Phonopore and phonoplex

F.D.M. telegraph systems used on railways in the late 19th century

Prof. D.G. Tucker, D.Sc., C.Eng., F.I.E.R.E., F.I.E.E.

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Abstract

The phonopore and the phonoplex were both systems introduced in 1885 for providing additional telegraph channels (or, alternatively, in the phonopore system, a telephone channel) in the frequency range above that of the ordinary d.c. or Morse channels. The phonopore, developed by Charles Langdon-Davies in England, used a special kind of coupling transformer/condenser, which is here analysed but shown to have had few useful special properties, and used a 'harmonic' telegraph channel, i.e. a keyed oscillatory signal. Edison's phonoplex used, for the highpass channel, signals derived from the transients produced by an induction coil. Both systems were made commercially, and had a certain success on railways. The Phonopore Syndicate (later Company) had an interesting but not successful history, here partially unravelled; from 1893, its managing director was C.E. Spagnoletti, F.R.S., Past-President of the Society of Telegraph Engineers, and newly-retired telegraph superintendent of the Great Western Railway. Although the company had, by 1895, raised around £100 000 of capital, it was in that year effectively purchased by the New Phonopore Telephone Co. for £2000. The new company continued in existence, with an issued capital reaching no more than about £8000, until it was purchased for £175 in 1916 by the Phonopore Construction Co., which finally ceased operations soon after 1920.

1 Introduction

The phonopore, patented by Charles Langdon-Davies first in 1884, and the phonoplex, patented by Thomas Alva Edison first in 1885, were basically frequency-division-multiplex (f.d.m.) telegraph systems, the former explicitly and the latter implicitly, although the phonopore was first proposed as a means of superposing a telephone channel on a telegraph wire without mutual interference. In this respect, the system was similar to, and quite probably stimulated by, the van Rysselberghe system, which was the means by which long-distance telephony became economically and technically feasible in many countries in the decade starting in 1882.[1,2] The antecedents of this kind of f.d.m. system had a relatively long history, but we shall here mention only a few significant steps.

The first proposal was that of E. Highton[3] in 1850, and it is interesting that Edison's phonoplex was practically the same as Highton's system. Explicit f.d.m. telegraph systems were proposed by Alexander Graham Bell[4] and by Elisha Gray[5] in 1876, and, although the former had perhaps the better understanding of the fundamental requirements of such systems, it was apparently only the latter whose system went into even experimental practical service.

Langdon-Davies was probably too late to compete with van Rysselberghe on simultaneous telephony and telegraphy, and quickly turned over to the 2-channel (or multichannel if desired) f.d.m. telegraph system, which proved successful technically and was adopted on a limited scale by several of the British railway companies from 1887 onwards. The Phonopore Company was established to exploit the system, but it seems certain that it was not a commercial success.

Edison's phonoplex was also used by railway companies, probably only in the USA, and, again, only on a limited scale.

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Prof. Tucker was formerly Head of the Department of Electronic & Electrical Engineering, University of Birmingham. He is now retired, and is Senior Fellow in the History of Technology, Faculty of Science & Engineering, University of Birmingham, PO Box 36, Birmingham B15 2TT, England

A somewhat similar system used by the British Army is also mentioned briefly at the end of this paper.

Technically, the phonopore was interesting in that it involved a very special kind of transformer, which was not understood at the time. An analysis of this device is therefore given in this paper.

2 The phonopore

2.1 Early conception and patents

The first reference to the phonopore principle by Langdon-Davies appears to be his patent of 1884.[6] At this stage, however, he was thinking in terms of the superposition of a telephone channel on an existing telegraph line on much the same basis as the much better known system of F. van Rysselberghe. Nevertheless, the distinguishing feature of Langdon-Davies's system shows clearly here in the special coupling device which he at this stage called the 'electrophone'. Typical circuit arrangements from his patent specification are shown in Fig. 1. The electrophone was

> 'composed of two or more conductors laid together but insulated from each other .... Fine copper wire covered with silk or other insulator may be employed. Two or more of these are laid together and are then again covered with silk or other suitable material. The duplex or multiple wire thus prepared is usually wound upon a bobbin .... I call the instruments .... electrophones, because they permit the passage of electrical sounds but arrest the passage of electrical currents, or at any rate, of such currents as are capable of actuating telegraph instruments .... One end only of each strand is carried to a terminal, the other end is insulated.'

