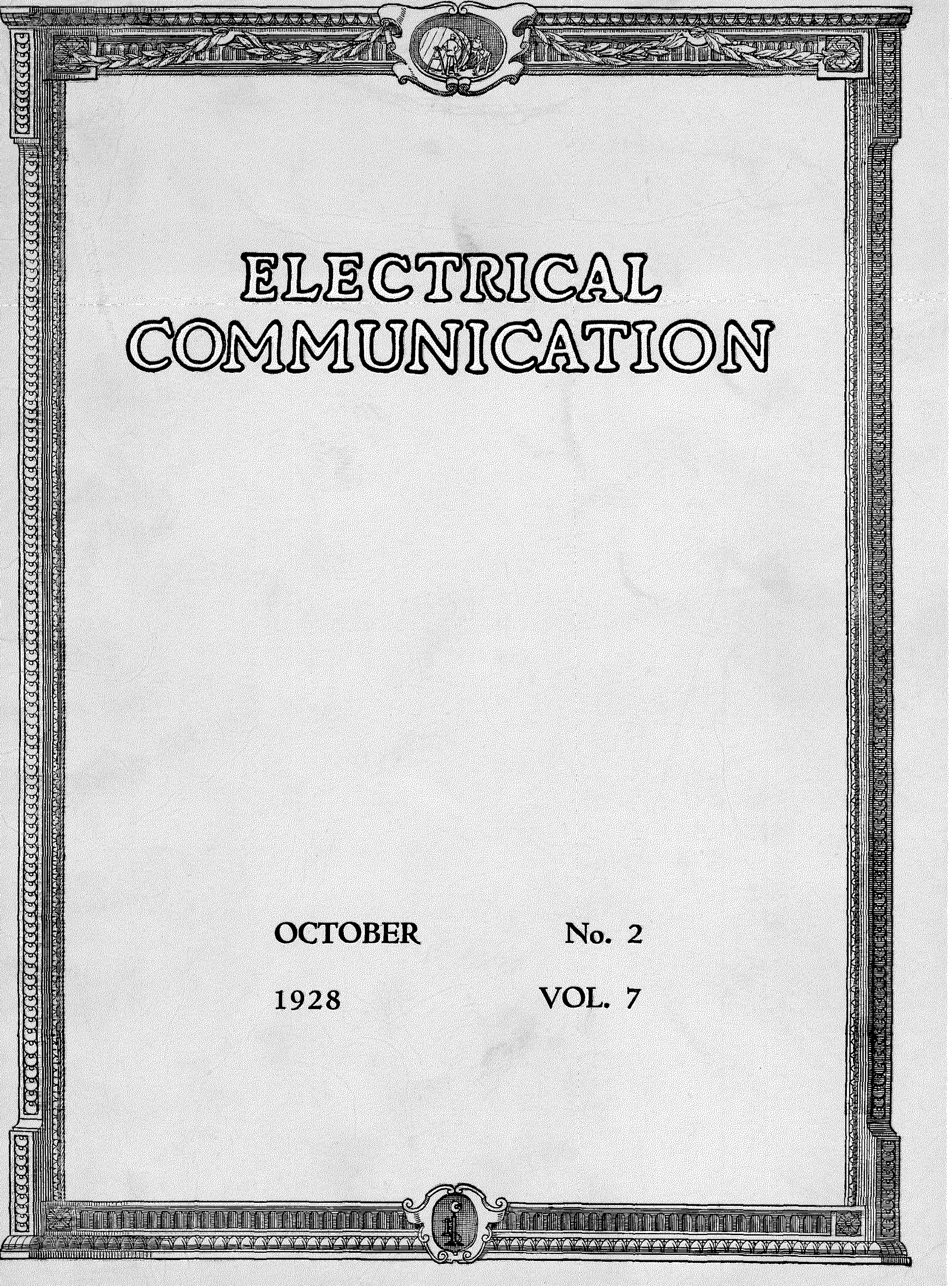

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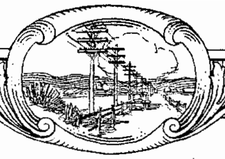

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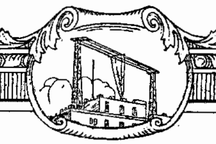
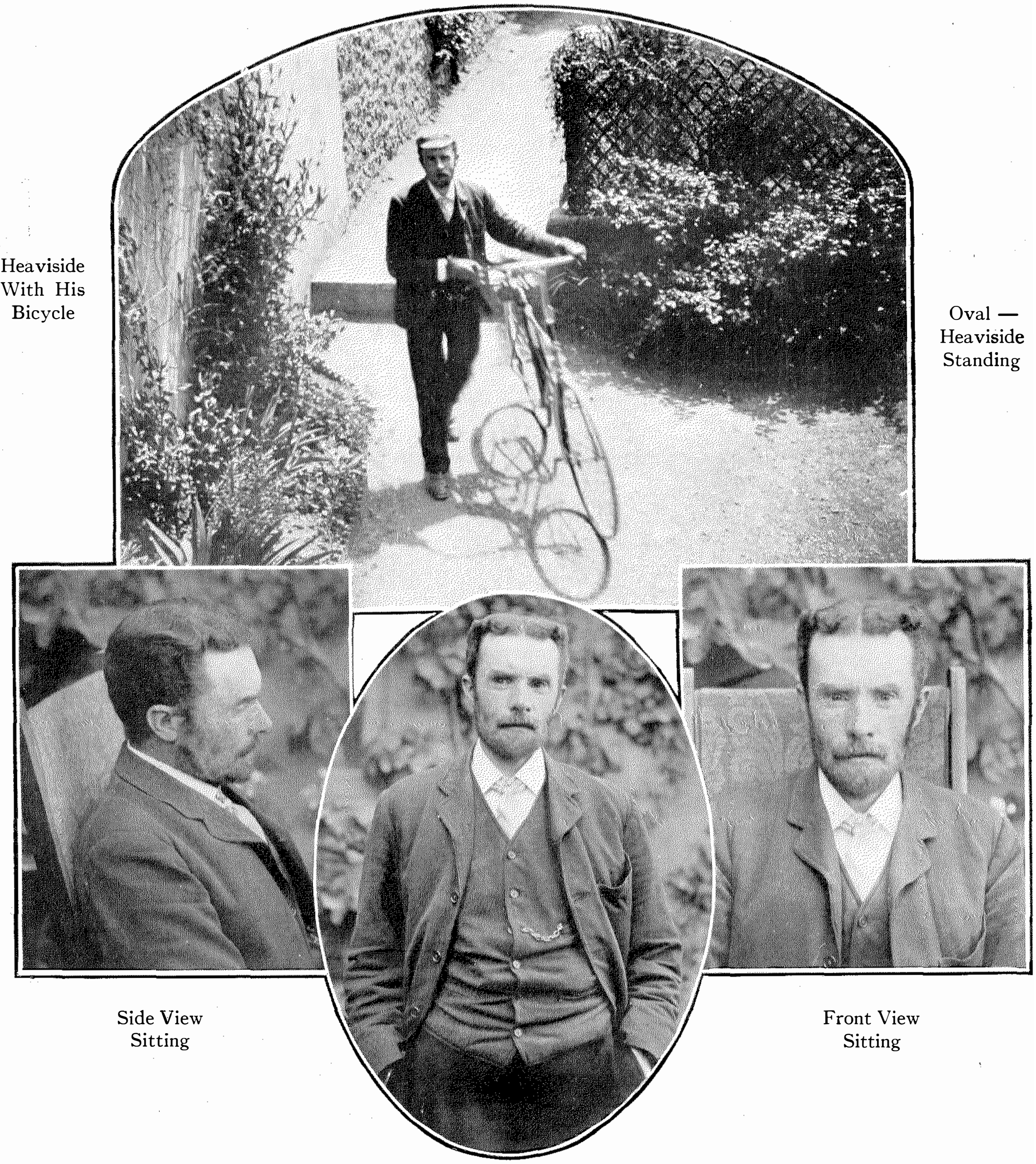




Heaviside
With His
Bicycle

Oval —
Heaviside
Standing

Side View
Sitting

Front View
Sitting

Oliver Heaviside

Pioneers of Electrical Communication

Oliver Heaviside —VIII

By ROLLO APPLEYARD

European Engineering Department, International Standard Electric Corporation

OLIVER HEAVISIDE, whose name a generation ago was synonymous with all that in the theory of telegraphy and telephony is most abstruse, is to-day acknowledged one of the most brilliant of the English pioneers of electrical communication. His discoveries and teachings provided the impetus that was needed to lift practice from the rut of contentedness with moderate achievement, and to render possible the establishment of a speech and signaling network to embrace the world. During a half-century of intense activity he wrote much. He survived to see his contributions collected, reprinted, and republished in volumes easily accessible. Those books will, for all time, relieve biographers from the task of recounting in detail the scientific and technical battles he fought and won. There is consequently freedom to dwell upon the story of his life, to indicate his relationship with his contemporaries, to glance at his correspondence, to penetrate into his character, to find if possible in what manner he acquired knowledge of mathematics and physics, and to account in some measure for his eccentricities.

His collected *Electrical Papers*, in two volumes, and his *Electromagnetic Theory*, in three volumes, form the chief portion of his contributions to mathematical physics in the particular territory where he ruled supreme. What is available in addition now includes certain of his manuscripts, mathematical notes and printed books, and a precious selection of his letters, recently acquired by the Library of the Institution of Electrical Engineers. Some of the notes were entered by him with scrupulous care in a series of manuscript books that must have occupied several years in preparation. Beyond the fact that the manuscript books bear marks that indicate that they were purchased in London, there is little to indicate where this mathematical work was done. At or near the time of his death, about fifty of his printed books by various authors, other than the books acquired by the Institution of Electrical Engineers, were sold and scattered.

Oliver's great-grandfather was George Heaviside, a northern English farmer, who married Elizabeth Winlow, of Dunston near Newcastle-on-Tyne. They had four sons, of whom Thomas, the fourth, was born on July 4, 1785, and died on April 1, 1859, aged 74 years. He was a builder and contractor at Stockton-on-Tees. He married Hannah Smith on January 22, 1809, who was born on December 26, 1787, and who died on January 27, 1852, aged 65. They had 13 children. Thomas, the father of Oliver, was the fourth. This Thomas Heaviside—who was born on October 6, 1813, and who died on November 16, 1896, aged 83—was a wood-engraver, draughtsman and painter in water colour. He married, on April 2, 1842, Rachael Elizabeth West, born December 17, 1818, died October 31, 1894, aged 76. She was the third child of John Hook West, of Taunton, Somerset, and of Hannah Bowditch, of that town. They also had four sons: Herbert Thomas (born December 31, 1842), Arthur West (born June 30, 1844), Charles (born November 13, 1846), and Oliver (born May 18, 1850). Oliver never married. Charles married; and the sister of his wife was Miss Way, of Homefield, Lower Warberry Road, Torquay, a good soul who for some years extended kindness to Oliver. Homefield was structurally altered in 1927–1928 and its name was then changed to Highwold. The Way family was related to the family of Bidder, the "calculating boy." An uncle of Oliver was Sir Charles Wheatstone (born 1802, died in Paris, October 19, 1875), who married on February 12, 1847, Emma West, the sister of Oliver's mother.

The facilities offered to printers by processes of photographic reproduction wrought havoc amongst wood-engravers, and it has been suggested that Thomas Heaviside, the father of Oliver, migrated to London to seek more remunerative means of livelihood.

To obtain particulars of the birthplace of Oliver, it has been necessary to search at the

General Register Office, Somerset House, London, and also to examine the archives at the Town Hall, Saint Pancras, London. The result is to discover that he was born at 55 King Street, Camden Town (Figure 1), and to confirm the date, May 18, 1850. The investigation has revealed that his father and mother became tenants there a few months after September, 1848, probably in 1849. They left this house at some time between 1862 and 1871. The rateable value of the house in 1850 was £35 a year. There is no doubt about the identity, for since the date of Oliver's birth, the numbering of the houses in that part of King Street has remained unaltered. That the work of Thomas was of a high order can be inferred from Figure 2, which is reproduced from an engraving by him of a drawing by Godwin. The inscription written by Oliver in the margin of the proof of this engraving throws light upon conditions at the time.

> "This was done in less than a fortnight (12 days, I think) under great pressure from Mr. Godwin when father . . . was very ill. £20, 1870. Franco-German war. (He asked £22.) Partly stress. Partly usual practice. Copy in bound volume also. Mr. Godwin had sole permission from Her Majesty to give a picture. Owing to these circumstances, was very proud of it, but it would have been better to have had time to finish it finer. O. H. But note in his book says fell ill October 15, whereas block is dated June 28. . . . There are four blocks down from October 8 to November 29 and Edwin was on all except first one."

The Edwin referred to was Edwin Heaviside, a wood-engraver, another brother of Thomas. In 1866, Edwin lived at 27 Fetter Lane, London.

An artist and engraver still more distinguished than Thomas or Edwin was their brother, John Smith Heaviside (sometimes Heavyside), whose name appears in Bryan's Dictionary and in Bénézit's Dictionaire, as a wood-engraver, in London and Oxford. He was born at Stockton-on-Tees on December 2, 1811, and he died at Kentish Town on October 3, 1864. A small portfolio, undated, now in the Library of the Institution of Electrical Engineers, has pencilled within it "J. S. Heaviside, 6, Belle Vue Cottages, Camden Street, Camden Town." His engravings enrich the writings on architecture of John Henry Parker. An example of his work is reproduced in Figure 3. The conclusion is inevitable that it was amidst the struggles and victories of art rather than those of science that the boyhood of Oliver was passed. There exist two of his sketches (Figures 4 and 5) that suggest that he had some early training and considerable skill in drawing. He has himself written under the first: "The Cart Horse. By Oliver Heaviside. Aged 11," and under the second: "2nd work by O. H. (No others preserved.)"

Positive evidence concerning Oliver's education is entirely lacking; there is a legend that he was at an early stage taught by his mother. In 1876 his father became the tenant of 3 Saint Augustine's Road, Camden Town, London, Figure 6. This house fortunately remains, and it has not been renumbered since 1866. It was owned by the Midland Railway Company. To make provision for widening, the neighbouring house was, some years ago, demolished. The rateable value of No. 3 in April, 1889, was £45 a year.

It is certain that from 1876 Oliver subjected himself to strenuous training. His habit was to retire to his room at about 10 o'clock at night and to work there until the early hours of the morning. He closed his door and windows, lighted his oil lamp, and allowed the air to become hot and stifling. He worked also during the day, in seclusion. In order that he might not be disturbed, his food was placed outside his door, and there it remained until he was disposed to take it. Thus he transgressed most of the rules that modern conventions prescribe for health. On the other hand, he enjoyed walking, and occasionally he had more vigorous exercise, for he was a good gymnast.

Amongst his loose papers is a list of gymnastic exercises, and there is also a list, prepared by himself, of measurements that related to him. The figures are here recorded. They are obviously to be interpreted as inches. The height is in agreement with what is remembered of him by a survivor of the family:

> "(1878.) Height 64½, leg 33, hips 34½, waist 28, chest 35 to 37 (latter under scapula), shoulder width 17, girth chest and arms 44, neck (smallest) 13, biceps 13, below elbow 11, wrist 6¼, hand 7, girth palm 8, foot 10, ankle (above) 7¾, calf 15¼, knee 12¼, thigh (groin) 21½, mid thigh 19½, round both knees 21½, mid thighs 31½, width hips 13, girth head (brows) 22, height of shoulder 54."

Briefly, he was a short, red-headed Englishman of autocratic disposition, and of superb powers of mental penetration and intuition, to which was added relentless scorn of masqueraders—some of whom he named the "scienticulists."

To account for his departures from convention, it is necessary to remember that he suffered from deafness. At rare moments his hearing was perfect, and he would then be the first amongst his youthful companions to detect the sound of a distant voice, or of the warbling of a skylark on the wing. Years afterwards, one of his manuscripts refers to similar temporary restoration, where he writes: "Episode in the struggle for life. Got rid of deafness partly. . . . Everything in this life that you want, comes too late." Also, he had little if any sense of smell. These defects had their mental counterparts in his qualities, for he became self-centered and possessed of suspicions that too often settled into more or less fixed prejudices. Happily, though his wit was acid and his satire occasionally ill-directed, he was blest with unfailing humour and a disposition that in the end prevailed upon him to forgive even his worst "enemy"—unfortunately then long dead.

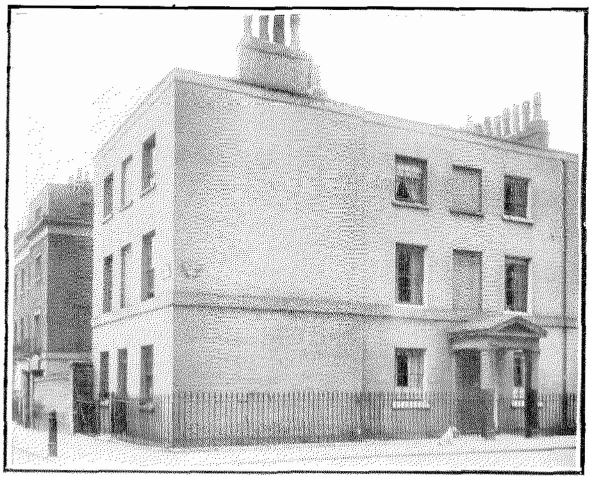


Figure 1—The House, 55 King Street, Camden Town, London, where Oliver Heaviside was born, and where he passed his boyhood. It is the one with the portico.

In one of his letters to a friend, he speaks of music as having been one of his recreations:

> " . . . In old days I went to concerts, very long and highly classical; I always got wearied. I could not take it in—except the divine Shubert. Now there are a lot of very fine overtures of the Freischutz type. People hear them again and again, and so get to know them. May their performance be never discontinued.
>
> . . . I am very deaf. . . . I have no technical knowledge (of music) nor am I a pianist, though I once taught myself B's Opus 90. I liked it better than anything else. Truly the conflict between the intellect and the heart."

In those "old days" he also devised a musical notation intended to be easier to read than the orthodox system of lines, bars, and notes. Later he found some pleasure in playing an "Aeolian." The instrument he used still exists.

Only here and there is it possible to obtain a tangible clue to his personal history in his middle life. According to one account, after leaving school, he held a post with the Great Northern Telegraph Company, at Newcastle - on - Tyne. Positive proof of this has not been found amongst his papers. There is, however, a statement made by himself that he first observed a phenomenon relating to signaling through heterogeneous telegraph circuits at Fredericia, so that he evidently visited Denmark. From July, 1872, when he made his entry into technical and scientific literature, the surest guide to his career is his published work. An elder brother, Arthur West Heaviside, was a Divisional Engineer of the British General Post Office at Newcastle-on-Tyne. For a considerable period, Oliver worked closely with him, especially at solving such electrical problems as arose. There is a memorandum to the effect that on January 15, 1873—perhaps the happiest day of his existence—Oliver and Arthur made experiments "on duplex working with an artificial line and rough resistances at Beckett's shop." With single-needle instruments, they met with complete success "obviously to the delight of all parties." They proceeded to arrange a similar system between Newcastle and Sunderland. Messages were sent "simultaneously from both stations as fast as they could be transmitted by key." An entry in his note-book, relating to his paper in the *Philosophical Magazine* for June, 1873, states with satisfaction: "I was credited in America with having described quadruplex first, or suggesting it." His paper that followed it in the same journal in 1874, on the working of cables with condensers, was, he says, "the first that took terminal apparatus into account at all." In 1878 he directed attention to the importance of self-induction in telegraph instruments and telephones. Another glimpse of what he was doing is obtained from a draft agreement, dated September 14, 1880, relating to a patent for neutralising disturbances in cables. The next year there was a movement, on the part of his brother, to obtain for him other employment. At that time, the Chief of the Engineering Department of the British Post Office was William Preece—who was afterwards Sir William Preece. A letter to Oliver from Arthur explains what was in contemplation:

> "(November 22, 1881.) Preece states that the Western Union of America are about to adopt the Wheatstone, having ordered 24, and that he has the nomination of about six clerks to manage them, with salaries of about £250, and then he asked after you and I told him you were a student still—obvious—should you apply I believe he would nominate you."

