The First Cross-Channel Telephone Cable: The London-Paris Telephone Links of 1891

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INTRODUCTION

The first telephone link across the English Channel, opened in April 1891, came 40 years after the first telegraph link[1] and 13 years after the first commercial exploitation of the telephone. When the telephone link was first planned, in 1889, there was no experience of operating, or even designing, such relatively-long submarine telephone cables; but the 40 years experience of working submarine telegraph cables all round the world had left practically no unsolved problems of a mechanical nature for the designers of the telephone cable to grapple with. Their problems were entirely electrical.

W. H. Preece, Electrician to the Post Office at the time,[2] and later Engineer-in-Chief (and Sir William on retirement), was a very active innovator and had given much thought to the problems of long-distance telephony. We discuss how Britain had fallen behind most other advanced countries in long-distance telephone services, but British theoretical work on the subject was well ahead. Preece had a theory of long-distance telephone transmission; unfortunately it was fallacious in many respects, but it did provide him with some means of calculating speech possibilities, and on the basis of it he was able to show that telephone communication with France should be possible. Wisely, he set up some experiments which supported this conclusion. On 26 April 1889 he submitted a memorandum formally proposing the provision of a London-Paris telephone link and giving the estimated costs. This important document is transcribed later.

This document certainly gives the impression that the initiative for a London–Paris telephone link came from Britain, i.e. from Preece. There is room for doubt on this point, however. The Paris correspondent of *The Times* had over two weeks earlier reported[3] that:

> 'M. Coulon, Director of Posts and Telegraphs, has directed experiments to be made, with a view to telephonic communication between Paris and London',

and in the long account of the project which *The Times* gave in 1891[4] was the statement:

> 'The proposal to connect Paris and London by telephone came originally from the French administration about the time of the negotiations for the purchase of the submarine telegraphs'.

These negotiations were in early 1889.[5] There had, indeed, been indications of a French interest in a telephone cable over a year earlier.[6]

This appears to be all that was made public on the matter. However, in the Post Office files is a record of the negotiations between the British and French administrations. On 8 April 1889, Preece had recorded that:

> 'when M. Coulon (Director-General of Postes et Telegraphes) was in London the week before last, after completing his negotiations with reference to the purchase of the Submarine Co's cables, he appealed to Mr. Jackson (of the British Treasury) to favour a proposal which he said he was about to make for the introduction of telephonic communication between France and England.'

Coulon's proposal was to use the existing telegraph cables for telephony as well, using the van Rysselberghe system which we shall discuss later. Preece continued:

'M. Coulon urged that some experiments should be made, and I undertook on behalf of the Department that when his officers were ready, the Engineering Officers at the Post Office should be requested to arrange with them to make experiments on the existing cables. This, of course, would not commit us to any particular line of policy.'[7]

In his memorandum of 26 April Preece made an altogether different proposal, namely that a special new cable should be provided for cross-Channel telephony. Thus, while lip-service was for a time paid to the French proposal, and the experiments desired by Coulon were carried out, there is no doubt that the scheme as finally adopted had its origins in Britain – probably stimulated by Coulon's proposal. There is also no doubt that Preece and his assistants played the dominant part in the design and specification of the system, and the cable was manufactured by a British firm. It was laid by the British cable ship *Monarch.* The project was successful technically and the cross-channel telephone traffic was heavy from the opening of the service.

The route of the land-lines and cable is shown in Fig. 1.

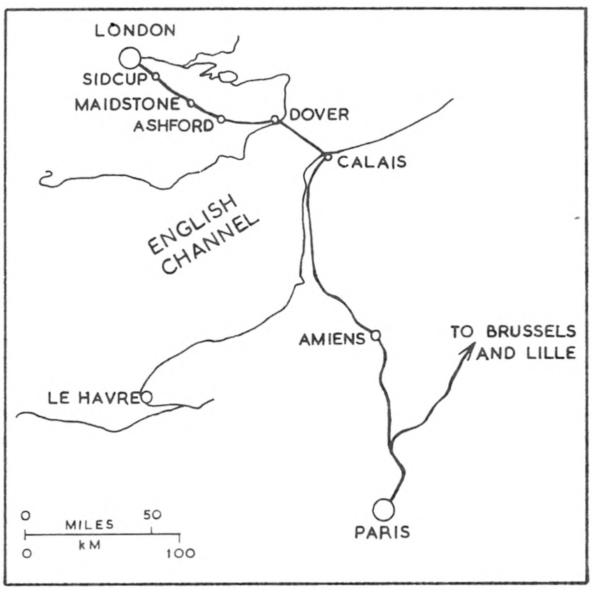

Fig. 1. Route of London–Paris telephone line of 1891

THE BACKGROUND: LONG-DISTANCE TELEPHONY IN THE 1880's

(a) *Technical Considerations*

Commercial exploitation of the telephone started in 1878, and the use of the telephone spread rapidly, especially in the U.S.A., where there were over 60,000 telephones by 1880 and nearly a third of a million by 1885. (Growth in other countries was much less rapid, and by 1885 the number of telephones in Britain was only about 13,000.) The electric telegraph had already been established for 40 years, and there was a worldwide telegraph network before the telephone came into use. Thus, at first, the telephone was regarded as a means of improved local communication, but not as a competitor to the telegraph for long distances. This attitude was encouraged by the large vested interest in telegraphy and by the known technical difficulties of long-distance telephony.

The primary technical obstacle was the 'induction' (or crosstalk) from telegraph currents. Even in telegraphy, the induction of interference from one telegraph wire into another was not negligible, but the interference caused by the transients of telegraph signals into neighbouring telephone lines was usually intolerable, often even on short routes. As late as 1887, W. H. Preece, Electrician of the British Post Office, said:[8]

'I defy anybody . . . to speak from the top of the General Post Office down to the bottom if the wire passes through the chasings carrying the instrument leads to the Central Telegraph Station. It is impossible to speak

> through 100 yards of a heavy street line; . . . and the reason is very simple – that the mutual induction currents from these powerful currents used for Wheatstone transmitters are . . . probably 100,000 times greater than the currents that are used to work a telephone transmitter.'

