Beginnings of long-distance telephony, 1882-87

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Economic and technical difficulties facing long-distance telephony in 1882 were largely solved when Francois van Rysselberghe superimposed telephone circuits on existing telegraph lines. Many countries in continental Europe and elsewhere therefore developed long-distance telephone networks long before Britain, where William Preece and Oliver Heaviside attempted to develop appropriate theories of long-distance transmission, the former erroneously, but the latter successfully

Commercial exploitation of the telephone started in 1878, and the use of the telephone spread rapidly, especially in the USA, 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, Engineer-in-Chief of the British Post Office, said:[1]

'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 160 km 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.[2] 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 50 km. Expense prevented the adoption of metallic-loop circuits for long overhead routes. So, in the early 1880s, 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.[3]

Another important contribution that van Rysselberghe made was to show, by a series of experiments in the USA 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 1600 km (i.e. New York to Chicago) was achievable, and that even transcontinental telephony was a possibility.

In Britain, W. H. Preece also made some experiments during 1885–87 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. These matters are the subject of this article.

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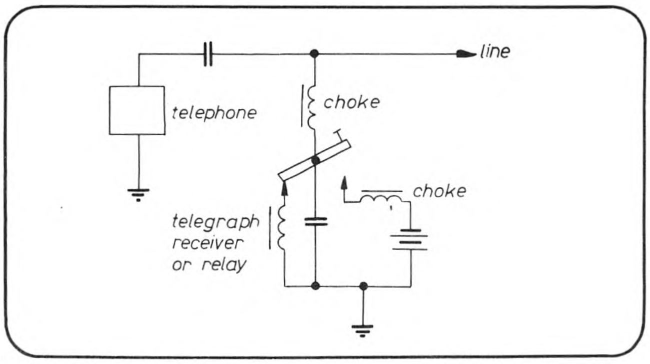
The van Rysselberghe system

F. van Rysselberghe was employed in the Belgian Meteorological Observatory, but evidently had been giving much thought to the problems of telephony, because during 1882 he filed several patents covering his ideas for solving them. They were all technically sound. His first concept[4] was to smooth the telegraph signals and thus remove the transient currents which caused interference with telephony. For this purpose, he inserted chokes and/or capacitors in the telegraph circuits. His second concept[5] was to superpose the telephone circuit on the same wire as a telegraph circuit by means of capacitor couplings, a typical arrangement being as shown in Fig.1. The first concept was tried experimentally on the 16th January 1882 on the route from the Royal Observatory at Brussels to the Meteorological Station at Ostend (about 125 km). A special wire run on the telegraph route was used for the telephone traffic, and conversation proved satisfactory. The experiment was later repeated in the presence of the director and chief engineer of the Belgian Telegraphs.

The success of this experiment led to collaboration between the Belgian and French authorities in an experiment of simultaneous telephony and telegraphy over the same wire, according to van Rysselberghe's second concept, from Brussels to Paris (about 335 km) on the 16th and 17th May 1882. Potentially interfering telegraph circuits were smoothed, and it was found that, even during the busiest periods of telegraph traffic, telephony was excellent; the Press of France and Belgium now urged their Governments to provide a long-distance telephone network. Other experiments confirmed the success of van Rysselberghe's method.

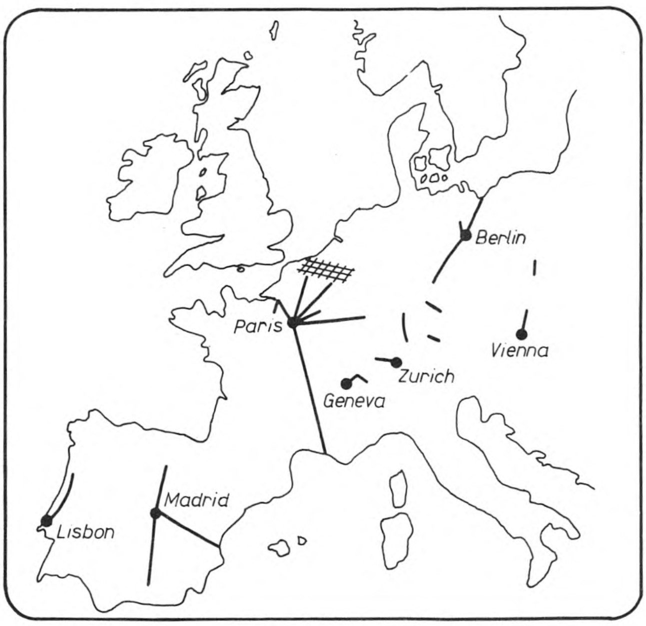
The Belgian Government had earlier formulated a plan for the construction of 600 km of new telephone line at a cost of 3 million francs. They now had to consider whether they should replace this plan by one using van Rysselberghe's system at a cost of only 150 000 francs. The cheaper proposition won. Messrs. Mourlon & Cie, of Brussels, contracted to manufacture the equipment. The new service was inaugurated on the 1st September 1884 by the relaying of a concert from Brussels to Antwerp over the new telephone line. What faith they all had in the new system! However, it was justified, for the demonstration was a resounding success.[6] By mid1887 Belgium had over 7000 km of telephone line operating on this principle, and only 260 km of telephone-only lines.[7]



