Beginnings of the telephone service

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Abstract

After the invention of the telephone in 1876, telephony developed rapidly, and a public telephone service grew up in most countries. Growth was much more rapid in the USA than elsewhere. Telephone exchanges were introduced from 1878, and interurban links came into use as the density of exchanges grew. Technical difficulties, commercial rivalries, and, outside the USA, governmental policies, held back the development of long-distance or trunk lines until the middle 1880s. In Europe, and some other places outside the USA, long-line development was greatly accelerated by the system of simultaneous telephony and telegraph invented by Francois van Rysselberghe, so that by 1887, Europe had over 17 000 km of long-distance telephone lines. In the USA, long-distance telephony developed at about the same time on a basis of metallic-loop circuits. In 1891, Britain scored a notable success in providing telephony between London and Paris, although Britain had no effective internal long-distance system until 1896. Commercial telephony over a distance of 1625 km, between New York and Chicago, was established in the USA in 1892. The technical improvement of both exchanges and transmission systems proceeded rapidly, with the introduction of coil loading of cables and long lines, electromechanical telephone repeaters in the first decade of the present century, and the exploitation of electronics and modulation in the second decade.

1 Introduction

Commercial development of the telephone began quite soon after the initial inventions of Bell and Gray in 1876. Bell's company started in 1877, changing its form rapidly at first, and became well established in the USA, with subsidiary companies in Britain and elsewhere, by 1879. The Western Union Telegraph Company, a large and long-established organisation, having unwisely turned down an opportunity to obtain Bell's patents in 1876, developed a competing telephone company on the basis of Gray's patent and further commissioned inventions by Thomas Edison. This company was successful, and so Bell started an infringment action against it. At the end of 1879 Western Union decided to settle out of court, on the basis that it would withdraw from the telephone field in return for royalties for 17 years. Independent telephone companies that Edison had set up in London and elsewhere amalgamated within a further year or two with the Bell or other suitable companies in their locality. Nevertheless, there were numerous inventions of new or modified forms of telephone transmitter and receiver, and numerous companies set up to exploit them.

The concept of the telephone providing a public service on a basis rather different from that provided by the telegraph sprang up quickly. Individual telephone renters, or 'subscribers', would require to be connected to another subscriber on demand, and, to provide this service, telephone 'exchanges' were introduced by Bell from 1878 and by Edison from 1879. At first, of course, the service was entirely local, but, as exchanges became more numerous, the need for interconnecting them became apparent. Thus an interurban telephone network started to grow; its growth and usefulness were considerably restricted by the fact that in many areas each exchange, or small group of exchanges, belonged to a separate company using different technical and commercial methods. Also, since many governments actively discouraged the development of interurban links from fear of competition with state-owned telegraphs, it is not surprising that it was only in the USA that a significant telephone network had developed by 1884. Statistics published in 1885 showed[1] the USA to have 140 000 subscribers with 800 exchanges, while for the rest of the world, the list was topped by Britain with a mere 10 000 telephones; interurban lines in the USA numbered over 800, while there were only about 80 in Britain.[2] It is probable that the USA had more than twice as many telephones and interurban lines as the rest of the world put together.

Inevitably, as interurban telephony developed, a demand for interregional or long-distance telephony arose. But the technical difficulties were such, and the performance of the few lines that were provided was so poor, that the demand grew only slowly at first, and it was the middle 1880s before any serious programme of provision of long-distance lines emerged – and then Europe (except Britain) was well to the fore, for reasons which will be discussed later.

In spite of disparities in telephone densities in different countries, proportional growth rates represented by a doubling of numbers and wire mileages every two or three years were maintained almost everywhere.

2 Telephone exchanges

The idea of connecting one subscriber, on request, to a another, by means of a flexible switching system had, on a very small scale, been applied to local telegraph subscribers in the USA and Britain before 1877. During 1877, one or two very small private telephone exchanges had been tried, also in the USA, but the first commerical telephone exchange was that at New Haven, Conn., opened on the 28th January 1878. In this, eight lines (with 21 telephones connected) could be connected in pairs by means of a direct cord with a plug at each end; calling 'annunciators' were provided, operated by direct current from the subscriber's battery. A 20-line exchange was fitted six months later at Bridgeport, Conn. During the same year, the American District Telegraph Co. opened an Edison exchange in Chicago, also using direct interconnection by single cord. Calling for subscribers who already had a telegraph instrument was by telegraph; for others, calling relays were used. This switchboard grew rapidly and several boards were needed, with inter-board connections and two operators involved in most calls. It was here that the 'jack-knife' switch, forerunner of the well-known 'jack', was introduced by C.E. Scribner, engineer of the Western Electric Manufacturing Co.[3]

1879 might well be regarded as the year of the telephone exchange, for it saw the introduction of double-cord interconnection via intermediate connecting bars (which could run the length of a whole suite of 25-line boards); of the 'multiple', (whereby outgoing access to subscribers' lines was repeated throughout the suite, so that each operator had direct access to every subscriber), of several line-engaged testing arrangements, and of the first exchange in Britain. This last innovation was opened by the (Bell) Telephone Co. in August 1879 at Coleman Street, London, and had calling indicators, jacks, cords and connecting bars.[4, 5]