The basic circuit of Fig. 1*a* could be improved by the addition of a 'double' (as opposed to 'multiple') electrophone in series at the point A in the telephone branch, as shown in Fig. 1*b*, since 'this arrangement is very efficient in cutting off telegraph noises'. Another arrangement which has a 'marked beneficial effect in deadening telegraph noises' is the shortcircuited winding of Fig. 1*c*.

In his patent, Langdon-Davies gives no word of explanation as to the principles involved in his remarkable device, but an account of how he was led to it appeared later in an article in *The Times*[7] that he had undoubtedly inspired:

'It has long been known that if a telephone be inserted in a wire situated near to a line of telegraph wires, every passing telegraph current will produce noises in the telephone, although the telephone wire is perfectly insulated from the telegraph wires. These noises are termed 'induction noises', and they constitute one of the greatest obstacles in the way of long-distance telephony. Engaged in investigating the phenomena of induction with the view of finding means to obviate its effect in telephones, Mr. C. Langdon-Davies has had occasion to examine it under a variety of conditions, both at home and abroad. On a very long telegraph wire – perhaps one of the longest direct wires in the world – from Amsterdam to Berlin, very strong currents were used, producing so powerful an effect on a neighbouring telephone as to lead Mr. Davies to the hypothesis that the so-called induction was caused by some form of electric force which might be separated from currents, and which could pass freely through insulators impassable by currents, and further that if this were so a new series of instruments might be constructed for the employment of this force, and which, moreover, could be put into action in company with current instruments on the same wire. The line of research thus indicated has been perseveringly followed by Mr. Davies, and has, after long and patient research, led to the completion by him of a variety of instruments of apparently great practical utility, as was recently demonstrated to us by Mr. Davies at his offices, 110 Cannon Street, London. The remarkable results they produce speak for themselves; the reasons why they are produced constitute new problems in mathematical physics which have yet to be solved. The only form of electric force which finds free passage through them appears to be always capable of being associated with sound .... The first phonopore constructed, of which those subsequently made are modifications, may be described as a reproduction of a line of telegraph wires under conditions favourable to the transmission of phonoporic impulses .....'