Of course, it was not always as bad as that, and on relatively interference-free lines, telephony over distances up to about 100 miles was achievable. It was known that one way of reducing such interference to tolerable levels was to use a metallic-loop telephone circuit in place of the normal single wire with earth return, and to put a twist (or transpositions) into it.[9] This practice was adopted in underground cables, but transmission limitations owing to high capacitance (and low inductance too, as was later discovered) restricted telephony in cables to about 30 miles. Expense prevented the adoption of metallic-loop circuits for long overhead routes. So, in the early 1880's, long-distance telephony was unsatisfactory and expensive, and where lines had been provided, traffic was sparse.

It was in this situation that the Belgian, Francois van Rysselberghe entered the scene at the beginning of 1882 and made his big impact on it. He had invented (or, at any rate, had made practicable) a system whereby not only could the interference from telegraph signals be largely eliminated, but the telephone circuits could actually be operated on the existing telegraph wires without mutual interference between telephone and telegraph messages. At one stroke he had solved both the technical and economic problems. After initial demonstrations, the use of his system spread widely in Europe and in many other parts of the world, but not in Britain. By 1887, Europe had at least 17,000 route kilometres of long-distance telephone circuits using the van Rysselberghe system (and very little not using it); but it was 1890 before London was connected telephonically to any other town, except for a link to Brighton.[10]

Another important contribution that van Rysselberghe made was to show, by a series of experiments in the U.S.A. in the winter of 1885–86, what were the limiting distances for telephony using various kinds of wire; and he made the then startling discovery that good speaking over distances of 1000 miles (i.e. New York to Chicago) was achievable, and that even trans-continental telephony was a possibility.

In Britain W. H. Preece also made some experiments during 1885–1887 in long-distance telephony, and proposed a theory for determining the limiting distance. In 1887 Oliver Heaviside started publishing his theory of telephone transmission; it showed clearly that Preece was wrong, and laid the foundation for later understanding and practical developments, in particular the inductive loading of lines.

(b) *Britain's lag in the provision of Long-Distance Telephone Lines*

We referred above to the way in which the continent of Europe was provided with a long-distance telephone network many years before one was developed in Britain. The explanation of our lag was twofold:

1. The Post Office, as the authority operating the telegraph network in Britain, feared that the development of a long-distance telephone network would greatly reduce telegraph traffic and thus produce an unacceptable loss on the telegraph service. It was part of official Government policy to argue that there was no demand for 'trunk' telephone service since the telegraph service was so good.[11] When, in 1883, a private company – the Long Distance Telephone Co. – was formed with the express purpose of providing the long-distance telephone service the country so obviously lacked, it was very quickly suppressed.[12, 13].

2. The telephone service was in the hands of local telephone companies, and they were each restricted, by legal powers given to the Postmaster-General, to their own local areas. Indeed, from 1882 to 1884 they were not even allowed to link the towns within their own areas, any links the P.M.G. considered necessary being provided by him – or, rather, not provided. After 1884 some notable local inter-urban telephone networks were developed by the companies, that of the Lancashire and Cheshire Telephonic Exchange Co. being outstanding – and very exceptional – with nearly 2000 miles of inter-urban lines;[14] but there was no general development of inter-area lines.

The rather curious relationship which thus existed between the Post Office and the telephone companies was mentioned in internal P.O. correspondence[15] as a difficulty in relation to the negotiations for the London-Paris line, but in the event no trouble arose from this cause.

PREECE'S EXPERIMENTS AND THEORY OF LONG DISTANCE TELEPHONY

Preece in 1885 obtained authority to carry out experiments in long-distance telephony and had a special overhead line, free of adjacent telegraphs, constructed from the outskirts of London to Warrington, via Atherstone, Stafford and Nantwich, using a metallic loop of iron wire of approximately 5 mm diameter, with a single-wire resistance of about 12 ohms/mile. There were a few short sections of underground cable with copper conductors. Later, a similar line was constructed in South Wales. Preece was also able to take advantage of a new overhead telegraph route being opened in the winter of 1886–87 from London to Nevin (North Wales) as part of a new Irish telegraph route. It used copper wires of approximately 2.7 mm diameter, with a single-wire resistance of 6 ohms/mile. Before it was brought into use for telegraphy, Preece was able to experiment with telephony on it.

The results of these experiments[16] show limiting distances of 40–50 miles for underground cable, 120 miles for open iron-wire loop, and about 250 miles for open copper-wire loop.

Preece attempted to fit a theory to his results. He based this on Thomson's law[17] (now known as Kelvin's law) by assuming that the time constant of the line, which he took to be proportional to the product of its total resistance and total capacitance, was the reciprocal of twice the highest frequency that could be transmitted through the line, and that this highest frequency should be about 1600 Hz. This seemed to agree with some observations he had made with telephone signals on a submarine cable in 1878. He then concluded that, if x is the limiting distance for telephony, k is the capacitance per mile, and r the resistance per mile, then:

$$x = (A/kr)^{1/2}$$

where A is an empirically determined constant having the value 15,000 for overhead copper wire, 12,000 for copper wire in cable and 10,000 for overhead iron wire.

The weaknesses of this formula are evident. It takes no account of speech quality and it ignores the effect of inductance and leakance. Preece believed that inductance was negligible anyway. His constant A was determined from too few observations.

Interlude: Heaviside's correct theory of long-distance telephone transmission.

Oliver Heaviside has been described as an eccentric genius; he was a recluse yet kept closely in touch with developments and published his work extensively. He had a very low opinion of Preece and said so. On Preece's theory of the self-induction of wires, he was particularly outspoken.[18] He was publishing a long series of articles in the *Electrician* at the time of the experiments discussed above, and he devoted Parts 40–47[19] to long-distance telephony and connected matters. Another useful publication was the section *On telegraph and telephone circuits* in his *Electrical Papers.*[20] He saw clearly that Preece's theory was quite inadequate, and that the two factors which were really important were: (a) attenuation, i.e. the loss due to dissipation in the resistance and the leakage of the line, and (b) distortion owing to the signal transmission varying with frequency. The condition for no distortion was, in modern symbols, $R/L = G/C$ where R,L,G and C are the resistance in ohms, inductance in henries, leakance in mhos and capacitance in farads, all per unit length. When this condition is met, (b) is disposed of, but we are still left with (a), which Heaviside could not deal with as a practical limit to telephony because of all the unknown factors such as microphone and receiver performance, noise on the line, etc. Distortion on a long submarine cable would be decreased by increasing the inductance, and he thought that, if this were done, telephony would be possible over 3000 miles.