It could fairly be said that the manual telephone exchange of the form that became so ubiquitous in the first half of the 20th century arose directly out of the developments just described. Many technical and operating improvements were introduced, of course; e.g. making the engaged signal a click when the operator touched the tip of her calling plug on the outer ring of the jack, the use of small lamps as calling and supervisory signals etc. But this type of switchboard was not the only one. The National Bell Telephone Co. in the USA in 1880 introduced a board using an array of horizontal and vertical bars, one of each for each line, so that interconnections could be made by inserting a plug at the crossing of two lines. In Britain, the Edison Telephone Co. used a similar arrangement. It was, however, not suitable for expansion by the 'multiple' method, and so it died out.

The reliance on batteries at each subscriber's premises was obviously undesirable. Common-battery signalling, with a central battery at the exchange, was introduced by J.J. Carty at Boston as early as 1880, and the use of a central battery for both speaking and signalling, patented by C.A. Bell in 1886, was further developed by H.V. Hayes of the American Bell Telephone Co.), and later chief engineer of the American Telegraph & Telephone Co.), and first came into commercial service at Lexington, Mass. in 1893.[3]

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For many decades there was no economic incentive to try to use automatic exchanges, for operators were cheap and equipment was expensive. Nevertheless, A.B. Strowger of Kansas City began the development of his automatic switching system in 1889; the first commercial automatic exchange was working by 1897, and by 1898 the USA had 22 such exchanges. The first one in Britain was at Epsom in 1912.[4]

In the early days, different companies had different ideas as to the best way to expand the telephone exchange system. Some maintained a single exchange in a town, with all subscribers connected to it. Others used several smaller exchanges, each serving a much more limited area, with linking lines, then often called 'trunks', between the exchanges. Sometimes the links were all connected to a central 'trunk exchange', through which all interexchange calls had to be routed. Examples of these arrangements in Britain were

(*a*) Manchester as a single exchange system
(*b*) Glasgow with six exchanges all interlinked
(*c*) London with 20 exchanges all linked to a central trunk exchange, and also having a certain number of direct interexchange links where the traffic warranted them.[6–8]

3 Telephone companies, competition, and the State

The manner in which the telephone service developed in different countries was influenced very largely by the attitudes of the governments concerned. The beginning of telephony in nearly all countries was due to commercial companies, the only important exception being Germany, where the state took control from the start. In the USA the companies were, and are still, left to organise themselves according to the ordinary rules of competitive enterprise; the stronger became stronger and took over the weaker ones, thus enabling an effective public telephone service to be established with full interconnection facilities as the interurban network grew. The dominant company became the Bell organisation, working through regional subsidiaries. In Europe, however, the companies came under government influence at a very early stage, and in several countries, notably France, Belgium and Switzerland, there was complete state monopoly before 1890.[9]

The initial formation of a company was usually based on the possession of rights in some patent for a new design of transmitter or receiver which was thought not to infringe the Bell patents.[10] Litigation over these patents was the most usual cause of failure of these companies and their consequent absorption by the Bell companies. This happened in Britain, but the position here was complicated by legal action taken by the British Government in 1880 against the United Telephone Co. which had just been formed by the amalgamation of the Bell and Edison companies. The Government's contention that the telephone was a telegraph within the meaning of the Telegraph Act of 1868 was upheld by the court, and thus the Post Office acquired control over all telephone activity in Britain.[11] This it exercised by giving licences to companies in return for a 10% royalty on their business; but it also began to set up telephone exchanges itself, notably at Newcastle upon Tyne.

The pattern of company formation, amalgamation, reformation, and the setting up of subsidiaries, not to mention the British Post Office's activities, was very complicated, but may be followed in as much detail as we can here afford by reference to Fig. 1.[12] By 1889

