Reprinted from the *Journal of the Institution of Electronics & Telecom. Engrs.*, 1976 Vol. 22, No. 3, pp. 101-106

GUEST EDITORIAL

The Invention and Early Use of the Telephone

D. G. TUCKER*

The centenary of the first intelligible telephone speech was on 10 March 1976. The invention of the telephone is more than a century old, however. In this paper some of the more fundamental aspects of the origins of the telephone are discussed, together with the way in which telephony spread rapidly throughout the world in the decade which followed its commercial exploitation. Finally, a brief account is given of the beginning of telephony in India.

THE centenary of the telephone was celebrated in Britain, by a special meeting of the Institution of Electrical Engineers and by the opening to the public of a special exhibition at the Science Museum in London, on 10 March 1976. The reason for this choice of date was that it was on 10 March 1876 that Alexander Graham Bell first achieved intelligible, articulate speech over a telephone link. Using a variable-resistance transmitter, he shouted into it, to his assistant Thomas A. Watson who was holding an electromagnetic reed receiver to his ear at the other end of the line, the now-famous words : "Mr. Watson, come here, I want to see you." Watson heard, understood, and came. Before this, telephonic speech had sounded like speech, as distinct from mere noise, but had not proved intelligible. There was, therefore, good reason to choose 10 March 1976 for the centenary.

This date, however, is not the centenary of the invention of the telephone. It is always hard to establish when anything was invented, and it is difficult, in a case such as the telephone, to establish who was the inventor. Bell filed his first telephone patent on 14 February 1876; Elisha Gray filed a caveat (a sort of provisional patent application) for a telephone system in the same Patent Office in Washington on the same day, but a few hours later. But in many respects both had been anticipated, sixteen years earlier, by Johann Philipp Reis, who constructed a telephone (and used that name for it) in 1860 and demonstrated it in Frankfurt-am-Main in 1861. And, earlier still, the young French telegraph engineer Charles Bourseul had in 1854 suggested (but not made) a telephone system very much like that which Reis later demonstrated.

Some millions of words have been written about the invention of the telephone over the last century—contemporary reports in the technical and popular press, contemporary books by scientists and engineers and others, volumes of patent litigation, and numerous later serious studies continuing to the present time. A few are cited here (References 1 to 7). We shall now give a critical summary of the matter, and then proceed to the more important question of how the telephone came into public service.

*Senior Fellow in the History of Technology and Honorary Professor in the University of Birmingham, UK.

THE INVENTION OF THE TELEPHONE

There can be little doubt that the basic principles on which the telephone has always, and still does, depend are (*i*) the modulation of a strong electric current, supplied by a battery or generator, by the sound waves which are required to be transmitted over the telephone system, and (*ii*) the utilisation of the modulations of the current to reproduce, at the receiving end of the system, sound waves corresponding to those at the transmitter.

Bell's patent specification of 14 February 1876 (Fig. 1) did not really disclose these principles, for, although a variable-resistance type of transmitter was mentioned in passing, the practical designs were based on the use of the electromagnetic receiver also as a voice-powered transmitter—a very feeble arrangement, lacking the inherent amplification of the modulation type of transmitter, which provides the signal power from a battery or generator. On the other hand, both Reis's and Gray's systems met the requirements (*i*)

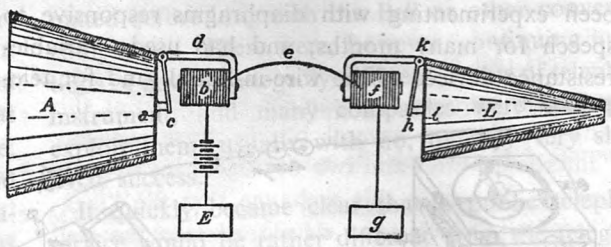

Fig. 1. Diagram from Bell's patent filed on 14 February 1876. (U.S. Patent No. 174 465, issued 7 March 1876).

