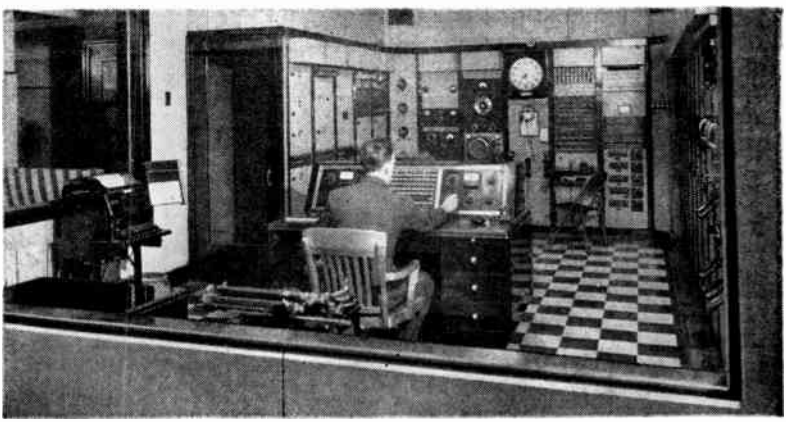
Beneath the dials in a KDKA studio control room passes a "current of varying intensities," the electrical counterpart of the sounds in the studio. It is a complete radio program, but it must still be sent to the transmitter and attached to a carrier current before it can be broadcast.

What passes beneath the dials in the control room is the familiar "current of varying intensities," an electrical counterpart of the sounds in the studio. It comes from the microphones in the studio where sound waves are changed into a chain of electrical impulses. But these feeble impulses must be equipped with electrical wings before they can fly through space to your radio.

In the control room they undergo their first treatment. Passing through a series of triode tubes, they are amplified—given strength to help them along in the journey they are about to start. From here they are sent to the master control room, a large, glass-enclosed, soundproof room in the reception room of KDKA. Every program that goes on the air passes through this room. Some programs, like network shows, are carried to it by telephone wires from New York or Chicago or Hollywood. But no matter where the show originates, it passes through the master control room before it goes on the air.

Here the weak current is amplified again and sent by telephone wire to the transmitting station, about 10 miles away. By the time it arrives, it needs another boost in strength to keep it going. And here at the transmitting station it is given its wings.

In a separate chamber in the transmitting station is a vacuum-tube *oscillator* controlled by a tiny quartz crystal. This tube is generating an electric current which moves evenly back and forth exactly 1,020,000 times a second. This is the carrier current, the current which determines the frequency on which the station is broadcasting, the number of complete electromagnetic waves the station



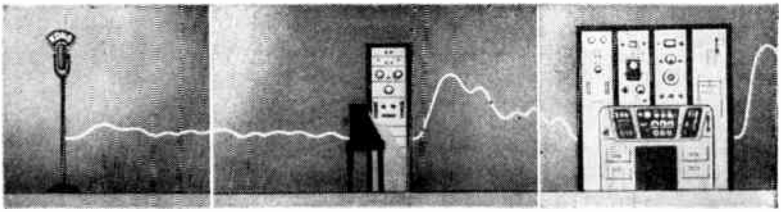
All programs pass through the master control room. Programs from KDKA's own studios come here direct; network shows from other large stations are carried here by telephone cables.

sends out each second. KDKA operates on a frequency of 1,020 kilocycles; 1,020,000 complete radio waves leave its antenna every second.

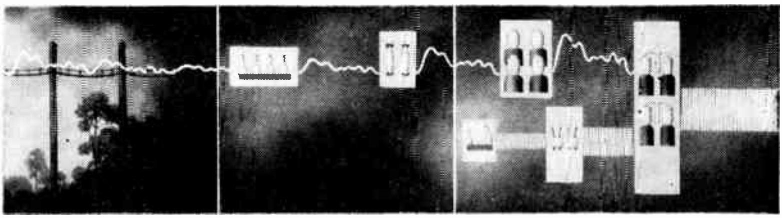
The carrier current could be sent directly to the antenna and broadcast, but so far it has no program on it. It must first pick up the current from the studio. This current, you recall, is a current of varying intensities—sometimes strong, sometimes weak, depending on the sound waves which created it. When it is attached electrically to the oscillating carrier current, it strengthens and weakens the carrier current in proportion to its own strength or weakness, or, in the language of radio engineers, it "modulates" the carrier current.

Now the two currents are combined—the carrier current, with its power to produce electromagnetic waves to hurtle through space, and the "voice" current, the electrical duplicate of sound waves. The program is ready to go on the air. It is given a final boost in strength, sent to the towering antenna, and off it flies into space—a complicated chain of electromagnetic waves speeding out in all directions at 186,000 miles a second—1,020,000 leaping from the antenna every second, some weak, some strong. The program is on the air.