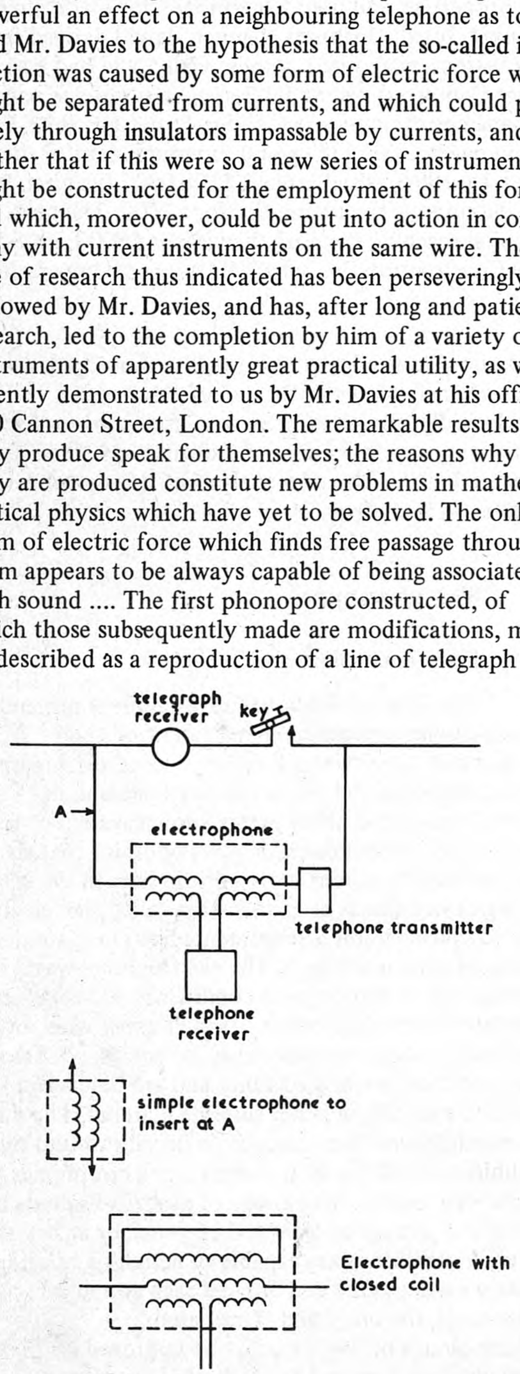

Fig. 1
Electrophone (later called the phonopore) of Langdon-Davies's 1884 patent

In passing, it is interesting to note that *The Electrician* was very annoyed by this article, criticising it as 'absurdly unscientific'[8] but did not otherwise report the demonstration. *Engineering* published a report in somewhat more scientific language a few weeks later.[9]

The Electrican did not again refer to the phonopore for nearly three years!

Although Langdon-Davies never quite abandoned the idea of using his device for telephony, we find in the year 1885 the first and main patent for its use in multiple telegraphy.[10] In the provisional specification, dated the 11th April 1885, the device is still called the electrophone; but, in the complete specification, dated the 11th January 1886, the name phonopore has been substituted without explanation. (It was later stated[11] that the '-pore' came from the Greek *poros*, meaning passage, so that phonopore meant a passage for sound.) The phonopore was, in this patent as often in later practice, combined with a vibrator for generating the a.c. signal which was interrupted by a key to produce the telegraph signals for the a.c. channel. Several such devices, vibrating at different frequencies, could be used to form a multichannel system. Since a vibrator, using make-and-break contacts in a local circuit, had to have a winding on an iron core, it was an obvious simplification to wind the phonopore windings above the vibrator coil on the same former, and thus the phonopore became an iron-cored device. Since the signal-circuit windings were bifilar and there was an iron core (actually a bundle of soft-iron wires), there was excellent capacitive and inductive coupling between the windings. A curiosity of the device at this stage was that the vibrator winding was composed of four single-layer windings, joined in parallel, and then in series with another winding, wound bifilar with one of the four windings but of high-resistance wire. It is believed that, whereas later devices retained the multiple windings, the high-resistance winding was omitted. In what way this peculiar winding arrangement was thought to improve the working of the system has never been made clear.

Reception of the a.c. signals was by tuned reed; when the signal in the driving coil of the receiver caused the reed to vibrate, the resistance of a contact point normally pressing on the reed was increased, and so caused a relay to release and indicate the presence of the signal.

Call signals operated a 'sensitive flame' that normally burnt 'flat upon the gauze, but when suitable harmonic currents pass in the coils, burns as a tall slim flame'.

Many of Langdon-Davies's contemporaries regarded the phonopore line windings as merely a particular kind of condenser. He himself claimed, in another patent of 1885,[12] that, even as a plain capacitor, the phonopore had an important advantage over ordinary capacitors, in that it was far more resistant to lightning discharges and suchlike disturbances that ruined ordinary condensers. We show later that the phonopore is equivalent to a condenser and inductor in series, and it can therefore be seen that there could well have been some truth in the claim.

To gain a real advantage over ordinary telegraph systems, the phonopore system had to be able to work duplex on both ordinary and a.c. channels. This was covered in a patent of 1886,[13] which showed the necessary circuit arrangements, and also described some other technical improvements to the transmitter. Really all that was involved was to include another phonopore in the balance circuit of the a.c. channel.

Two other later patents may be mentioned now,[14,15] but they added little to the art and nothing to the science.

2.2 Analysis of the principle of the phonopore

Any winding such as that coupling the vibrator to the system in Fig. 2 is irrelevant to the basic principle of the phonopore. We therefore take as the arrangement for analysis the 2-winding phonopore shown in Fig. 3. Terminals 3 and 4 are left disconnected. The current flowing into and out of the device is I. The voltage between terminals 1 and 2 is V, that between 1 and 4 is V_1.

