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Developments in the Art of Telegraphy

By R. B. STEELE *

WE speak today of the many inventions brought about by man's insatiable desire for speed, for speed in making things, for speed in doing things—for speed in getting from one place to another, for speed in collecting and distributing information. History tells us that this desire for speed is not new and that it is this desire, existing even before the days of written records, that is responsible for telegraphic communication.

The earliest legends tell us of the distribution of information by word-of-mouth, first in the form of what we term today rumors and later, when more definite requirements arose, in the form of definite messages conveyed by definitely appointed messengers. These messengers were first on foot, but later in the interests of speed were mounted. Then came the day of the written message which could be handed from one messenger to another and relays of messengers were used. But, even a relayed message carried in the fastest possible manner was too slow and some early communication engineer, if we may term him such, conceived the idea of conveying messages by means of signal fires and columns of smoke which could be observed from a distance. Signals so conveyed were infinitely faster than the best mounted messenger and this scheme of signaling by means of fires may be considered to be the first telegraph.

Signal fires took time to build, however, and the number of signals that could be conveyed by this means was limited. Other schemes were worked out in the attempt to increase the speed, flexibility and reliability of these early telegraph systems and these schemes ranged all the way from groups of characters or letters, set up on high points where they could be observed from a distance, to light signals, flags and peculiar windmills with adjustable arms.

One of the earliest telegraphs of which we have now a direct representative, was a system of flag signals introduced about the middle of the seventeenth century by the Duke of York (afterwards James II of England) who was at that time admiral of the English fleet. This scheme was introduced for the purpose of directing the manoeuvres of the fleet and modifications of it are still in use in practically all navies in the world.

Chappé's Telegraph

One of the most successful of the telegraph systems of the pre-electrical era made use of a mechanical device conceived and built by two French college boys. The boys, Claude and Ignace Chappé were attending a college at which they lived and studied in different buildings and where the rules forbade communication between the residents in these different buildings. As college boys do even today, they resented this restriction and set about finding a way of getting around the rule. Their efforts resulted in the construction in 1784 of a signaling device consisting of a horizontal arm mounted on the top of a pole and equipped with two movable arms, one of these hinged to each end of the horizontal arm in such manner that the two movable arms could be set at various angles with respect to each other and to the horizontal arm. With this device the brothers were able to make nearly 200 distinct signals and by means of two of these devices, each so displayed as to be visible to the other building, and a pre-arranged code, they were able to carry on conversations.

This telegraph system of the Chappé brothers was so successful that about

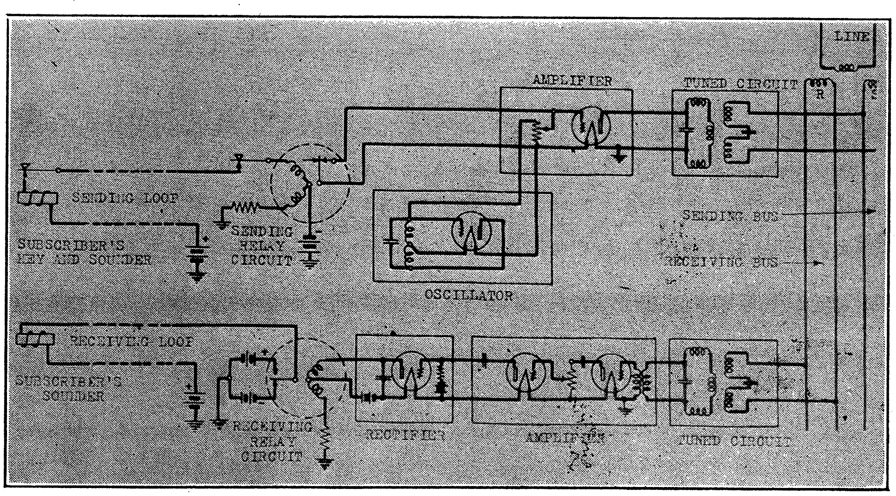

Fig. 1. Type B carrier telegraph. Essential elements of a single channel terminal.

†*Presented before the Club, December* 10, 1930.
* *Asst. Chief engineer, Canadian National Telegraphs.*

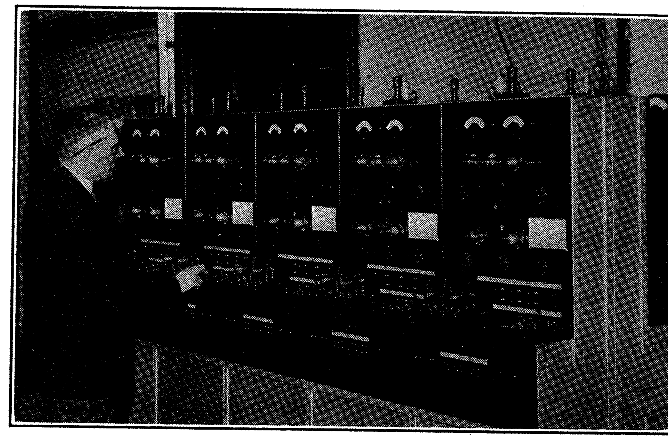

Fig. 3. Panels for carrier system.

1794 the French government adopted it and retained Claude Chappé as chief telegraph engineer to set up an extensive system of these semaphore stations. A modification of this semaphore signaling device is in use along many railway tracks today for conveying a simple set of signals to the locomotive drivers.