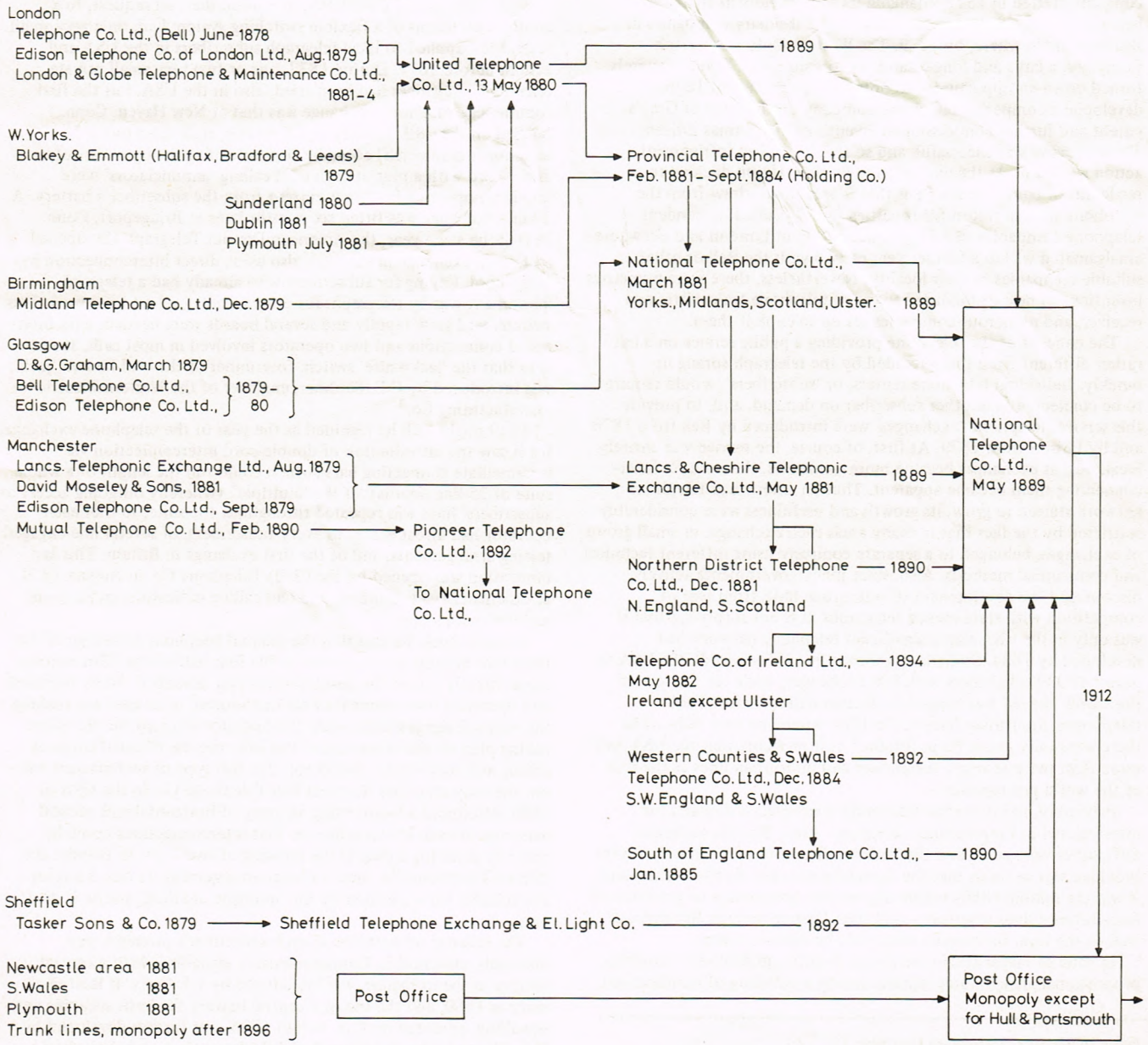

Fig. 1
Telephone companies and the British Post Office, 1878–1912

the National Telephone Co. had almost a monopoly of company telephone business; there were just a few minor companies outside their organisation, but these have not been included in Fig. 1. The number of subscribers on the Post Office exchanges was very small in relation to the number connected to the National Telephone Co., but the technical standard of the Post Office was high, with metallic-loop lines instead of the single-wire lines of the company. Around the turn of the century, there was a small third group of telephone undertakings, the municipal exchange systems.[9] These were, in general, unsuccessful, and at the time of the takeover of the National Telephone Co. by the Post Office in 1912, only two had survived.

Detailed accounts of the telephone systems in the other countries of Europe in the 1890s are given by Bennett.[13]