What transpired is not recorded, but there is no doubt that, in June, 1882, this "student" was at 3 Saint Augustine's Road, experimenting at home with microphones, particularly to ascertain the effect of pressure at the contact surfaces. His apparatus consisted of a battery, carbon contact-blocks, a watch and a galvanometer. His note upon these experiments reveals him still an imp, and his father an experienced observer:

> "Father smells acid in the room. Two or three evenings. I said, at hazard, it was the electricity. Query, ozone generated by sparking, or nothing to do with it. Father says it is just like the battery he made when he was a boy, and that it is my battery. I didn't say it wasn't. What is the best arrangement to get the greatest variation of resistance in the circuit? I find that the internal and external resistance must be equal."

Among his smaller manuscript note-books now treasured in the Library of the Institution of Electrical Engineers is one that contains what he describes as "An abridged account of experiments in May, 1886, London." It relates to various arrangements of Wheatstone bridges, and it includes notes on condensers, telephones, galvanometers, relays, batteries, inductance balances, interference tests, lightning, and cohesion. He there refers to an experiment made by him as early as 1868. Another of these note-books gives an account of induction experiments carried out by him in July, 1883. The part he took in seeking for a "theoretical explanation" of the experiments carried out by his brother, A. W. Heaviside, in Newcastle, is alluded to in paragraph 216 of Vol. 1 of *Electromagnetic Theory*, and in *Electrical Papers*, Vol. 2, p. 323.

Referring to his paper in the *Philosophical Magazine* of November, 1886, he has an entry: "Most remarkable fact, was speaking by telephone between two circuits $\frac{1}{4}$ mile square, $\frac{1}{2}$ mile between centres."

It must always be regretted that circumstances so soon placed him out of direct touch with practical telegraphy and electrical apparatus; for his skill in experimental researches would inevitably have led to important developments. Moreover, in experiment, he would have found the natural antidote to ills consequent upon unremittant concentration upon theory.

At the prime of his life there was a dramatic change in his environment. In the autumn of 1889, Oliver with his father and mother left London and took up their residence at Paignton, in Devonshire. This was partly on account of his parents' failing health, but it was also because his brother Charles was able to offer accommodation; for Charles, who had a music shop in Torquay, had lately opened a branch at Paignton. Oliver's mother died at Paignton on October 31, 1894. His father died there on November 16, 1896. From about 1897 to midsummer of 1909, Oliver dwelt in comparative solitude at a house known as Bradley View, in the neighbouring town of Newton Abbot, near Dartmoor. At Newton Abbot, he suffered tortures on account of molestation by boys of the locality. A more serious trouble was a bad attack of malarial jaundice. Miss Way, though herself old and frail, thereupon offered him quarters at the house, Homefield (Figure 7) in Torquay, which ultimately became his by purchase, and where he remained to the end of his life.

The portraits of him, reproduced in the Frontispiece, probably were taken in the year 1893. They are from old negatives long stored in a cardboard box bearing the inscription in his own hand:

"NEGATIVES of photographs of the present Dr. Heaviside—(taken by C. T. H.) at Palace Avenue, Paignton. Keep dry and the film sides in contact. The one with hands in pockets is perhaps the best, though his mother would have preferred a smile."

It must have been the portrait "with hands in pockets" that his friend Professor FitzGerald contrived to obtain from him in 1898, and concerning which FitzGerald wrote:

"I am sorry you did not give a less retiring view of your face. If you were one of those who had a great reputation for getting on by brazen pushiness, I could understand your fearing that your portrait being published might be misconstrued."

Heaviside scoffed at those who publish their photographs:

"It makes the public characters think they really are very important people, and that it is therefore a principal part of their biz. to stand upon doorsteps to be photographed."

Concerning a contemporary photograph of a group of members of the Institution of Electrical Engineers he remarked:

"Giants at the back. Pigmies at the front. I gave it, framed and glazed too, away to a Newton Abbot furniture dealer, for nothing, along with an old kitchen table."

In Figure 8, which is from a photograph of members of the Heaviside family, taken at Berrypomeroy Castle, Totnes, about the year 1893, Oliver is just to be seen in the far background, smoking his pipe. His father and mother are standing side by side near the centre of the picture; and next to his mother, on her other side, is Miss Way. Arthur West Heaviside is standing on the extreme right of the picture holding his hat in his left hand. Immediately in front of Oliver is Basil Bell Heaviside. Charles Heaviside is stooping down between his father and his brother Arthur. In front of Arthur is Colin, the third son of Arthur. Miss Ethel Heaviside is standing behind, between Oliver's father and mother.

Here, for a moment, it is well to consider his mode of working and his attitude of mind. Throughout his mathematical work in its final form, his writing was singularly neat, although it appears from marginal notes that he was often troubled to find a pen that suited him. An editor, hard to please in other respects, was constrained to confess: "No other contributor can approach the admirable clearness of your copy and the cleanness of your proofs." Mathematical solutions were not obtained by him on all occasions easily—they were frequently the result of strenuous labour and repeated trials. In proof of this, scattered amongst the drafts of his attempted solutions of problems, his perplexities at moments find expression in interjected remarks:

"This is fearfully complex. . . . Don't see how to simplify it at present, but I think it will work down to something simple in the long run. . . . Which is *right?* . . . Winna du! . . . No go! Save all this bother. . . . Notes on the Brays of the British Asses! Notes on the Brays! (British Association members.) . . . Hope. Hope. Hope. Swine. Swine. Swine. . . . All this is very fishy. . . . Revise it. . . . The subject is enshrouded in difficulties and ambiguities. . . . I cannot manage it to-night. . . . Quite fagged. . . . One success only leads to more failures. . . . Hinc illae lachrymae. . . . So it is dubious. . . . Patience. . . . Bah!"

For preliminary drafts of his mathematical writings he often used the backs of waste invoices from his brother's music shop—an investigation of a Fourier's series thus finds a few square inches on the reverse side of a stray account to somebody for a copy of "Love's Old Sweet Song," concerning which, alas, no trace of a corresponding term appears in any of Heaviside's equations.

In his extensive numerical work he would have saved himself much trouble if he had used a slide-rule, but he preferred to employ ordinary arithmetic, and occasionally a book of logarithms. He ciphered in bold figures, and so long as there was hope that a solution might be found, he was never thwarted by the labour of the calculations. He possessed a strong desire, amounting almost to a passion, that his work should be published as written. Ultimately, he nearly achieved his purpose. It was a requirement beset with difficulties, many of which were self-imposed. He wrote: "Experience has taught me that the refusal of a paper by any journal, for unconvincing conventional reasons, implies that the paper is unusually original and good. Fact!" There was, however, another side to this. In

1886 his wrath was kindled against an official who was suspected by him of having hindered the issue of a description of a system of telephony with which his brother had been associated. The charge was that this official "fell foul of it in a savage and even insulting manner and blocked the paper." To make matters worse, the technical press, at the zenith of his activities, was passing through an exasperating period of litigation. Even his staunch supporter, C. H. W. Biggs, then editor of *The Electrician*—who before the scientific world had learned to bow to the prerogative of Heaviside's genius, exhibited tolerance towards his obscurities and tact towards his idiosyncrasies, and who at last was thanked by him, "for the opportunity he gave me of exercising my philanthropic inclinations"—was constrained to admonish him:

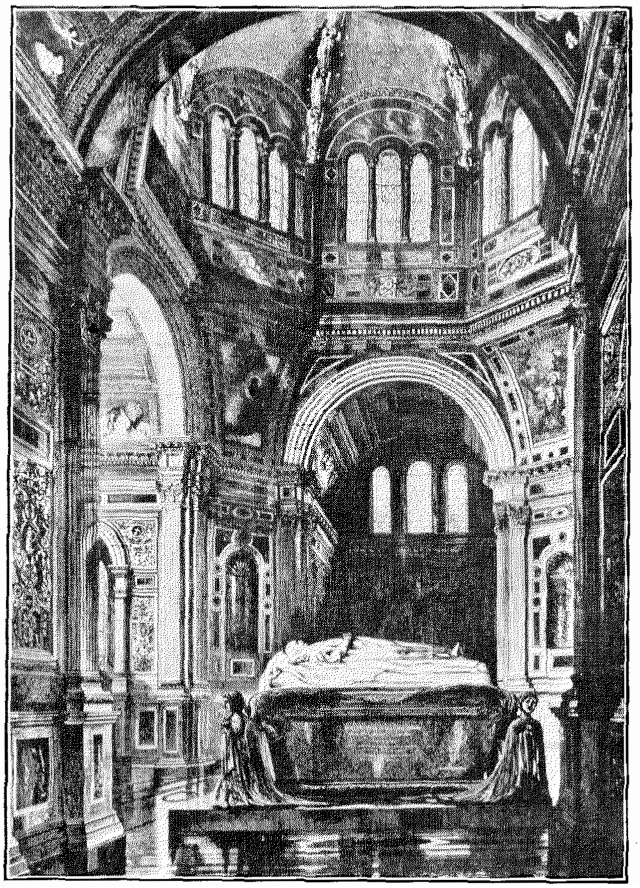


Figure 2—Engraving of the Royal Mausoleum, Frogmore, Windsor, by Thomas Heaviside (Oliver's father).

> "(May 30, 1887.) I would use your letter if I could, but it is dangerous in the present state of the law. . . . I may tell you that at present six of us have two libel suits each against us, or a round dozen altogether, and I venture to think that the cost even if we successfully defend ourselves will be considerable. . . . Candidly then I am afraid to use it, not personally, but . . . ."
>
> "(June 1, 1887.) Do you not think it rather infra-dig in a scientist to be so moved at the doings of a scienticulist?"

Several years afterwards, Heaviside recorded that in 1887 he came for a time to a dead stop, exactly when making applications in detail of his theory "with novel conclusions of considerable practical significance, relating to long-distance telephony in opposition to the views at that time officially advocated." In that year also the editor of the *Philosophical Magazine* found that as no one, so far as he could discover, read Heaviside's articles, he could no longer afford space for them.

In 1888 another editor complained that the articles, so far as could be ascertained, were only read by a few professors, and "Professors, you see, do not advertise." Refined chastisement was also administered on October 31, 1891, from another quarter, when he received a letter as follows:

> "I am desired to return you the thanks of the Royal Society for your Paper
>
> *On the Forces, Stresses, and Fluxes of Energy in the electromagnetic field*
>
> and to inform you that the Committee of Papers have directed it to be published in the *Philosophical Transactions*. . . .
>
> P. T. O.
>
> Both our referees, while reporting favourably upon what they could understand, complain of the exceeding stiffness of your paper. One says it is the most difficult he ever tried to read. Do you think you could do anything; viz., illustrations or further explanations to meet this? As it is, I should fear that no one would take advantage of your work.
>
> Yours truly,
>
> RAYLEIGH."

With reference to this he records in his note-book:

> "It took six months before I heard that the paper was accepted for the Transactions. Then 3 months

to get it set up in proper type. About 4 months (or 5) more before published. Great delays in correction. Printers humbugs."

Again, Heaviside resented the action of the Royal Society when the Secretary, on July 26, 1894, wrote to him:

> "I am desired to return you the thanks of the Royal Society for your Paper
>
> *On Operators in Physical Mathematics.*
> *Part III*
>
> and to inform you that the Committee of Papers, not thinking it expedient to publish it at present, have directed your Manuscript to be deposited in the Archives of the Society."

His annoyance in respect to delays of this kind lasted to the end of his life.

The same was true of his books. Volume 1 of *Electromagnetic Theory* took three years to put through; Volume 2 occupied a little more than four years. He calculated that if Volume 3 was to be first presented as serial articles, it would consume twelve years. So he gave up the idea of proceeding in that way.

It is necessary here to remember that Heaviside was not a mere equationist. He was a man of high purpose—a reformer. To establish his reforms he had to encounter conventions, and thus he was forced to think, to appear, and to act, as an individualist. In 1913 he wrote to a friend: "Pray don't ever call me a mathematician. I am a physical mathematician or mathematical physicist, and repudiate all mathematicians." This is the key to a great deal that is puzzling in his writings. In his time, a school had arisen that was intent upon finding physical significance in mathematical processes. With this movement, Heaviside was in whole-hearted agreement—but he went further, he made a direct attack upon extremists among pure mathematicians. He said:

> "Three pernicious results of looking for over much rigour may be mentioned. First, its enfeebling action on the mind . . . secondly, it leads to the omission from mathematical works of the most interesting parts of the subject because the authors cannot furnish rigorous proofs. Thirdly, it leads to mental inability to recognise the good that may be in other men's work should it fail to come up to their standard of rigour."

To account for his abstruseness, there is primarily the fact that his mathematics was of a higher order than could readily be grasped by his contemporaries. Like Newton's *Principia*, his works were for this reason destined in any case to be more admired than studied. He confessed that he was a voice crying in the wilderness—for vectors. His obscureness was further deepened because, following Maxwell, he strove to express his results in the most general form—not always as explicit cases that would have been more readily understood. To add to the difficulties, there was lack of continuity arising from transformation of serial articles and scattered memoirs, irregularly issued, into a treatise. His worst fault, however, was the omission of steps in the argument, especially when the breaks arose from needless digression to attack quaternions, scienticulists, 4π, or an "enemy."

He once expressed his motives thus to an editor:

> "(November 1, 1890.) Posterity. I don't think posterity will care to go to the British Museum to read up back volumes of the . . . . I write, or rather wrote, for the present generation. It was a stiff-necked generation. But I am assured by competent judges that I made some impression upon it in spite of its objection to be born again. . . . I never have, and do not intend to have anything to do with *contentious* discussions, as I understand 'contentious,' contending for the sake of contending, about nothing worth contending about. Legitimate scientific reasoning means that if anyone puts forward views which I consider wrong, and am interested in, and the matter is worth correcting, I have the right to do it, on scientific grounds."

With regard to learning, he said "sit down and work—all that books can do is to show the way." He insisted that we are, from first to last in contact with those quantities which are believed to have physical significance—instead of with mathematical functions of an essentially indeterminate nature—and also with the laws connecting them in their simplest form. His advice was to avoid "groping after mare's nests"—for example, in electrical theory, to shun potential—and to keep as close as possible to such variables as are known. He was proud of having been at one time a "practitioner" himself, and his correspondence shows that when practical men approached him in a way of which he approved, he was ever ready to assist them, as well as men of science, with their problems.

Repeatedly he was asked by editors to have mercy upon their readers, to write less "poetry" and more "prose," or to write an easy synopsis—but he was remorseless and relentless. His reply was:

> "Synopsis? Can't. The Lord will provide. He always does. I am aware and so is everybody that the practicians only glance at my articles, and that the readers thereof are a small minority. It always was so, save a few exceptional articles, and it always will be so. I am afraid you will think the above very unsatisfactory in relation to commerce. I can't help that, though I am very sorry. . . ."

Let us glance at the range of subjects at which this reformer worked. Physical science, when Heaviside entered it, had for two centuries been the battle-ground of contentions about the ether, vortex motion, light, electricity, magnetism, and gravity. During his boyhood and youth, Faraday, Thomson, Tait, Stokes, Rayleigh, Helmholtz, Weber, Gauss, and Maxwell had swept over the field. Moreover, an Atlantic cable had been made and laid, land telegraphs in a multiplicity of forms had been successfully developed, and practical details concerning the behaviour of dielectrics and transmission were thereby accumulated far beyond the range of what was then contemporary theory.

Advance in electrical communication systems in his time called chiefly for improvements in methods of measurement of the quantities to be dealt with in practical telegraphy and telephony, and for the interpretation of results in quantitative terms. To prepare himself for the tasks thus suggested, Heaviside faced the drudgery and self-sacrifice needed to render himself efficient; he grasped firmly the weapons of mathematics and practical experience, and he strode into action at the point where the work was most strenuous.

The article—his first—in the *English Mechanic* of July 5, 1872, is concise and convincing. Of like quality are his papers in the *Philosophical Magazine* of February, 1873, on the best arrangement of Wheatstone's bridge for measuring a given resistance with a given galvanometer and battery, and on duplex telegraphy. The years 1874 and 1876 are characterised by marked development; his papers on telegraphic signaling with condensers (*Phil. Mag.*, June, 1874), and on the "extra" current (*Phil. Mag.*, August, 1876), show that, equipped with the calculus, this youth of Camden Town had made Fourier's theorem his own, he had mastered what Sir William Thomson had revealed with regard to arrival-curves, and he had gone a long way towards interpreting Maxwell. Thus he was able to attack some of the new and then incomprehensible problems that accompanied the introduction of the Bell telephone. To the mystery of such questions he refers in his analytical paper—a treatise in itself—on electromagnets (*Jour. Soc. Tel. Eng.*, 1878), where he remarks that "this most sensational application of electricity appears to be very indifferent to resistance (sometimes), it being said to be sufficient merely to make earth 'through the boot and a blade of grass.'"

Telephonic currents were thenceforward to be his principal theme. If at this stage the telephone had not won his attention, he would probably have devoted himself to designing dynamos; for his paper, *Jour. Soc. Tel. Engs.*, June, 1881, on magneto-electric current generators was full of promise. His two great contributions, however, (1) On induction between parallel wires, and (2) On the theory of the propagation of current in wires, written respectively in 1881 and 1882, gave direction to his efforts, and firmly established him as a leader in rational telephonic and telegraphic engineering; for it was Heaviside who finally deposed guesswork, and who provided means that ultimately led to precision in telegraphic and telephonic transmission.

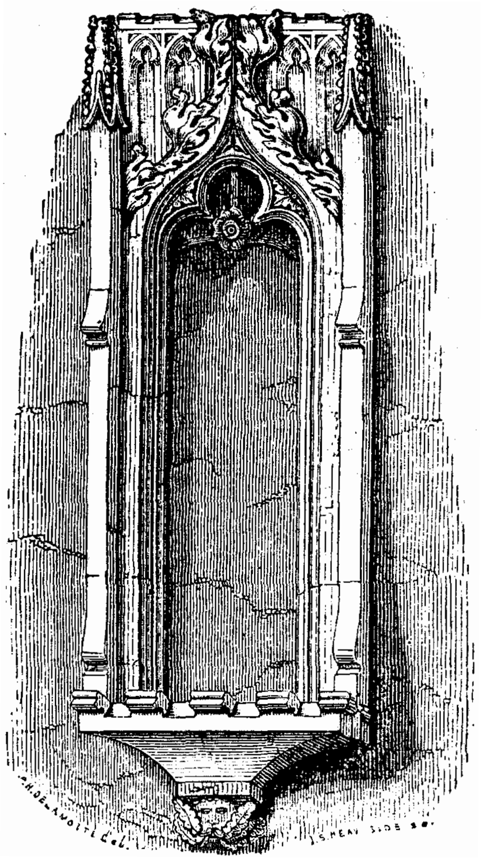
It was in the autumn of 1882 that he began his famous "Electrician" series of papers, about 500 pages, on electrical theory—vectors, potentials, units, energy, thermo-electricity, propagation of electrical disturbances through a medium, induction balances, models of viscous liquid—all mental equipment for the age of telephony and power transmission that was about to begin. This series led to contributions in 1885 that continued to the autumn of 1887, on electromagnetic induction and its propagation. To him, the ether was "the great store-house of energy." He studied the mechanics of a rotational ether in which magnetic force is allied with rotation. Maxwellian as he was, he complained that Maxwell had left gravitation out in the cold, and he directed attention to the fact that electrification is always found associated with matter.