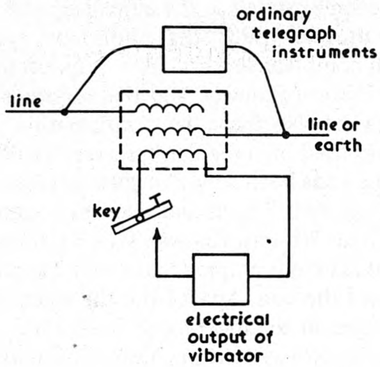

Fig. 2
The phonopore for coupling an a.c. telegraph channel to an ordinary telegraph line

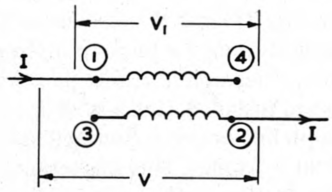

Fig. 3
Basic phonopore for analysis

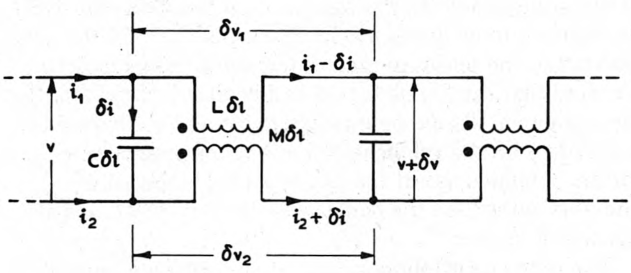

Fig. 4
Notional structure of central part of phonopore

The device is a distributed system of which the structure can be represented as in Fig. 4, where each 'section' is a very small part δl of the total length l of the phonopore, which has self inductance L per unit length, mutual inductance M per unit length, and capacitance C per unit length. Resistance and leakance are assumed negligible. With the notation shown in the diagrams, we have

$$i_1 + i_2 = I \tag{1}$$

$$\delta i = vj\omega C\delta l \tag{2}$$

$$\delta v_1 = (i_1 - \delta i)j\omega L\delta l + (i_2 + \delta i)j\omega M\delta l \tag{3}$$

$$\delta v_2 = (i_2 + \delta i)j\omega L\delta l + (i_1 - \delta i)j\omega M\delta l \tag{4}$$

Now, it was specified that the two windings were bifilar, i.e. were wound on together as a twin wire. It is therefore reasonable to assume that the magnetic coupling is perfect, so that $L = M$. Then

$$\delta v_1 = \delta v_2 = Ij\omega L\delta l \tag{5}$$

$$\delta v = 0 \tag{6}$$

$$V_1 = \int_0^l dv_1 = Ij\omega L_T \tag{7}$$

and, from eqn. 2,

$$v = \frac{1}{j\omega C}\frac{di}{dl} = I/j\omega C_T \tag{8}$$

where the total inductance $L_T = L\int_0^l dl = Ll$

and the total capacitance $C_T = C\int_0^l dl = Cl$

The overall voltage drop V is therefore

$$V = I(j\omega L_T + 1/j\omega C_T) \tag{9}$$

which means that the equivalent circuit is merely a series connection of L_T and C_T, as shown in Fig. 6. The voltage distribution along the windings is as shown in Fig. 5.