It is estimated that signals could be made at the rate of about 2 to 5 words per minute using either the flag system of the Duke of York or the semaphore device of the Chappé brothers, and since a code was used with both of these devices any desired message could be transmitted. But they, in common with all the other schemes of the pre-electrical era, depended upon good weather conditions, or good visibility for their successful operation and the distance over which signals could be sent was limited to the distance the human eye, aided by a telescope, could see, unless relaying was resorted to, which materially reduces the speed at which a message can be transmitted.

About 1729 a discovery relative to electricity, was made which diverted the efforts of scientists from the development of mechanical or visual telegraph systems to telegraph systems making use of the force electricity. The first electric telegraph system was proposed in 1753. This system which will be described later was impractical and, records indicate, was never tried out. The first practical electric telegraph scheme was proposed about 1820. You will note that even at the time the Chappé brothers were introducing their visual system, the development work on the electric telegraph was taking place.

Stephen Gray

The progress of the development of the electric telegraph hinged upon a number of discoveries. In 1729, Stephen Gray discovered that the influence of electricity could be conveyed to a distant point by means of an insulated wire. Between 1767 and 1800 scientists including Galvani and Volta discovered the phenomenon connected with the voltaic pile and constructed this device for providing a sustained source of electrical energy. In 1805 Romagnesi discovered that a wire carrying an electric current is capable of deflecting a magnetic needle. In 1820 Schweigger discovered that if a coil of several turns of wire carrying a current is placed around the magnetic needle the deflecting force is increased. In 1825 Sturgeon discovered that a bar of soft iron was rendered temporarily magnetic if surrounded by a coil of wire through which an electric current was passing. About 1830 Joseph Henry worked out the design for electromagnets suitable for responding to currents received over telegraph lines and about 1833 Gauss and Weber discovered that they could transmit telegraph signals over a line making use of induced currents produced by the motion of a coil of wire surrounding a bar magnet. These are probably the fundamental discoveries upon which our present electrical communication is based.

At the time of Stephen Gray's discovery, static electricity, together with the means of generating it and of detecting its presence was known. The generating device was the electrophorus and the detecting device was the electroscope. It was perfectly natural, therefore, that the first proposal for an electric telegraph should make use of such electricity for the operating energy and of the electroscope for the indicating instrument. The proposal was made by Charles Morrison of Renfrew, Scotland, in 1753. Morrison's scheme made use of one line wire for each character to be transmitted, 26 wires in all, the transmitting operator electrifying the wire associated with a particular character and the receiving operator knowing the character being sent by the response of a particular electroscope. It is estimated that messages could be transmitted over this system at the rate of about 6 words per minute, which is a speed of about 2/10 words per minute per wire.

Morrison's scheme was followed by a series of similar schemes proposed by other scientists. These schemes made use either of the electrophorus and the electroscope, or, later, when the devices became available, of the voltaic pile and the galvanoscope or galvanometer and still later of the dynamo electric machine and the electromagnet. Many of these schemes were quite interesting and some of them involved rather novel features. Time will not permit of a complete description, but I will point out the important features of some of these proposed schemes.

Ronalds' Dial Telegraph

In 1816, Ronalds proposed a scheme making use of a dial at each of the two stations, the dials rotating in synchronism and exposing to view, one at a time, a list of characters required for the transmission of a message. The dials were rotated once a second but other limitations of the system held the transmission speed down to the rate of about 5 words a minute, which however, was over one line wire. This was the first scheme proposed making use of the synchronous operation of units at the

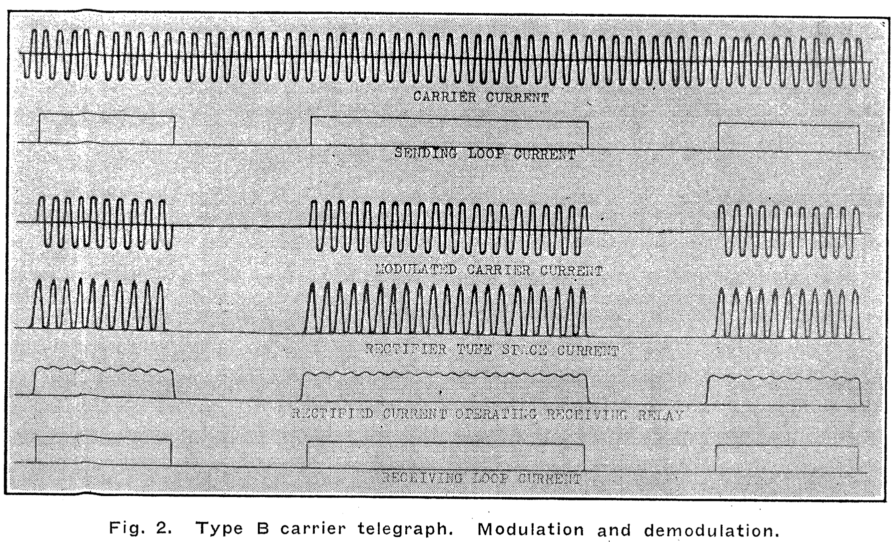

Fig. 2. Type B carrier telegraph. Modulation and demodulation.