Although, to gain the advantage of symmetry—and to be able to treat electromagnetic problems as elastic solid problems—he established, as nearly as he could, parallelism between electricity and magnetism, and he laid emphasis upon the absence of a magnetic conduction current. Thus magnetism to him, as to all the pioneers, was the transcending mystery of the universe. He introduced, in 1885, for those purposes of symmetry, the fictitious quality: "magnetic conductivity." To describe the general parallelism, he adopted, not quite happily, the word "duplex," and in this sense he exhibited the electric, magnetic, and electromagnetic equations in "duplex" form; i.e., symmetrical with respect to electric and magnetic notions. The immediate objects of his attention then became the corresponding *fluxes* and their variations. Potentials he relegated to a secondary place. So far as they concerned the state of the medium, potentials were in fact treated by him as auxiliary quantities, devoid of physical significance.

The experiments of Hughes, in January, 1886, confirmed Heaviside's theories of surface conduction along wires. In the spring of that same year, Heinrich Hertz definitely established by experiment the wave character of electromagnetic transmission through space and through wires. The experiments and writings of Hertz produced upon Heaviside a profound and stimulating effect.

The introduction to Heaviside's papers on self-induction in wires, beginning with his article in the *Philosophical Magazine*, 1886–1887, indicates that he was led from his early experiments on Wheatstone's bridge to his investigation of the induction and resistance of long solenoids containing cores, and thence to the mathematical study of the transmission of current "into" wires by diffusion from the external dielectric. With these papers may be grouped his remarkable article, written in 1887, but not published until 1892, on telegraph circuits, and his communications to the *Philosophical Magazine* of December, 1887, on resistance and conductance operators, the whole comprising, in about 200 pages, the foundation of modern theory of telephonic and telegraphic transmission, united with dynamics in the conception of forces and stresses. In effect, Heaviside's Expansion Theorem enables an *explicit expression* for the currents as functions of the time to be derived, for any network, from the *differential equations*, by means of intermediate *operational equations*, under the conditions (i) That the currents are initially zero, and (ii) That given potential differences are applied at various given points of the network. Or conversely, his theorem enables the potential differences to be derived from the currents. His method consists in prescribing rules for obtaining the operational equations, and rules for translating the solution of the operational equations into solutions of the original differential equations.

Another group of investigations, almost inseparable from the preceding, had its origin in his article in the *Philosophical Magazine* for February, 1888, on electromagnetic waves, especially in relation to the vorticity of the im-



Kidlington, Oxfordshire, c.1450.

Figure 3—Example of Engraving Work by Oliver's Uncle, John Smith Heaviside.

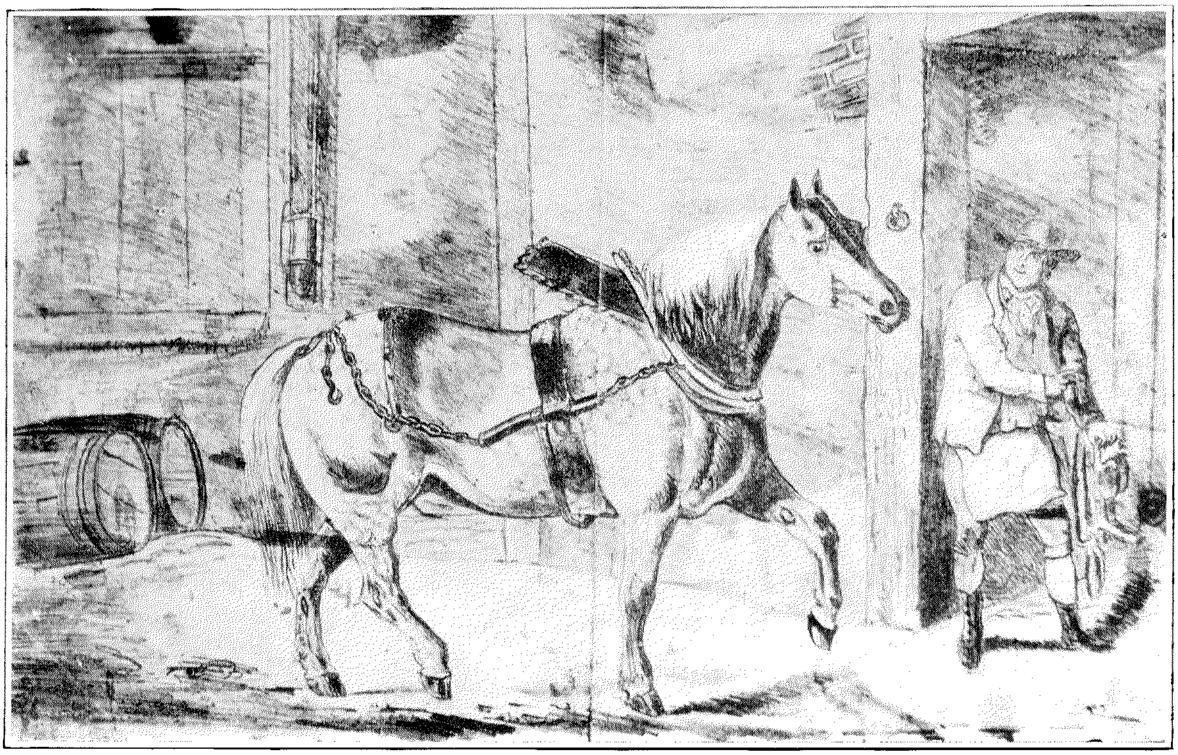


Figure 4—Drawing Inscribed "The Cart Horse. By Oliver Heaviside. Aged 11."

pressed forces, and on the vibrations of electromagnetic systems. By "vorticity" he meant the "curl," familiar enough at that time to a few Cambridge, London, Dublin and Scottish mathematicians, but to the rank and file of his contemporaries, a sore perplexity. Lastly came his treatment of electromagnetic radiation, and the Heaviside Layer, concerning which it may be helpful to observe that in Volume III, Chapter X, of *Electromagnetic Theory*, 1922 edition, p. 331, his article bears the superscription: "Theory of Electric Telegraphy. Encyclopaedia Britannica. Tenth Edition. Reprinted by permission of the proprietors of The Times. Written June 1902." This forms part of his treatment of "Waves in the Ether." He begins with the case of radiation between two coaxial conical conductors with a common apex. The radiation is supposed to go from the inner to the outer cone symmetrically in spherical sheets, with the apex as centre. By assigning various values to the semi-vertical angle of the cone or cones, he derived several cases, some corresponding to "wireless" transmission—a flat plane and a vertical wire projecting from it at the apex, spherical waves from the apex, waves from a Hertzian vibrator, two parallel wires, waves along wires containing sharp bends, and "wireless" waves across sea-water. He explained that the waves accommodate themselves to the surface of the sea in the same way that waves follow wires. Then comes the important statement:

> "The irregularities make confusion, no doubt, but the main waves are pulled round by the curvature of the earth, and do not jump off. There is another consideration. There may possibly be a sufficiently conducting layer in the upper air. If so, the waves will, so to speak, catch on to it more or less. Then the guidance will be by the sea on one side and the upper layer on the other."

There is reason to suppose that this article was published towards the end of the year 1902, and that it was the last the editor of the *Encyclopaedia Britannica* (Tenth Edition) received before publication of the volume in which it is contained. Priority for the layer is not discussed by Heaviside. Regarding priority, therefore, the wise will follow the advice of Newton touching the origin of the theory of light: "To avoid dispute, let every man here take his fancy."

Figure 5—Drawing Inscribed by Oliver Heaviside "2nd Work by Oliver Heaviside (No others preserved)."

Amongst Heaviside's loose manuscripts is a draft in which he has recorded that in 1902 the cable companies were already considering what the effect of wireless telegraphy might be upon their enterprises. He entertained doubt whether it would have serious influence upon them unless a quick method of automatic wireless signaling were adopted. He was at that time prepared to be consulted as a scientific man, and as an old "telegrapher," but "he was not disposed to do sums set by unscientific practicians who despised mathematics." He saw that what was needed was experiment. To his mind, the scientific work had been done. He had shown the way to improve cable telegraphy—beyond what was possible by more copper and less capacity—"first by the principle of increase of inductance, and next by the invention of a practical substitute for uniform inductance—coils at intervals, one per mile for instance." The memorandum points out that the cable companies were free to explore the matter, for he says: "I did not protect it. There can be no patent for it in England except for improvements thereon. . . . Now the wireless telegraphy frightens them. Well, I wish they may have good reason to be frightened."

Concerning the prospects for wireless telephony, he expressed himself, on April 3, 1914, as follows:

> "The atmospheric disturbances will be very troublesome perhaps. Still the idea of talking from pole to pole is rather attractive, or to hear yourself talk 24,000 miles."

The sequestration in which he existed robs the biographer of the ordinary means of approach to knowledge of him. Yet his seclusion, like that of Barrie, was comparatively well known. Fortunately, the opportunity occurs to disclose for the first time some of his correspondence. The introduction of extracts from this source will disturb continuity, but there is compensation for a broken story in a new impression.

It is first necessary to piece together some scattered facts relating to electromagnetic wave history. The experiments of Bezold (*Berichte der Bayrischen Akad. d. Wissensch.*) on electric waves along wires were described in 1870. They were then unknown to Heinrich Hertz, and they were unknown to FitzGerald (born August 3, 1851; died February 22, 1901). On November 17, 1879, FitzGerald (Figure 9) read a paper before the Royal Dublin Society on the possibility of originating wave disturbances in the ether by means of electric forces. He there directed attention to Maxwell's statement of the hypothetical conditions under which an electrical disturbance might be propagated in free space. FitzGerald at that time (1879), taking a case of insufficient generality, arrived at the wrong conclusion that Maxwell's displacement currents, however produced, will "never be so distributed as to originate wave disturbances propagated through space outside the system." In May, 1882, however, after referring to a more general solution of Maxwell's equations, given by Lord Rayleigh, he withdrew his earlier expression of opinion, and he admitted that "a simply periodic current would originate wave disturbances such as light." He added that it might "be possible to obtain sufficiently rapidly alternating currents by discharging condensers through circuits of small resistance." The crucial experiment of Hertz was in 1886.

It was FitzGerald who reviewed, in 1893, Heaviside's Electrical Papers, and who acknowledged their value

> ". . . because they teach a sound theory of telegraphs and telephones, and of other matters . . . which, there is every prospect, may lead to vast improvements in telegraphy and may even make it possible to work a telephone across the Atlantic."

Regretfully this learned and sympathetic reviewer complained that Heaviside jumped deep double fences and introduced short-cut expressions that were woeful stumbling blocks to the slow-paced average man; he criticised also the frequent repetitions, and he never forgave him for abandoning quaternions. Nevertheless he ascribed to Heaviside the credit for having cleared away the débris of the battle fought by Maxwell. Heaviside, he observed, had reduced the maze of symbols—electric and magnetic potential, vector potential, electric force, current, displacement, magnetic force, and induction—practically to two, electric and magnetic force. He had established symmetry throughout the whole of electromagnetics. He had extended the theory of wave-propagation in complicated media; and he was responsible for the most important application of electromagnetic theory to telegraphy and telephony. Then comes the highest tribute of all:

> "Since Oliver Heaviside has written, the whole subject of electromagnetism has been remodeled by his work. No future introduction to the subject will be at all final that does not attack the problem from at least a somewhat similar standpoint to the one he puts forward."

The world in 1886 awoke from its lethargy and became conscious of the existence of electromagnetic waves. Men to-day who remember the delight with which the convincing experiments were at last seen, discussed, and repeated, will recall the pleasure of discovery that in 1886 pulsed through the world. It was a victory in which all rejoiced. By doing full justice to Bezold, Hertz won more than fame. His attitude, equally correct, towards Heaviside can now be traced; for amongst correspondence just made available are letters that tell their own story. The first, from Hertz at Karlsruhe to Heaviside in Devonshire, is dated March 21, 1889:

> "I more clearly understood your methods from your letter than from your book, where they lie hidden beneath a great number of special cases. I am quite of your opinion, that you have gone further on than Maxwell, and that if he lived he would have acknowledged the superiority of your methods. A great point is, I think, that you do away with unnecessary potentials. Electrostatical (scalar) potential and magnetical (scalar) potential ought to remain I think, but in statical phenomena only; in dynamical problems no potential ought to occur, and no vector potential ought to occur at all. I had also reflected on these things. . . . I find it so very difficult to follow your symbols and your very original mode of expressing yourself. You know mathematical symbols are like a language and your writing is like a very remote dialect of it. . . . Your methods are more than your symbols. . . . I was very interested to hear you had come so near to see yourself electromagnetic waves, and was glad for my sake you did not follow up the indication you had. I cannot quite agree with what you write about the propagation of spirals. I cannot but think that from a good theory quite a distinct velocity ought to come out, and very simply.
>
> If Maxwell lived, I think he would have more joy in my experiments and would have more reason to be proud in their result, than I can have."

The reply is unknown, but on May 5, 1889, Hertz continued:

"The fact is that the more things became clearer to myself and the more I then returned to your book, the more I saw that essentially you had already made much earlier the progress I thought to make, and the more the respect for your work was growing in me. But I could not take it immediately from your book, and others told me they could hardly understand your writing at all, so I felt obliged to give you warning that you are a little obscure for ordinary men."

Again, on August 10, 1889, now from Bonn, Hertz wrote:

"Theory goes much further than the experiments, for the experiments hardly come to tell in a whispering voice what theory tells in clear and loud sentences. But I think in due time there will come from experiment many new things which are not now in theory, and I have even now complaint against theory, which I think cannot be overcome until further experimental help. You speak of calculating the frequency of such oscillating systems as I make use of. I often tried to get the oscillating time exactly after Maxwell's theory but did not get any. I then considered a simple sphere perfectly conducting in a perfect dielectric. There were no more difficulties in the analysis, but yet I got no more oscillating time. I think there is none. Did you ever work out the problem completely? To my great grief, I have no time to go further on in these things for a year or so, having to spend too much time with my lectures, laboratory, examinations, etc."

To this, Heaviside probably responded promptly, for on September 3, 1889, from Bonn, Hertz explained:

" . . . As to the oscillation or oscillations of a sphere, I attacked the problem just in the way you propose but got no result. I think the damping is so great that disturbances go away almost aperiodically. This ought to be otherwise in very elongated ellipsoids, but in these the analysis becomes very difficult. . . . You may believe that I was fully in earnest when I said you could not learn very much of my experiments. I meant to say, that he who was fully convinced of the truth of Maxwell's equations and was able to interpret them, did know as much about these things before my experiments as after them. I did not mean to say by this that the experiments were of little worth, for there were many people not convinced of those equations or not able at all to see what they meant. And then I hope for many new things to come from the experiments. . . . The motion of the ether relatively to matter—this indeed is a great mystery. I thought about it often but did not get an inch in advance. I hope for experimental help; all that has been done till now has given negative results. . . . Take a copper sphere rotating in a homogeneous magnetic field. You cannot treat the case without having recourse to action at a distance. Maxwell's solution is by action at a distance. And I do not see how it could be otherwise before we know if the ether turns round with the sphere or is at rest, or where is the frontier between the moving and the resting ether. . . .

As to the structure of the ether, . . . the structure of all the models imagined until now is certainly not the structure of the ether; in these points I am absolutely of your opinion."

In this letter Hertz enumerated the particulars in which, in his judgment, Maxwell's theory required to be amended:

" . . . for example the strains imagined by Maxwell to account for the motions of ponderable matter—these strains would tend to give motion to the interior of the ether itself, except in the very special case of statical problems. Now if no such thing occurs (which I think probable) the system is false; or if such a thing occurs, the system is incomplete."

Though Hertz and Heaviside never spoke face to face, their friendship deepened sufficiently to enable Hertz to write from Bonn on December 31, 1890:

"Dear Heaviside,

I send you my very best wishes for a happy New Year. . . . If you would only take a good form, a book of yours on the theory of electricity would have a great success in England and abroad. But I fear you have some pride in this, not to yield to the understanding of others. I think this is a false pride, you certainly are not aware how very difficult your papers are to understand to others, and it is old wisdom that the many will expect you to come to them and not come up to you, be your merits ever so great."

Thus it was not for lack of good advice that Oliver continued to indulge in the luxury of his own obscurity. Towards Hertz, he had the kindliest feeling. He concluded that, so far as the ether, as distinct from matter, was concerned, the Karlsruhe experiments fully confirmed Maxwell's theory. Matter would require further consideration. Maxwell's application of electromagnetics to explain phenomena associated with waves of light and heat in solids and liquids he knew to be imperfect, but the best available.

There is strange irony in the fact that Heaviside's secluded home in Devonshire, half buried amongst its brambles, its doors closed to all save the rarest visitors, its interior too often comfortless, should at the same time have been to a large section of the most advanced men of science a temple of wisdom, the place of the oracle, the court of ultimate appeal. The proof of this is in his correspondence. Physicists at Oxford who wrote to him referred occasionally to his hermitage as "The Inexhaustible Cavity," and there is a story that a letter addressed to him at "Inexh. Cavy. Torquay" was duly delivered. The reference, no doubt, was to the cave of Adullam (I. Samuel, XXVII, v. 2) into which everyone gathered that was in distress. Sometimes the perplexing problems sent to him were relieved by lighter matter, such as the following from C. V. Burton:

> "Crookes (P.R.S.) was dined at Jesus Coll. Oxford a little time ago. All sorts of 'nutts' came to meet him, but he spoke hardly a word to anyone. According to one account, he has found that if he talks too much after dinner he makes no new discoveries the next day."

There was a desire to prevail upon Heaviside to clear up the distinction between his vectors and quaternions, and to establish harmony if not coincidence. He held, however, that—

Figure 6—The House, 3 Saint Augustine's Road, Camden Town, where Oliver Heaviside resided from 1876 to 1889.

> "As vectors are not quaternions, the algebras cannot be naturally the same. Quaternions should come into vector algebra as quaternions—not as vectors. . . . Quaternions belong to trigonometry, which is the science of ratios between differently directed vectors. . . . Vector calculus belongs to physics."

The playground remained covered—as ever, since Descartes—with broken models of the ether. One of the first to acknowledge the wisdom that emanated from the inexhaustible cavity was Sir Joseph Larmor, who confessed in a letter dated October 12, 1893:

> "I am practically a convert to vector analysis and I mean to learn up the machinery immediately I have time."

Later he added:

> "My present view is that atoms are vortices in the medium, then magnetism is their vorticity, and a magnetic field tends to align them."