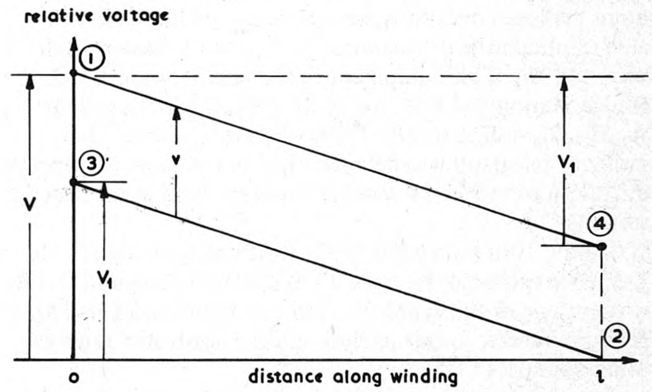

Fig. 5
Voltage distribution along the windings

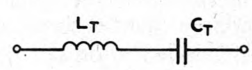

Fig. 6
Equivalent circuit of phonopore

It would be interesting to know what the values of L_T and C_T were in phonopores actually used. The only information now available is a comment[16] that Silvanus P. Thompson (who took the phonopore very seriously[17]) measured the capacitance between the terminals we have numbered 1 and 3, with the iron core removed, and obtained the value 0·083 μF; and that John Hopkinson measured the apparent capacitance between terminals 1 and 2, with the core in, and obtained 0·5 μF. Now Thompson's measurement was of the true C_T, and would have been hardly affected by the iron core anyway. Hopkinson's measurement indicates, by the large apparent capacitance, that he was operating near the resonant frequency, but, unfortunately, the method and frequency of measurement is not recorded. If we assume, however, that he was measuring by bridge at ω = 5000 rad/s, then, with C_T = 0·083 μF, we obtain $L_T \simeq$ 0·4 H and a resonance around 1000 Hz.

It is difficult to see how the use of the phonopore gave any real advantage over a simple capacitor in the 2-channel telegraph system, and, in the earlier proposal for simultaneous telephony and telegraphy, it would have been inferior, as it would have distorted the frequency response of the telephone channel. Its advantage as a lightning protector could have been more real. The combination of the phonopore transformer/capacitor device with the vibrator for harmonic or a.c. telegraphy may have been the explanation of how it kept its identity as the basis of a patented and competitive telegraph system in an age when few chief telegraph engineers could have made the simple analysis set out above. Thus the fact that it was using no essential principles not already established by others seems largely to have escaped notice.

2.3 Promotion of the phonopore as the basis of a multiple telegraph system, 1886 onwards

The beginning of Langdon-Davies's promotional campaign to get the phonopore taken up commercially seems to have been the demonstration which *The Times* reported in its article of the 27th May 1886, from which we have already quoted some explanatory paragraphs. The demonstrations were then made using an artificial line, which, we can now see from its description, bore no relation to real lines. Nevertheless, the tests made did show the potentiality of the phonopore, and *The Times* was right to be impressed.

Langdon-Davies was not slow in arranging trials under more realistic conditions, on real telegraph lines. He was able to obtain the co-operation of the South Eastern Railway, and fitted his equipment to the line between London Bridge Station and Folkestone. It worked with complete success, according to *The Times* observer, whether the ordinary telegraph was being worked in the same or opposite direction, or was being worked between the intermediate stations.[18]

On the 10th December 1887, the Phonopore Syndicate Ltd. was registered. Its capital was £90 000. Langdon-Davies was not one of the syndicate, and was to be paid £36 000, partly in shares, for his patents and the rights in numerous other countries.[19,20]

Langdon-Davies continued developing his system. Early in 1889, he gave another demonstration on a railway telegraph route, this time on the Midland Railway between St. Pancras Station (London) and Derby, a distance of 130 miles, with the phonopore channel connected between London and an intermediate station at Leicester, using a printer-receiver. This demonstration received a very favourable report, not only in *The Times,*[21] but also in a long and technically satisfactory article in the previously critical *The Electrician.*[22]

The article in *The Times* also mentioned the complete flexibility of the phonopore system, including the possibility of attaching it to a line already working quadruplex. Since the phonopore could readily work duplex (and it was generally agreed that its adjustments for duplex working were much less critical than was the case with the ordinary telegraph), this meant that 'sextuplex' working was possible. Now quadruplex working was quite well established ten years before these demonstrations (a history and technical description of quadruplex was given by Prescott in 1877[23]), and sextuplex working using a vibrator-generated signal for a duplex a.c. system superposed on a quadruplex system was proposed by Edison[24] in 1877, and by Field[25] in 1881. It is not known whether either of these proposals was used in practice, but, as the a.c. channels were not coupled through capacitors, but were directly in the line, it is unlikely that they could have worked as well as the phonopore sextuplex could.

It was also generally agreed at this time that the phonopore channel was much less susceptible to increases of line resistance than an ordinary telegraph. Indeed, much later, in 1893, it was claimed that, on four different lines, the phonopore channel had gone on working after the ordinary channels had failed owing to breakages of the wire![26]

How long Langdon-Davies went on working on the phonopore is not known, but it seems that his connection with the syndicate, as also with the subject, had ceased by 1894, since, in that year, a new patent[27] involving the phonopore (but not in any basic way) was filed by the company and an E.W. Smith.