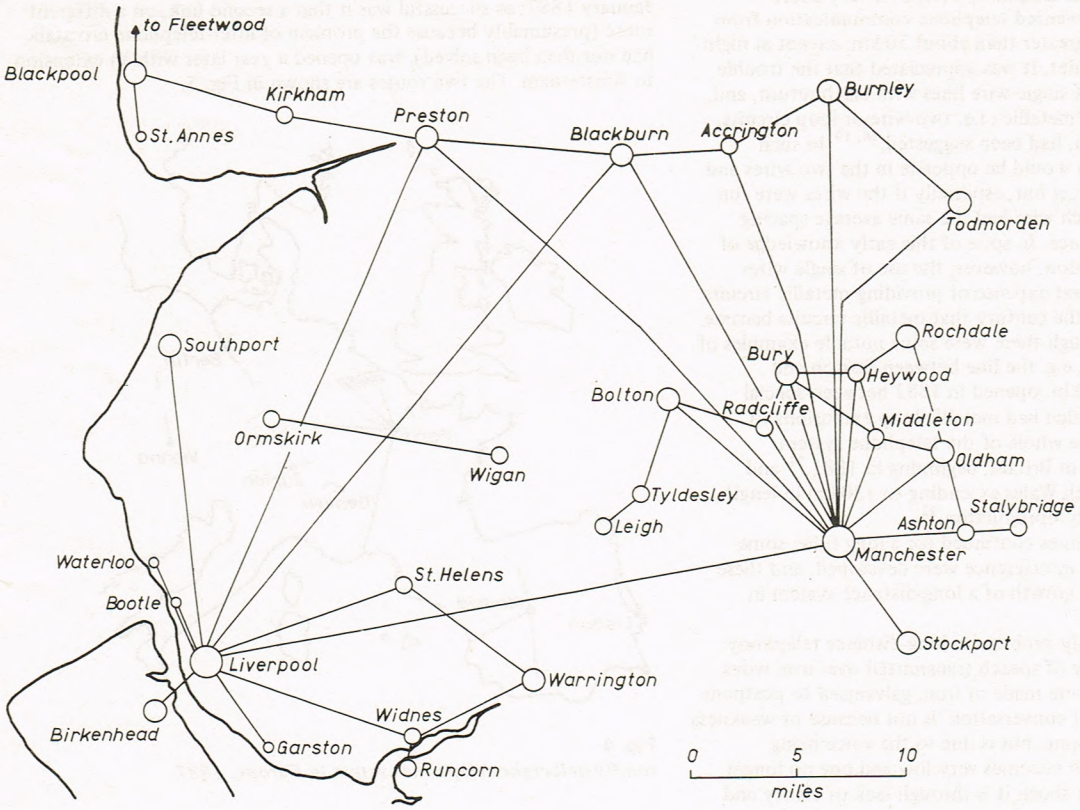

Fig. 2
Interurban network of the Lancashire and Cheshire Telephonic Exchange Co., 1886

4 Growth of interurban telephone networks

As the number of telephone exchanges grew, so did the demand for links between the exchanges in neighbouring places. Subscribers' lines were usually of the single-wire type with earth return, so that there was no difficulty in linking them by means of single-wire interexchange lines. In the USA, there was no obstacle other than transmission and commercial considerations to the growth of interexchange networks. In Britain, however, there were legal difficulties imposed by the licensing system. In granting a licence to a company, the Post Office restricted the area to be served under the licence to a radius of four or five miles. It was thus impossible for a company to develop a network which could be classed as interurban. This disability was removed in 1884,[14] and thereafter a few notable interurban networks were built up, an outstanding example being that of the Lancashire and Cheshire Co., which by 1886 had about 3000 km of interurban lines, as shown in Fig. 2.[15] The position of interurban telephony in Britain as a whole is shown in Fig. 3, the data for which has been obtained from 24 separate reports in *The Electrician* between 1881 and 1887.[16] It will be seen that the various local networks are not linked; in modern terminology, there were junctions but not trunks. Although there were technical difficulties in providing good enough long-distance lines, they were overcome in other countries which had the will to go ahead. Britain, almost alone, took the line – at least the British Government did, for I quote the Postmaster General[17] – that 'having regard to the cheap and swift means of communication which at present exist by means of the telegraph between the principal towns in the UK, . . . it is extremely doubtful whether there would be much public advantage in establishing telephonic communication generally between those towns'. At this time (1887) continental Europe had about 17 000 km of long-distance telephone lines, as we shall see later.

Fig. 3
Interurban telephone system in Britain in 1887

5 Long-distance telephony: technical problems

The main obstacle to the achievement of effective long-distance telephone communication was the interference due to telegraph signals on adjacent wires. This 'induction', as it was called, could seriously interfere with telephony even over very short distances, and it entirely prevented telephone communication from taking place over distances greater than about 50 km, except at night when the telegraphs were quiet. It was appreciated that the trouble was largely due to the use of single-wire lines with earth return, and, as early as 1877, the use of 'metallic', i.e. two-wire-or loop circuits, without an earth connection, had been suggested.[18, 19] In such circuits the lateral induction would be opposite in the two wires and would therefore tend to cancel out, especially if the wires were run on a twist system so that each wire had the same average spacing from the source of interference. In spite of this early knowledge of the technical cure for induction, however, the use of single wires continued because of the great expense of providing metallic circuits. It was not until the turn of the century that metallic circuits became more or less universal, although there were some notable examples of their use in the early 1880s, e.g. the line between Boston and Providence, USA, about 80 km, opened in 1882 between special switchboards at each end which had metallic-loop extensions to special subscribers;[20] and the whole of the telephone system operated by the Post Office in Britain, beginning in 1881,[21] and including trunk lines in South Wales extending to 130 km in length, was said to have good speech reproduction.[22]

As the use of single-wire lines continued for a long time, some special methods of reducing interference were developed, and these had a great influence on the growth of a long-distance system in Europe, as we shall see later.

Induction was not the only problem in long-distance telephony; another was the poor quality of speech transmitted over iron wires. At the beginning, all wires were made of iron, galvanised to postpone its rusting away. The limit of conversation 'is not because of weakness of sound heard in the telephone, but is due to the voice being profoundly altered; the pitch becomes very low and one no longer recognises the speaker . . . in short, it is through lack of clarity and not through excessive feebleness of sound that communication becomes impossible.'[23] The explanation of this effect, given by Wietlisbach in 1886,[24] was that it was due to the resistance of iron wire rising rapidly with frequency. For an iron wire of diameter 4 mm, the resistance doubles (with respect to the d.c. value) at 300 Hz, and quadruples again by 1000 Hz, and so it does not require a great length of line for the distortion of speech to become noticeable. The use of iron wire in telephony was only slowly abandoned, but most long-distance lines were of copper or phosphor-bronze from the middle 1880s.