"The armature *c* is fastened loosely by one extremity to the uncovered leg *d* of the electromagnet *b*, and its other extremity is attached to the center of a stretched membrane *a*. A cone, *A*, is used to converge sound vibrations upon the membrane. When a sound is uttered in the cone the membrane *a* is set in vibration, the armature *c* is forced to partake of the motion, and thus electrical undulations are created upon the circuit *Ebefg*. These undulations are similar to the air vibrations caused by the sound—that is, they are represented graphically by similar curves. The undulatory current passing through the electromagnet *f* influences its armature *h* to copy the motion of armature *c*. A similar sound to that uttered into *A* is then heard to proceed from *L*".

and (*ii*) above. Nevertheless, Reis's transmitter was not really suitable for speech transmission, and he does not appear ever to have claimed that it was. He seems to have thought rather in terms of transmitting singing. His receiver, which comprised a coil carrying the line current wound round a steel bar to which was coupled a sounding box, and evidently operating by magnetostriction, was, by contrast, quite suitable in principle for the reproduction of speech.

Reis's (1883) transmitter comprised, in essence, a diaphragm which vibrated according to the sound waves incident upon it, and a pair of contacts in a loop electrical circuit containing a battery and the receiver, one of the contacts being attached to the centre of the diaphragm and the other being fixed (Fig. 2). Thus, as the diaphragm vibrated, the contacts were opened and closed once in each cycle of vibration. The line signal was therefore what is now called an infinitely-clipped waveform, and we know that such a waveform when derived from speech does indeed retain a substantial measure of the intelligibility of the speech. It would seem that Reis's transmitter was potentially capable of giving some sort of reproduction of speech, but Reis did not claim this. Later writers have often suggested that the contacts could have been adjusted very delicately so that varying contact pressure could have varied the contact resistance without actual interruption, and so have given a continuous modulation of the current instead of the "on-off" modulation. But there is no suggestion that Reis ever had this in mind.

Gray's transmitter was undoubtedly a true variable-resistance device, for it was based on a wire, attached to the diaphragm, dipping into a conducting liquid. Vibrations of the diaphragm thus varied the resistance through the wire and liquid in a continuous manner. Gray had by 14 February 1876 acquired a great deal of experience of the principles involved, for he had been experimenting with diaphragms responsive to speech for many months, and had used variable-resistance devices of the wire-in-liquid kind for telegraphic purposes since 1867. He knew his telephone would work, but had not actually made one when he filed his caveat at the Patent Office.

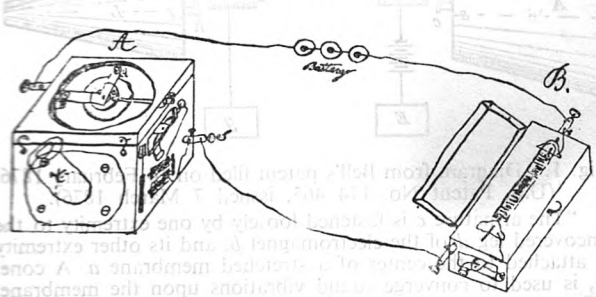

Fig. 2. Facsimile of drawing of Reis's telephone, sent by Reis to Mr. William Ladd, July 1863. (From J. Soc. Teleg. Engrs., 12, 1883)

A—"singing" station, *B*—hearing station, *AcB*— platinum angle piece; platinum contact point at *c* makes and breaks on a small platinum plate on the membrane below. The membrane is vibrated from inside the box, by singing into the mouthpiece at the front end of the box.

Although the telephone system which Bell patented on 14 February 1876 (Fig. 1) used a voice powered transmitter more-or-less identical with the receiver and was thus feeble, it had been made and tried—but it had not given adequate articulation for speech to be understood. For his success in obtaining articulate speech on 10 March 1876, Bell had made a variable-resistance transmitter like Gray's; indeed, he was accused of having received information about Gray's design through an irregularity at the Patent Office, although this was not proved.