1 Typical van Rysselberghe circuit for simultaneous telephony and telegraphy

Other countries in continental Europe were quick to adopt the van Rysselberghe system, and by mid1887 the routes established were as shown in the map of Fig.2, totalling at least 17 000 km. There were also several thousand kilometres in South America, China and Japan.

The system was not adopted in Britain until very much later, although it then persisted here, as elsewhere, as the 'composite' system, or as 'sub-audio' telegraphy, until relatively recent times. Preece, who was in charge of Post



2 Long-distance telephone network of Europe in mid1887, based on the van Rysselberghe system

Office engineering, said that it was not suitable for Britain, as he thought that it would not work well with the Wheatstone high-speed telegraph system; there was some justification for this view, as at speeds of 300 words/min, telegraph interference would be hard to eliminate. As far as is known, however, the system was never given a trial in Britain. Continental telegraph speeds were said to be much lower. The price Britain paid for having faster—and therefore cheaper—telegraphs was evidently

Table 1. Summary of van Rysselberghe's experiments in USA

Circuit	Length km	Type of wire	Diam. of wire mm	Result
Grafton–Parkersburg	166	Iron	4	Good
Grafton–Parkersburg	166	Copper	2·7	Splendid
River–Fostoria	366	Iron	5	Fair
Grafton–Fostoria	517	Iron	4·5	Unsatisfactory
Baltimore–Fostoria	1000	Iron	4·5	Nothing heard
Fostoria–New York	1168	Copper	2·7	Very weak
Fostoria–Albany	936	Copper	2·7	Good
Fostoria–Albany	936	Copper	2·1	Very weak
Fostoria–Buffalo	~480	Copper	2·1	Good
New York–Chicago	1616	Compound	6	Excellent

that of being one of the last countries to have a long-distance telephone network. It was 1890 before London could speak to Birmingham and 1891 before England could speak to Scotland.

Van Rysselberghe's experiments in the USA

No doubt greatly encouraged by his successes, van Rysselberghe went to the USA to experiment with telephony over greater distances than the European system yet permitted. He negotiated for the use of telegraph lines belonging to the Baltimore & Ohio Telegraph Co., and to the United Lines Telegraph Co., and fitted his equipment to the telegraph circuits on the routes involved.* A diagram of these routes is shown in Fig.3, and a summary of his experiments and results is shown in Table 1. Clearly, under the conditions of the tests, the limit of acceptable telephony was about 480 km on iron wires of 4–5 mm diameter and on copper wires of 2·1 mm; it was about 960 km on copper wires of 2·6 mm. On the compound wire, comprising a 3 mm steel core with a 1·5 mm layer of copper around it, the limit was far from reached at 1600 km.

Van Rysselberghe's report to his director conveys well the excitement of this last achievement. Achievement it certainly was, almost beyond belief at that time, and made possible only by van Rysselberghe's invention. Transcontinental, even transworld, telephony had suddenly become a real possibility. The present author has attempted to retain the feeling of the orignal French report in the following extract from his translation of it:

'The installations completed, it was with some anxiety that one of us, Mr. Maver at New York, approached the microphone, put the receivers to his ears, and called: Hullo, Chicago! "Hurrah! Hurrah!", he exclaimed; then turning towards us, all astonished, "It's unbelievable", he said. He had just heard the voice of Mr. Steward, the engineer at Chicago, with such an intensity of sound and such clarity that he imagined his colleague must be behind him, among us, in the same room, in New York, and not over 1000 miles (1600 km) away.