On February 12, 1898, he sent Heaviside "to look at" a copy of his paper on rotational ether, making the electric field of an electron both polar and circuital at the same time, in a way "that carried some evidence of naturalness." It had cost him three years to prepare, and yet he declared, "I am not so sanguine as to hope that more than say two people will read it." A few weeks later, Heaviside was able to send him Volume II of *Electromagnetic Theory*. For this Larmor, on May 8, 1899, thanked him, observing that it contains

> " . . . much wholesome castigation of my own profession, which is misled sometimes by the power of symbols into the belief that such a thing as rigorous exactitude can reign in any created product of the human mind. I see you still decline to countenance a rotational singularity or electron. . . . I believe I see signs that some previous oft heard opponents of all such notions now exhibit a tendency towards taking them for evident. But that is the way of the world, as you I presume are aware."

Sir Joseph Larmor was probably referring here to Lord Kelvin.

In 1898, Heaviside was consulted by John Milne with regard to seismographs and the interpretation of seismographical curves. Milne was prospecting and negotiating for a volcanic site near to Heaviside, on which to establish an observatory; for according to Milne—

> "If the National Laboratory is to be at Kew, so far as certain kinds of work are concerned it might equally well be on a sponge."

But the site Milne had prospected and coveted turned out to be not volcanic after all.

The gathering strength of the influence of Oliver Heaviside upon his contemporaries is everywhere apparent in the correspondence. Amongst the letters, for example, is one from David Hughes, dated May 19, 1899:

> "I should like to ask you if I am wrong in supposing that theory leads to the conclusion, 1st that self-nduction is beneficial to long-distance telephony, and 2nd that you would recommend for that purpose *Iron wires in place of Copper.* I mean wires of the same resistance."

There is another from David Hughes, dated June 6, 1889:

> "Remember that I fully agree with Hertz's experiments and think Maxwell's electromagnetic theory of light probably—but the only point in doubt in my mind is the permeation of a current from the inside to the outside. . . . If you can cite any experiment or any reasoning that would guide me in finding a method by which it could be demonstrated, your reply would be valuable to scientific truth."

Complete triumph came on January 10, 1889. The date is noteworthy because it is that upon which The Society of Telegraphic Engineers and Electricians altered its name to The Institution of Electrical Engineers. After the transfer formalities, Sir William Thomson (Lord Kelvin) took the Chair and gave an address on "Ether, Electricity and Ponderable Matter." He dwelt upon the history of electromagnetic induction in cable transmission, and he agreed that in his early theory he had not taken it into account at all:

> "But in the meantime it has been worked out in a very complete manner by Mr. Oliver Heaviside; and Mr. Heaviside has pointed out and accentuated this result of his mathematical theory—that electromagnetic induction is a positive benefit: it helps to carry the current. It is the same kind of benefit that mass is to a body shoved along against a viscous resistance."

The question of the choice of metal for conductors where "impulsive current" is concerned was discussed at a meeting of the Institution of Electrical Engineers on May 9, 1889, when Dr. J. Hopkinson was in the Chair. It was on this occasion (*Jour. Inst. Elec. Engrs.*, Vol. XVIII, p. 497) that Professor D. E. Hughes declared that "he could not agree with the theory of Oliver Heaviside if it leads to the conclusion that iron for telephone wires is better than copper." Dr. Hopkinson intervened and pointed out that Heaviside was very guarded in the statement, and had said "that an arrangement of iron was suggested which might be an improvement, but the ordinary iron wire was recognised as being very inferior in practical conductivity to copper wire. . . ."

Figure 7—Homefield, Torquay, Now Known as Highwold.

On June 26, 1893, an editor wrote that John Perry had been for a long time wrestling with the subject of telephoning through cables, and "felt" that Heaviside's conclusions were right but could not follow the working. It was remarks of this kind that elicited from the "cave" the observation that the new theory "is so obscure that it has attracted a good deal of attention." Perry realised that if Heaviside would write a book that could be easily understood "it might pay," and he thought that he himself would be a good "foolometer." From a letter of FitzGerald (February 2, 1894) it appears that Perry would have been glad to collaborate with Heaviside in this venture. The precise opinion Perry held at about this time is recorded in a letter (August 4, 1893) to a mutual friend:

> "Now I rank Heaviside with those two men (Kelvin and FitzGerald) but I never pretend to be

able to read Heaviside. I wish I could, and so do a lot of people like me. . . . Somebody will have to write down Heaviside to our level."

With refreshing candour, ever associated with John Perry by those who knew him, he wrote to Heaviside (March 4, 1896) his confession:

"I only dip into your work to take out what is useful to myself. I only know you to be the great man you are through him (FitzGerald)."

An important part of the task of freeing the works of Heaviside from their obscurity, of enhancing their value by numerical examples, and of inspiring them with new life directed towards practical achievement, was reserved for Henry Malcolm, who in 1912 began and in 1917 completed his classic treatise, "The Theory of the Submarine Telegraph and Telephone Cable."

The correspondence of Heaviside reveals his esteem for FitzGerald, who, as he expressed it, "belonged to the class of first-rate scientific men of the profounder sort who, not having any pretensions, only become known to their contemporaries." Concerning scientific men of the contrary type he observed: "There is no need to go without fame if you really want it." It is appropriate therefore to take the opportunity that now for the first time presents itself, of making known some of the opinions and criticisms that passed between these two remarkable philosophers. FitzGerald, at Trinity College, Dublin, began by tilting at Heaviside's innovations. He wrote to him:

"(September 26, 1892.) I hope you will succeed in making the ordinary mathematical physicist think in vectors, though I do not think your notation an improvement. You see, I was 'riz' on Tait and get very much muddled by your omission of S; and when one gets bothered every turn one naturally takes a dislike to the botheration. . . ."

"(January 4, 1894.) Trouton took up the telephone question rather by the way and has gone off on what he was at before, when he found it so complicated and unintelligible."

"(March 15, 1895.) You say Maxwell's (magnetic theory) is all a muddle. So it is: but there is an underlying stratum of explicability, I think, which must have been unconsciously guiding him."

"(June 21, 1893.) Maxwell's electro kinetic moment, A, was a crude way of imagining that the *current* had all the inertia, which is quite out of date now thanks to you—but it was very well when he wrote. . . . I cannot say that I am quite satisfied with your suggestion that in an imperfect conductor there are local electric currents with accompanying magnetic inertia as a way of getting over the statement that all the inertia is magnetic. It does not diminish the necessity for taking account of some inertia besides that appearing in the form of magnetic inertia round the current, because *wherever* a current exists some local energy is degraded *in situ* and if this has accompanying inertia without an external field we ought to add on to all our currents a term to express this. Just as the magnetic field due to two parallel wires cannot be completely supposed due to one wire between them carrying the sum of their currents, so, if we have to take account of internal fields between the molecules, we should proceed to do so, and *one* way of *representing* it would be in the *form* of inertia of current.

As regards the question of electric energy being potential, and magnetic kinetic, that is not in question here. When a spring is bent its energy is potential and still there is kinetic energy involved *during the time of its being bent.* What seems to me most likely is that during the time that displacement is taking place there are two sets of things going on. There is a magnetic force and accompanying induction (flow) taking place all round the displacement current which is proportional to the rate of change of the displacement and is the seat of *almost* all the kinetic energy. But besides this there is the change in structure of the medium going on which we call electric displacement and which is *increasing* as long as the rate of change continues constant; i.e., there is something increasing while the magnetic flow is constant. This is proved by the fact that there is electric force developed tending to push back the electric displacement. Now this something that is increasing must be some other motion than the magnetic flow, for magnetic flow cannot exist without calling up any reaction of the kind considered, and it seems to me as if this something increasing must have some inertia, for *no* change can take place without *some* inertia somewhere, and if this change *is* different from the magnetic flow then there *is* some inertia, maybe very little, in addition to the magnetic flow.

I think, however, there is a possible suggestion that what free ether resists is curl of magnetic flow, and then of course, the inertia of the flow would not differ from that of its curl—this latter being only a particular distribution of flow. But even then the *curl* is not increasing, it is constant, so that even though it is resisted, how can the resistance increase with the time? That is, I fear, special pleading, because the flow itself being a changing thing, its curl is so too. However, then comes the difficulty about what is happening between two spheres while the electric displacement is changing. There is no magnetic flow, therefore no curl, and so the curl of magnetic flow cannot be the something that is elastically resisted, unless of course you consider how the displacement *begins;* and in a non-conductor there must be the current to the inside of the sphere *somewhere* and there is accompanying curl somewhere; and from this point of view it is interesting to see *how* the electric energy grows at the various points within the sphere as they are gradually deserted by the magnetic force leaving its integral curl behind. Is that possible? I am afraid thinking these things out on a sheet of paper thus leaves them very muddly.

As to electric energy being essentially kinetic as well as magnetic energy, I have no doubt, but agree with you in thinking that provisionally it helps matters to consider one of them as kinetic and the other as potential. I return to my difficulty. Even in the case of curl being resisted, curl to be resisted must mean some changed structure other than uncurled flow, and this changed structure will have some accompanying inertia. Final thought: But perhaps different from the curly inertia.

I am afraid I am very hazy myself and am working more or less on my own model ether for concrete ideas, so that I am afraid I cannot make it very clear to another."

"(June 21, 1893.) When a current is started near a permanent magnet, the energy spent in producing it is quite independent of the presence of the magnet: Whence then in this case comes the energy of the field? I can only suggest that the permanent magnet is like a coil of a practically infinite self-induction, and that the energy of the field comes from it as it would from a neighbouring coil of perfect conductivity."

"(August 22, 1893.) Thank you very much for your letter. It clears up what I was quite hazy about. I had forgotten the momentum given to the ether, though I had been rather harping upon it lately in the case of the radiation of waves. . . . There is merely radiation of energy from two electrified bodies rotating round one another. There merely is a system of corkscrew waves being constantly generated . . . any regular periodic disturbance confined within a finite space must be continually creating new waves. . . . The action between two vortex rings in a perfect liquid is not . . . *propagated* from one to the other. It is due to the fact that each vortex ring is accompanied by motion everywhere, i.e., each vortex ring is itself really infinite and each ring involves all the others. Effects due to this kind of action not being propagated are simultaneous everywhere, and—as some actions of this kind must, I think, exist—it seems to me extremely probable that gravity is *the* action of this kind we are looking for. In that case there would be no question of its rate of propagation, it would be due to the fact that each atom of matter is infinite, *the* most probable hypothesis possible.

Yours sincerely,

GEO. FRS. FITZGERALD."

In March 1896, FitzGerald wrote to express his satisfaction that Heaviside had accepted the Civil Pension awarded in recognition of services to his country. He attributed the negotiation of the matter chiefly to John Perry and to Lord Rayleigh. An announcement that probably caused far more merriment in the "Inexhaustible Cave," however, was made by FitzGerald on June 8, 1896:

"I had a long correspondence with (Lord Kelvin) and his last letter says that he gives up everything he ever wrote about the ether. I hope he is not still quite so down in the mouth about it."

This was followed, on May 7, 1898, by a note to the effect that:

"Lord Kelvin, with his usual impetuosity has rushed at a single fluid theory of electricity—but he is very rash."

Formal correspondence was followed by a visit, of a few hours, of FitzGerald to Heaviside at Torquay and of cycle rides with him. They were men of such presence that those English lanes must have thought King Arthur and one of his Knights passed again to Camelot. The scene too quickly changed to Dublin, whence FitzGerald wrote:

"(May 7, 1899.) Have you worked at the propagation of waves round a sphere? A case of this is troubling speculators as to the possibility of telegraphing by electromagnetic free waves to America. It is evidently a question of diffraction and I think must be soluble. Perhaps the case of propagation round a cylinder would be easier. . . ."

"(September 21, 1899.) I am delighted to hear that you have set up that Aeolian. You are so fond of music I am sure it is very good for you and will help you to do more and better work than you could ever have done without it. . . ."

By this time the authoritative character of utterances from the oracle was recognised even by so distinguished a literary purist as Dr. Murray of Oxford, who, on March 17, 1899, appealed for the derivation of "Impedance." In reply, the lexicographer was referred to:

"The Electrician, July 23, 1886, p. 212; Electrical Papers, Vol. 2, p. 64, and to the quotation—'Let us call the ratio of the impressed force to the current in a line when electrostatic induction is ignorable, the Impedance of the line.' . . ."

Amongst the few contemporaries capable of appreciating to the full the merits of Oliver Heaviside was George Minchin who, from Trinity College, Dublin, had been appointed Professor of applied mathematics at the Royal Indian Engineering College, Coopers Hill, near Windsor. Mathematician, physicist, poet, and lawn-tennis player, he excelled in all that he set his mind and hand to do. He was a pioneer in photo-electricity and an early enthusiast in wireless telegraphy, especially in the use of an antenna; his skill in expressing in clear terms mathematical conceptions was unexcelled, and his joyous outlook made his friendship one of the best possessions. FitzGerald visited him at Coopers Hill College and wrote from there to Heaviside. This, so far as can be traced, was the last of their communications; for FitzGerald died but a few months later—died as did Maxwell and Hertz, before reaching fifty years of age.

Figure 8—Group of the Heaviside Family.

"(July 12, 1900.) I was fortunate in being with Larmor in Cambridge when your letter was forwarded to me, and so I asked him about the difference between himself and your work, and he pointed out at once what would have taken me some thought to discover. It all arises from the difference he takes between a *moving electron* and a changing displacement. The electron is certainly a change of place of the point, but we cannot say that the changing displacement is a real motion in the direction of the displacement. The electric displacement at a point is, no doubt, represented by a vector, but it is very unlikely that it is really a simple displacement of the point: it is much more likely to be a rather complex change in the structure of the ether at the point, which can be *represented* by a vector. In consequence of this difference, Larmor separates the electric force, which acts on the ether and produces the electric displacement, from the force on a moving electron due to its motion across a magnetic field. When matter moves across the ether in which there is magnetic force, this latter is what produces the electric current, i.e., a current of electrons. Its value is

$$V\dot{p}H$$

(V in FitzGerald's notation here represents vector product) while there is no electric force producing any displacement of the ether due to the motion: unless the induction changes owing to the moving matter and so produces an electric force that acts on the ether.

Larmor, working with his abominable potentials separates them as

$$\epsilon_1 = -\frac{dF}{dt} - \frac{d\phi}{d\eta}$$

$$\epsilon_2 = \dot{y}c - \dot{z}b$$

and the ether being considered as standing still $(\dot{x}, \dot{y}, \dot{z})$ can only refer to moving electrons. The two together produce the *displacement* which, when changing, is partly changing ether displacement and partly current of electrons, and are accompanied by the magnetic force,

$$\dot{D} = V\Delta H.$$

I think there is very great difficulty in deciding what is the best assumption to make as to the interaction of ether and matter when they are considered, as you consider them, as *continuous* interpenetrating media. Larmor, by assuming a definite hypothesis as to the nature of matter and its connection with ether by means of electrons, (is enabled) to decide which of different suppositions is best.

I have to go off now to help Minchin to put up some wireless telegraph poles. I was very sorry indeed to hear of your (bicycle) accident with the hen. Hope you are getting over it all right and that it won't make you afraid to continue to cycle.

Yours sincerely,
Geo. Francis FitzGerald."

In the introduction to the Collected Scientific Writings of FitzGerald, there is a letter from Heaviside—the real Heaviside, at his best—disclosing very tender feeling, written at the time of FitzGerald's death:

"I only saw him twice knowingly, once for two hours, and then again for six hours, after a long interval; yet we had a good deal of correspondence at one time, and I seemed to have quite an affection for him. A mutual understanding had something to do with that. You know that, in the pre-Hertzian days, he had done a good deal of work, not large in bulk but very choice and original, in relation to the possibilities of Maxwell's theory, then considerably undeveloped and little understood; and his way of looking at things was more like my own than anybody's. Well, he found that I had done a lot of work in the same line, and he was most generous in recognising and emphasising it. Too generous, of course . . . he used to write to me a good deal about electromagnetic problems, and I laid down the law to him like—like myself, in fact. He took it all very pleasantly. But I knew all the time that he had a wider field than myself, and no time to specialise much."

Between the years 1855 and 1912, during which the theory of electrical transmission through telegraph and telephone cables was built up, the three electricians chiefly responsible for advance in that theory were Maxwell, Kelvin and Heaviside. Heaviside's appreciation of Maxwell is manifest. Although his acknowledgment of Kelvin's early work is definite, it was not until the year 1889—when Kelvin acclaimed Heaviside—that their acquaintance with one another began to glow. There are two letters from Kelvin to him that serve to illustrate this:

"(Glasgow University. November 4, 1888.) Dr. Francis forwarded to me at Cambridge your letter with accompanying papers. I sent him back immediately the papers for publication in the *Phil. Mag.* but I don't agree that velocity of propagation of electric potential is a merely metaphysical question. Consider an electrified globe, A, moved to and fro, with simple harmonic motion if you please, to fix the ideas. Consider very quickly acting electroscopes B, B', at different distances from A. If the indications of B, B' were in exactly the same phase however their places are changed, the velocity of propagation of electric potential would be infinite; but if they show differences of phase they would demonstrate a velocity of propagation of electric potential. Neither is velocity of propagation of 'vector potential' metaphysical. It is simply the velocity of propagation of electromagnetic force—of 'electromagnetic waves' in fact."

"(Glasgow University. April 27, 1899.) I am not bigoted to either 'spin' or 'rot' or 'turn'; but I have always thought some of them better than 'curl,' as curl seems to me to involve the idea of either a helix or a flat spiral. I see I was wrong in attributing 'curl' to Clifford. He gives a good many such words, but it was, as you say, Maxwell that first gave *curl*, as he in fact tells us himself in the first volume of his *Electricity and Magnetism.* It is rather the symbolic system connected with it in your own and Maxwell's papers that I object to, than the word itself, and I cannot agree with any attack on Cartesian coordinates. All words that help us out of aphasia, provided they promote clearness instead of the reverse, are to be welcomed. . . . We want a thorough mechanical theory which shall include the undulatory theory of light with electrostatics, and electromagnetic force, and electromagnetic induction, with the *mobility of the medium and all the bodies concerned*, which is part of the essential nature of the affair.

Yours very truly,
WILLIAM THOMSON."

The problem of calculating the effective resistance of the inner conductor of a concentric cable was approached by Maxwell (*Electricity and Magnetism*, Vol. II, p. 690) for low frequencies, and only for a few terms of a series. Heaviside considered the whole "throttling" effect, i.e., the effective resistance, the effective inductance, and the tendency to surface concentration (*The Electrician*, May 3, 1884, p. 583), using two functions, M and N, which Kelvin later called the "ber" and "bei" functions. Heaviside developed this study (*The Electrician*, January 3, 1885), and Alexander Russell elucidated and extended it in a valuable review of the state of knowledge of the matter (*Proceedings of The Physical Society*, Vol. XXI, Part VI, December, 1909).

The date of an event of some consequence—a visit by Hertz to England—is recorded in a letter written on November 24, 1890, by Professor Ayrton.

"Dear Mr. Heaviside,

Professor Hertz is coming to stay with me for two or three days at the end of this week, and on Sunday some friends who are interested in electromagnetic radiation are coming to lunch with us to meet Professor Hertz. If by chance you will be in London Sunday next the 30th inst., we shall be delighted if you will come to lunch with us.

Sincerely yours,
W. E. AYRTON."