He considered long open lines of copper of low resistance to be an approximation to the distortionless line and quite different from the submarine cable, which has low L and low G.

He examined the problems of matching of line impedances, of shunts on a line, and suggested the possibility of adding loading coils to a line to improve transmission.

The idea of loading coils was taken up by Silvanus P. Thompson in 1891,[21, 22] although the type of series coil loading eventually adopted was not included among his proposals. No practical use of loading was made, however, until much later, after Pupin and Campbell had extended the theory and argued the case from 1899 onwards.[23]

PREECE'S PROPOSAL FOR A LONDON-PARIS TELEPHONE LINK, APRIL 1889

Here follows a transcription of the basic document we have already mentioned.

Memorandum

Telephone communication between London and Paris

I have often given the possibility of connecting London and Paris by the telephone, very serious consideration, and I have been to Dover and experimented upon the cable between Dover and Calais. I may say at once that any hope of communication between London and Paris by means of the existing cables is completely out of the question. Their electrical conditions are too indifferent for the purpose. The cables between Beachy Head and Havre and Dieppe are too long, while those between Dover and Calais and Folkestone and Boulogne are of too high a resistance and of indifferent quality as compared with the cables of the present day. But the question of communicating by telephone between London and Paris is beyond the stage of experiment. We know that it is possible, and we can specify exactly the conditions that will make it possible. In fact there is no electrical difficulty whatever in speaking telephonically between London and Paris. The question at issue is not a scientific one at all, it is the answer to the simple enquiry – 'will it pay?'

Now practice has shown that the distance to which we can speak is simply dependent upon the product of two electrical quantities of the line, the one called 'capacity' (K) and the other 'resistance' (R) and that if the product – KR – of these two quantities is equal to 10,000 speech is possible, if it is as low as 5,000 speech is easy.

I would propose to establish between London and Paris 4 wires of copper each weighing 220 pounds (100 kilograms) per mile. The wire between London and Dover should be entirely overhead and should be constructed on our usual 4 wire system, the wires rotating once in every quarter of a mile. The same system of rotation would exist in the cable naturally, but it is not of so much importance in the cable as it is on the land line, for this twisting of the land line would entirely obviate interference and disturbance from contiguous lines.

The distribution of this line will be seen from the following table, and it will also be noticed that the product, KR, is 3878. This means that good telephoning would result; and in fact I have produced by means of an artificial line exactly the conditions that would be involved in establishing these circuits between London and Paris, and I have been able without any difficulty to converse over such a circuit.

London to Folkestone (74 miles)	220 lbs. Copper	$R296^{\omega}, K.98$
	KR =	290
Folkestone to Sangatte (21 knots)[24a]	Cable	$R231^{\omega}, K7.5$
	KR =	1732
Sangatte to Paris (182 miles)	220 lbs. Copper	$R728^{\omega}, K2.55$
	KR =	1856
	Total KR =	3,878

I have assumed that the cable would be of our standard form.

Now in order to provide an independent line throughout including the cable, the estimated cost is £29,000, but this would be materially reduced if the existing supports could be utilized for the purpose. I am inclined to think that the existing poles are so laden with wires that it would be impossible to add to them 4 heavy twisted wires on the system proposed. The estimated cost of maintenance including renewals of the new line throughout would be £2,000 per annum. The annual expenditure that would have to be met might be estimated as follows:

	£
Interest on cost of land line and apparatus (£23,200 @ 3%)	696
Maintenance of land line, cable and apparatus including renewal and interest on cost of cable	2,000
Working expenses	1,000
	£3,696
	or say £3,700

There would be two circuits and in order to provide this revenue each circuit would have to produce £1,850 per annum which means £5.18.7d or 148 fr. per working day. Therefore supposing a charge of a franc a minute for conversation were made, each circuit should be occupied 148 minutes a day; and as our experience shows that the paying time our trunk wires are occupied for conversation is about 30 minutes per hour, it means that this rate of conversation should be maintained for 5 hours (nearly) each working day.

There remains the question of policy upon which I can say nothing. I would however point out that the newspapers of yesterday have referred to the fact that one difficulty that General Boulanger experiences in coming to London, is, that he has not the means of conversing by telephone with his friends in Paris. This would show that the telephone line between Paris and Brussels is used for other than legitimate commerical purposes. The conclusion therefore is that if the circuits became available we might fairly anticipate they would be used. It must be remembered however that their use for converstaion would mean the withdrawal of a certain number of messages between London and Paris, and therefore diminution in the Telegraphic Revenue. On the other hand we can scarcely anticipate that the wires will be used at all at night, and during the night it would be quite possible and practicable to use these wires for press purposes and thereby gain some additional revenue. Anyhow it is clear that the establishment of this telephonic communication between London and Paris is well worth serious consideration from a commercial point of view. As I have already said, from a scientific point of view it is perfectly practicable and feasible.

(Signed) W. H. Preece

26th April 1889'

It is interesting that the proposal set out in this memorandum was based on an erroneous calculation. Preece had added the *KR* products of the three sections of the route to obtain the overall product of 3878. However, this was a careless slip; he should, according to his own theory, have multiplied the sum of the capacitances by the sum of the resistances, which would have given an overall *KR* of nearly 14,000 – far too high for satisfactory speech. Presumably this error was discovered in good time, for the actual lines constructed were quite different, with much heavier conductors, and an overall *KR* of about 4500.

EXPERIMENTS DIRECTED TOWARDS THE DESIGN OF THE LONDON-PARIS SYSTEM

Preece had a number of experiments made to test the speech volume and quality received over telephone links involving cables of various kinds. Details of these have not been found, but it is known that the following routes were involved:

Holyhead – Dublin (submarine telegraph cable)

South Wales – Wexford (submarine telegraph cable)

Worcester – London – Baldock (open copper wire at the ends, with 27 miles of underground cable through the London area).