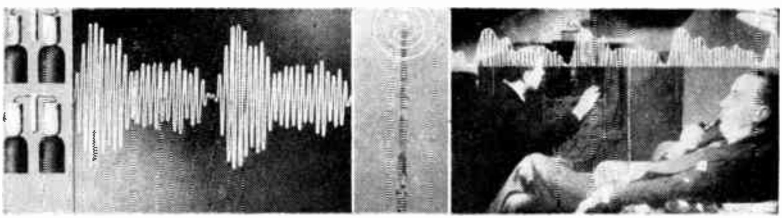
When these waves strike the aerial of your radio, they set up a tiny current, exactly similar in every detail to the current which was sent to the transmission tower, but much weaker. The job your radio must do is unravel this current. It does so by reversing the process by which the current was made. After the current is received, it is strengthened in a vacuum tube. Another vacuum tube



These pictures show how a KDKA radio program is transmitted and received. Sound waves striking the microphone produce a current of varying intensities. This is sent to the control room, where it is amplified, and then to the master control room, where it is amplified again.



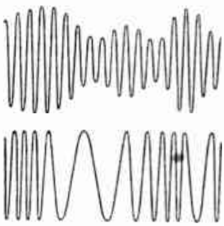
From the master control room, the current is sent by cable to the transmitting station. Here it is amplified several times. Meanwhile, a crystal-controlled vacuum-tube oscillator is generating a carrier current, a current which moves evenly back and forth 1,020,000 times a second. This, too, is amplified.



Now the current from the studio modulates the carrier current, making the carrier current strong and weak in proportion to its own strength and weakness. The modulated carrier current, ready for action, is sent to the antenna and broadcast. The receiver sorts out the back-and-forth motion of the carrier current, leaving, in effect, only strong and weak impulses similar to those which originally left the microphone. These go to the loudspeaker where they vary the pull on a large diaphragm, making the diaphragm vibrate and send out sound waves similar to those which originally entered the microphone.

—From Westinghouse sound motion picture, "*On the Air*" "rectifies" the current—takes out the back-and-forth oscillations of the carrier current, leaving, in effect, just the strong and weak impulses of the "voice" current. These impulses are again amplified and sent to the loudspeaker where they operate a diaphragm something like that in a telephone receiver but much larger. Each variation in current strengthens or weakens the pull on the diaphragm. The diaphragm vibrates and sends out sound waves—duplicates of the sound waves striking the microphone in the studio of the radio station.

Radio is still in knee-pants, but it shows signs of growing up to be quite a bright young fellow. Recently, its voice has been changing. The voice of radio used to crack and hiss whenever atmospheric static interfered with it. Now it has learned a smooth, crystal-clear way of talking. Radio men call it FM.



In AM, amplitude modulation (top), the amplitude, or strength, of the carrier wave is varied by the voice current, but its frequency is constant. In FM, frequency modulation (below), the frequency of the carrier wave is varied, but the strength is constant.

FM means *frequency modulations*. Both these words we have come across before. In radio, frequency means the number of waves that speed past a point in one second. Modulation is the word we used to express what happens when voice waves weaken or strengthen carrier waves.

The system of modulation you have just read about is called AM—*amplitude modulation*. In AM, the *amplitude* or strength of carrier waves is altered according to the strength of voice waves, but the frequency of the carrier waves is constant. In FM, frequency modulation, the *frequency* of the carrier waves is changed, but the amplitude or strength of the carrier waves remains constant. This system enables radio to speak with a clear, pure, static-free voice.

Though still a youngster, radio has been able to teach its foster parents—telegraph and telephone—a few useful tricks. Telephone and telegraph, for example, have learned from radio how to send many messages at one time through a single wire. They attach each message to a carrier current, like the carrier current generated at a radio transmitting station, and give each carrier current a different frequency. At the end of the line, the carrier currents are sorted out from one another by electrical filters, and each is sent its separate way.

Telephone messages across the ocean are very much like radio broadcasts, except that the message at the transmitting station is electrically scrambled and distorted so that people receiving it with ordinary equipment cannot make the slightest sense out of it. At the receiving end, however, is a device which electrically "unscrambles" the message and sends it by wire to its destination.

One of radio's latest tricks is to carry pictures as well as sound. Just as it takes sound waves, converts them into electrical impulses, and then changes them back into sound waves again, it now takes an image, or picture, changes it into an electric current, and then builds it back into a picture again.

The heart of a television camera is a special kind of

Dr. V. K. Zworykin invented the iconoscope, which he is shown holding, when he was a research scientist at the Westinghouse Research Laboratories. Dr. Zworykin is now Assistant Research Director of the RCA Laboratories.