It is safe to assume that Heaviside was not present. Three years later Ayrton wrote to him for a definition of inductance, and on January 25, 1896, he again asked him for assistance in calculating the size of a copper plate to represent, in metal, the sea. At that time an endeavour was being made by electricians, who consulted Ayrton, to estimate the practicability or otherwise of telegraphy from the shore to a light ship.

They knew that, owing to the swinging of the ship with the tide, a cable could only with difficulty be taken on board. The plan was to place a large coil at the bottom of the sea. Through the coil an alternating current was to be sent from the land to act inductively on a similar coil in the ship. Ayrton also enquired of Heaviside how the current in the coil would be affected by the sea.

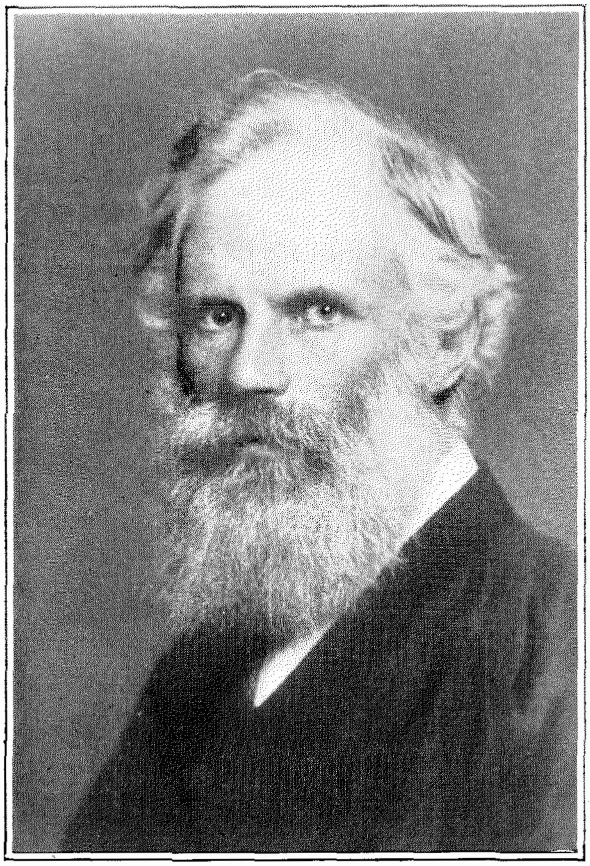


Figure 9—Professor George Francis FitzGerald.

In 1897 Heaviside was urged by a representative of the Northern Lighthouse Board to examine the proposal to utilise an induction coil and telephone in light ships to pick up signals from a corresponding coil at the bottom of the sea.

On March 8, 1905, a Cambridge mathematician wrote to him for a proof of the now familiar conjugate theorem that if a current, I, entering a solid object at A and leaving at B produces a difference of potential, V, between two other points, M and N, in the body, then a current I entering at M and leaving at N produces a difference of potential V between A and B.

His views on electrical matters were also requested by correspondents as distantly scattered as Mandalay, Calcutta and Alleghena.

The knowledge possessed by him of phenomena relating to submarine cables, and his profound study of mathematical principles relating thereto, enabled him to impart new life to a world of electrical communication that, in essentials affecting construction, had remained, for about thirty years, dormant. His advocacy of "loading" was not at first received with favour in his own country. For telegraph cables, Kelvin—recognising the analogy between electrical transmission and the diffusion of heat, examined by Fourier—had developed the "K R" law and had shown how to draw arrival curves for the case of a cable devoid of inductance and leakance, when both ends are put direct to earth. It was left to Heaviside to discover how to take account of inductance and leakance and how to develop equations to predetermine the effect upon the arrival current of the insertion of condensers and other apparatus at one or other or both of the ends.

It was also left to Heaviside to discover that there is a critical relationship between the four cardinal quantities—resistance, capacity, inductance, and leakance—in any telegraph or telephone circuit, and that, when this is fulfilled, received signals are an exact reproduction of those sent. He called this the "distortionless" condition—for his onomastic skill was unexcelled. He compared the case with that corresponding to greater inductance, and he exemplified the effects of reflection. His proposals for effecting improvement by adding inductance continuously, or in "isolated lumps," are described in *Electromagnetic Theory,* Vol. 1, pp. 444–446, where he sets forth his work of 1886–1887.

There is a marginal note in pencil on a stray reprint, that when he first suggested loading at a meeting of the Physical Society, a well-known physicist, Blakesley, at that time said, "it would be like making humps on a road to increase the speed of vehicles."

In common with all pioneers his mind turned at last to the question of the structure of matter;

here is a fragment, so far as is known, unpublished:

> "There are wheels within wheels, and the elementary volume itself may be a highly complicated dynamical structure with various sorts of energy in it, determinately connected with the external world. Nor is this mere mathematics. It seems to me that the state of things suggested is very likely that which prevails in the universe of molecules. The usual mathematics of continuous actions through elastic media takes matters in the gross. The unit volume must be large enough to contain an enormous number of molecules. The first approximation to a molecule is a little lump of matter banging about, exchanging its momentum and energy with its neighbours. But the molecule itself may be a little world, and on magnification, its affairs may be as complicated and important as those in our world. There is no absolute scale of magnitude in matters of length and time. Those wonders of wonders, thought and reason and memory, probably involve an inner mechanism of the atoms, especially as regards the storage of ideas involved in memory, to be lost sight of for long periods. Extremes meet, and the fast decaying brain of the old man brings to the surface the events of child life. The fact that the brain is subject to material change and replacement during life does not debar the theory of partial dependence upon the inner world of the atom. The replacement tends to follow established lines more or less perfectly; usually less, of course. We do not want a special kind of "mind-stuff." In any case, I cannot conceive the possibility of such a thing as long continued memory on the lines of mere external chemistry, and averages of molecules. It must depend on something deeper. Carlyle said: 'Go deep enough, there is music everywhere.' This dogma would perhaps have more truth in it, if for music were substituted 'thought.' At any rate, it is potentially existent in all matter which can go to make the man . . . how is it that early impressions sink deeper and deeper becoming harder and harder to recall, and come to the surface again only in old age? It looks as though they worked themselves in deeper and deeper into the atomic mechanism. At any rate, I can construct by ordinary magnetic coils and electrical condensers an arrangement which shall imitate this absorption and subsequent recovery—I do not refer to hysteretic condensers, but ideally perfect ones, the explanation of hysteretic condensers is in fact similar—in a weakened form, returning after many days like the bread that was cast upon the waters. If the inner parts of brain atoms are storage cells for very high frequency waves, if they are emitted they will sympathetically excite similar cells in other brains in an imperfect manner, and so provoke a vague impression, which the thinking part of the brain may develop to a picture. The power of emission may be great in strong mediums; receptivity will be small in a Huxley. Saints halos! Phosphorescence! Why not? they were funny fellows."

Elsewhere, in a marginal note, he expressed the same idea more concisely, but with less reasoning:

> "Life is an essential property of matter. All matter is alive, even the deadest. All phenomena are natural phenomena."

Only once amongst his papers is there found any trace of an attempt to write a story. It is entirely devoid of romance, and takes the form of a sketch entitled "Muscular Characters." It refers to his visits to a public gymnasium at the "Pimple"—presumably Primrose Hill—and his impression of youths who resorted there. And once, only once, is there any trace of his having descended into verse. The occasion was the dedication of Volume 1 of *Electromagnetic Theory* to the children of his brother Charles. He speaks of his nieces and nephews as "My dear Children." The verses are written in pencil on the fly-leaf of a copy he presented to Charles:

DEDICATION.

To MY DEAR CHILDREN.

1. I did not send you any cards,
   For I had none to send,
   So now I send you this here book,
   Whereby to make amend.

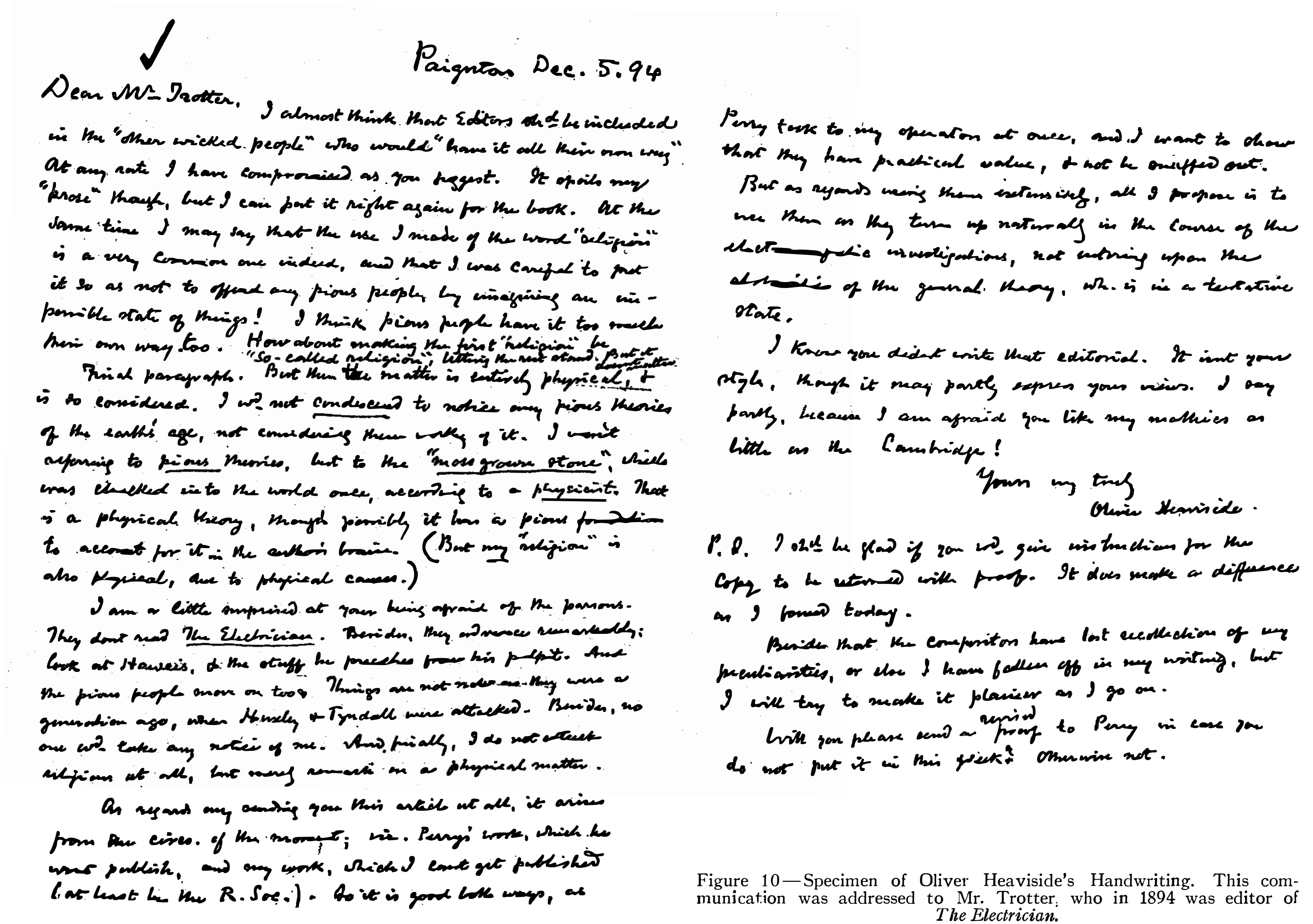
2. The first chap. is for Freddie,
   And may he always be,
   A credit to his parents,
   And an ornament to Torquay.

3. The next chap. is for Ethel,
   And may she read it well,
   And study it, and find it good,
   Nor think the book a sell.

4. The third chap. is for Charlie,
   And may he *never* be,
   A terror to his parents,
   And a torment to Torquay.

5. The fourth chap. is for Rachael,
   Because it is the best,
   And may she never *never* try
   To turn it into jest.

6. The preface is for Beatrice,
   Because it is so short,
   And may she never *never* think
   It all amounts to nought.



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Paignton Dec. 5. 94

Dear Mr. Trotter,

I almost think that Editors shd be included in the "other wicked people" who would "have it all their own way" At any rate I have compromised as you suggest. It spoils my "prose" though, but I can put it right again for the book. At the same time I may say that the use I made of the word "religion" is a very common one indeed, and that I was careful to put it so as not to offend any pious people, by imagining an impossible state of things! I think pious people have it too much their own way too. How about making the first "religion" be "so-called religion", letting the rest stand. But it doesn't matter.

Final paragraph. But then ~~the~~ matter is entirely physical, & is so considered. I wd not condescend to notice any pious theories of the earth's age, not considering them worthy of it. I wasn't referring to pious theories, but to the "moss grown stone", which was chucked into the world once, according to a physicist. That is a physical theory, though possibly it has a pious foundation to account for it in the author's brain. (But my "religion" is also physical, due to physical causes.)

I am a little surprised at your being afraid of the parsons. They dont read The Electrician. Besides, they advance remarkably; look at Haweis, & the stuff he preaches from his pulpit. And the pious people move on too. Things are not now as they were a generation ago, when Huxley & Tyndall were attacked. Besides, no one wd take any notice of me. And, finally, I do not attack religion at all, but merely remark on a physical matter.

As regards my sending you this article at all, it arises from the circs. of the moment; viz. Perry's work, which he won't publish, and my work, which I can't get published (at least by the R. Soc.). So it is good both ways, as Perry took to my operators at once, and I want to show that they have practical value, & not be snuffed out.

But as regards using them extensively, all I propose is to use them as they turn up naturally in the course of the electromagnetic investigations, not entering upon the abstrusities of the general theory, wh. is in a tentative state.

I know you didn't write that editorial. It isn't your style, though it may partly express your views. I say partly, because I am afraid you like my mathics as little as the Cambridge!

Yours very truly
Oliver Heaviside.

P.S. I shd be glad if you wd give instructions for the copy to be returned with proof. It does make a difference as I found today.

Besides that the compositors have lost recollection of my peculiarities, or else I have fallen off in my writing, but I will try to make it plainer as I go on.

Will you please send a revised proof to Perry in case you do not put it in this week's? Otherwise not.

Figure 10—Specimen of Oliver Heaviside's Handwriting. This communication was addressed to Mr. Trotter, who in 1894 was editor of *The Electrician.*

7. The Contents are for Pa and Ma,
And may they never know,
The pangs of tortured conscience,
Or the awful depths of woe!
Jan. 1, 1894.

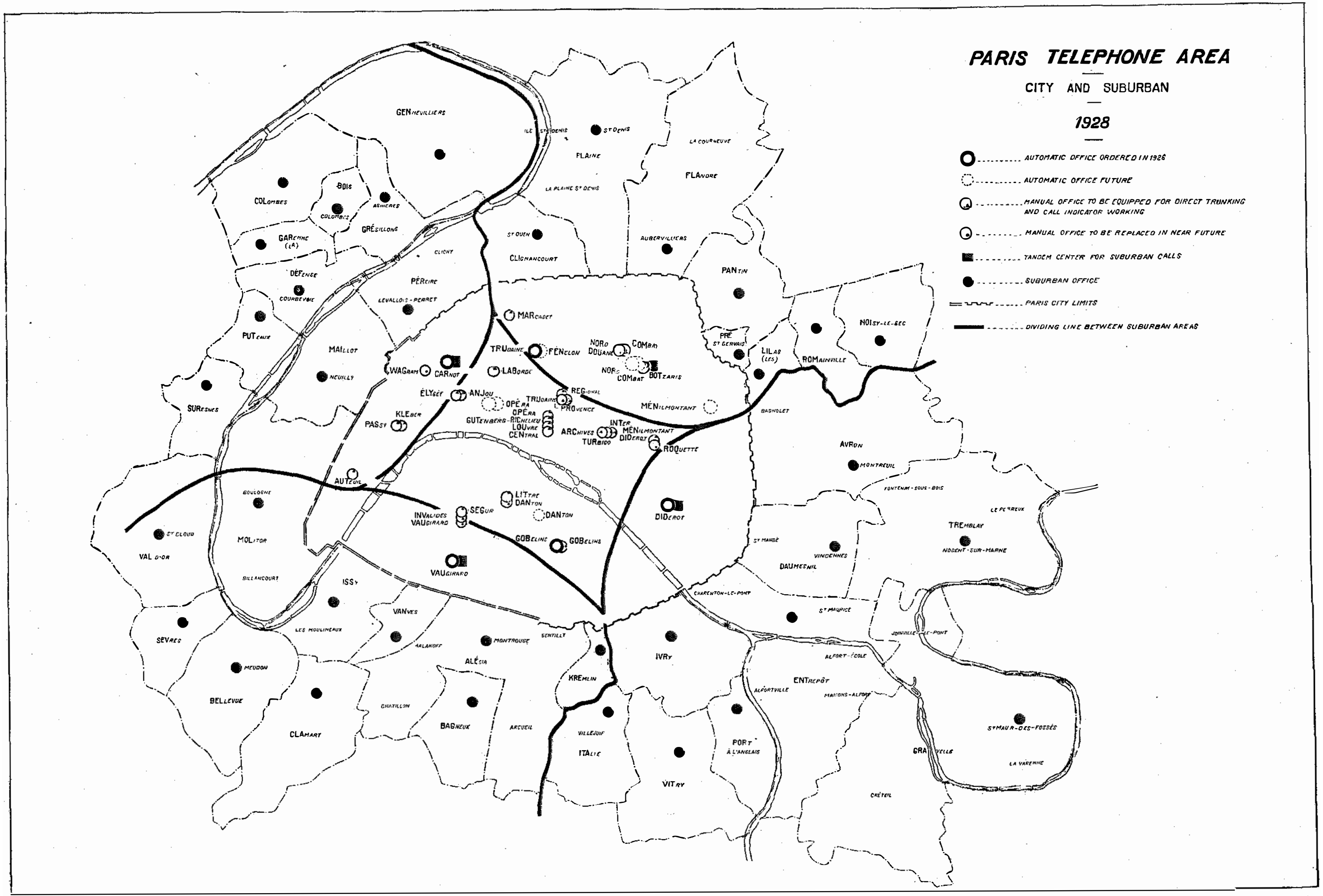
Amongst the fragments also is this:

> "Here we may stop to remark on the immortality of the soul. This doctrine, which probably had its first origin in the dreams of savages, survives all attempts to abolish it. In its old fashioned sense the principle may have already lost its hold upon a great many men and women of the highest attainments, and may be mostly held by those who are least capable of judging, as an article of unthinking and unquestioning faith. But it is part of human nature for all that. When old beliefs are found out of keeping with the spirit of modern knowledge, the proper way is not to abolish them, but to modify their interpretation. Now there is a far nobler sense in which the doctrine of the immortality of the soul is true, not as a matter of faith, but of fact. Everyone in living his life is making the world for those who will follow. Everyone makes some impression on the world, good or bad, and then dies. The good or the mischief he has done remains; the impression is left for all time. Not only the lives of those around us, but of our followers, are modified in consequence of our actions. The aspirant to immortality who is dissatisfied with the old conventions may then cry 'Non omnis moriar.' A part of us lives after us, diffused through all humanity more or less, and all Nature. This is the immortality of the soul. There are large souls and small souls. The immortal soul of the scienticulist is a small affair, scarcely visible. Indeed its existence has been doubted. That of a Shakespeare or a Newton is stupendously big. Such men live the best part of their lives after they are dead. Maxwell is one of these men. His soul will live and grow for long to come, and hundreds of years hence will shine as one of the bright stars of the past, whose light takes ages to reach us."