It was found, as the number of telephone lines on a long pole route increased, that induction, or crosstalk, between them could be serious, even when the induction from telegraph circuits had been largely eliminated by the twist system. Moreover, the twist system itself was difficult to erect and maintain, and so the transposition system came into use. In this the wires ran straight, but were periodically moved to different positions relative to one another. This had much the same effect as a twist, but had the advantage that different periodicities could be used for different circuits, so that crosstalk between them also could be neutralised.[25]

6 Interim development of long-distance telephony in Europe on the van Rysselberghe system

I have already referred, in passing, to the fact that single-wire working continued for a long time, and that special anti-interference methods were introduced. These were the invention of Francois van Rysselberghe, a meteorologist in Belgium, who was interested in the remote observation of meteorological instruments, and extended his interest into long-distance telephony. Realising that the interference from telegraph to telephone circuits was largely due to the transients caused by the rapid rise and fall of the telegraph impulses, he showed, early in 1882, that suitable chokes connected in the telegraph circuits could reduce interference to a satisfactory level on adjacent telephone lines. From there it was a short step to showing that the telephone circuits could actually be superimposed on the telegraph lines by means of capacitance couplings. Thus a technical and economic solution to the long-distance telephony problem was available, and was immediately taken up by the Belgian authorities and, before long, by many others.[26] Telegraph lines existed over Europe and in other countries on an extensive scale, and it was attractive to be able to work telephony over them at low cost. By mid-1887, there was a long-distance telephone network in Europe amounting to over 17 000 km in length, as shown in Fig. 4, all on the van Rysselberghe system; there were many similar lines in many other parts of the world, including South America, China and Japan. The European system was not linked into an interconnected international network, but Holland, Belgium, and France were linked together, the notable international line between Paris and Brussels (believed to be the world's first) being opened in January 1887; so successful was it that a second link, on a different route (presumably because the problem of inter-telephone crosstalk had not then been solved), was opened a year later with an extension to Amsterdam. The two routes are shown in Fig. 5.

Fig. 4
van Rysselberghe telephone system in Europe, 1887

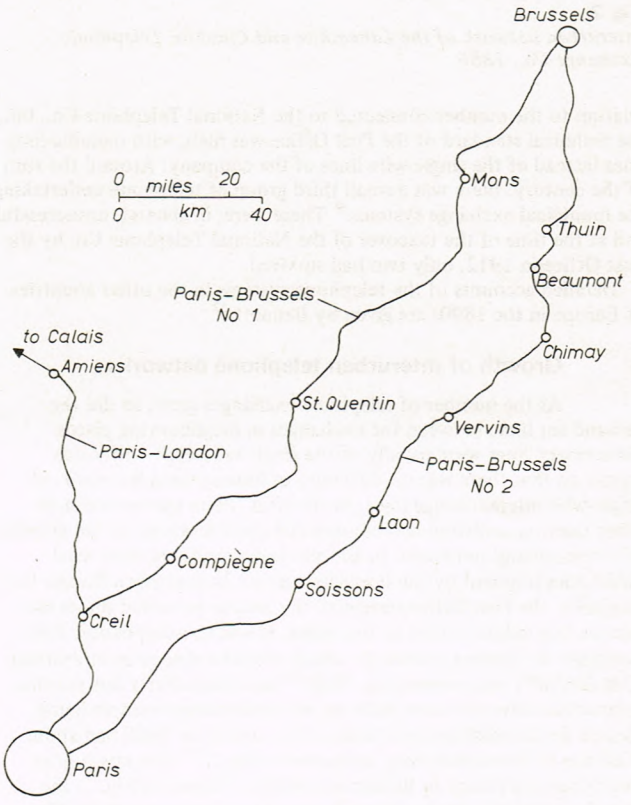

Fig. 5
Routes of the Paris-Brussels telephone lines, 1887, also showing the relationship with the London-Paris line of 1891

This development in Europe appears to have had little influence in the USA, where, as we shall see, long-distance telephony was beginning to grow, on the basis of metallic-loop lines independent of the telegraph network. In Britain there was little development of long-distance telephony by 1887, as we have seen; one reason for this being

the anti-telephone policy of the Government. Another and better reason was that the smoothing chokes of the van Rysselberghe method limited the speed of the telegraph channel, and would have hampered the high-speed Wheatstone telegraph system widely used in Britain.

The working of the van Rysselberghe system was not restricted to single-wire lines; indeed, the Paris-Brussels lines were metallic-loop but they had telegraph circuits working simultaneously on each wire. As the telephone network grew, with several telephone circuits on each pole route, it was inevitable that loop working had to displace single-wire operation, and the use of the van Rysselberghe system gradually became less attractive technically and economically and largely died out.