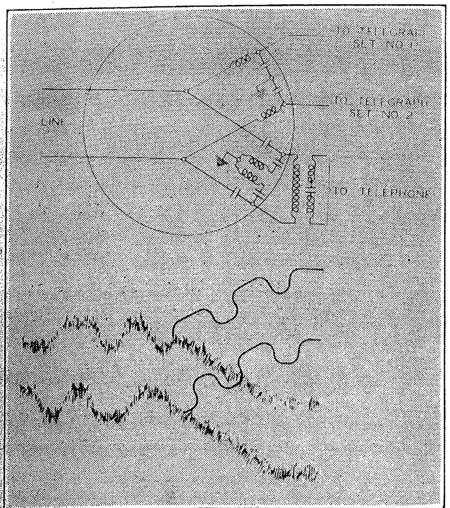

Fig. 4. Composite set.

two stations. In 1820, Ampere proposed a system quite similar to that of Morrison's, requiring one wire for each letter of the alphabet, but making use of the then available voltaic pile and the galvanoscope. The notable feature of Ampere's scheme was the use of a transmitting keyboard, consisting of a number of keys, one for each character to be transmitted, arranged in the same manner as the keys on a piano. Because of the keyboard and the faster operating equipment used, Ampere was able to better Morrison's speed and to handle about 10 words per minute over his system. However, since Ampere used the 26 wires, the speed of transmission was only about 4/10 words per minute per wire.

In 1832, Schilling proposed a telegraph scheme which with modifications and improvements is still in use today. Schilling's scheme made use of the voltaic pile and the galvanoscope. A single line wire was proposed and was equipped with a single galvanoscope at the receiving end. Signals were handled by means of a code and the novel feature of Schilling's system is that it made use of current reversals, the current flowing first in one direction and then in the other over the line wire to form the signals. With the codes then available it is doubtful whether messages were handled over Schilling's system at speeds greater than about 10 words per minute, but this was over one line wire and was, therefore, quite a step forward. Such polarized signals are employed in most of our present-day high speed telegraph systems. In 1831, Henry was able to construct some electromagnets, based on Sturgeon's discovery of a few years previous, and to him undoubtedly belongs the credit for setting up the first system making use of an electro magnetic receiving device. Henry's telegraph receiver looked much like a present-day single acting bell and literally rang out the signals when connected to the end of a relatively long laboratory line.

Morse's Invention

In 1837, Morse patented a form of self-recording, electromagnetic telegraph and because of the publicity his invention received he became known as the "Father" of the telegraph. Morse's original transmitter consisted of a set of blocks bearing various numbers of projections on one surface and a contact making device through which the blocks were passed to open and close the circuit. His original recording receiver consisted of a pendulum, bearing a pen at the lower end, and so suspended with relation to an electromagnet that when the magnet was energized the pendulum moved. A strip of paper was passed under the pen by means of a clockwork mechanism and the strokes of the pen recorded the signals on the paper as the pendulum moved. Morse proposed the use of a numbered vocabulary in connection with his instruments to serve in interpreting the signals recorded on the tape.

To assist with the work of patenting his invention, Morse entered into an agreement with Alfred Vail and two others by which they were to share the expense and labor and likewise the returns on the invention. Vail took hold of the telegraph and in short order so improved Morse's instruments that they are still in use today for the manual transmission of the Morse code with only minor changes and refinements in design. Vail was also responsible for the improved code known as the American Morse code. With this code and the telegraph system set up by Morse and Vail, it is probable that good operators could handle messages at the rate of 20 to 25 words per minute using a single line wire. Subsequent improvements have increased this speed to approximately 35 words per minute.

In England, Schilling's telegraph system was later improved by Cooke and Wheatstone and became the standard telegraph system of the Continent. A somewhat different code was used with it, the Continental code, and it is capable of transmitting messages at the rate of approximately 20 to 30 words per minute.

Early in his experience with transmission over a line circuit, Morse discovered that satisfactory transmission could be obtained only over lines of limited length and that if a longer circuit was to be worked some means of repeating signals from one section of the line to another had to be devised. Such a repeater, today known as the single line repeater, was first used by Morse in 1838. This was a crude device and required the attention of an operator whose duty it was to throw a switch which reversed the direction of the repeater and permitted the receiving operator to talk back to the sending operator. This mechanical switch was not eliminated until about 1855 when a scheme of relays was worked out, which permitted transmission of telegraph signals in either direction through one of these repeaters. This repeater is important mainly because it eliminates the manual relaying of messages at the end of each section of line. Manual relaying seriously delays the transmission of a message, multiplying the time required for the initial transmission by the number of line sections, or, to provide a concrete example, effectively reducing the rate of transmission from 25 to 8 words per minute on a message handled at two relay points.

Duplex Telegraphy

A very important step in telegraphy was the employment of one line wire to convey more than one message at a time. A solution of the problem of transmitting two messages simultaneously, one in each direction, was attempted by Dr. Wm. Gintl, of Vienna, in 1853, and later by several others. None of the methods proposed were satisfactory because they all left out of account the electrostatic capacity of the line. It remained for J. B. Stearns, of Boston, to take this feature into account and arrive at the correct solution, in 1871. The balancing scheme used by Stearns to take care of the line capacity is still used today on land line telegraph circuits. The duplex set effectively doubles the speed of transmission of a circuit since it permits the simultaneous transmission of two messages.

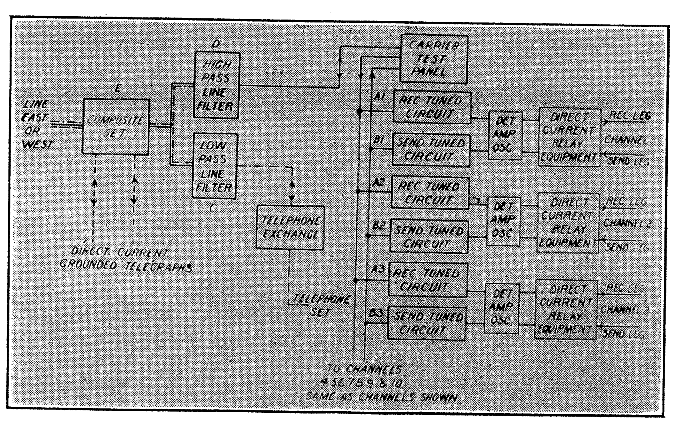

Fig. 5. Type B carrier telegraph. Terminal connections.