According to the published report, telephone communication through the last-mentioned route was 'very good' and confirmed in a very satisfactory manner the calculations which have been made.[25] However, according to a private report[26] which Preece sent to the Secretary of the Post Office on 12 Aug. 1889, it was possible to speak from Baldock to London with clarity; speech from London to Worcester was 'a little blurred owing to the large amount of underground work (i.e. cable)', and Baldock could speak to Worcester with 'greater difficulty, but still with ease'. Preece went on:

'The result of the experiment is to prove incontestably the correctness of the conclusion that I have previously arrived at, and that is that it is practically possible to maintain commercial telephony between London and Paris'.

The logic of this last statement is not immediately apparent!

Experiments were also made according to the agreement with the French government which we recorded earlier, over the Calais-Dover telegraph cable in June 1889; and also over the Dumpton Gap – Middelkirke (Belgium) cable in November 1889 in association with the Belgian authorities. Detailed reports on these experiments have survived.[27, 28] Speech was satisfactory on the former, and quite possible even when other cores of the cable were in use for Hughes and Morse telegraphy, but was not possible when open lines were connected at the Calais end. On the 61.5 nauts of the Belgian cable, with *KR* = 17,349, speech was almost impossible. It was commented that the conditions were similar to those of the Holyhead-Dublin cable which had a length of 61.05 nauts, with *KR* = 20,278.

In these French and Belgian cable experiments, it seems clear that the main purpose was to determine what effects were obtained by the use of different microphones and receivers. In the opinion of the British engineers, the French engineers 'who were sent to this side expressed a belief that the experiments . . . . would prove of no practical value.'[29] Little difference was found from one set of instruments to another. It seems that the Belgian experiments were made entirely at the request of the Belgian authorities.[30] Nevertheless, the experience was not without value to the British engineers.

Another set of experiments was made in September 1889 on the telegraph cable from St. Margaret's Bay, Dover to Sangatte, Calais, this being on the route of the proposed telephone cable.

Once again, different instruments were tried, and this time a special induction coil (i.e. transformer) of toroidal form was experimented with. This had an interesting result[31]:

> 'The normal speaking . . . was distinctly drummy, and the articulation was not by any means clear, but when the circular coil was connected as a shunt across the apparatus, the speaking was distinctly clearer. It will be remembered that a similar result was observed during the Baldock-Worcester experiment, when an electro-magnet was placed across the two lines in London as a derived circuit.'

It is evident that the shunt inductance served as a primitive equaliser, making the attenuation/frequency response more nearly uniform. In spite of this first-hand experience, Preece and his staff continued to ignore Heaviside's teaching on distortionless transmission.

PROPOSALS TO WORK SIMULTANEOUS TELEPHONY AND TELEGRAPHY ON THE CROSS-CHANNEL CABLE

We have seen that the original French proposal of April 1889 was that telephone communication should be superposed on the existing telegraph circuits in the existing telegraph cable. This was to be done by using the van Rysselberghe system in which the low-frequency telegraph signals were smoothed by inductance coils or 'anti-inducteurs' and the telephone signals coupled to the line through condensers. The proposal was quite reasonable, as the van Rysselberghe system was giving general satisfaction on the Continent, and was working satisfactorily on the 200-mile long international line from Paris to Brussels; and it had not then been proved that the old cable was not suitable for telephony.

The experiments of June 1889 showed that the use of the existing cable for speech from London to Paris was impossible, and Preece's proposal for a separate, new cable was readily accepted. However, it was still thought that telegraphy should be combined with telephony on the new cable.

During August 1889, van Rysselberghe himself came to London (and also went to Paris), representing a Belgian Company of which he and C. Mourlon were directors – the 'Compagnie de Telegraphie et de Telephonie Internationales' – to try to persuade the authorities to accept an offer from his firm to provide the cross-Channel cable at the firm's expense and risk. Simultaneous telegraphy and telephony would be provided, and the authorities were offered the telegraph service absolutely free of charge; the company would, however, try to recoup its costs by a royalty on telephone business. The only obligation on the part of the authorities would be to provide the land lines.[32] Van Rysselberghe was evidently received courteously by the Postmaster-General (Sir Henry Cecil Raikes), Mr. J. C. Lamb (Assistant Secretary in charge of the Telegraph Department) and Preece, but the P.M.G. considered that control of the cable must lie with the Governments. The French authorities held the same view, and van Rysselberghe's proposal was eventually turned down.[33]

Up to August 1889 Preece had not taken van Rysselberghe's system of simultaneous telephony and telegraphy very seriously. He had repeatedly asserted that it was not suitable for Britain, and that it would not prove satisfactory with our high-speed Wheatstone system of telegraphy. In this latter point he may well have been correct, although there is no evidence that he made any experiments or calculations to prove it. Indeed, there is evidence that he held van Rysselberghe's system in contempt.[34] This attitude seems to have been completely changed by van Rysselberghe's visit and by Preece's own visit to Paris in September 1889. During this visit he was able to observe the working of the Paris-Brussels telephone line, which also operated *two* Hughes printing telegraph systems on the same pair of wires by the van Rysselberghe system; and he was allowed to experiment on the system.[35] He was enormously impressed:

> 'The conclusion left on my mind by this experiment is unmistakably that it is quite practicable to construct a telephonic circuit between London and Paris, and work upon it at the same time telegraphically with Hughes apparatus.'

In the light of this, the Post Office put its proposal to the Treasury (on 13 Jan. 1890) as a *telegraph* cable, needed because those cables purchased recently from the Submarine Cable Co. were old and in poor condition, with a rider that it would be possible to work telephony on the new cable, if warranted, by using the van Rysselberghe system. On this basis, Treasury sanction for £14,900 (of which £4,200 was to be repaid by the French as their share of the cable) was obtained on 22 Jan. 1890.[36] (The French authorities did not receive sanction for an expenditure of 400,000 fr. for their part of the scheme until 24 July 1890[37]).

After all this emphasis on the telegraphic operation of the new cable it must have been extremely embarrassing to Preece to discover on his next visit to Paris, in Aug. 1890, that the French now said that the van Rysselberghe system was unsatisfactory and had been abandoned on the Paris-Brussels line. Obviously they gave him no adequate explanation, for he wrote to the Secretary thus:

> 'It was working so well when I was in Paris last year that I cannot quite understand the reason of the failure; and I propose . . . to proceed to Brussels . . . to have a conference with the Belgian authorities on the subject.'[38]

Unfortunately no record of the Brussels discussions can be found. The cable project went ahead, but it became a purely telephonic scheme.