It was established through extensive litigation during the few years that followed that legal priority to the invention of the telephone lay with Bell. This did not prevent the argument from continuing in technical circles, as it still does.

Both Bell and Gray had been working for years on rather similar lines in the development of multiple telegraphy, or harmonic telegraphy, or what we would now call multi-channel voice-frequency telegraphy. They both saw this as much more important than telephony. Gray got his multiple telegraph system to a very advanced state of development and it operated quite well in practical trials. Bell probably was less advanced in practical terms, but he understood better than Gray the basic requirements of the system, and saw that the tones which were switched on and off by the telegraph key should ideally be of sinusoidal waveform if they were to be properly separated or "analysed" by the receiver—he called them "undulatory". Gray used square-wave signals generated by a vibrator with make-and-break contacts. Both saw the telephone as a natural development of harmonic telegraphy.

THE TELEPHONE TRANSMITTER

It was evident that the transmitter was the key to the practical success of the telephone and Bell may have belatedly appreciated that the variable-resistance transmitter was to be the type on which the future depended.* But the wire-in-liquid type was not satisfactory; it suffered from electrochemical polarisation, and it was not mechanically suitable for general use. The company which Bell's backers formed went ahead with commercial exploitation of the telephone on the initial basis of the electromagnetic transmitter.

The Bell Company had at first offered Bell's patent to the Western Union Telegraph Co. for $ 100,000. Western Union then saw no future for the telephone

*He had indeed included this type of transmitter in his claims, but it was added as an afterthought; at the time of filing he clearly did not regard it as important (Finn 1966).

and refused the offer. A year later, towards the end of 1877, the obvious success of the telephone showed them how great had been their error, and they decided to enter the field on the basis of Gray's patent and with further development which they commissioned from Thomas Edison. There was already a connection between Gray and Western Union, because the latter's subsidiary, Western Electric Manufacturing Co., had been virtually founded by Gray several years earlier. Gray did no further work on the telephone himself, but Edison designed the fore-runner of the loose-contact carbon microphone which has provided the transmitter for telephony ever since. To avoid using Bell's receiver, Edison also developed a new kind of receiver in which the speech currents produced a varying drag on a stylus which conducted them into a rotating chalk cylinder moistened with potassium iodide solution; this varying drag produced vibrations in a diaphragm coupled to the stylus. This receiver was not very satisfactory, but Western Union went ahead with the manufacture and supply of their telephone system, and achieved considerable commercial success. The Bell Co. took action against them over patents, but when the very extensive court testimony began to indicate very clearly that Western Union would lose, they came to an agreement with the Bell Co. whereby Western Union would withdraw from the telephone field in return for 20 per cent royalties for the duration of the patents.

There were numerous other patents for variable-resistance transmitters, and there was much litigation and bargaining over them; but in the end it was established that Edison had priority.

THE TELEPHONE RECEIVER

Bell was well aware that, in order to get reasonable sensitivity and quality of reproduction from his receiver, he had to provide a permanent magnetic field in addition to that produced by the speech currents. At first he relied on a permanent current in the coils, but by the beginning of 1877 he had replaced this by the use of permanent magnets. It seems that neither he, nor any of the other workers of the time, such as Gray , understood why this permanent field was necessary. It appears that the first proper explanation of this very fundamental requirement was given by Oliver Heaviside (1887); his account is very clear and concise, and we cannot do better than quote it here :

"Suppose that there is a permanent field of intensity H, producing a steady stress proportional to H^2 and that we vary the stress by means of the magnetic force of undulatory currents in the coils. Let h be the amplitude of the undulations of magnetic force, small in comparison with H, so that we vary the real magnetic force from $H - h$ to $H + h$, through the range $2h$. This is quite independent of H, so that if it were a mere question of the intensity of the magnetic force, we could just as well do without the permanent field, except for a reason to be mentioned later. But the stress varies from being proportional to $(H-h)^2$ to $(H + h)^2$; or the range is $4Hh$, not troubling about any constant multiplier. That is, the stress-variation is proportional to the *product* of the intensity of the permanent magnetic force into that of the undulatory magnetic force. This contains the explanation."