The Quadruplex

Next the problem of sending two messages in each direction was worked out. This involves the simultaneous transmission of two messages in the same direction. Dr. Gintl also tackled this problem, in 1853, but without marked success. The first successful method was worked out by Edison in 1874 and his method, with some modifications, is still used. In 1876, Gerrit Smith of the Western Union Telegraph Company invented a system and his scheme became known as the Western Union standard quadruplex. The quadruplex effectively multiplies the transmission speed over the line by four since it permits the simultaneous transmission of four messages, two in each direction.

Quadruplex systems, however, have faults and are noted for their erratic action in times of bad weather. This fact, together with an urge for still greater speed of handling messages over the telegraph lines led experimenters to work along the lines proposed by Moses G. Farmer, of Salem, Mass., in 1852. Farmer's scheme made use of a commutator arrangement which connected the line circuit successively to a number of local circuits and later became known as a multiplex. A similar and much improved scheme was proposed by P. B. Delany, in America, about 1888. Delany's scheme, making use of brushes rotating synchronously over the faces of commutators at each of the two ends of the line, permitted as many as six operators to transmit messages simultaneously in each direction. If each of these operators worked at a speed of 30 words per minute the system was capable of transmitting 180 words per minute in each direction, or a total of 360 words per minute over a single wire. To attain this speed, however, 24 operators experienced in the Morse code were required, 6 sending and 6 receiving at each end of the circuit.

Printing Telegraphs

Sometime after Morse patented his telegraph, a different type of telegraph system was brought out which per-

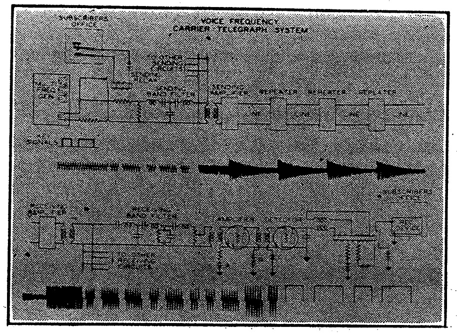

Fig. 7. Voice frequency telegraph system.

mitted an operator to type the message on a keyboard and provided for the reception of the message at the other end by actually printing or typing it out on a tape or a sheet of paper. These systems were known as printing telegraph systems because of the particular method of recording the message at the receiving end of the circuit. The first of these printing telegraphs was patented in 1846 by Royal E. House of Vermont. This system was first introduced commercially between New York and Philadelphia in March 1849, and could handle messages at the rate of about 43 words per minute. This speed was obtained over a single line wire, but transmission was effected in only one direction. A number of other printing telegraphs were brought forth, all similar to that of House, but in 1875 Phelps introduced an innovation in printing telegraph schemes which consisted of the inclusion of an electric motor in the printer itself to operate printing mechanism. This electric motor replaced clockwork mechanisms of earlier models and our most modern present-day printing telegraphs make use of a similar electric motor for the operation of the printer mechanism.

Multiplex Telegraphs

In 1900 a Frenchman, Baudot, brought out what was termed a multiplex printing telegraph system. Baudot's scheme made use of the printing telegraph, of the multiplex proposed by Farmer and of the duplex, thereby permitting the simultaneous operation of six printers in each direction over a common line wire. The printer itself differed little from other models, but the keyboard was a simple affair making use of only a few keys and requiring the knowledge of a code on the part of the transmitting operator. The printers were capable of operating at a speed of 30 words per minute and at this speed a total of 360 words per minute could be handled over this system. The Baudot system was little improvement over the Delany system as both required operators having the knowledge of their respective codes.

Baudot's system was really the forerunner of our present-day high speed multiplex telegraph systems, which however, as used in the plant of the Canadian National Telegraphs makes use of somewhat different equipment. Our multiplex system may be said to be based on the multiplex introduced in 1888 by Delany and consists of a four channel multiplex circuit operated in conjunction with 8 start-stop Morkrum printers, 4 working in each direction. The Morkrum printer is one of the more modern of the printing telegraphs. Approximately 50 words per minute can be handled over each printer circuit and this provides a transmission speed of 200 words per minute in each direction or 400 words per minute for the system and does not require operators trained in the Morse or Baudot code.

Carrier Current Telegraphs

We have discussed the various development phases of the electromagnetic telegraph and have endeavored to describe some of the modern, high speed forms of the telegraph. The telegraph equipment so far described is known as direct-current equipment because of the fact that it makes use of direct-current line signals. In addition to the hand speed Morse circuits and the high speed printer and multiplex circuits, we have in the plant of the Canadian National Telegraphs several types of carrier telegraph systems.