PREPARATIONS FOR INVITING TENDERS FOR THE CABLE

The French authorities prepared a specification for the cable and sent it to the Post Office shortly after the Post Office had received sanction for the expenditure on the scheme. The P.O. invited tenders, but during February 1890 received replies[39] from almost all the manufacturing firms complaining that the specification was quite wrong and that they could not tender. Preece looked into the matter, and gave his assistant Kempe the job of preparing a proper design for the cable. It was then on the basis of Kempe's work that a new specification was prepared by the Post Office and sent out for tender.

Kempe's design procedure was sound and very interesting; a summary of it is therefore given here. Kempe's internal report[40] was published under Preece's name after the latter had presented it at the British Association meeting in Leeds in September 1890.[41] There can be little doubt that Preece had inspired much of the design process and that he supplied, or at least approved, the data used.

THE DESIGN FOR THE CROSS-CHANNEL TELEPHONE CABLE

Preece specified that the product KR of capacitance and resistance should not exceed 7500 μF. ohms for the whole London-Paris line. If the capacitance and resistance of the whole 250 miles of overland open line are K_o and R_o respectively, and those of the cable are K_c and R_c then

$$KR = (K_o + K_c)(R_o + R_c) = 7500 \qquad (1)$$

The object of the design process was to optimise the design of the cable, it being already agreed that the open lines should comprise 400 lb/mile copper loop, an increase in gauge as compared with the original proposal. Let D be the diameter of the dielectric of each conductor (four identical, separately-insulated cores were specified) and x the diameter of the wire itself. Then

$$R_c = a/x^2 \text{ and } K_c = b/\log_e(D/x) \qquad (2)$$

where a and b are constants. Substituting (2) in (1) and rearranging, we obtain

$$\log_e D = (A + 1/x^2) \,/\, (B - F/x^2) + \log_e x \qquad (3)$$

where

$$A = R_o/a;\ B = (KR - K_oR_o) \,/\, ab;\ F = K_o/b \qquad (3b)$$

To make the cable as small, and therefore as cheap, as possible we require to minimise D within the restriction imposed by (1). We thus minimise $\log_e D$ by differentiating with respect to x.

$$d \log_e D/dx = 0 \qquad (4)$$

is then the condition for minimum D. Performing the operations implied by (4), and solving the resultant expression for x gives

$$x = [(B + AF)^{1/2} + (B + AF + 2BF)^{1/2}] / B\sqrt{2} \qquad (5)$$

To obtain a value for x, and hence for D, from this equation it is necessary to know the values of K_0 and R_0 which are contained in A, B and F. No measured data was available for 400 lb/mile copper wire, nor were any capacitance measurements available for loop circuits. So Preece and Kempe had to estimate the required values from measured data on single 200 lb/mile copper wire. The resistance value was, of course, reliable at R_0 = 1,125 ohms for the 250-mile double line. Unfortunately, capacitance measurements were not very accurate as they ignored inductance. Preece took the capacitance of a single 200 lb conductor at a height of 30 ft above earth, as 0.015 μF/mile; this was about 60% too high. Thus his figure of 0.0156 μF/mile for a single 400 lb conductor was also about 60% high. However, he did not understand – in spite of having seen Oliver Heaviside's published theory,[42] which was perfectly correct and not difficult to understand – how the capacitance of a loop line was related to that of a single wire. He assumed that

'in the case of a looped wire, the total capacity equals half that of a single wire',

whereas in practice as well as in theory it is almost the same. Thus in taking the loop capacitance as 0.0078 μF/mile he was compounding two large errors of opposite sign which, fortunately for him, left the resultant value of K_0 = 1.95 μF only about 15% too low.[43] Since the capacitance of the cable considerably exceeded that of the open lines, the effect of Preece's error was quite small.

From the observed resistance and capacitance of existing telegraph cables, Preece and Kempe estimated the constants in (2) as

$$a = 3{,}124{,}884 \qquad b = 4.356481 \tag{6}$$

(The number of figures quoted is astounding). To make the estimate of b, they assumed that the capacitance of a loop circuit was one-half of that of the single wire, as for the open-line calculation. This time, however, they were near-enough correct, as the conditions in a cable are quite different from those of an open line, as Heaviside showed very clearly in a paper rejected for publication by the Society of Telegraph Engineers (probably at Preece's instigation) in 1887, but eventually published in 1892.[44]

Thus, using (1), (3a) and (6) in (5) and then (3), they obtained the optimum design as:

$$D = 0.38 \text{ inch} \qquad x = 0.10 \text{ inch approx.}$$

The cable was therefore specified as having four cores of copper with a resistance (single-wire) of between 7.632 and 7.478 ohms/naut at 75°F, weight 160 lb/naut, with insulation comprising three alternate layers of Chatterton's Compound and gutta-percha with a total weight of 300 lb/naut, and with a capacitance not exceeding 0.3045 μF/naut (single-wire).

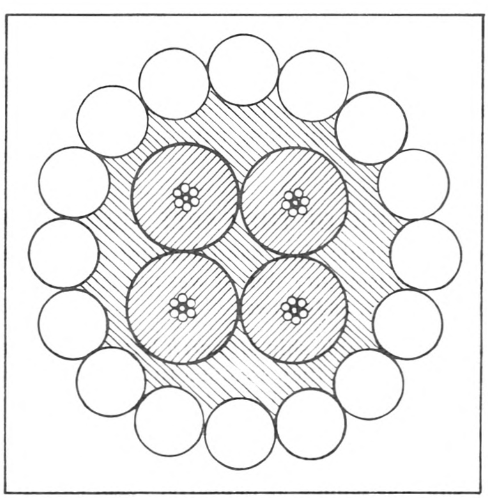

Fig. 2. Cross-section of the cable

THE CABLE AS MANUFACTURED

The cable was the joint property of the British and French Governments, but all the design, manufacture, supervision, laying etc. was done by the British Post Office and Messrs. Siemens Bros., the contractors for the cable. Final specifications for the work were agreed during a visit by Preece to Paris in August 1890, and tenders were immediately invited for the manufacture and supply of the cable.[45] Siemens were awarded the contract in October,[46] and the cable was laid in March 1891.