Thus Heaviside showed that the sensitivity was proportional to the permanent field. He also went on to show that if $H = 0$, then the sound produced is not only very weak but is also at double the proper frequency. On the other hand, the permanent field cannot be increased indefinitely, for two reasons : one, that a strong permanent stress causes the diaphragm to be very stiff and thus insensitive to variations in the stress; and secondly, that the core may be nearly saturated and thus unable to produce stress variations in response to the current variations.

This understanding was an important step forward.

THE BEGINNING OF TELEPHONE SERVICE

We have seen how commercial development of the telephone proceeded rapidly after the initial inventions of Bell and Gray in 1876. Bell's company, in which Bell himself played no effective part after the first year or two, started in 1877, and changed its form and policy rapidly at first. It had become well-established in the USA, with subsidiary companies in Britain and elsewhere, by 1879. We have seen, too, how its main rival, the Western Union Telegraph Co. (which acted through its telephone subsidiary) was effectively eliminated from the telephone field. Independent telephone companies which Edison had set up in London and elsewhere, amalgamated before long with the Bell or other convenient companies. There were, however, continuing inventions of new, or allegedly-different, forms of telephone instrument, and many companies were set up to exploit them, usually with no, or only very short-lived success.

It quickly became clear that a public telephone service would be rather different from the telegraph service. Individual telephone renters, or "subscribers" as they soon became known, would require to be connected to one another on demand, and to provide this service, telephone "exchanges" were provided—from 1878 by the Bell Co., and from 1879 by Edison's company. The initially purely local service soon raised a demand for inter-connections between exchanges, and so an inter-urban telephone network began to grow. Its growth and usefulness were considerably restricted by the local nature of

most of the early telephone companies, many operating only one exchange or one small group of exchanges, and using widely varying technical and commercial systems. Moreover, many governments actively discouraged the development of inter-urban links from fear of competition with their state telegraph business. It is therefore perhaps not surprising that only in the USA had a significant telephone network developed by 1884. Statistics published in 1885 (Ref. 10) showed the USA to have 140,000 subscribers with 800 exchanges, while Britain surpassed the rest of the world with a mere 10,000 telephones. The USA had over 800 inter-urban lines, while Britain had perhaps 80. It is likely that more than two-thirds of the world's telephones were in the USA.

In most places telephone numbers and wire mileages doubled every two or three years.

TELEPHONE EXCHANGES

Before telephones came into being, there had been some private telegraph subscribers in many places, and in a few of these places there had been a system of interconnection on demand, using small switchboards. When telephones started to come into use, one or two of these telegraph exchanges were converted or extended to provide telephone exchange facilities. One example was at Newcastle upon Tyne in England, in 1882. However the first commercial telephone exchange was that at New Haven, Connecticut, USA, opened on 28 January 1878. In this, eight lines serving 21 telephones could be connected in pairs by means of cords with a plug at each end. Calling "annunciators" were provided; these operated by dc from the subscriber's battery. Six months later, a 20-line exchange was installed at Bridgeport in the same state. Also in 1878, the American District Telegraph Co. opened a telephone exchange to Edison's design in Chicago, also using single cord interconnection. In this exchange those subscribers who already had a telegraph instrument used it for calling the telephone operator; others were provided relays for the purpose. Expansion was rapid at this exchange, and soon several boards were needed, with interboard links and two operators involved in most calls. It was in this exchange that the "jack-knife" switch, which soon developed into the well known "jack", was introduced.