The carrier telegraph system is a result of discoveries made about 1886 by Elisha Gray, Bell, Edison and others. A simple experiment in physics consists of the setting up of three tuning-forks a short distance apart on a table or bench. Two of these tuning-forks are adjusted to exactly the same frequency. We will call these forks A and B. The third tuning-fork, C, is of some different frequency, not a harmonic of the frequency of forks A and B. Now if fork A is made to vibrate, in a few seconds fork B will of its own accord start vibrating in response to the impulses received through the air from fork A. Fork C being of a different frequency remains in a non-

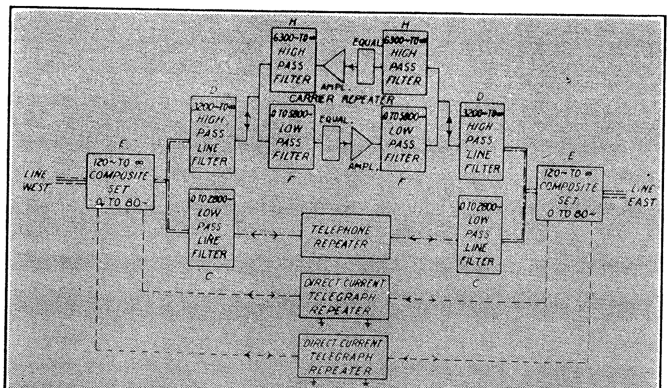

Fig. 6. Type B carrier telegraph. Repeater connections.

vibrating condition. Gray used in his harmonic telegraph, the first carrier telegraph system, this principle of sympathetic vibration of tuned reeds or forks. At the transmitting end of his system he set up three vibrating forks each equipped with a contact to open and close a circuit carrying an electric current. Electric currents interrupted at the three different frequencies of these tuning-forks were transmitted over the line to the receiving end where the signal impulses were made to operate on similar tuning-forks or tuned reeds through electro magnets. Obviously the receiving fork in any particular channel would respond only to impulses from its particular sending fork at the distant end and telegraph signals impressed on the carrier currents generated by the tuning-forks could thus be transmitted over a line circuit. Tuned reeds were used at the receiving end in place of tuning-forks because of the more rapid response of the reeds. Even with the reeds, however, this system was sluggish and signaling was at a low rate of speed.

About 1892 several investigators, Pupin, Hutin and Leblanc, and John Stone independently invented about the same time the electrical method of selection of carrier frequencies. These investigators conceived the idea of using tuned circuits, including capacity and inductance, providing two tuned circuits for each channel, one at the transmitting end and one at the receiving end. The tuned circuit at the transmitting end prevented the transmission of all frequencies, except the channel frequency, to the line and the one at the receiving end prevented the reception of all frequencies, except the channel frequency by the channel receiving circuit.

In 1894, John Stone, at that time with the American Telephone and Telegraph Company, started development work which, with later contributions made by others, resulted in the installation in 1917 of a four channel experimental carrier telegraph system. This experimental system was operated between Chicago, Ill., and Maumee, Ohio. Two years later, in 1919, the first commercial carrier telegraph system was placed in service, a 10 channel system, between Pittsburgh and Chicago.

Major General G. O. Squier, of the United States Signal Corps, in 1910, carried on experiments with carrier currents. Using high frequencies or frequencies in the radio range and using largely radio equipment he successfully operated carrier systems over relatively short telephone lines.

Since the installation of the first commercial carrier telegraph system by the American Telephone and Telegraph Company in 1919 a considerable amount of development work has been done with the result that today there are several types of highly efficient carrier telegraph systems available for use.

In the plant of the Canadian National Telegraphs there are two types of carrier telegraph systems, one a 10 channel system and the other a 12 channel system. The 10 channel system makes use of alternating currents of frequencies ranging from 3,000 to 10,000 cycles and provides 10 two-way telegraph channels over one pair of line wires. The second or 12 channel system, makes use of alternating currents in the range 400 to 2,300 cycles. This system requires for its operation two pairs of line wires and on these two pair of wires provides 12 two-way telegraph channels.

You will observe that one of these systems makes use of very much higher frequencies than does the other. The alternating currents, or carrier currents as we call them, used on the line wires are quite small and require for their successful transmission specially constructed line circuits. The requirements in connection with line facilities for use with carrier telegraph systems become more severe as higher carrier frequencies are used. The line requirements of the 10 channel system, therefore, are much more severe because of the high frequencies used than are the line requirements of the 12 channel system and for this reason we can afford to use the two line circuit to obtain the equivalent of 6 two-way channels per line pair with the lower frequency carrier currents.

The Canadian National Telegraphs is now installing and expects to place into operation shortly a third type of carrier telegraph system using still higher carrier frequencies than does the 10 channel system and this system is expected to provide 24 two-way telegraph channels on one pair of line wires.

Combined Telegraph and Telephone

A feature of these carrier systems not previously mentioned is that their operation on the line wires does not prevent the use of these same line wires for other services. We are now obtaining a voice telephone circuit and two direct-current telegraph circuits of the simple Morse type from the same pair of line wires that is used to handle the carrier currents of the 10 channel system. The same additional communication facilities will be obtainable from the pair of line wires used in connection with our 24 channel system. Because of the carrier frequencies used by the 12 channel system, a telephone circuit cannot be operated over the same line wires, but one direct-current telegraph circuit can be operated over each line wire making a total of 12 two-way carrier telegraph channels and 4 two-way direct-current telegraph channels obtainable from the 4 line wires.