To remove misapprehension it should be recorded that Oliver Heaviside was neither destitute nor in desperate poverty. Financial troubles came to some extent because, throughout his career, he was devoid of business acumen. He refused much that life had to offer him—even medical attendance in his illness. From several directions his friends approached to offer amelioration. Some of the astutest intellects of his country conspired to find a way of supplying him with funds in a manner that he might not resent. They succeeded only in part. At the back of his mind was the complexity that he ought to have received from the commercial world early acknowledgment and remuneration for his work in telegraphy and telephony. He suffered, as many an inventor has, to see that the prize had slipped from his grasp into other hands. That being lost, he preferred to live in his own way. Yet one compensating delight he had: the sense of supremacy in his own domain of mathematical physics. This supremacy was derived primarily from his powers of intuition—exceptionally developed, almost unfailing, and ever inspiring. Heaviside penetrating towards an immortal generality can only be compared with Faraday prospecting for eternal truth in a wilderness of experimental facts.

He detested alcohol in all its forms, but he was an inveterate smoker—a pipe of the strongest tobacco was his delight. At Homefield, in the years 1913–1914, he scarcely ever went beyond his garden. If his friends gained admission, they were gladly received and they found him entertaining, jocular, and still a tease. In 1921 he was less accessible. By 1924 he had increased his troubles by getting at loggerheads with local authorities concerning accounts. During the last years of his existence he dwelt alone. He purchased supplies of food and other necessities through the kind voluntary services of Constable Henry Brock, a worthy representative of the Devon County Police, who refused all remuneration from him.

At about that time his health rapidly failed, for pneumonia intervened with other complications. In January, 1925, after a serious attack of illness, he was removed to a nursing home, where on February 3, 1925, he died, at the age of 75 years. He was buried in the grave of his father and mother in the Cemetery of the Urban District Council, at Paignton.



Frontispiece—Plan of the Paris Telephone Area, showing the city proper and the surrounding suburban area which has been brought into the automatic switching scheme. The first three letters of the office prefixes shown in large type are those which the subscribers will dial.

The Rotary Automatic Telephone Introduced Into Paris

By G. DEAKIN

Vice President and Technical Director, Le Matériel Téléphonique

Introduction

THE first step in the actual conversion of Paris from manual to automatic operation was brought to a successful conclusion on Saturday night, September 22d, on which date approximately 3500 working lines were transferred to the new Rotary automatic office, Carnot.

The study of the Paris telephone requirements was begun by the French Telephone Administration a year or so before the outbreak of the World War. What, up to that time, had been considered a necessity, became a luxury and it was not until 1924 or the early part of 1925 that the study was again seriously taken up. This unavoidable delay was not entirely without advantage. It gave the Administration the opportunity to study the methods and systems which had been chosen by other Administrations and to profit by the experience gained by these Administrations in the operation and exploitation of the chosen systems.

The French Government was not slow to take advantage of this opportunity. It appointed two committees, one a technical committee and one a general committee, to study the telephone requirements of the city of Paris and to determine what system would best meet these requirements. The technical committee made a thorough study and investigation of all of the major automatic systems then in operation in Europe and on July 27, 1925, the Government issued a *cahier de charges* calling for tenders for the manufacture in France and the installation of automatic equipment for four 10,000 line offices.

With the additional data gained from the resulting tenders, the two committees again examined the subject and the pros and cons of all systems. In the end, the two committees unanimously chose the Rotary system for Paris and on October 14, 1926, the contract for the first four offices was awarded to Le Matériel Téléphonique. The contract carried with it the proviso that standard Rotary apparatus shall be employed throughout and that the circuits shall be designed by Le Matériel Téléphonique, to meet the requirements of the Administration and that the full responsibility for the successful operation of the system under normal and specified conditions shall rest with Le Matériel Téléphonique.

Paris Telephone Area

The Paris telephone area as now planned for automatic working is illustrated in the frontispiece to this paper. It comprises the solidly built up and densely populated city proper within the now obsolete fortifications and the variously settled and populated suburban areas which surround Paris on all sides. These suburban areas vary from highly industrial to almost entirely residential.

The city proper is now served by twenty-two manual switchboards located in fifteen buildings, in addition to the new Carnot automatic office.

The suburban area is served by fifty-seven manual offices, some very small. This number will be reduced to thirty-seven as indicated in the frontispiece. Each of these thirty-seven ultimate suburban office centres has been assigned a prefix suitable for automatic working. These prefixes are now in use, one prefix often applying to two or more offices. To distinguish between towns having the same prefix, the subscribers in such towns are allotted numbers in different thousands, thus enabling the answering operator to distinguish the office by the numerical suffix.

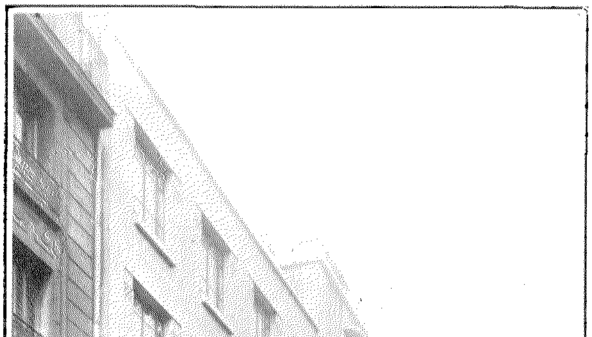
The total telephones in Paris and the suburbs are about 340,000.

Manufacturing and Installation Accomplishments

Carnot at the present moment has equipment installed and tested for 6,000 lines and additional equipment in process of installation for another 4,000 lines, which will bring the total equipment up to 10,000 lines. The contract required the completion of the first 6,000 lines in twenty-one months; that is, by July 14, 1928. This date was kept. The requirement for 100 per cent French manufacture also was met.

As the original factory premises at 46, Avenue de Breteuil were entirely inadequate for a large automatic programme, a new factory was built on the Company's property in Boulogne, just outside of Paris. Work on the first quarter section of the new building was started in May, 1925, and the work on the last section is just now being completed. The great effort made by the shop to build up a personnel, which grew from about 1,500 to 5,000 in less than a year, and to construct the necessary special tools for the manufacture of the automatic equipment, is a story by itself.

The installation in Carnot of the first piece of automatic equipment took place December 23, 1927. Between that time and July 14, 1928, some 750 cabled and combined bays have been placed in position, cabled, wired and tested, including tests with the junction equipment to and from the various manual offices—a considerable achievement in view of the fact that the Installation Department recruited most of its staff from green help. The following log may be of interest:



View of the Telephone Building. The wing which contains the new Carnot Exchange is at the rear of the building and runs parallel with the street.

October 31, 1927—Installation of switch racks at Carnot started
December 23, 1927—First automatic selector bay received
February 18, 1928—First combined bay received
March 25, 1928—Installation estimated to be 50 percent complete
May 12, 1928—First semi-B call sent through
May 25, 1928—First automatic to automatic call sent through
June 26, 1928—First call sent via tandem call indicator position to a manual office

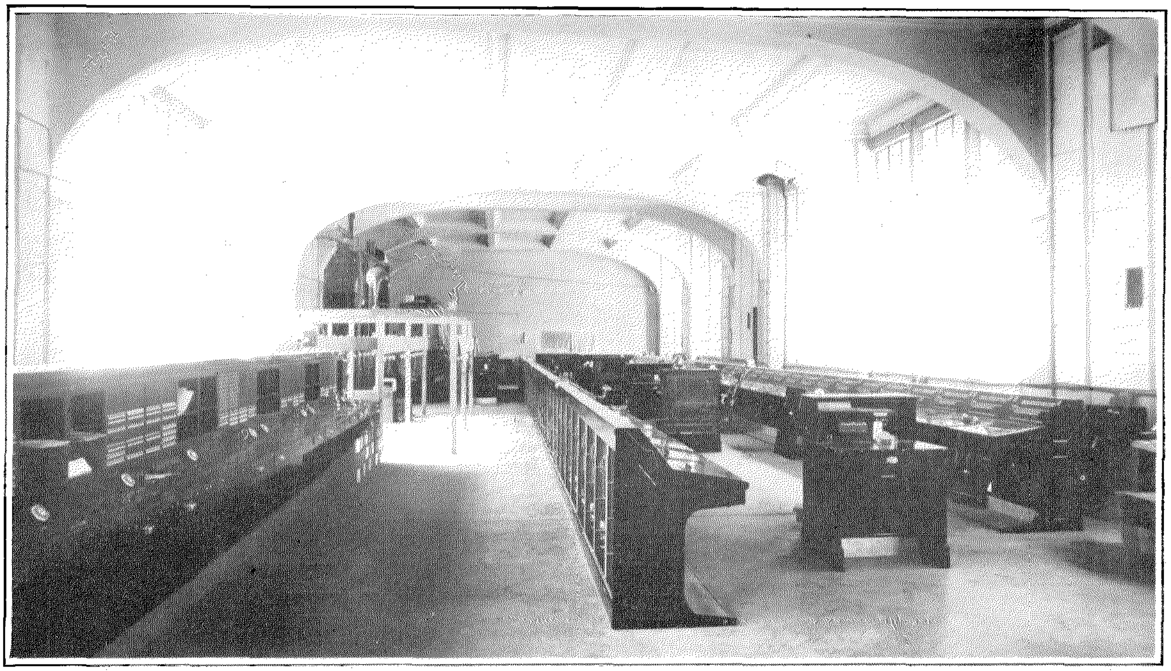
Description of Equipment

The Carnot office occupies four floors of a newly constructed wing of the telephone building at 27, Rue Guyot. The power plant is in the basement and is of the continuous float type. A single battery potential of 48 volts is used for all purposes except for metering, for which purpose a booster battery of 70 volts is supplied.

On the first floor are two main distributing frames, one for subscriber lines and the other for junction lines. These frames may be extended to accommodate a second 10,000 line office. On this floor are also the service meters, the wire chief's desk and the register and junction equipment exclusive of the selectors for the temporary semi-B and tandem call indicator positions.

The second floor contains the manual operating room, the incoming third selectors, the out junction test panel and the junction intermediate distributing frame. The operating room contains thirty-five semi-B positions, thirty-eight tandem call indicator positions, information and complaint positions, toll switching positions and the usual supervisors' and chief operator's desks.

The third floor is devoted exclusively to automatic equipment and accommodates all of the automatic equipment with the exception of that



Carnot Operating Room. At the right are thirty-eight call indicator positions and in the center, thirty-five semi-B positions. At the extreme left is the information desk. In the distance is the manual toll switching section. The temporary structure in the middle was erected for supporting the test telephones.

previously referred to on the first and second floors.

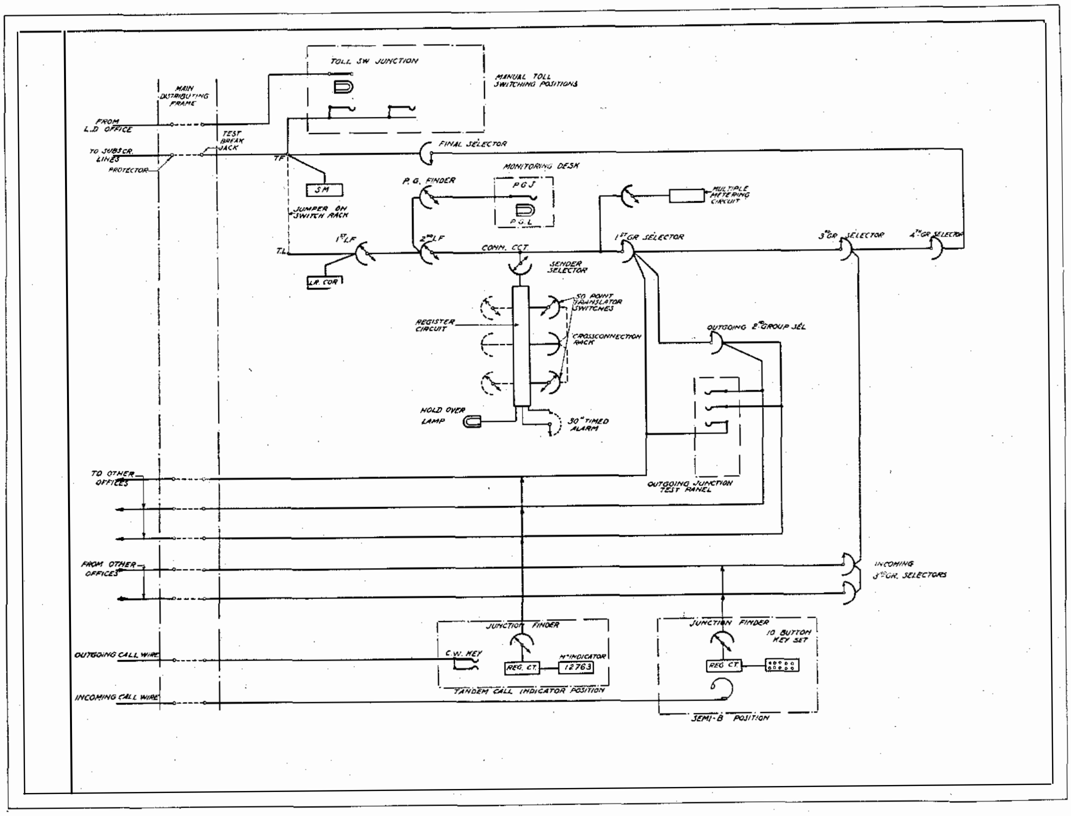
Except for the arrangement of equipment, all Paris automatic offices will be alike. An idea of the equipment involved may be had by reference to the accompanying junction diagram, which shows the general arrangement of the equipment for Carnot.

The outside cables terminate on protectors of the usual type. The switchboard side of the main distributing frame is fitted with test break jacks, which experience in Europe shows are a great help to the wire chief, since they permit the line to be picked up by a line number and not by a cable number which requires reference to a cable record. The use of test break jacks also obviates trouble at the protector due to the unavoidable disturbance of the heat coils and carbon blocks by the insertion of a test shoe into a protector.

The test break jacks are cabled to terminal strips placed on top of the switch racks immediately above the final selector bays. On the same switch racks adjacent to the final selectors are the first line finder bays which also accommodate the line and cutoff relays. Jumpering between the two sets of terminal blocks makes the use of a separate intermediate distributing frame unnecessary. Main and P.B.X. lines may be mixed at will, thereby making it possible to more or less uniformly distribute the traffic and thus to avoid the necessity of having an unduly large number of selectors in certain groups.

The service meters are cabled to the switchboard side of the main distributing frame. The meters are of the multiple metering type, similar to the well-known standard meter, but equipped with a differential winding to cause the meter armature to restore to its normal position when the operating booster potential is removed.

When a subscriber calls, his line relay is energised, whereupon the associated group of first line finders hunts for the calling line. The first to reach the calling line makes it busy, whereupon the associated group of second line finders forming part of the connection circuits hunts for and selects the first line finder. Immediately following this the sender selector of the connection circuit hunts for and selects a free register. All this normally takes place on an average in one half to one and one half seconds, the average generally being nearer to one half a second than to one and one half seconds.

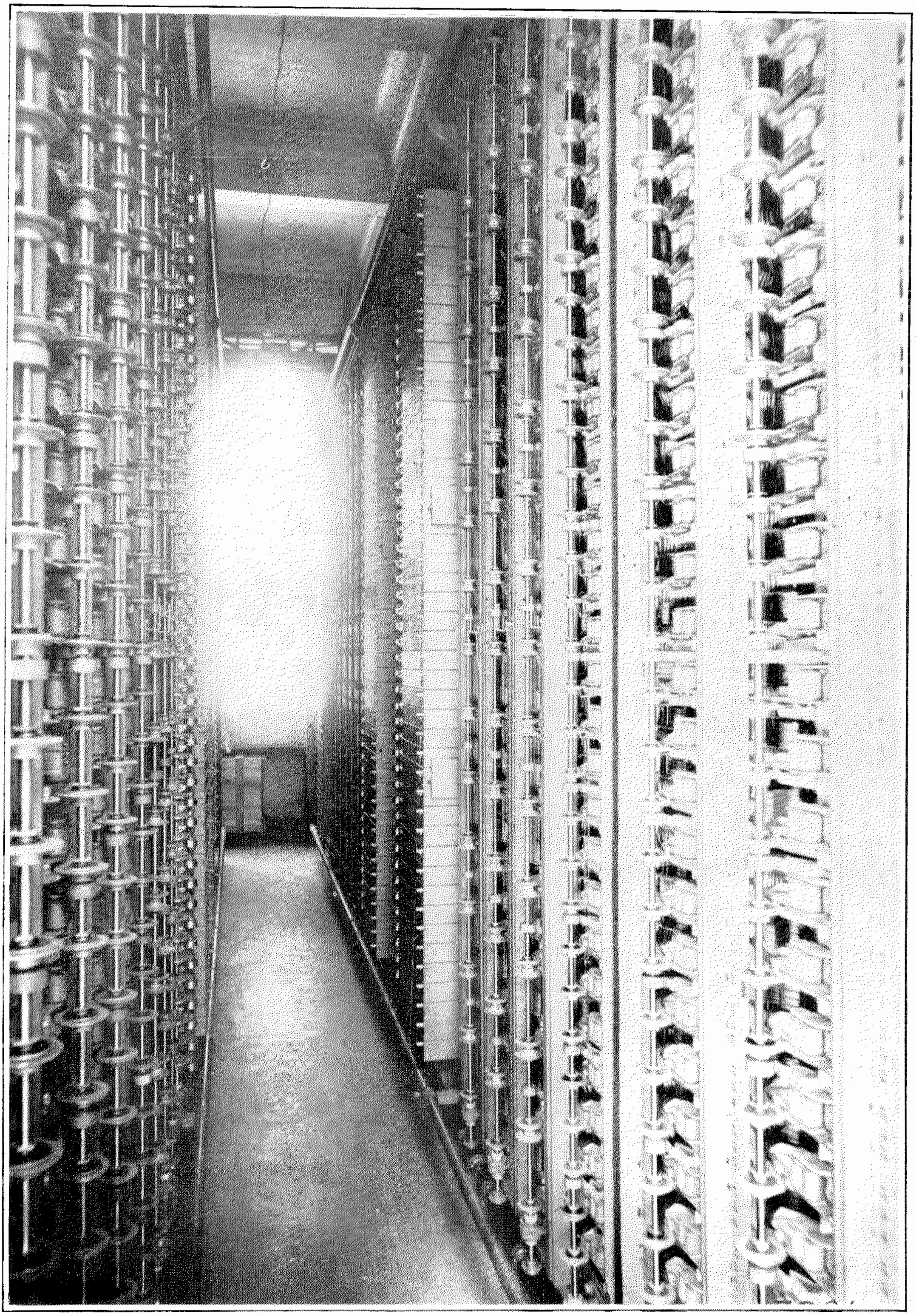


Junction Diagram, Carnot Office.