2.4 The phonopore and the Great Western Railway

We have already referred to trials of the phonopore on the South Eastern Railway and the Midland Railway, and contemporary references[28] certainly indicate that more permanent installations were provided at least on the Midland. The managing director of the Phonopore Co. Ltd. (as it had then become) stated at the annual general meeting of the company in April 1893[29] that phonopore systems were working 'with complete success' from London to Cambridge on the Great Eastern Railway, and also on other railways, including the Great Northern. No confirmation that the phonopore was used on a regular basis on any of the railways mentioned has been found in spite of a search of the minute books of their boards and relevant committees.[30]

With the Great Western Railway (GWR), however, things were different. There is ample record that the phonopore was widely used thereon. Apart from the statements of the managing director at the meeting of April 1893, who said that the phonopore was working between London and Birmingham and between London and Bristol, and the statement in the *Electrical Engineer* that it was also working from Bristol to Plymouth, we find frequent reference to the phonopore in the minutes of the board and of the Engineering Committee of the GWR. Moreover, we learn from another report in *The Times*[32] that Langdon-Davies had returned to the idea of using the phonopore to provide a telephone channel on a telegraph line, and that the Phonopore Syndicate had installed such a system on the block-signalling telegraph line between Southall and Brentford, a distance of about 3·5 miles. This was reported as giving great satisfaction, but no further reference to this use of the phonopore has been found.

From the minutes of the Engineering Committee,[33] we learn that authority for the first trials of the phonopore between London and Bristol was given on the 27th May 1891, the expense to be borne by the Phonopore Co. On the 25th November, the telegraph superintendent C.E.Spagnoletti reported that the 6-month trial had been successful and that the equipment should be purchased. He was authorised to negotiate with the syndicate for a long-term agreement for the extended use of the phonopore. The board of directors authorised the contract in January 1892, and it was sealed in June.[34]

The purchase of phonopores, which had been on trial between Paddington (London) and Birmingham and between Bristol and Plymouth and 'which have been found of much advantage in facilitating the transmission of telegrams', was approved by the committee on the 15th February 1894. The provision of phonopore apparatus at Exeter was approved on the 21st October 1896. The telegraph circuits in South Wales were rearranged in 1897, and two sets of phonopore equipment were provided at Cardiff and one at Swansea.

The financial arrangements in the agreement of 1892 are interesting. Rentals depended on the length of the line and the number of intermediate stations, but were typically of the order of £100 per annum. There was a special rebate of 30% over five years 'should the Great Western Co. be one of the first three English railways to adopt the Phonopore Telegraph'.

2.5 The Phonopore Syndicate and Company, and successors

We have already noted that the Phonopore Syndicate was registered on the 10th December 1887 with a capital of £90 000, of which £36 000 was to be paid to Langdon-Davies for his patents. As we have seen, a lot of money was spent on promotional activities, numerous trial installations being made at the syndicate's expense. By 1892, the syndicate was in financial difficulty, and raised additional money by admitting more people to its management. Relations with Langdon-Davies had become strained, though from what cause is not known.

In August 1892, the syndicate was reformed into a company, the Phonopore Company Limited. The Rt. Hon. Sir Mountstuart E. Grant-Duff, G.C.S.I., was appointed chairman, and C.E. Spagnoletti was appointed managing director.

The new company held its first Annual General Meeting on the 19th April 1893. Both the chairman and the managing director spoke about the company's problems. One of these was that the phonopore had not been able to work over as great a distance as had been hoped; for instance, although it worked well from London to Bristol and from Bristol to Plymouth, it would not work through from London to Plymouth. Yet, if they were to have a good overseas market, these longer distances were most important. Another important matter that seems to have been aired for the first time was that the phonopore had not always given satisfaction to some of the railway companies that had used it. The chairman said, however, that, now that Mr. Spagnoletti had taken over, many improvements were being made in the phonopore apparatus and that they were confident of obtaining the greater distance of working and of giving more satisfaction. It was made perfectly clear that they had had a lot of trouble with Langdon-Davies, that he had proved very costly, and that they had now settled with him. Langdon-Davies spoke at the meeting and tried to prevent the chairman's report from being adopted. He failed. This was probably the end of his association with the company.