The carrier telegraph systems provide a transmission circuit for telegraph signals equivalent to that provided by a high grade copper wire circuit. Each one of the telegraph channels is, therefore, capable of handling the signals of one of the high speed automatic telegraph systems and we are working today four-channel

Fig. 8. Equipment for one terminal of 24-channel system.

multiplexes operating at overall speeds of 400 words per minute on many of the carrier telegraph channels. Now, if we equip each of the two line wires of a pair with a four-channel multiplex, the total signal speed obtainable over the pair would be 800 words per minute. On the other hand, if we equip this pair with a 10 channel carrier system we can operate the line wires themselves to obtain a transmission rate of 120 words per minute and by operating a four-channel multiplex on each carrier channel we can obtain a total of 4,000 words per minute over the carrier system, which makes a total of 4,120 words per minute for the pair of line wires or 2,060 words per minute per wire. This appears to me to be quite an appreciable increase in transmission speed over the five words per minute possible with the flag signals or the Chappé semaphore described in the first part of this paper. The use of the 24 channel carrier telegraph system will provide an even greater speed. No one knows when we will cease our endeavour to obtain still higher speeds of communication, but you may rest assured that we have by no means reached the limit, and the near future will see further improvements in telegraph service making for still greater speed in handling messages.

These amazing increases in the speed of handling telegraph messages, brought about by the use of the carrier telegraph, may make one wonder, perhaps, as to just what this carrier telegraph is. We have already indicated in describing the experiments of Elisha Gray, the general idea upon which the carrier system is based.

The 10 channel carrier telegraph system referred to previously is known as the Type B, or high frequency, carrier telegraph system. It consists of 10 individual transmitting and 10 individual receiving circuits at each end of the line and for the transmission of signals over the 10 two-way channels twenty different carrier frequencies are provided. The use of twenty frequencies is necessary in order to permit of the separation by means of tuned circuits of the frequencies used by the 2 one-way carrier circuits making up a single carrier channel. The elements of one terminal of a single carrier channel are shown in Fig. 1. We see from this figure that the subscriber is provided with two loops. One of these, the sending loop, contains a telegraph key and a sounder, and the other, the receiving loop, contains only a sounder. We note that when the subscriber operates the telegraph key in his sending loop a relay connected in the loop is actuated by the loop signals. The contacts of this relay are connected in series with a modulating circuit bridged across the input of an amplifier tube. A vacuum tube oscillator adjusted to work at the carrier frequency of the particular channel supplies carrier current through a gain control device to this same amplifier tube. The operation of the modulating circuit serves to open and close what is in effect a short circuit across the input of the amplifier and in so doing either permits carrier current to flow through the amplifier to the line circuit or reduces the carrier current reaching the line circuit through the amplifier approximately to zero. The modulating device, following the signals made with the telegraph key by the subscriber, transmits to the line long and short impulses of carrier current to correspond with the signals made with the telegraph key. This modulated carrier current is transmitted through a sending tuned circuit and through a line transformer to the line. The other nine transmitting circuits of a terminal are connected in parallel with this transmitting circuit to the sending winding of the line transformer.

Carrier currents being received from the distant end pass from the line through the line transformer to the 10 receiving circuits of the terminal connected in parallel with each other. Each receiving circuit is provided with a tuned circuit which permits of the passage through its networks of the carrier frequency to which it is tuned, but offers resistance to the passage through its networks of carrier currents of all other channel frequencies. The receiving tuned circuit functions, therefore, to select the carrier current of a particular channel. This channel carrier current, having been separated from the nine other channel carrier currents on the line, passes through a two stage vacuum tube amplifier provided with a gain control. From the amplifier the incoming carrier signals are passed to the rectifier or detector tube in which they are changed from alternating to direct-current signals such as can be used to operate a relay. The rectified carrier signals are of a low current value, a value of the order of 5 milliamperes, and this small current is used to operate a receiving relay which in turn repeats much stronger direct-current telegraph signals to the receiving loop where they operate the sounder in the subscriber's office. The current in the receiving loop is of the order of 60 milliamperes.

A carrier telegraph channel provided with two loops as shown in Fig. 1 is known as a full duplex channel and permits of the simultaneous transmission of a message in each direction. Means are provided in the direct-current telegraph circuits of each carrier panel for so connecting the sending and receiving relays together, that the receiving loop to the subscriber's office may be dispensed with and signals both transmitted and received over one loop. Such a circuit arrangement provides a half duplex channel and provides for the transmission of only one message or for the transmission in only one direction at a time. Certain classes of telegraph service make such a connection desirable.

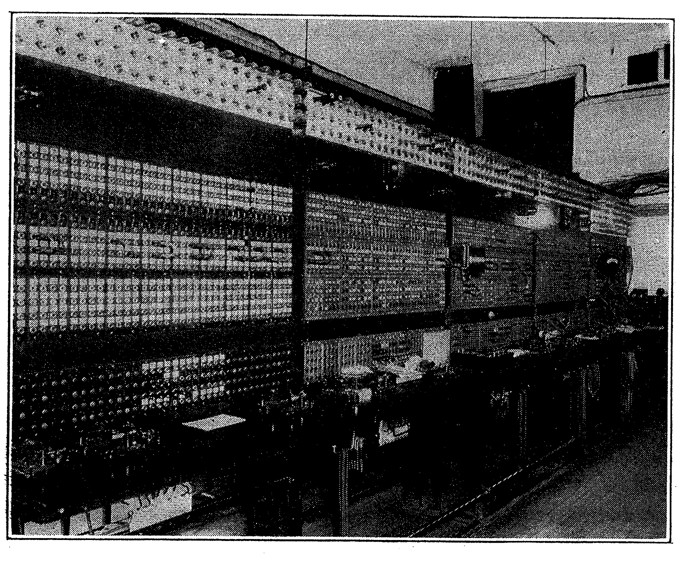

Fig. 9. Telegraph switchboard in Montreal office, Canadian National Telegraphs.