'I took the telephones myself, and I was literally astonished at the result. The voice was vibrant and precise, with an admirable clarity, without the least distortion and of an astounding intensity. I could hold the telephone 3 or 4 cm from my ears without failing to understand my interlocutor. When other persons had a receiver applied to their ear, one could hear the sounds coming from Chicago, through the apparatus, at the outside of the telephone.

'Persons who had never before used the telephone conversed over the system with astonishment, without needing to have any word repeated. Indeed, a common woman, caretaker of the cable house in which we were working, who had never seen a telephone, conversed without hesitation with Mrs. Steward, whose fine voice was heard to perfection. In short, the telephone communication between two stations in the same town is rarely as satisfactory as that which we obtained with our apparatus over a circuit of which the total length (of wire) was over 2000 miles (3200 km), two-thirds of the distance which separates the coasts of the old and new worlds.

'The intensity of the voice was such that all those who were present at the experiments have not hesitated to conclude that, with the same conductors and the same apparatus, one could converse without difficulty to three times the distance. As for me, I would dare to guarantee success to double the distance, and I believe success might be possible (with the same wire) to four times the distance. With a wire of suitable diameter I would guarantee success at any required distance, were it that of Paris to Peking.

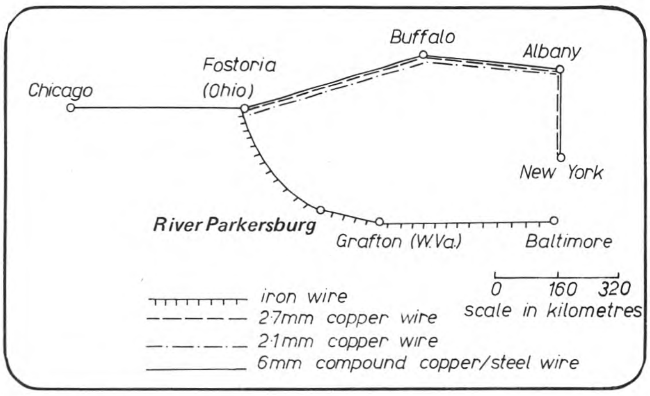
'However, let us remain in the world of facts and summarise the results achieved. We have communicated in a commercially satisfactory manner with a wire of 2·1 mm diameter to a distance of 300 miles (480 km), with a wire of 2·7 mm to 585 miles (936 km), with a wire equivalent to 5 mm to 1010 miles (1616 km) with perfection; and it seems certain that with the same wire of 5 mm one could communicate to over 2000 miles (3200 km) satisfactorily.'

*The information in this section is based on van Rysselberghe's report to his director, published (in French) in *L'Electricien*, 1886, **10**, pp. 307–313

This great achievement of van Rysselberghe undoubtedly had a great influence on thinking in Britain and Europe, but appears to have had little impact in the USA itself. Over seven years later, the President of the American Telephone & Telegraph Co., which styled itself the 'Long Line' Co., claimed[8] that his company, in providing experimental telephone communication between New York and Chicago in 1893, was demonstrating for the very first time 'the feasibility of transmitting speech over the theretofore unapproached distance of one thousand miles'!

Preece's experiments and theory

Preece in 1855 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 19·2 Ω/km. 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 9·15 Ω/km. Before it was brought into use for telegraphy, Preece was able to experiment with telephony on it.



3 Route diagram of van Rysselberghe's American experiments

The results of these experiments[9] show limiting distances of 64–80 km for underground cable, 192 km for open iron-wire loop, and about 400 km for open copper-wire loop. These compare unfavourably with van Rysselberghe's results.

Preece attempted to fit a theory to his results. He based this on Thomson's law[10] (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 unit length and r the resistance per unit length, then:

$$x = \sqrt{(A/kr)}$$

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. As a result we find that there is a substantial disagreement between van Rysselberghe's observations and calculations made by the use of Preece's formula.

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.[11] 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[12] to long-distance telephony and connected matters. Another useful publication was the section 'On telegraph and telephone circuits' in his *Electrical Papers*.[13] 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 leakance 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 4800 km.

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 thought this was the explanation of van Rysselberghe's success, and he was probably right in this.

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,[14,15] 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.[16]

It can be seen that the five years 1882–87 saw the foundation of the art and science of long-distance telephony, and that much of the credit for this is due to the little known Belgian, Francois van Rysselberghe. His system of superposing telephony on existing working telegraph circuits helped to establish long-distance telephony in those early days when traffic was too light to make it economical to provide separate metallic-loop circuits.

*For assessments and reviews of Heaviside's work, see the IEE's *Heaviside Centenary Volume*, 1950

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