The cable had four separately-insulated cores, as already stated, each conductor comprising seven copper wires. The cross-section is as shown in Fig. 2. The cores were twisted so as to neutralise any inductive interference, although, with the sea-water and armouring around the cable, this interference would have been small; the two wires of each telephone pair were taken in the diagonal cores. The twisted cores were served with tarred hemp, over which was laid the sheathing of 16 galvanised iron wires, each 0.28 in. diameter, with a breaking strength of 3500 lb. A mineral-pitch and sand coating protected the whole.[47]

THE LAND-LINES AS INSTALLED

The long land-line on the French side of the Channel was not erected quite as specified by Preece. Instead of 400 lb/mile, the copper conductor used was of 600 lb/mile, and initially only one pair was run instead of two. It is believed that the second pair was run quite soon after the opening of the service. The French lines were transposed every six poles – i.e. the conductors corresponding to each circuit were moved round to a different position with respect to each other and to the other pair, in order that any inductive 'pick-up' would be largely neutralised. At the Paris end there was a length of 7 km. (about 4 miles) of underground cable, which was regarded as 'unfortunate' by the British.[48]

The British Post Office considered that the London-Paris line should have very special treatment, and provided an overhead route right into the terminal station in London's Postal Headquarters. The wires were 400 lb/mile, copper, and were run on the twist system, so that between adjacent poles each wire ran to the next position round the 'circle' of four positions, revolving clockwise, and coming round to its first position after four spans. Preece thought his was the better system, but at a later date it was abandoned in Britain in favour of the transposition system already used by the French. Both systems normally gave a satisfactory suppression of cross-talk, and also of disturbance from electric power wires, etc.

In order to bring the lines into London overhead, the route from Dover, on reaching Sidcup, left the road and followed the South Eastern railway to Cannon Street Station. There was a lot of difficulty here in connecting the line to the terminal section to the Post Office. The line had to cross the roof of the Station Hotel, and the Manager of the hotel positively refused access. Special arrangements had to be made, including a remotely-operated testing station. There were other difficulties in getting the route into first-class order, including such silly ones as the fact that the inner insulators on each pole-arm had been fitted so close to the pole that a lineman working on the line had to stand on the top of the insulator – with grave risk of cracking it – because he could not get his foot into the gap between the insulator and the pole! Some cross-talk difficulties were feared because of uneven twisting of some other trunk lines that ran along part of the route. But eventually everything was cleared up.[49]

THE LAYING OF THE CABLE, MARCH 1891

The Times[50] gave an excellent, graphic, first-hand account of the operations, which is well worth reading. The cable when laid was satisfactory, but it was not laid without trials and tribulations. The diary of the operation was, in summary, as follows:

Tuesday, 3 March: in the evening the cable ship *Monarch* left her moorings, called for a short time at St. Margaret's Bay (the English terminal), then steamed to Sangatte (the French terminal), where she arrived on the Wednesday afternoon. The wind was too strong and the visibility too poor for cable laying, so she remained idle, at anchor, until the morning on Monday, 9 March, when there was good visibility, although the breezee was rather strong.

Monday, 9 March: the shore end was landed at Sangatte, using two lifeboats made into a raft which was towed by the steam launch. Cable laying from the *Monarch* commenced at about 11 a.m. By 3 p.m. 10 miles had been paid out, but the wind had freshened and a drizzle commenced. Soon there was a blinding snowstorm and the visibility became negligible. Nevertheless the ship continued laying until about one mile from shore. She then anchored and awaited the end of the storm. The snow ceased by about 5 p.m., but in the gale and strong tide the cable had fouled the anchor. At 8.15 p.m. the rest of the cable was paid out to avoid having to cut it, and the end was buoyed; the ship ran for the Downs and remained at anchor there until

Thursday 12 March: returned to the cable and found it coiled four times round the anchor with no hope of getting it disentangled. The tangled part was therefore cut out and the cable buoyed again. A fresh gale forced the ship to return to Dover, where she stayed until

Saturday, 14 March: better weather permitted a return to work. Five miles of the cable towards Sangatte were relaid to clear a bight in the Calais-Dover cable, and the ship got back to St. Margaret's Bay at 3.20 p.m. The shore end was then laid, and the whole operation completed by 6.22 p.m.

Thus the laying of the cable had taken 11 days of ship's time, of which only one day in total was effective work.

OPENING OF THE SERVICE BETWEEN LONDON AND PARIS

The establishment of the telephone link as such was formally inaugurated by exchanges of civilities on 18 March 1891.[51] The Prince of Wales transmitted the first message, and there were then numerous speeches over the link between Ministers and others.

It was announced that the public service was to start on 1 April 1891, and the following notice was issued[52]

> 'TELEPHONIC COMMUNICATION BETWEEN LONDON AND PARIS
>
> On and after Wednesday, April 1st, telephonic communication between London and Paris will be open to the public.
>
> Call offices have been established at the General Post Office, West (Bath-street), open always, and the Threadneedle-street branch Post Office (Stock Exchange), open on week days from 8 a.m. to 8 p.m. As soon as possible a call office will be established at the West Strand telegraph office (Charing-cross), open always.
>
> The charge will be 8s. for a conversation of three minutes. Not more than two consecutive conversations can be allowed, except when no other applicant is waiting at any of the offices to use the telephone.
>
> In making appointments for conversations correspondents should bear in mind that Paris time is about ten minutes in advance of London time.
>
> Persons desirous of speaking to Paris direct from their own houses or offices in London can be provided with the necessary wires and apparatus, on terms to be ascertained on application to the Secretary, General Post Office, E.C.
>
> These wires can be used not merely for the purpose of communicating by telephone with Paris, but also for the purpose of sending telegrams for transmission within the United Kingdom or abroad. They can also be used to call a messenger for the express delivery of a letter or parcel.'