In August 1895, it was announced[35] that the nominal capital of the company was £150 000. The number of £1 shares taken up was 118 343, of which 79 405 had been issued fully paid; the full amount was being called on the remaining issued shares.

Bearing in mind the prices charged for the phonopore, which we indicated in the preceding Section, it is clear that an enormous number would have to be sold or rented to warrant this large investment.

A month later, it was announced[36] that a new company called the New Phonopore Telephone Company Limited had been set up, with an agreement to purchase from the phonopore Co. a new patent[37] and exclusive licences in various countries, the purchase consideration being £2000. The object was obviously to exploit the possibilities of the Phonopore for simultaneous telephony and telegraphy. In view of the way in which the van Rysselberghe system had become established in so many countries, however, this was rather a forlorn hope.

Although it has not so far proved possible to trace the technical and manufacturing activities of these companies much further, the financial side of their operations can be followed in the successive annual volumes of Garcke's 'Manual of electrical undertakings'. It seems that the Phonopore Co. was effectively defunct after the New Phonopore Telephone Co. was formed, but that the latter continued in business for over 20 years. Starting with an authorised capital of £10 000, its issued capital slowly increased from £3515 in 1896 to just over £8000. By 1908, it had a factory at Southall, Middx. With so limited a capital, it must have been a very small factory. What it made is not clear, but, in 1916, the Phonopore Construction Company Ltd. was 'formed to construct and sell electrical apparatus of all kinds, especially telephonic, signalling, lighting, and power distribution apparatus; to take on lease the works, plant and goodwill of the New Phonopore Co. Ltd.: purchase consideration £175 in founder's shares'. So, after 20 years, the New Phonopore Telephone Co.'s business was worth no more than £175! The Construction Co. had an authorised capital of £4175, and this amount was indeed issued, although it had only four shareholders. It was still in existence in 1920, but became defunct soon afterwards.

From the terms of reference of the Phonopore Construction Co., it is clear that, if phonopore equipment was still being made, it was no longer the main product. Some evidence that phonopore systems were still in use on the railways, however, comes from the textbook 'Telegraphy and telephony' by E. Mallett, published in London in 1929. Mallett says, on p. 98, that 'the phonopore, in which one extra (telegraph) channel is provided by buzzer signals.... is used to some extent on the railways', and, on p. 207, that, 'if the vibrator is replaced by a microphone circuit, simultaneous speech and Morse signalling is obtained. The system is then known as 'the phonopore', and is in considerable use on the railways'.

2.6 C. E. Spagnoletti

The appointment of Spagnoletti as managing director of the Phonopore Co. is interesting. He had been telegraph superintendent to the Great Western Railway for nearly 40 years, having been appointed as chief of the telegraph department in 1855. He was a very distinguished engineer, having served as President of the Society of Telegraph Engineers (soon to become the Institution of Electrical Engineers) in 1885. He was born in 1832 in London, of noble Italian descent,[38] and died in 1915. He was a Fellow of the Royal Society. At the GWR, he had been responsible for the introduction of the phonopore. No doubt this was his main attraction to the Phonopore Co. He retired from the GWR and took up his post with the company on the 1st August 1892. He did not sever his connection with the GWR altogether, for he was retained by them for some years as a consultant.

The record of his last few years of association with the GWR may be found in the minutes of the board of directors[39] from July 1891 to August 1895; the interested researcher will find there several intriguing questions which are not answered.

3 The phonoplex of Thomas A. Edison

At about the same time that Langdon-Davies filed his first patent for the phonopore, Edison filed a patent[40] for a rather similar system, which provided a telegraph channel additional to that of the ordinary d.c. or Morse channel. The essential differences were that Edison's system which he called the 'phonoplex' or 'way-duplex', while using sound as the basis of reception on the additional channel, did not provide the alternative of a speech channel; and that the additional telegraph channel was separated from the first, not by using 'harmonic' currents, as in the phonopore system, but by using induced current pulses of extremely short duration compared with the standard Morse signals.