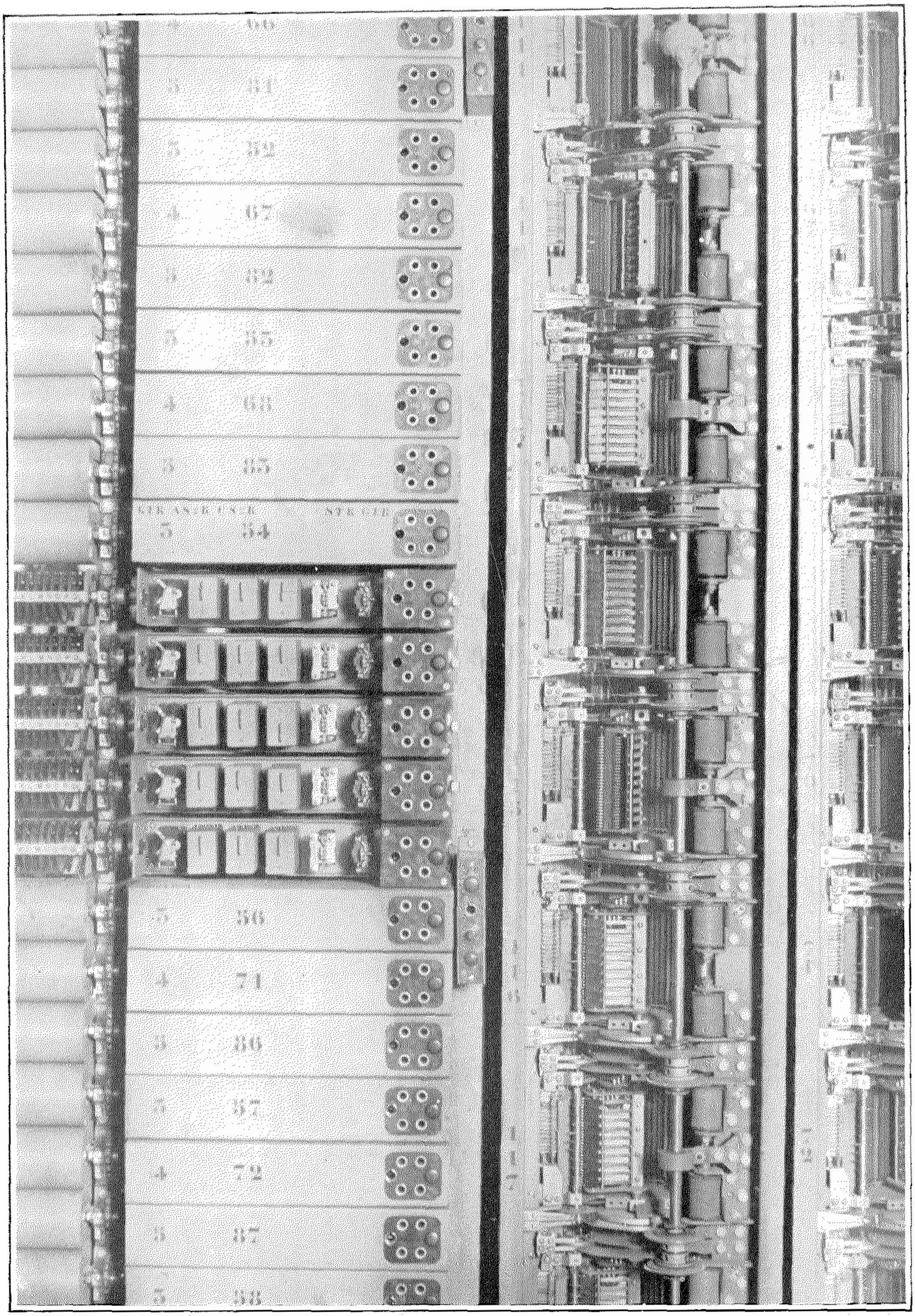
The subscriber now dials the three first letters of the wanted office and then the four figures, regardless of whether the wanted number is in the city or in the suburbs. When the first office code letter is dialed the translator switch, which forms part of the register circuit, hunts for the first letter position and stops provisionally on the first office prefix position commencing with the letter dialed. When the next two letters have been dialed, the translator switch hunts for the wanted office prefix, the maximum delay after dialing the third digit being about one half a second. The flexibility of the system permits all office prefixes beginning with the same letter to be grouped together thus permitting, as just indicated, a partial selection to be made before the completion of the dialing of the office prefix. When the wanted position is found, the first, the second and tandem selectors are caused to extend the connection. When the first of the four figures is dialed, the selection may be extended to the third selector and when the second figure is dialed, to the fourth selector. When the third figure is dialed, the trip spindle of the final selector may be set and when the fourth figure is dialed the brush carriage may select the wanted line.

For the time being calls from Carnot to all other offices pass through tandem call indicator positions located in Carnot. The number dialed appears on a number indicator before the tandem operator whereupon the operator passes, by means of an order wire, the wanted number as well as the junction number to the associated *B* operator in the wanted office. This practice was adopted for the cutover of Carnot, since time did not permit the installation of permanent call indicator equipment in those manual offices which are to remain. The manual end of the present tandem junction is in reality a standard manual *B* junction circuit with a relay added to obtain the required control.

Incoming calls to Carnot for the time being are made through order wire semi-B positions, the *B* positions differing from those previously made by Le Matériel Téléphonique in that the register



View of Aisle Between Rows of Finished Connection Circuits.



Front View of an Incoming Third Selector Bay and a Portion of the Associated Combined Bay. The incoming third selectors, without change, may be associated with any of the various manual offices in Paris and with other automatic offices. The character of the out-junction equipment thus remains unaltered regardless of the type of the distant office. In Paris, there are five or six distinct types of manual offices of four different makes.

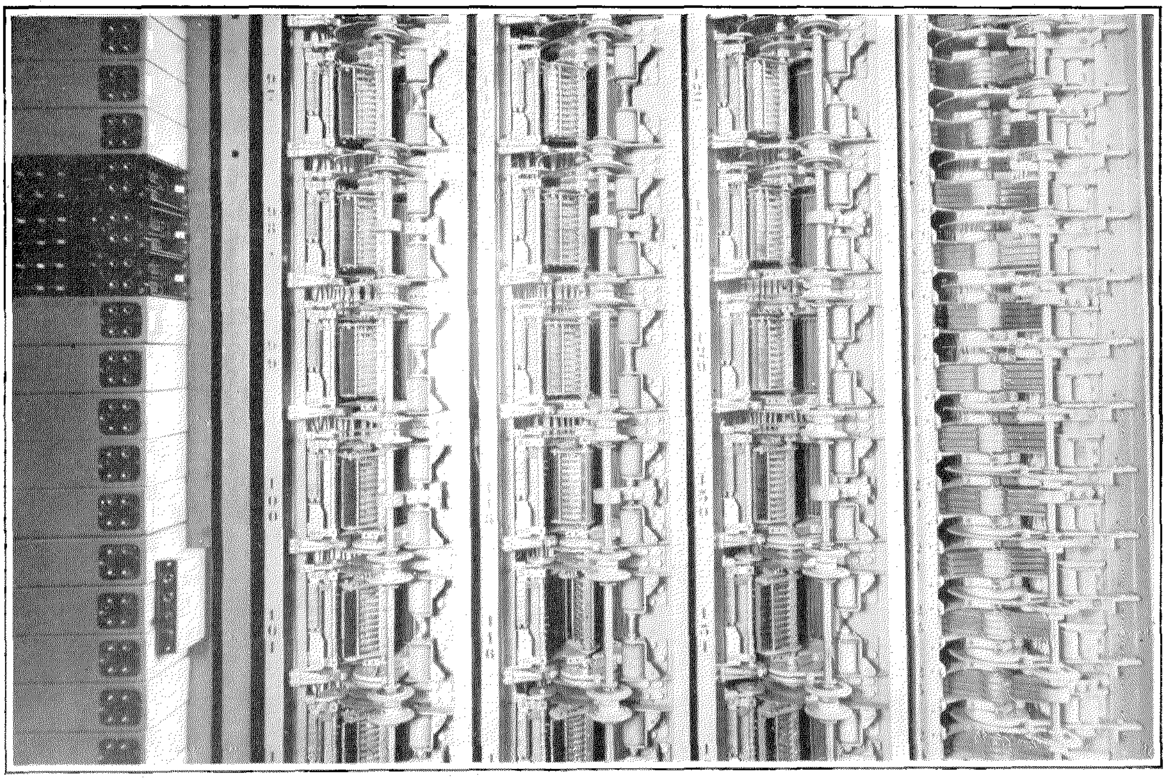
circuit is substantially the same as that which will be installed in the manual offices for direct trunking to automatic.

The arcs of the first group selectors are cabled through various distributing facilities direct to the main distributing frame, to a sufficient number of groups of outgoing second selectors to obtain the required out junction paths, or direct to third selectors. This arrangement is shown on the junction diagram. The local and incoming third selector arcs are cabled in multiple to the fourth selectors. The fourth selector arcs are cabled to the final selectors.

The incoming third selectors are of the universal type. They may, without change but with suitable simple cross connection properly provided for, be connected to an incoming junction from another automatic office, to an incoming junction from a manual office equipped for direct trunking, or, as at present, to an incoming junction from a manual office served by a semi-B position.

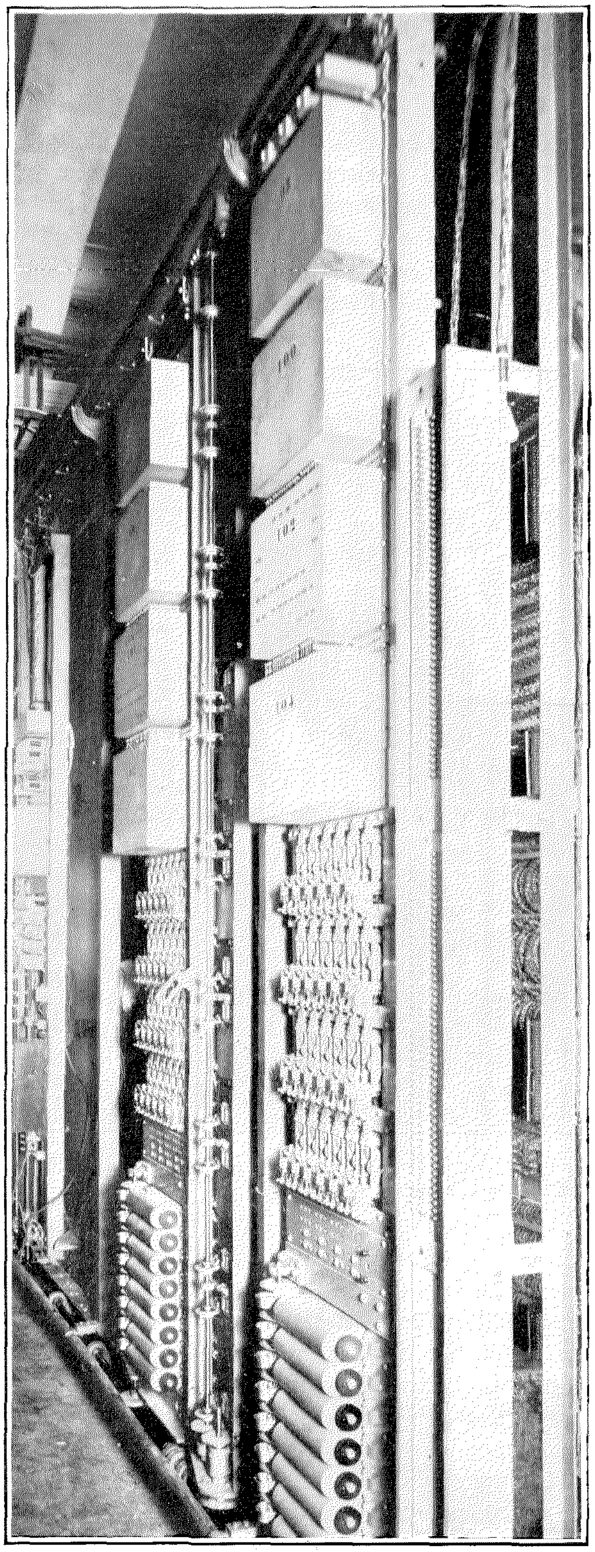
The fourth selector circuit differs from those previously used in the Rotary system in that it contains the ringing relay and ringing and busy tone facilities.

The final selector is of the universal type and may be used indiscriminately with main or P.B.X. lines. Any group of adjacent lines in any final arc may be adapted for P.B.X. working by the simple procedure of shunting the *C* wires of the first and last lines in the group with resistances. The function of the first resistance is to cause the final to hunt in case the first junction is busy. The function of the second resistance is to cause the final to stop hunting in case all junctions in the group are busy. The final always functions as a main line final when no shunt resistance is used.



Front View of Three Connection Circuit Selector Bays, a Portion of a Combined Relay and Sequence Switch Bay to the Left and a Sender Selector Bay at the Right.

Grounded lines are automatically transferred to the monitoring desk after a lapse of 30 seconds. A P.G. (permanent glow) finder picks up the first line finder and lights a lamp on the monitoring desk. The connection circuit and register



Two Register Bays with the Common Translator Bay in Between Are Shown in the Foreground. Each register bay accommodates four register circuits.

are then freed. Failures to complete dialing are also automatically transferred to the monitoring desk after a lapse of 30 seconds counting from the last dialing of a digit. The monitor may plug into the P.G. jack and test the line or he may speak to the calling subscriber if there is one.

With each group of connection circuits are associated a few multiple metering circuits. These are brought into action at the end of a successful multi-charge connection, the register having previously signaled this fact to the connection circuit. Single meterings do not involve the multiple metering circuit. The connection circuit automatically takes care of such meterings.

All out junctions pass through a test panel by means of which a quick test may be made of each junction. With each jack is associated a push button key, which, when thrown, makes the junction appear busy at the outgoing end.

Any two wire junction may be made busy at the incoming end by opening the fundamental circuit by removing the ground from the *A* wire. The first and second selectors make two tests, first a test of the *C* wire to ascertain whether or not the junction is free at the outgoing end and then a test of the *A* wire to ascertain whether or not the junction selector is in its normal position at the incoming end. If either of these tests show the junction busy or off normal the selector passes on without stopping to the next junction.

Should a properly dialed call fail to go through for any reason whatsoever, the calling subscriber is automatically freed after a lapse of 30 seconds providing he waits at his telephone. The register circuit, the connection circuit and any other circuits involved in the incomplete connection are held and the "hang up" signaled to a switchman.

The routine testing facilities provided for the Carnot permanent equipment are very complete and fully automatic in operation. The major circuits are divided into convenient groups or by switch racks, and one routine test circuit is provided for each group or switch rack. A routine test circuit selects the circuits to be tested one at a time and puts them through a complete series of cycles, checking all of the essential features. When a fault is found the routine test circuit stops and automatically signals the attendant.

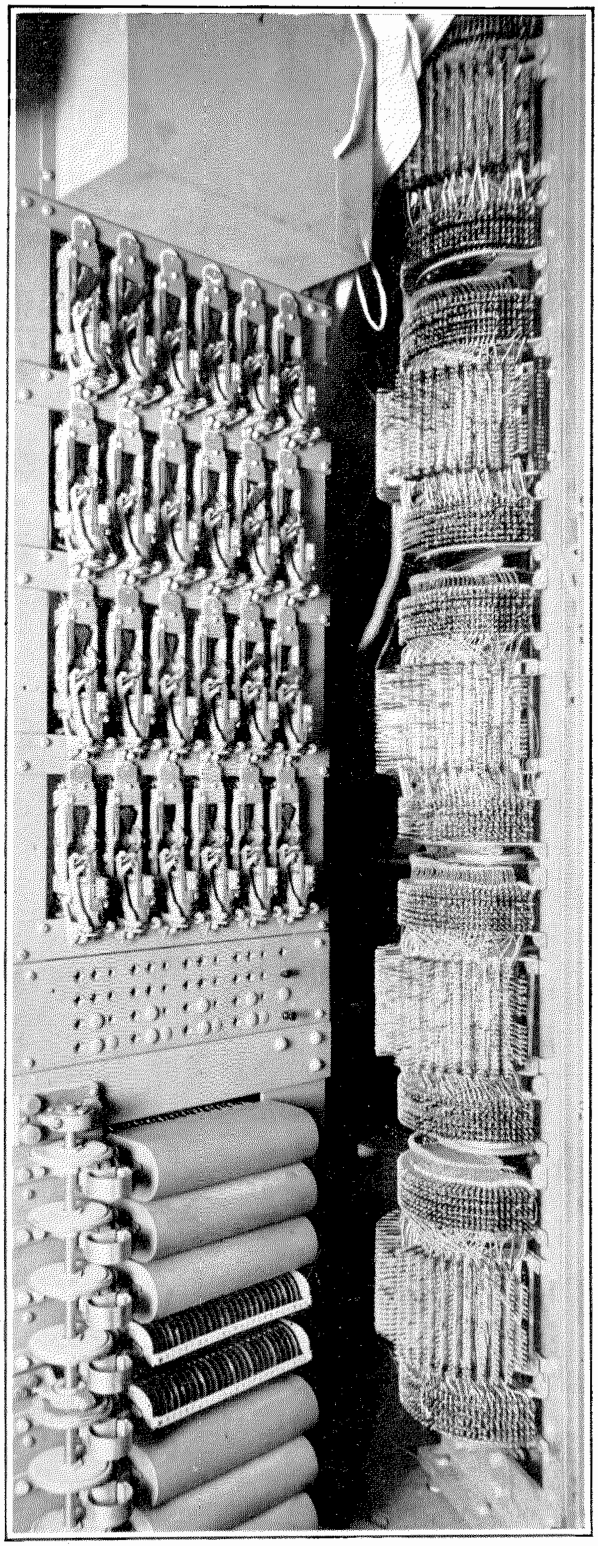
By inserting a wooden plug into the test jack which is associated with each circuit, the routine test circuit may be permanently attached to that circuit and the tests repeated indefinitely. Each routine test circuit includes a service meter to record the number of complete tests made.

Automatic routine test circuits permit the attendants to be non-skilled. The duties of the attendants are merely to record the time of stoppage, the number of the faulty circuit, the position it stopped in and the position of the routine test circuit. A ticket with this data is made out and handed to a skilled mechanic who repairs the trouble.

Three traffic observation positions are installed in Carnot and similar equipment will be placed in all other automatic offices. A single contact jack is installed on these positions for each second, third and fourth selector and by means of these jacks and associated cord equipment, the traffic passing over any group of junctions may, without trouble, be accurately determined. No group of associated junctions exceeds 150; that is, grading or inter-mixing is not extended beyond this figure. Each position may record 150 junctions simultaneously. A smaller number of junctions may also be supervised. The method of recording traffic with these facilities is as follows:

A plug is inserted into the jack of each junction forming part of the group to be observed. When the plugging up is complete, all meters are read or photographed and the starting key thrown. The time is recorded. At the end of the observation period, usually an hour, the starting key is restored, whereupon all meters cease operating. The new readings are taken or photographed. The difference between the two sets of readings gives the following information:

1. Total number of calls, completed or otherwise.
2. The time in two second intervals that each junction in the group was occupied. This record permits one to determine whether or not certain individual junctions were underloaded and the common junctions overloaded or vice versa, etc. The re-



A Close Up View of a Portion of a Register Bay and Its Associated Translator Bay. At the bottom of each register bay are located the sequence switches. Next above are the control lamps and then the rotary step-by-step switches which receive the dial impulses from the subscriber. Above them are the controlling relays. The translator switch bay is hinged so that the rear of the bay may be swung out into the aisle for cross-connecting purposes. It is shown partially swung out. The attendant is not required to work on the bays from the rear. The jumpering may be seen between the translator switches and the semi-circular strip between them.

cords give an exact picture of the distribution of traffic by junctions.