TECHNICAL PERFORMANCE OF THE LONDON-PARIS LINE

It will have been noted that the telephone service on the new route was based on the use of special call boxes at each end, to which intending speakers had to go at the times they had booked in advance. The suggestion that the line could be extended at each end to subscribers' own premises was a little optimistic in view of the technical reports on the line, made by Preece's assistants Kempe and Brown,[53] who had been in Paris, and Cooper and Chapman,[54] who had been at the London end. These reports showed that, while conversation between the ends of the line was satisfactory, there was noticeable cross-talk interference at the Paris terminal from the other lines which ran alongside the London line on the French pole route for many miles at the Paris end (see Fig. 1), notably from the Paris-Brussels and Paris-Lille lines which, in spite of the information Preece had been given in the previous August, were still working simultaneous telegraphy and telephony on the van Rysselberghe system. Even using the telephone instruments which gave the best results, it was found that extending the line by a mile or two to the Treasury in London, or by nearly 4 miles to the Observatory via the Telephone Exchange in the Avenue des Gobelins in Paris, over the local telephone network, caused a serious deterioration in volume and intelligibility and a marked increase in interference, especially at the Paris end, so that converstaion was not regularly practicable.

Tests were made also to see if simultaneous telegraph and telephone working would, after all, be possible on the cross-channel cable. 'In deference to the opinion of the French Officers regarding the van Rysselberghe system,' this system was not consciously tried, tests being confined to what the

British engineers thought was the Jacob system. This was a system, which later became known as the 'phantom' system,[55] in which additional telegraph or telephone circuits could be superimposed on a metallic-loop circuit by using the two wires of the loop, through suitable decoupling arrangements, effectively as a single conductor for the additional circuit, which had an earth return. Jacob,[56] in 1882, patented such a system which used a resistance network for decoupling; but what was used on the cross-channel tests was a system with inductance decoupling, and this was first patented by none other than van Rysselberghe in 1883![57]

The circuit used in the tests given in Fig. 3; this figure is a redrawn version of that given in Kempe and Brown's report. Morse working as indicated produced relatively little interference on telephone conversation; Hughes and Wheatstone telegraph working both produced much more interference and were not satisfactory. It was concluded that simultaneous Morse telegraphy might prove practicable, but it is believed that it was not actually adopted.

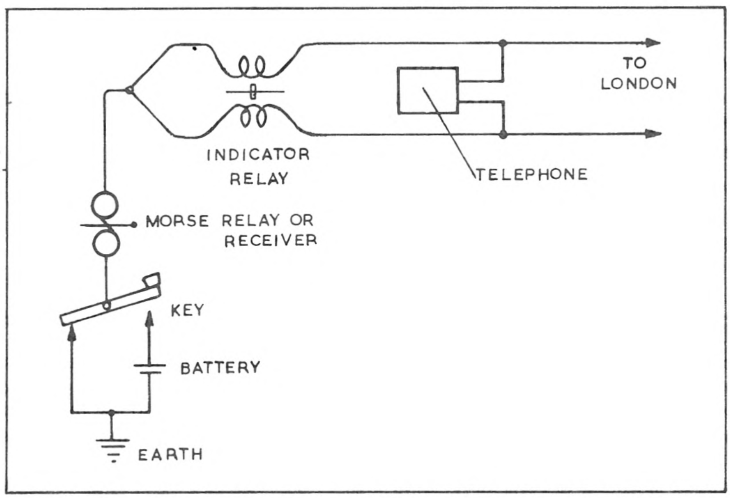

Fig. 3. Circuit used for tests of simultaneous telegraphy and telephony on the cross-Channel cable, March 1891 (French end)

The somewhat marginal telephone performance of the new London-Paris line as revealed by the reports quoted above contrasts somewhat sharply with Preece's published account[58] :

> '. . . its success, telephonic and commercial, had exceeded the most sanguine anticipations. Speech has been maintained with perfect clearness and accuracy. The line has proved to be much better than it ought to have been.'

Preece describes conversation over the extended line from the Treasury in London to the Observatory in Paris as 'quite practicable', whereas Kempe and Brown had reported that it was 'only possible with difficulty'.

Tests had been made over the line with the Paris-Marseilles telephone line in tandem.[59] The latter line was of massive copper wires and was probably Europe's best long-distance telephone line. The overall circuit, London-Marseilles, was just over 700 miles in length. Preece reported that it had proved possible to speak over it 'with difficulty'. It is interesting to note that a year later, presumably with improved instruments,

> 'Conversation has been carried on with complete success between London and Marseilles on several occasions, but it is not intended to open this route to the public at present.'[60]

TRAFFIC ON THE LINE, EFFECT ON TELEGRAPH TRAFFIC, OPERATING DIFFICULTIES

Whatever the technical deficiencies of the new cross-channel telephone line, there is no doubt it was well used. Traffic increased month-by-month; figures for the first six months show a steady increase from 1220 calls (counting calls originating in Paris as well as those booked in London) in

April to 2311 in September 1891. There were approximately three calls booked in London for each two booked in Paris. It seemed that the availability of telephone communication with Paris had some effect on the telegraph traffic; whereas for some years up to 1890 the foreign telegraph traffic from England had increased by between 8 and 10 per cent per year, in 1891 it had increased by only 0.3 per cent.[61]

In accordance with the original announcement, which we reproduced earlier, provision was made for calls to be made from and to subscriber's offices in London and Paris, but the extension lines concerned were special ones, not involving the general telephone network, and were switched on to the international line by special switches. Thus extra losses and noise were largely avoided. Trouble arose, and numerous complaints were made by the public, because the French operating arrangements were inferior to those in London. For example, the French had no simple way of telling when a call had finished, and much time was wasted. The French system of allocating time between the Bourse and the general public was inflexible and caused large delays to one group of callers even when both lines were not really busy. Each caller was officially allowed only three minutes on the line, but whereas in London the expiry of three minutes was automatically signalled, there was no such arrangement in Paris. All this had to be ironed out by tactful negotiation.[62]

CONCLUSIONS

Although the London-Paris telephone system may have sprung from a proposal of the French administration, its design and execution was almost wholly British, and the credit for its success must go to W. H. Preece and his staff in the Post Office Engineering Department. In those days there was no means known for amplifying telephone signals, and a standard of telephone transmission had to be accepted which would be quite unacceptable now. Admittedly Oliver Heaviside had shown by his theoretical work how telephone transmission could be substantially improved by the appropriate addition of inductance to the lines, but his work was not understood by the more practical engineers of his time (nor was it by those of later generations, but his conclusions became generally accepted and applied.) Preece, in particular, would not accept Heaviside's teaching, and consequently used principles of design which were falsely based, and misinterpreted data. To some extent, therefore, it was luck that the London-Paris line provided adequate telephone transmission. However, Preece had the sense to make many experiments, had a vast and wide experience of electrical engineering and undoubtedly had a feeling for what would work. He seems to have been a good and inspiring leader; perhaps, like George Stephenson, a man of vision rather than of science. At any rate, the project was a notable engineering success. It was also a commercial success, and two new cables were provided in 1897 to meet the growing demand.