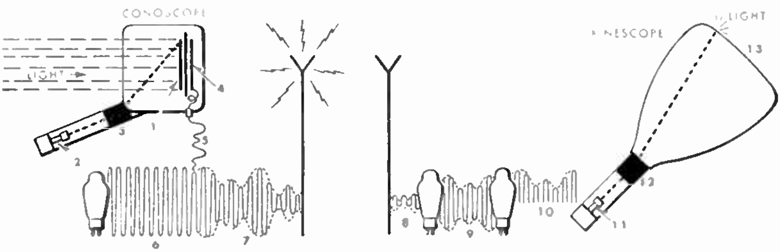
electronic tube called an *iconoscope*. An image entering the television camera is focused on a small screen in the tube—a screen covered with thousands of tiny separate globules of light-sensitive chemicals. These chemicals, silver and caesium, give off electrons when light strikes them. The brighter the light, the more electrons they give off. When the electrons leave the globules, they are drained away through a positively charged metal plate.

Losing electrons leaves the light-sensitive globules with a positive electrical charge, a charge which is strongest where the light is strongest and weakest where the light is weakest. In effect, the image is changed into thousands of tiny, separate electrical charges, each one representing one tiny portion of the image.

Behind the screen of globules, or *mosaic*, as it is called, and separated from it by a thin sheet of mica is a metal plate. As the globules become positively charged they create an electrical charge on the metal plate. You might think of the metal plate as one side of a delicate balance scale and the globules as tiny cups of water on the other side of the scale. As the globules lose some of their water

—or, in other words, as they become positively charged—the scale tips a little in favor of the metal plate.

At the opposite end of the tube is an *electron gun* which fires a stream of electrons at the mosaic. The electrons from this gun pass through some electromagnets which act just like lenses: they focus the stream so that it falls on one single spot on the mosaic. At the same time, another set of electromagnets swings the stream of electrons back and forth across the mosaic in much the same way as the muscles of the eye direct your vision as you scan these lines of print. In fact, the process is called *scanning*. Line by line, the stream of electrons from the electron gun



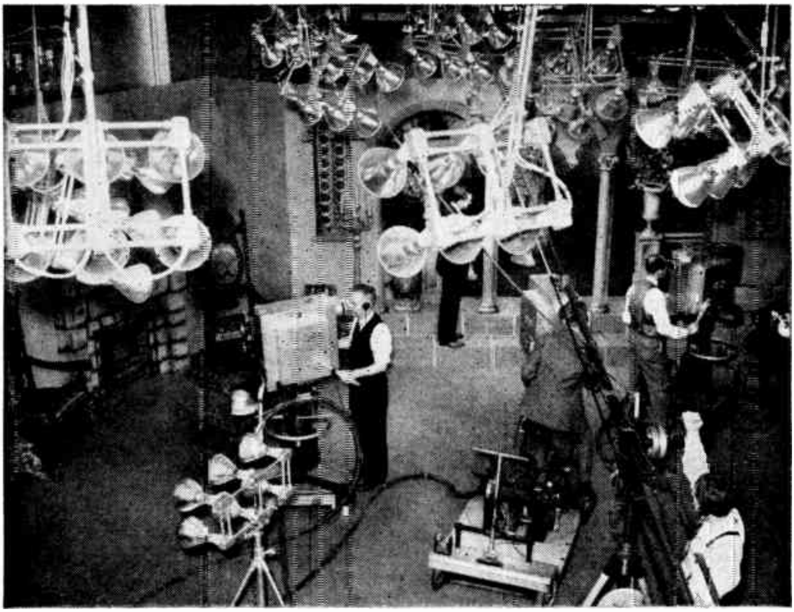
How pictures are sent by electricity. Light entering the iconoscope sets up thousands of tiny electrical charges on the mosaic (1). These charges are an electrical counterpart of the image. They are strong where the light is strong, weak where the light is weak. An electron gun (2) fires a stream of electrons at the mosaic. Guided by electromagnets (3), the electron stream scans the image on the mosaic, releasing from the metal plate (4) a series of electrical impulses (5), strong when the electron stream hits a bright spot, weak when it hits a dark spot. This series of impulses is amplified and then made to modulate a carrier current (6). The modulated carrier current (7) is sent to the antenna and broadcast. It is picked up by the receiver (8), amplified (9), rectified (10), and sent to the kinescope, where it controls the electron stream leaving the kinescope's electron gun (11). This electron stream is guided by electromagnets (12) so that it scans a fluorescent screen (13) in precisely the same way as the electron stream in the iconoscope is scanning the image on the mosaic. The fluorescent screen converts the energy of the electron stream into light, bright where the electron stream is strong, dark where the electron stream is weak.

scans the entire surface of the mosaic at the almost incredible speed of 525 lines in 1/30 of a second.