Modulation and Demodulation

We have discussed briefly the operation involved in modulation and demodulation in a carrier telegraph channel. Reference to Fig. 2 will perhaps make this explanation somewhat clearer, for this figure shows the direct-current signals made in the transmitting loop by the operation of the telegraph key, shows the unmodulated output of the oscillator and shows the carrier current, modulated by the direct-current sending loop signals, as transmitted to the line.

Similar modulated carrier signals arrive with usually small changes in the envelope at the receiving terminal and are selected by means of a particular receiving tuned circuit, amplified to a value governed by the gain control device and applied to the grid of the rectifier tube. Fig. 2 shows the pulsating current derived from the rectifier and shows the rectified current signals reaching the sensitive receiving relay after passing through an elementary filter connected between the rectifier and the relay. The figure also shows the signals repeated into the receiving loop. You will note, by comparison, that the signals made in the sending loop appear to be received without change in the receiving loop at the distant end of the circuit. Unfortunately this is a very rare occurrence owing to the fact that the wave shape of the direct-current signals is affected by the inductance of relays and other pieces of equipment connected into either of the loops and owing to the fact that the envelope of the modulated carrier signal undergoes changes in its transmission over the line circuit due to the characteristics of the line and to the presence of various filter networks in the line circuit. An accelerating or bias correcting device is, however, provided in each receiving circuit of the channel which, functioning in conjunction with the rectified current signals, tends to counter-balance somewhat the effect of the sending loop and the line circuit on the signals.

Figure 3 shows operating panels installed at Montreal.

Filter Networks

As indicated, other services besides a carrier telegraph system can be operated over the same pair of line wires. This is so, providing the various types of service lie in different ranges in the frequency spectrum. When such is the case these various services can be separated at terminals and at repeater points by the use of filter networks. If, for instance, we are to operate two direct-current telegraph circuits, one on each line wire, at the same time that we are operating the carrier, a composite set is required at each point where it becomes necessary to separate the line currents of the two kinds of telegraph. The composite set is shown in Fig. 4. In this figure, we have endeavoured to show graphically the manner in which the two kinds of signals are separated, the direct-current signals passing through one branch, the low-pass side of the composite set, and the higher frequency or alternating-current signals passing through the other branch or high-pass side of the composite. Similarly, if on the same line with the carrier and the d.-c. telegraph we are to operate a voice telephone circuit, the voice currents are separated from the carrier currents by means of what may be termed high frequency composite sets. Such a composite set will consist of two filters, a high-pass and a low-pass filter connected in parallel either to the line, when no d-c. telegraph is being used, or to the high-pass side of the composite set when this set is installed. The use of such a high frequency composite set is shown in Fig. 5.

Line Circuits

As indicated, carrier telegraph systems require somewhat special line circuits. The every-day d-c. telegraph circuit makes use of a single line wire and uses the ground for a return path. The line currents used by the carrier telegraph system are of a very low value and if an attempt was made to operate a carrier system on a ground return circuit the interference reaching the carrier receiving circuits would be such as to prevent the operation of the system. It is necessary, therefore, to provide a metallic circuit or a pair of wires on which to operate a carrier current system and it is further necessary to transpose or interchange at intervals the positions of the two line wires with respect to the other wires on the same pole line. This transposing is done merely by shifting the line wire from one pin position to that of its mate at the same time shifting the mate to the pin position of the first wire. This transposing so arranges the two wires of the pair that interfering currents picked up along any one section or sections tend to neutralize themselves so far as the terminal equipment of the circuit is concerned. The higher the frequencies used by a carrier system, the more frequently must these transpositions be made to secure satisfactory operation and freedom from cross-talk and foreign interfering currents.

Because the line currents used by a carrier system are very small in value and because there is a practical limit to the sensitivity that may be built into a carrier receiving circuit, the length of line over which carrier transmission can be effected between two terminals is limited, unless we install some intermediate means of amplifying or reinforcing the line currents. In connection with the ten channel carrier telegraph system, use is made of vacuum tube amplifiers spaced at distances of between 150 and 300 miles along the line to extend the range of the system and by the use of such amplifiers we are able to operate a system with the terminals approximately 1,200 miles apart. This is not the maximum operating limit, but happens to be the longest distance between terminals of any carrier system in the plant of the Canadian National Telegraphs.

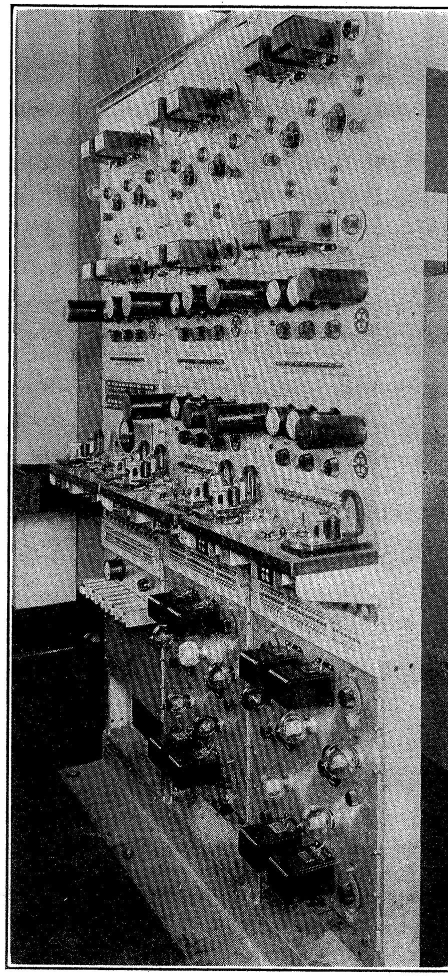

Fig. 10. Terminal equipment for five two-way telegraph channels.