The other important character in our story was F. van Rysselberghe. Although in the end he had little effect on this particular project, he was a vastly important and almost dominant influence in the early development of long-distance telephony; but his story is the subject of another paper.

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DISCUSSION

Mr. TRAFFORD opened the discussion by asking when amplifiers were first used in telephony. The AUTHOR replied that telephone amplifiers were not introduced into commercial service until about 1910; these were electro-mechanical devices. Mr. HALSEY said that electronic amplifiers were used in France during the first world war. He went on to ask Prof. Tucker about the later history of the cable. Prof. TUCKER replied that he had no information; he had found that it was much easier to find out the beginnings of things than their ends.

Mr. Rex WAILES asked what cables came ashore at Dumpton Gap. Prof. TUCKER said that the earlier Anglo-Belgian telegraph cable landed there. Unsuccessful telephone experiments were made on it before deciding to proceed with the 1891 telephone cable.

Dr. R. EARL asked about the life of gutta-percha cables and whether they were salvaged and re-used. Mr. SCOWEN said that cables were seldom picked up because of the slow picking-up speed (about one knot) and the consequent cost.

Mr. Torsten BERG asked if the cable conductors were of copper or iron. The AUTHOR replied that they were of copper. Iron had been used for early telephone circuits but was being abandoned by 1890 on the majority of telephone routes because of its unsatisfactory transmission characteristics; phosphor-bronze conductors were used on the Paris to Brussels circuits.

Mr. J. A. WILLIAMS asked when the loading of telephone lines was introduced. Prof. TUCKER replied that Pupin's work in the U.S.A. was done in 1899 and the first loaded cables were in that country. Heaviside had proposed the use of loading in 1887 and S. P. Thompson was one of the few persons in this country who believed in his work. The first British loaded cable was equipped in 1903. Mr. HALSEY said that submarine cables were 'continuously' loaded and Professor TUCKER added that submarine cables often had continuous loading whereas land lines were always 'lump-loaded'. Mr. Williams remembered seeing loading coils on open-wire pole routes. The Author said that this had never been done in the U.K., but was once a regular feature in the U.S.A.; however, loading pots have been used on aerial cable routes.

Mr. P. N. WILSON asked about the reason why the telephone was used less in this country than in the U.S.A. Prof. TUCKER replied that even Belgium had had a long distance telephone network since 1883; it was a Government decision not to set up a trunk network in the U.K. where it would compete with the telegraph service. The telephone system was operated by private companies under restrictive licence from the Post Office which took over the trunk routes only in 1896. In about 1885 the then Postmaster General said that we had a very good telegraph network and that no one wanted the telephone. The Long Distance Telephone Company was set up in 1882 to develop the long distance trunk network but were stopped by the Government. Mr. R. J. LAW said that the U.K. then had a very good postal service and instanced having seen postcards saying 'can you come to tea this afternoon?'. Mr. HALSEY added that Preece, shortly after Bell's invention, had said that the telephone was not required in the U.K.; we had a very good messenger boy service!

A visitor asked whether a licence was required for providing telephone circuits. Prof. TUCKER replied that this was so, but he could not remember when licences were introduced. Mr. GEDDES added that the date was 1880.

The PRESIDENT asked whether the differences between the U.K. and U.S.A. telephone services were because the latter was run by private enterprise. The AUTHOR replied that Government interference in the British system was the underlying reason for the differences.

Mr. D. H. TEW asked how long it was before this country caught up with the Continent. Prof. TUCKER replied that a properly planned trunk network was provided for the U.K. by the Post Office in 1896 when they assumed the monopoly of the trunk system. This network had a good standard of transmission. Exchanges were mainly controlled by the National Telephone Company. This company was taken over by the Post Office in 1912, leaving only the municipal systems at Portsmouth and Hull; the latter is still independent. The PRESIDENT said that some of his acquaintances still used the expression 'National telephone' when speaking about the Post Office instruments. Mr. J. G. B. Hills had also met this custom.

Prof. TUCKER said that Preece retired in 1899 with the title of Engineer in Chief and a knighthood. He did not believe in Heaviside's work until its general acceptance forced him to. In 1907 he read a paper to the British Association giving his own explanation of how loading worked. Many eminent engineers said that very much was owed to Heaviside but Preece disagreed!

Mr. STANDEN asked if there was any connection between the consulting firm of Preece, Cardew & Rider and telephone work. The AUTHOR replied that, as far as he knew, that firm only undertook power station work. Preece (the father of Preece in the firm) was a consultant on power stations especially during the period 1884–1897. He had been connected with perhaps fifty power stations and joined the firm on his retirement.

Mr. J. W. BUTLER asked if the French also laid a cross-channel telephone cable. Prof. TUCKER replied that the early cables, while a joint venture in financial terms, were made and laid by the British. Three fifths of the traffic originated here. Could Mr. Halsey say whether the French had laid any submarine telephone cables? Mr. HALSEY replied that later the French and British Post Offices made and laid cables in turn.

Mr. J. C. ROBINSON asked about the spacing of the telegraph and telephone cables to avoid cross-talk interference. Prof. TUCKER replied that the spacing did not matter; the telephone cables used twisted metallic loop circuits which were relatively free from external interference. The overhead land lines suffered from telegraph interference if they used an earth return. This trouble was largely avoided by using loop circuits and by transpositions.

Mr. J. W. BUTLER asked if any cable had been brought to the surface by ships' anchors. The AUTHOR had no information on the matter.

Proposing the vote of thanks, Mr. K. GEDDES said that the Science Museum had a sample from the 1897 cross-channel cable but not of the 1891 cable. The vote of thanks was carried with acclamation.

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