In effect, the stream of electrons might be compared with a thin stream of water which fills the globule-cups. Each time a cup fills, the scale tilts; each time a globule on the mosaic gets back from the electron gun the electrons it gave off when light struck it, a tiny electrical impulse leaves the metal plate behind the mosaic. In this way, the electrical charges on the globules are picked off line by line and changed into tiny electrical impulses varying in strength according to the amount of light which struck the globule. In 1/30 of a second, thousands of electrical impulses leave the plate, each one representing one spot of the picture. The impulses are then amplified, attached to carrier waves, and broadcast.

As usual in electrical communication systems, the receiver unravels the work of the transmitter. The varying current, representing lighter and darker spots in the image, is sent to a tube called a *kinescope*. Here it controls, or modulates, a stream of electrons, allowing more electrons to flow when the current is strong and fewer when the current is weak. The electron stream is made to follow almost magically the same course as the stream from the electron gun in the iconoscope. Line by line it scans

The kinescope converts electrical impulses into pictures.



Bright lights and action! A television program is on the air. Notice how cameras are focused at different stage sets. The director, by flipping a switch, can broadcast any scene he wishes.

the surface of a fluorescent screen, where the electrical energy of the electrons is changed into light. The more electrons hitting the screen, the brighter the light. A bright spot in the original image, changed at first into a strong current and then into a stream of electrons, is finally changed back into a bright spot on the receiving screen. Bit by bit, the light and shade of the image is spread out on the screen, and in 1/30 of a second the entire image has been reconstructed. Since our eyes hold an image for about 1/16 of a second, the image on the screen does not disappear before the next one is painted on. The total effect, as image after image flashes on the screen, is of one, continuous picture such as on a motion picture screen.

To some of us, television seems like the last word in the drama of man's effort to use electricity for communication. Actually, it is more like the end of Act I. Today we know the power of electricity, the intricate, complicated things it can do. We can control it with almost undreamed of delicacy. We can unleash its power in almost any conceivable way. Electricity is no longer a mystery. It is a willing, obedient servant, ready for the command of men with daring imaginations—men who can still dream of new eyes and ears for the millions.

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722

Things You Can Do

1. Experiments with electromagnetism. (A) Magnetize a steel sewing needle by stroking it with a magnet, or by winding about 50 turns of bell wire around it and running current from a dry cell through the wire for a few seconds. Suspend the needle from its center by a silk thread about 4 feet long. When it comes to rest, note which end points north. Mark this end with black ink. Place a wire directly below the needle. Touch the ends of the wire to a battery. Note which way the needle jumps. Now place the wire above the needle and do the same thing. Reverse the poles of the battery and repeat the experiment. Make a record of your results.

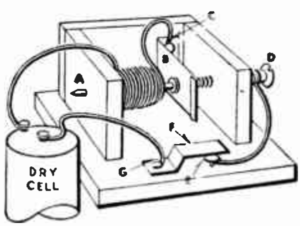
(B) Wind 100 turns of wire into a solenoid (see illustration on page 5). Send current through the wire, and hold one end of the solenoid near the needle. Notice which way the needle jumps. Reverse the poles of the battery and repeat.

(C) By taking several tests, determine how far the needle must be from the solenoid to be unaffected by the magnetism of the solenoid. Now slip a nail through the center of the solenoid and repeat this experiment. Is the solenoid a stronger magnet with or without the nail?

What rules might you draw from these experiments? Can you devise other experiments to test these rules?

2. From the information in this book and other information you can get from the library, make a wall chart picturing the historical development of communication by electricity. You might limit the information on the chart to the famous inventors and scientists in this history, to the electrical devices invented, or to the growth of electrical communication. Or, if you are ingenious enough, you might be able to combine all these on a single chart.

3. Arrange a group visit to a radio station or to a telephone or telegraph office. Prepare a report describing what you saw and learned.



4. With a few simple materials, you can make a Code buzzer. *A* is a nail with about a hundred turns of insulated bell wire around it. *B* is a strip about 3 inches long from a tin can. The free end is about ⅛ inch away from the end of nail *A*. The other end is held firm by tack *C*, to which the wire from *A* is connected. *D* is a screw or bolt so adjusted that it presses against the free end of strip *B*. A wire runs from *D* to *E*, a small nail standing about ¼ inch above the board. *F* is another strip of tin can which serves as the key. Its free end, when pushed down, touches nail *E*. The other end is fastened down by tack *G*, from which a wire leads to a pole of the battery. With better materials, you can improve this, but here is a buzzer on which you can begin to learn Code. Can you explain why the buzzer buzzes?

SCHOOL SERVICE

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