Repeaters

We have not as yet found repeaters which will amplify all frequencies in the range, zero to 10,000 cycles and for this reason it becomes necessary at each one of the repeater points to separate the line currents of the various types of systems operating on a pair of wires. This is done by means of composite sets and high frequency composite sets, as it was at the terminals, and once the various line currents are separated, those for each kind of communication service are amplified or repeated by means of equipment especially suited to the particular line currents. I have told you that the ten channel carrier telegraph system makes use of twenty different carrier current frequencies, ten of these being used in each direction. In order to provide a two-way repeater for the carrier current some means of separating the carrier currents traveling in the two directions must be devised. Filters are used for this purpose; a group or pair of what are termed directional filters, one a high-pass and the other a low-pass. A pair of these directional filters is connected to each side of the carrier amplifier equipment and these filters separate the two groups of carrier currents traveling in opposite directions permitting the amplification of the group traveling in each direction by means of a separate amplifier. The connections at such a repeater point are shown in Fig. 6 for a repeater station at which direct-current telegraph signals and voice telephone line currents, as well as the carrier currents, are amplified. You will note that an equalizer is included ahead of each carrier amplifier in this figure. This is necessary because of the fact that while the frequency characteristic of the amplifier is practically flat the frequency characteristic of a section of line is not, and the equalizers are installed in an attempt to provide an equal transmission equivalent from terminal to terminal on a carrier telegraph system for all the carrier frequencies of either frequency group.

Voice Frequency Carrier Telegraph

In addition to the ten channel carrier telegraph system making use of a pair of line wires I have mentioned a 12 channel carrier telegraph system making use of a different portion of the frequency spectrum and requiring for its operation two pairs of line wires. This particular system was really designed for operation over long cable circuits where a quad or group of four wires is available for each telephone or carrier telegraph circuit. Because of the frequency characteristic of cables which does not permit of the transmission of high frequencies unless loading is resorted to, the frequencies of this system were kept as low as possible and are, therefore, in the voice range. Because a quad, or group of four wires, was available which would provide two distinct transmission circuits, one to be used in each direction, it was not necessary to use different frequencies for transmission in the two directions. The system, therefore, makes use of the same frequencies in one direction as it does in the other. We have no very long cable circuits in the plant of the Canadian National Telegraphs, but because this system may be used on practically any open wire pairs suitable for telephone service and because it may readily be modulated onto the channels of any one of a number of types of carrier current systems, it is useful. Two systems are in operation over open wire lines and the 24 channel system to which I referred will make use of two of these 12 channel systems modulated onto the channels of still another carrier current system. Fig. 7 shows, in diagrammatic form, one complete transmission circuit of a 12 channel or voice frequency carrier telegraph system. The transmission circuit in the opposite direction makes use of identical equipment and of an identical line circuit. For convenience in operating, the sending and receiving equipment of each channel is assembled as a channel unit although, unless the channel is being operated as a half duplex circuit the transmission circuits of the 2 one-way circuits making up the channel are entirely separate. Fig. 8 shows the equipment for one terminal of the 24 channel system. The four left-hand bays in this figure hold the equipment for the high frequency carrier channels onto which the two 12 channel systems are modulated. The next three bays hold the battery supply and carrier current generating equipment for the 12 channel systems while the eight right-hand bays, two groups of three channel bays and one filter bay each, hold the terminal equipment for the 12 channel systems. This installation is in our Toronto office.

Because of the fact that the voice frequency carrier telegraph system makes use of carrier frequencies in the voice range a telephone channel cannot be operated on the same conductors, but each of the pairs of line wires may be equipped with composite sets and the four line wires may be used for both direct-current and carrier telegraph purposes.

The description given and the figures shown thus far cover the carrier current and line equipment only. Power obtained from storage batteries is used to operate the carrier current equipment. In addition to the power, the operation of the carrier current and other telegraph systems requires the making of many different circuit connections between lines or subscribers loops and the telegraph equipment. This is done by means of patching cords at the office switchboard. Fig. 9 shows the switchboard installed in the Montreal office. It has a capacity of 120 main line wires.

Fig. 10 shows the terminal equipment of still another carrier current telegraph system recently installed in the plant of the Canadian National Telegraphs. It provides 5 two-way channels, uses frequencies in the range 5,400 to 12,800 cycles and can be used on circuits up to 450 miles in length. It is intended for short haul use on routes not requiring the facilities supplied by a 10 channel carrier system.

I have attempted to discuss briefly the historical background of the telegraph and have attempted to provide a picture of the present-day high speed direct-current and carrier current telegraph systems.

CLUB NOTES

The Spring schedule of papers to be delivered before the Radio Club of America is as follows:

March 11, 1931—C. J. Franks—Radio Frequency Laboratories.
"Design and Construction of Standard Signal Generator."

April 8, 1931—A. B. DuMont—DeForest Radio Company.
"Modern Trend in Television."

May 13, 1931—W. F. Diehl—RCA-Victor Corporation of America.
"Test Methods and Equipment."

June 10, 1931—S. D. Gregory—Westinghouse Electric & Mfg. Co.
"Common Frequency Broadcasting."