The next year, 1879, saw many significant advances. Among these we may mention:

(*i*) the introduction of double-cord inter-connection via intermediate connecting bars, which would run the whole length of a suite of 25-line boards to provide the means of connecting subscribers terminating on different boards,

(*ii*) the invention of the subscribers' "multiple", whereby outgoing jacks for subscribers' lines were repeated throughout the suite so that each operator had direct outgoing access to every subscriber, thus eliminating the involvement of two operators in local calls,

(*iii*) the introduction of several "line-engaged" testing devices,

(*iv*) the opening of the first telephone exchange in Britain, by the (Bell) Telephone Co. at Coleman Street in London, in August.

The various developments outlined above led directly into the typical manual, exchange of the first half of the present century. There were, of course, many other technical and operating improvements. However, there were for a time some other types of exchange. In 1880, the National Bell Telephone Co. in the USA introduced a board using an array of horizontal and vertical bars, one of the latter for each line so that inter-connections could be made by the insertion of a plug at each intersection of any one horizontal bar with the two lines to be connected. A similar arrangement was used by the Edison Telephone Co. in Britain. This type of exchange, however, was not suitable for extension by the use of a multiple, and so died out.

Automatic exchanges, by eliminating the need for operators to a large extent, had a certain appeal from the early years; but it was not then an economic appeal, for labour was relatively inexpensive, and equipment was not. In spite of this, A. B. Strowger of Kansas City started to develop his system in 1889, and had the first commercial automatic exchange in operation by 1897. In the USA the growth of automatic switching was fairly rapid, for there were 22 automatic exchanges by 1898. Different economic circumstances may account for why Britain did not have her first automatic exchange until 1912.

INTER-URBAN TELEPHONE NETWORKS

The demand for links between exchanges naturally grew. As companies amalgamated, technical difficulties diminished, and as in most places the subscribers' lines were of the single-wire and earth-return type, there was no difficulty in linking them with similar lines. In the USA there was no real obstacle to the growth of inter-exchange networks within reasonable distances, but in many countries, notably in Britain, there were legal difficulties imposed by the governments, who did not wish to see the telephone business grow into a successful competitor to their telegraph systems. In Britain, telephone companies could work only under licence from the Post Office, and the Post Office restricted the area to be served under a licence to a radius of only four or five miles. Thus no company could develop an inter-urban network. This restrictive practice was removed in 1884, and then a few good inter-urban systems came

into being, notably that of the Lancashire and Cheshire Co., which by 1886 had about 3000 Km of inter-urban lines.

LONG-DISTANCE TELEPHONY

The problems and controversies concerning long distance telephony which attracted a good deal of attention in the years 1882-1887, and the solutions which were then found, have been recently described by the author (1974) and the matter will not, therefore be discussed here in any detail. Suffice it to say that the man who enabled progress to be made was Francois van Rysselberghe of Belgium. He designed a method of so greatly reducing interference between adjacent telegraph and telephone lines that it even became possible to superpose telephone signals on existing telegraph lines. This enabled an extensive long-distance telephone network to be provided at very low cost. While the traffic was small, and there was no need for many lines on each route, this system gave reasonable satisfaction, and certainly enabled the benefit of long distance telephony to be appreciated; it must therefore have contributed greatly to the development of telephony.

By mid 1887 there was in Europe, but not in Britain, an extensive long distance telephone network amounting to about 17,000 Km or more, all on the van Rysselberghe system. There were many similar lines in other parts of the world, including South America, China and Japan, but not, as far as the author can determine, in India.

In Britain, the government had a strong anti-telephone policy. This gave way to public pressure eventually, and by 1896, when the Post Office took over all trunk lines by compulsory purchase, a reasonable trunk network was established. By this time, long-distance telephony was normally using metallic-loop circuits, with independent working, and twists or transpositions to avoid interference. This always had been the case in the USA, where long distance telephony was well established even earlier than in Europe. New York—Chicago (1600 Km) lines were opened by 1892; but it was not until 1915 that, with the help of loading coils, phantom working and amplifiers, the American continent was bridged between New York and San Francisco (Tucker 1976).