7 Long-distance telephony in Britain

I have previously referred to Government attitudes in Britain that effectively led to a great retardation in the growth of long-distance telephone services compared with the rapid development taking place elsewhere. Obviously, however, this unsatisfactory position could not continue indefinitely. A curious situation had arisen in 1889, when two London-Paris telephone circuits were planned, with a new cable between St. Margaret's Bay (Dover) and Sangatte (Calais),[27] since at that time it was not possible to telephone from London to any other town in Britain except Brighton. The Anglo-French lines, opened in 1891, were a great success, and by then London had also been linked to Birmingham and Merseyside. Nevertheless, it is hardly surprising that agitation arose in Parliament for the provision of a proper trunk network. After widespread discussion and debate, it was agreed in 1892 that the British Post Office should purchase the companies' trunk lines, improve them where possible, and construct a complete trunk network of high standard, to which all telephone subscribers should have access. This was rapidly put into effect, the transfer taking place in 1895, and the new Post Office network being substantially completed by 1896.[28] Fig. 6 shows the position then reached; the data for this map have been collected from over 70 individual reports in the technical press for the years 1888-96. By the time of the transfer, all company lines were in the hands of the National Telephone Co., from whom about 46 000 km of line were purchased; to this the Post Office added nearly 33 000 km.[29]

Fig. 6
Trunk telephone network in Britain, 1896, distinguishing between the lines taken over from the National Telephone Co. and those built by the British Post Office

Fig. 7
European telephone network in 1896; main lines only

New trunk exchanges were provided by the British Post Office, on which all these lines terminated, and they had local links to the companies' exchanges with agreed operating procedures. It could fairly be claimed that Britain had at last a reasonable trunk network. Nevertheless, it remained a long way behind many other countries of Europe in its general telephone development, especially in rural areas.[30]

8 Long-distance telephony in Europe

By the time the trunk network had been developed in Britain as just described, that in Europe had also grown into a largely interconnected system, as shown in Fig. 7. Only the southernmost parts were left without international links. This map has been compiled from data scattered over more than 60 separate reports in the contemporary technical journals, and consequently may well be incomplete.

Telephone development generally (as distinct from trunk line provision) varied enormously from country to country.[30] The highest development, represented by one telephone for every 144–328 inhabitants, was achieved by Norway, Sweden, Luxembourg, Switzerland, Denmark, and Finland. An intermediate development, represented by one telephone for every 449–700 inhabitants, was shown by Britain, along with the German Empire and States, Holland and Belgium. France came next, with one telephone to 1432 inhabitants, then the other countries, with rates down to one in 13 000.

9 Long-distance telephony in the USA

Interest in the use of the telephone over long distances arose in the USA very soon after the commercial introduction of the telephone. Long telegraph routes were available for trial of the telephone, and as early as 1879–80 claims were being made for successful telephone communication over vast and unlikely distances:

(*a*) Omaha-St. Louis (434 km),[31] New York-Cleveland (689 km)[31] and other similar claims are credible
(*b*) New York-Chicago (1625 km)[31] is, in the light of later results, not incredible
(*c*) Bethlehem, Pa.-North Bend, Nebraska (about 3000 km)[32] with 'every whisper audible', is extremely unlikely
(*d*) San Francisco-Torbay, Nova Scotia (4372 km, including 636 km of submarine cable)[31] can reasonably be rejected as a false claim.

The experiments of the Belgian, F.van Rysselberghe, in the winter of of 1885–6 are, however, convincingly reported and are acceptable;[26, 33]

his achievement of undoubtedly good telephone conversation over 500 km with 2·1 mm diameter copper wire, 941 km with 2·7 mm diameter copper wire, and 1625 km (New York-Chicago) with compound conductor comprising 1·5 mm of copper over a 3 mm steel core, was a very real success, especially in view of the fact that the lines were simultaneously carrying telegraph traffic.

The Southern New England Telephone Co., opened in 1884 for public service, a metallic-loop circuit (claimed to be the first metallic long-distance telephone line ever built) between New York and Boston, approximately 450 km in length.[34] This proved very satisfactory.

In 1886 the newly-formed American Telephone and Telegraph Co. (generally referred to as the 'Long Distance Telephone Co.' and a subsidiary of the Bell Co.) embarked on a programme of long-distance lines, several routes being opened in 1887–9 over distances up to about 700 km.[35, 36] The success of these led to the construction in 1892 of a through metallic-loop circuit from New York to Chicago,[37] with copper conductors of number 8 gauge (121 kg/km or 435 lb/mile), a substantial increase in conductor size over the previously used number 12 gauge (48 kg/km or 172 lb/mile). The lines could be extended at each end to give through speaking between Boston and Milwaukee, a distance of about, 2100 km apart, but this was considered rather beyond the limit of satisfactory transmission. Normally, special soundproof booths were used at New York and Chicago. The plan of the main-line development is shown in Fig. 8.