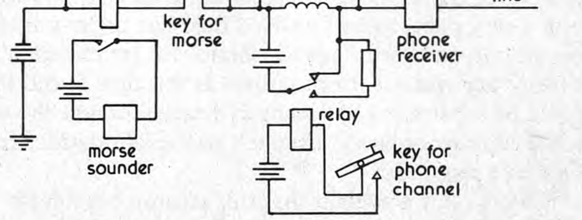

Fig. 7
Arrangement of terminal station of phonoplex system

A good description of the phonoplex system was published in *The Electrician* in 1886,[41] and Fig. 7 has been derived from it. The additional channel is called the 'phone' channel, and is joined in series with the ordinary telegraph. The transmitting key of this channel operates a relay that breaks the circuit of the induction coil, which then transmits a transient current pulse of very short duration through the line, almost instantly followed by a much weaker one produced by the making of the reverse contact through the resistance. On releasing the key, another pair of impulses is produced, the weaker one first. The pattern of these two pairs of impulses was quickly learnt by the operator as the means of recognising the complete signal unit. The capacitor shunting the ordinary instruments permitted the passage of the impulses without interfering with the ordinary channel. The signals of the latter were sufficiently smoothed by the relay inductance to avoid interference with the additional channel.

The signals on the additional channel were detected by the telephone receiver. It was a special kind of receiver, which gave sharp clicks when the impulses were received.

This system met with a good reception in America, for, quite soon after its invention, it was reported[42] that it was being used successfully on the Kansas & Southern Railroad, the Santa Fé Railroad, the Baltimore and Ohio Railroad & Telegraph Co. and the Great North-Western Co. of Canada. A little later, it was in use on the Lehigh Valley Railroad, the Philadelphia & Reading Railroad, and the Richmond & Danville Railroad.[43] These users were evidently very pleased with it, and, indeed, the Lehigh Valley reported[44] that, after several months' experience, they had no failure to report

> 'except, of course, such failures as occurred by the giving out of the line itself, and even then we have, in some cases, been able to work the Phonoplex when the line was interrupted so as to be useless on the Morse side'.

It will be recalled (from Section 2.3) that the same claim was later made for the phonopore, and it is hard to see the explanation.

One of the advantages of the phonoplex, which, in fact, it shared with the phonopore, was that it permitted the tapping on the line of an intermediate station without having to readjust the duplex balance.

Unfortunately, no record of the subsequent history of the phonoplex has been found, and it is therefore not known how long this system remained in favour and how extensive was its adoption.

A system almost identical to the phonoplex was patented in 1886 by Rosebrugh.[45] As has been said earlier, the basic idea of using a second channel distinguished by having its signals of the form of the derivative of the normal Morse signal was patented by Highton in 1850; so, clearly, Edison was neither the first nor the last inventor of this principle.

4 Cardew's military telegraph

A system similar to those of van Rysselberghe, Langdon-Davies and Edison was used by Major Cardew of the Royal Engineers in the early and mid-1880s, and is worth a passing mention.[46] It was basically intended as a system for transmitting and receiving telegraph messages over a very poor, badly insulated field line under military conditions, and used a keyed vibrator for transmission and a telephone receiver for reception. It was then found that it could be superposed by means of a capacitor and choke on a line carrying ordinary telegraph traffic. Quotations from Cardew's paper are:

> 'Of course it is evident that this separator system is practically the same as van Rysselberghe's.'
>
> 'Quite recently an account has appeared in the papers of a somewhat similar system brought out by Mr. Edison.'
>
> 'The system .... was invented by me five years ago, has been kept secret by us hitherto ....'

5 Conclusion and acknowledgments

It can be seen that the phonopore and phonoplex systems were serious and useful contributions to the problem of reducing the cost of providing electrical communication services, but that the high hopes with which the phonopore (at least) was launched were not realised. The reasons for its lack of commercial success are not yet understood, for it was certainly quite cheap and appears to have been reasonably effective. The amount of success achieved by the phonoplex has not yet been determined.

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