THE BEGINNING OF TELEPHONY IN INDIA

Commercial telephony spread with great rapidity throughout the world. In the East, telephone exchanges had been opened in Sydney (Australia), in Christchurch and Auckland (New Zealand), and on a demonstration basis, in Madras, before the end of 1881 (Ref. 13). In India, telephone development was in the hands of the Oriental Telephone Company, who seem to have come to some arrangement with the government. This company, which had been responsible for the demonstration in Madras, opened exchanges on a permanent basis in Calcutta and Bombay, as well as Madras, on 28 January 1882. The Company had wide geographical interests; they also opened exchanges in Rangoon (Burma) and Cairo (Egypt) early that year. It was reported that the Indian exchanges used the Law system rather than the magneto system which was much used elsewhere (Ref. 14). This was an American system: we quote a description of the Calcutta exchange:

"The switch boards are mounted upon an erection of wood work, which is rigidly held in place by six iron pillars, fixed to the ceiling. The whole is surmounted by an ornamental moulding . The three switch boards themselves consist of 75 longitudinal connection strips running the entire length, and entirely disconnected from each other. Just below this is projected a small table supporting the 300 private lines of subscribers which terminate in a weighted cord and plug. The system is now simplicity itself. The operator, upon receiving a call by the telephone, which is always on circuit on a call wire, merely takes up the two plugs of the two lines and connects them to one strip, touching them both before connection to a battery strip, thus giving the signal to both parties at once."

The Oriental Telephone Co. formed subsidiary companies in each town. Initially the operators were male, but female operators were introduced in Calcutta in 1883, and probably a little later in Bombay (Ref. 15). Growth was not particularly rapid; Bombay, for instance, had 147 subscribers in January 1883, and only 350 four years later (Ref. 16). Single-wire circuits with earth return were used; phosphor-bronze wire had largely replaced iron wire by 1887.

REFERENCES

1. Count du Moncel. The Telephone, the Microphone, and the Phonograph. 1879. Kegan Paul, Trench & Co. London.
2. Thompson (SP). Philip Reis, Inventor of the Telephone. 1883. Spon. London.
3. Prescott (GB). Bell's Electric Speaking Telephone. 1884. Appleton. New York.
4. Rhodes (FL). The Beginnings of Telephony. 1929. Harper. New York.
5. Marland (EA). Early Electrical Communication. 1964. Abelard Schuman. London.
6. Hunt (FV). Electroacoustics. 1954. Harvard Univ. Press.
7. Hounshell (DA). Elisha Gray and the telephone. Technology and Culture. **16**, 1975; 133-161.
8. An interesting drawing and description made by Reis himself and held in the archives of the Inst. of Elect. Engrs., London, were reproduced in J. Soc. Teleg. Engrs. **12**, 1883; 70-72. and, with additional editorial comment, in Electrician. **10**, 1883; 467-469.
9. Heaviside (O). Some notes on the theory of the telephone. Electrician. **18**, 1887; 302-303.
10. Elect. Rev. (New York). **6**, 1885; 6-7.
11. Tucker (DG). Beginnings of long-distance telephony, 1882-87. Electronics & Power. **20**, 1974; 825-827.

12. TUCKER (DG). The beginnings of the telephone service. Proc. Inst. Elect. Engrs. **123**, 1976; in course of publication.

13. Electrician. **8**, 1881-1882; pages 33, 65, 66.

14. Ibid, 237-238.

15. Electrician. **9**, 1882; 385. **11**, 1883; 553. **18**, 1886-7; 410-411.

16. Ibid, **10**, 1882-1883, 265. **18**, 1886-1887; 410.

17. FINN (BS). Alexander Graham Bell's experiments with the variable-resistance transmitter. Smithsonian J. of History. **1**, 4; 1966; 1-16.