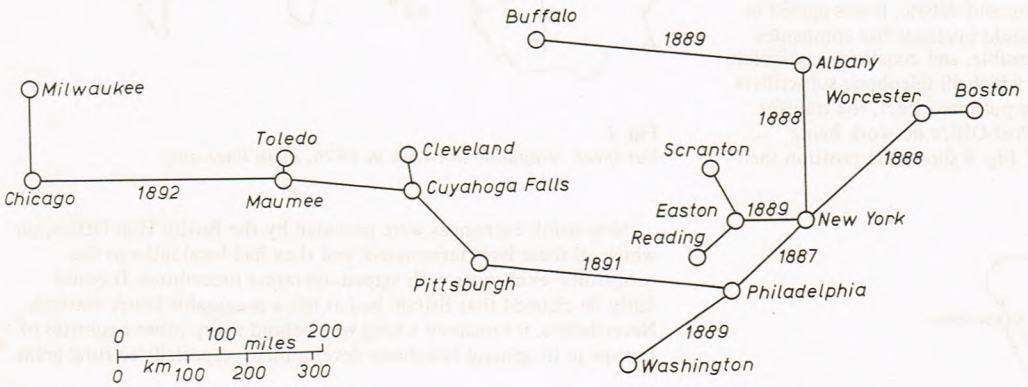

Fig. 8
Development of the long-distance telephone network in the USA, 1888–92, (American Telephone and Telegraph Co.)

In addition to the American Telephone & Telegraph Co.'s network, there were also other interurban lines constructed by local companies, some of considerable length, and some much further west, as instanced by the line from Kansas City to Wichita, Kansas, which was about 300 km long, built in 1889–90 by the Missouri and Kansas Telephone Co.[38]

By the early years of the 20th century, the American Telephone & Telegraph Co.'s network had linked all major towns in the eastern half of the USA.[39] The first transcontinental line, from New York to San Francisco, was opened in 1915.[40] This, however, depended for its operation on the use of coil loading, phantom working, and, most important of all, telephone repeaters or amplifiers. These important matters must now be considered.

10 Developments in long-distance telephony in the early 20th century

10.1 Inductive loading

There is little doubt that full credit is due to the British genius Oliver Heaviside for determining the condition for distortionless transmission of telephone signals, and for showing that an increase of inductance will generally improve transmission.[41, 42] In qualitative terms he may have been anticipated by the Swiss engineer, V. Wietlisbach, but not in the formulation of a comprehensive theory.[43] Practical engineers, like W.H. Preece, the Electrician to the Post Office at the time, refused to believe that the addition of more impedance, either in series or in shunt, could possibly do other than still further distort and weaken the signal.[44] A few people supported Heaviside's ideas, like S.P. Thompson, who thought that the addition of loading coils to a cable might make trans-ocean telephony possible;[45] there were also a few apparently independent but similar proposals.[46] However, nothing effective was done until Pupin and Campbell, in the USA, took up the subject and extended the theory (from 1899 onwards).[47, 48] Development was then rapid, and successful experimental loading of short cables in both the USA and Britain during 1902[49, 50] led to the operational use of loaded cables within a year or two. It was this which introduced the consideration of cables as a basis for a trunk network in regions of moderate size, such as Britain. Previously the transmission in a cable, with its high capacitance and low inductance, had been too poor to permit its use in anything but a local network. Cable design had been much improved by the invention of the 'dry-core' paper-insulated cable around 1890,[51] and with the improvement due to loading, up to a factor of three on workable length, cable routes of many hundreds of kilometres were built in the USA soon after 1910. In Britain, cables were used for short trunks, but the main trunk network remained overhead at this stage.

In the USA, where trunk lines of thousands of kilometres were being operated, it proved worthwhile to add loading coils even to open lines. Heaviside had indicated that open lines approached the ideal condition naturally, and for the shorter distances of the British trunk network, the additional cost of loading was hardly justified, and loading was not applied to open lines. The situation was different on very long lines, and by loading a heavy-gauge (321 kg/km) open line, successful commercial telephony between New York and Denver, a distance of about 3400 km, was achieved in 1910. In this case, however, the transmission loss was further reduced by the use of phantom circuits, which will be considered below.

Submarine telephone cables were another case where improved transmission was desirable. The Anglo-French cable of 1891, and its successors of 1897, gave commercially-acceptable speech transmission, but it was too poor for general extension over the trunk network. The new cable laid in 1910, while of the same general design as the earlier ones, had loading coils built into it at intervals of one nautical mile.[52] The transmission was greatly improved, by an amount measured as about 20 miles of standard cable (approximately 20 dB). Continuous inductive loading was also used on submarine cables; this consisted of wrapping soft iron wire round the copper conductors before the cable was assembled.

10.2 Phantom circuits

The increased expense of providing metallic-loop circuits as opposed to those using a single wire and earth return was greatly reduced by the use of 'telephone duplex', which later became known as 'phantom' operation. In this system each pair of wires used for a metallic-loop circuit is also used effectively as a single conductor (i.e. with the two wires effectively in parallel) for another telephone circuit. The system could conveniently take the form shown in Fig. 9, where two metallic-loop circuits are used to provide a phantom circuit (number 3) of metallic-loop type, using the two wires of circuit number 1 as one conductor and the two wires of circuit number 2 as the other. Another phantom circuit of the earth-return type can also be provided by using all four wires as one conductor, as shown. Thus three induction-free circuits can be obtained from four wires, together with another circuit suitable for operators' use or for shorter lines.

An interesting, but not entirely accurate account of the early invention and development of phantom circuits has been given by Rhodes,[53] who credits the basic principle to F. Jacob in 1883 (it was patented by Jacob in Britain early in 1882),[54] although in fact Black

and Rosebrugh had patented it in 1879.[55] These early patents used resistance bridges in place of the transformers which were later introduced. The first correct use of transformers for phantom working was shown by van Rysselberghe in 1883,[56] and more fully

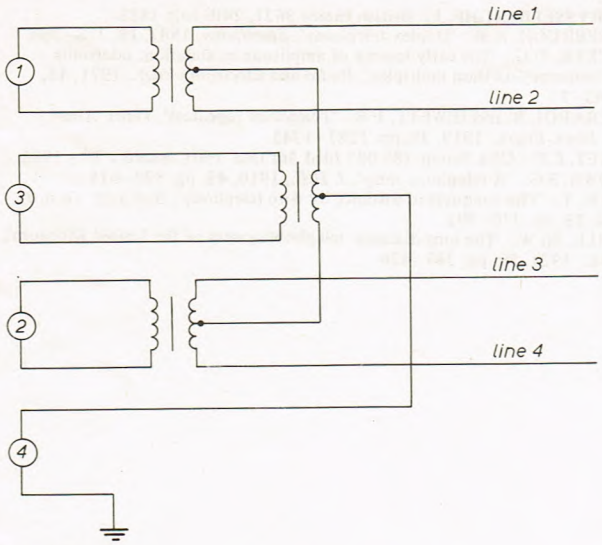

Fig. 9
Arrangement of phantom circuits at one terminal

developed for speech transmission by Rosebrugh in 1886.[57]

Phantom working was widely applied to cables, where the wires were laid up in quads for the purpose. On long open lines they had an equally economic appeal; but there was also the important point that the transmission loss of a phantom circuit was considerably lower than that of the 'side' circuit, which was why the long New York – Denver line, already mentioned, was made up of phantom circuits.

10.3 Telephone repeaters

If progress in the telephone service is measured by the growth in the area over which any subscriber can achieve telephone communication, i.e. by the distance over which speech is possible and the density of line provision which is economically possible, it must surely be conceded that the factor which led to the most profound, almost revolutionary, changes was the introduction of electronic technology in the second decade of the present century. The availability of amplifiers, then called telephone repeaters by analogy with the repeaters used to relay telegraph messages, which could be inserted in telephone lines at suitable intervals, led to the possibility of an almost unlimited distance for telephony over lines comprising quite small gauge conductors. Moreover, not only were distance and economy thus achieved, but also a profound change in the quality of communication. Before repeaters were used, the accepted standard of transmission over long lines was that which enabled communication to be just possible; the London – Paris links of 1891 had to be used between special call-offices at each end, and the New York – Denver links of 1910 could not be extended outside the terminal areas. An overall transmission loss in the trunk link of 30 dB was acceptable. Repeaters changed all this; overall losses of the order of 10 dB were quickly expected, and by the 1930s overall losses of 3 dB were normal, and zero-loss was possible. Thus trunk calls could be almost indefinitely extended in distance. The introduction of modulation and carrier telephony, and the concepts of frequency- and time-division multiplex, although transforming the economics and planning of trunk networks, has not greatly changed the nature of the telephone service.

So great has become our dependence on electronics that it is salutory to be reminded that most of the developments just mentioned had been invented, and in many cases successfully used, before the invention of the thermionic valve in 1904–6.[58] The telephone repeater was first developed and used as an electro-mechanical device.[59] The first proposals by J. Lyons in 1900, and by C.D. Ehret in 1901,[60] were to use the negative-resistance characteristic of an asynchronous rotating generator. A more practical repeater, designed by H.E. Shreeve in 1903, consisted in principle of a telephone receiver coupled to a microphone, so that weak incoming signals could produce greater modulations on the direct current in the microphone. Such repeaters were used in limited commercial service in the USA around 1910, and attempts made to operate them as two-way devices in order to avoid the need for separate *go* and *return* circuits. This meant that the use of the differential transformer, or 'hybrid coil', and the design of impedance-matching networks, were understood before electronics were introduced. Other kinds of nonelectronic repeaters were developed, e.g. that of S.G. Brown in Britain,[61] who modulated a microscopic arc, but it is believed that none of them was used commercially.

The culminating triumph of Shreeve's type of repeater was to be used in the first transcontinental telephone line from New York to San Francisco, in 1915, when speech reproduction was satisfactory. But this was also its swan song, for repeaters had also been made using thermionic valves, and they gave better results and at once displaced the electromechanical type. The length of the line was 5400 km; the transmission loss without repeaters and under good weather conditions was 60 dB, the total repeater gain was 40 dB, and the line operated with an overall loss of 20 dB.[62]

In my study of the early days of the telephone service, this great achievement may reasonably be regarded as the 'end of the beginning'. The commercial use of repeaters did not start in Britain until the 1920s, when a new trunk network based on repeatered cables was commenced.[63]

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