3. The number of times all circuits in the group were found busy.
4. The total duration of the time in two second intervals that all junctions were engaged.
5. In addition to these meter records a recording milliamperemeter gives a graphic picture of the distribution of the load during the hour or observation period.

It was not thought necessary to duplicate this equipment for the first line finders, connection circuits, registers and finals. For these circuits totalizing or overflow meters are provided.

In addition to the totalizing meters for registers one meter is provided for each office prefix. Such a meter operates each time a call is made to the associated office. Thus the distribution of the total out junction traffic is automatically obtained.

General Engineering Problem

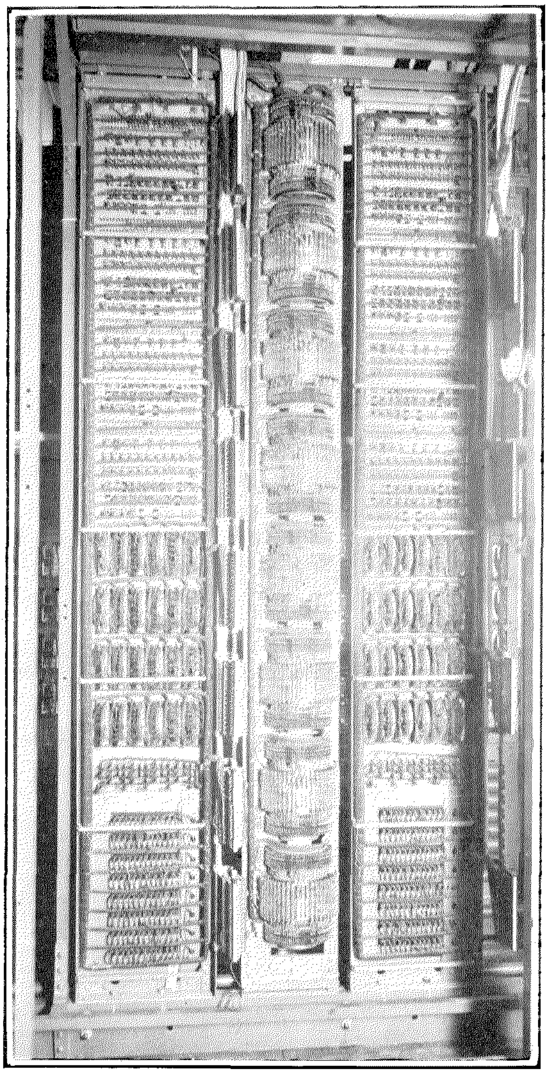
The preparation of engineering plans, and the design of circuits, particularly those for Carnot, could not be started until January, 1927. The time which had elapsed since the signing of the contract was devoted to a discussion of details with the engineers of the Administration. The *cahier de charges* previously referred to, had been prepared very largely to obtain information to enable the Administration to compare the relative merits of the different systems and to make their choice of a system, and was not, therefore, of much use in preparing working plans.

Four classes of telephone service are encountered in Paris—

City service,
Suburban service,
Short haul two number service
  called "regional,"
Long distance service.

In working out the final plans for Paris with the Administration, it was agreed that the *cahier de charges* would have to be departed from in a number of respects in order to meet the methods of operation desired by the Administration. It is not necessary to discuss the differences in this paper. It will suffice to outline briefly or to refer to the initial and ultimate methods of operation finally agreed upon; and in this connection the reader is referred to an article[1] by Monsieur Pocholle, on the transformation of the Paris area which appeared in a previous issue of ELECTRICAL COMMUNICATION.

The present full automatic system is planned to care for the city and surrounding suburban areas. It may, however, ultimately be extended should the Administration find such an extension desirable. The maximum switching capacity of



Rear View of Two Register Bays; and, in Between, the Rear View of the Translator Switch Bay, Including the Semi-Circular Terminal Strip. With each register is associated two translator switches and between them is a distributing strip by means of which the office prefix and junction routing may be varied at will.

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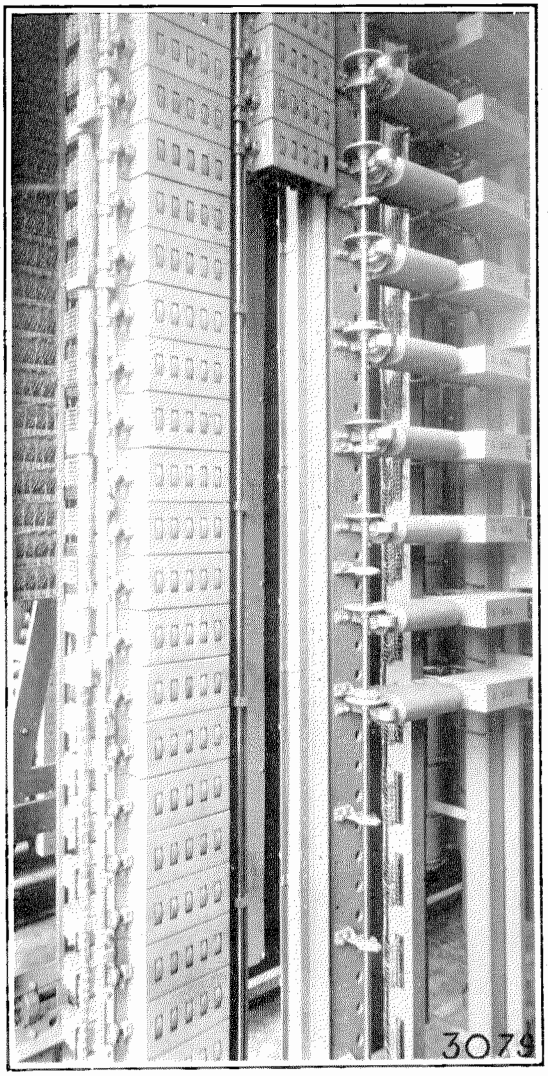
[1] "La Transformation du Réseau Téléphonique de Paris en Automatique," ELECTRICAL COMMUNICATION, Vol. 6, No. 3, January, 1928.

the present full automatic register circuits is 150 office prefixes, or 1,500,000 lines. Allowing for the impossibility of assigning every line, it may be said that the practical switching capacity of the present equipment is between 1,000,000 and 1,200,000 lines. It is estimated that the requirements in the next ten or twelve years will be about 400,000 lines. By the addition of translator switches to the register circuits or by increasing the capacity of the existing switches, the capacity of the area may be almost indefinitely extended.



View of Timed Alarm Devices Which Transfer Grounded Lines and Incompletely Dialed Calls to a Monitoring Desk after a Lapse of Thirty Seconds. The device also gives a visual indication of the time a circuit is held.

The first problem the Administration had to solve was the selection of suitable office prefixes for the entire automatic area, such that no first three letters of any office prefix would be numerically the same as the first three letters of any other office prefix. This was settled as illustrated in the plan for the Paris telephone area.

The lettering and numbering of the Paris dial are very similar to the lettering and numbering of the New York dial. The Paris dial is shown on page 142 of the January, 1928, issue of ELECTRICAL COMMUNICATION and the New York dial on page 91 of the October, 1925, issue.

A fundamental requirement of the Administration was that the system had to be flexible and capable of meeting any reasonable distribution of subscribers' lines and junctions. To meet these requirements the register circuit was designed to permit, among other things, the following:

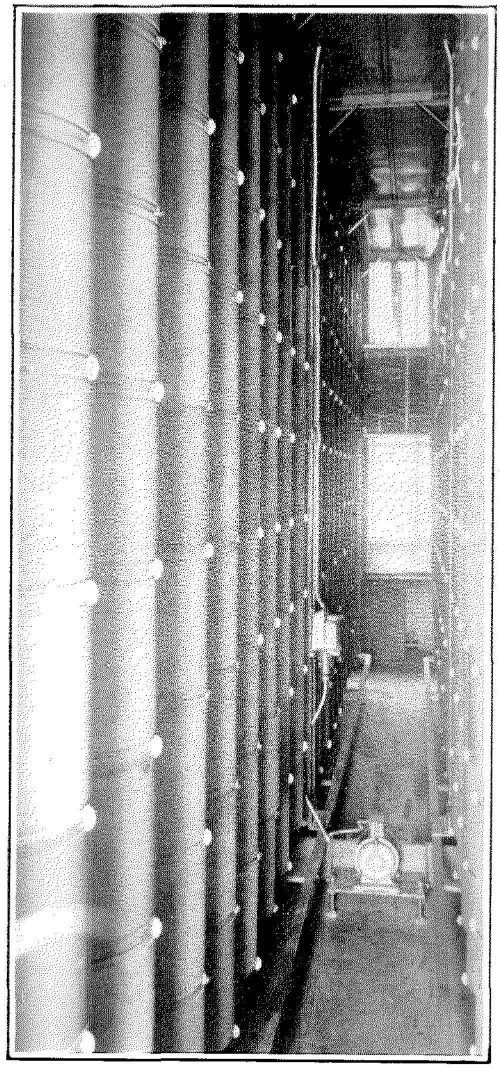
1. An office name may be changed without changing the position assigned to the office in the translator switch. That is, there is no numerical connection between the letters in the office prefix and the position occupied in the translator switch as is usual in systems arranged for office prefix translation.
2. Calls may be completed by direct junctions or passed through one to three tandem offices or selectors.
3. Multiple metering is provided for. By suitably cross-connecting the various positions in the translator switches, calls to the various offices, city and suburban, may be automatically metered one, two or four times, depending upon the rates prescribed.
4. Calls to the special services such as information, recording, etc., are automatically not metered, but the answering operator can meter such calls when necessary by depressing a key.

The present and temporary method of trunking to and from Carnot has been briefly described. The permanent trunking plan is as follows:

Calls from the automatic offices to the manual offices which will remain for some years, will be handled by call indicator positions to be installed shortly in the manual offices.

Calls from automatic offices to those manual offices which will be replaced within the next two or three years, will continue to be handled by the temporary tandem call indicator positions located in the automatic office.

Direct trunking was chosen as the means for establishing connections outgoing from the permanent manual offices to the automatic offices. Order wire trunking, even after many years of continued effort, has not proved entirely successful. Even in America, where a few years ago order wire trunking was universal, it has been replaced to quite a large extent by the so-called "straightforward trunking" system in which the request is passed over the trunk instead of over an order wire. Order wire trunking is costly, slow, and the cause of many errors, prominent among which are double connections and wrong numbers. It requires a high degree of team work, which it is difficult to realise and to maintain, between operators in different offices. The direct trunking plan for Paris is briefly described in the article[2] by Monsieur Pocholle. The equipment of the *A* positions is extremely simple. Each position receives a ten button key set which is in no way associated with the manual cord circuits and a few individual jacks for each office. These jacks are connected to the arcs of finders attached to the outgoing junctions to the automatic offices.



Rear View of Selector and Finder Bays Showing the Manner of Protecting the Rear of All Bays by Sheet Iron Covers, Thereby Guarding the Cable and Wiring Against Mechanical Injury, Dust, etc. The covers also serve to localize any fire which may start in the cabling and wiring.

An operator, upon receiving a request for a subscriber to an automatic office, inserts the calling plug into an idle junction jack assigned to that office. A double connection is impossible as the jack is not multipled on any other position. The operator completes the connection by depressing one after the other the four key buttons corresponding to the wanted number. She cannot depress the keys too quickly providing she depresses each key fully and then allows it to return fully.

Direct trunking equipment of this type was installed by the Bell Telephone Manufacturing Company for the Swiss Government in Bâle, a description[3] of which, by Mr. E. Fry, appears in *Technische Mitteilungen*, the official publication of the Swiss Telegraphs and Telephones. According to this article, *A* operators receiving from the public calls automatically distributed to idle plugs, trunk from 53 percent of the originating calls and complete the remainder in the multiple field before them. The average answering time is 2.34 seconds and the average load per operator during the busy hour is 425 calls. These figures are far beyond anything possible with order wire trunking, and it is expected that the installation of direct trunking equipment on the *A* positions in Paris will not only improve the service but will also save the Administration many millions of francs a year in operators' salaries.

The temporary semi-B positions in the auto-

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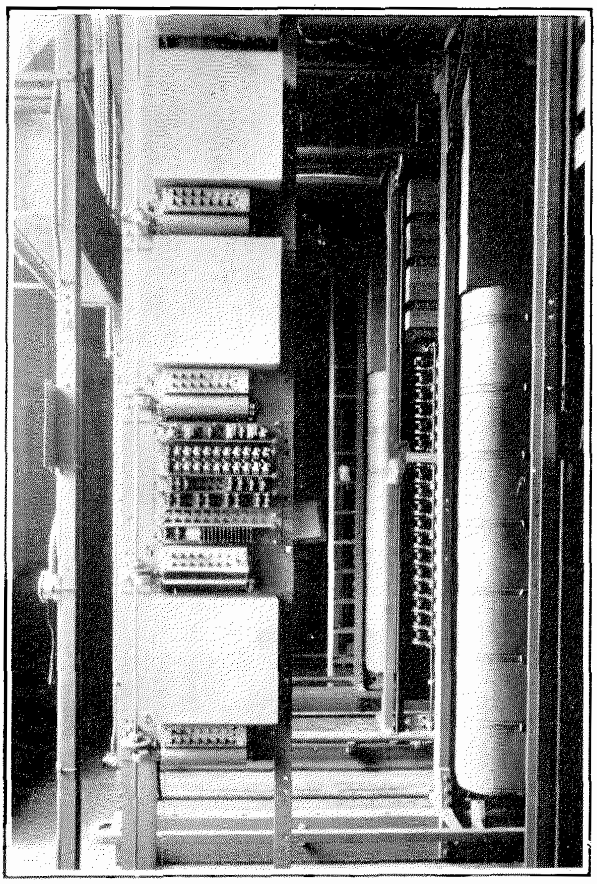
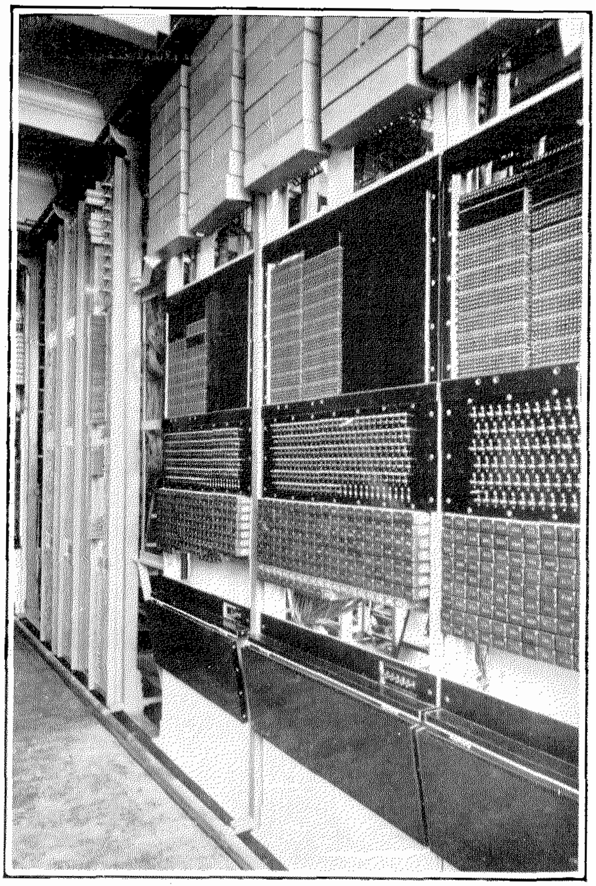
[2] Loc. cit.

[3] "Les centrales téléphoniques locales de Bâle," *Technische Mitteilungen*, Issues 2 and 3, 1928.



One of the Routine Test Bays with Equipment in Position for Four Final Selector Routine Test Circuits.



Front View of Three Automatic Traffic Recording Positions. The single conductor jacks for the second, third and fourth selectors are shown above. Next are the single conductor plugs and associated keys and near the bottom the service meters. At the extreme left are shown two monitoring and service observation positions.

matic offices will be retained for the next two or three years to handle calls incoming from the temporary manual offices.

During the ten or twelve years that it will take to eliminate manual offices from Paris and suburban areas, automatic offices will be installed at random in both areas.

Calls between an automatic office in the suburban area and an automatic office in Paris will be completed in exactly the same manner as a call between two Paris offices, the only difference being that a successful connection will be metered twice instead of once. Calls from one automatic office in the suburban area to another automatic office in the suburban area will also be completed automatically in the usual way. The charge here, however, may involve one, two, or four operations of the meter, depending upon the distance. The routing of the junctions may be made in the most convenient and direct manner.

During this transition period the suburban area will be divided into four districts as indicated on the plan for the Paris telephone area, each district being reached from the city or vice versa through a tandem centre indicated by small black squares. These tandem centres are now in course of construction and will be in operation the early part of next year. A Paris automatic subscriber desiring a connection with a manual suburban subscriber will dial the full number listed in the directory. The number will appear upon a number indicator before the proper tandem call indicator operator. The operator will complete the call manually. When the calling party hangs up after a successful connection, his meter will automatically operate twice. It will be seen that as far as the Paris automatic subscriber is concerned, the method of calling a subscriber in the suburban area is the same, whether that subscriber is connected to a manual office or to an automatic office.

Incoming calls from a suburban area to Paris will go into the same tandem office but on positions equipped for direct trunking to the desired automatic office or to call indicator positions in the manual offices so equipped.

Two number short haul toll calls require no special comment. The subscriber dials the proper special service two-digit number and arrives at the short haul toll board. The wanted party is obtained manually and a ticket is made out for the call.

For long distance calls, a manual switching section is provided, so that the completion of long distance calls is the same as in a manual office.

There are no party lines in Paris, only main and P.B.X. lines, and multiple metering requires that each line shall have a service meter.

As lines without toll deposits are refused long distance service, sections of the equipment are arranged to send calls for recording from such lines to special operators.

Acknowledgment

In conclusion, the author wishes to acknowledge the whole-hearted cooperation received, first, from the engineers of the French Telephone Administration and, later on, from all branches of that Administration. The rapid completion of plans and the subsequent rapid execution of the work could not have been achieved had not the Administration shown, in the most conclusive way, its real desire to be helpful. It has been a great pleasure to all who have been personally involved in this project, to have been able to have worked under such satisfactory conditions.

Sloane Exchange, London

By R. W. FRASER

Engineering Department, Standard Telephones and Cables, Ltd.

Introduction

WITH the introduction of the new automatic exchange at Sloane, another important stage in the conversion to automatic working of the London telephone area was completed. Cutover was successfully accomplished at midnight on Saturday, July 28, 1928, when 5,100 lines were transferred to the automatic equipment.

When the British Post Office decided to adopt for London that particular modification of the Step-by-Step system which provided the translation facilities which are so valuable in a great metropolitan area, a large amount of development work remained to be done before the system could satisfactorily meet the requirements which are considered essential by the British Post Office for good public service, and the operating conditions standardised and specified by the Post Office Engineers. This development was undertaken by the various manufacturers in conjunction with the Post Office Engineers. The Sloane equipment, installed to the specification of the British Post Office, is typical of the Step-by-Step Register-Translator system adopted for the service of the largest cities of Great Britain. Similar equipments are being installed by Standard Telephones and Cables, Ltd., at other exchanges in the London area including Bermondsey, Temple Bar, Langham and Fulham.

The new Sloane exchange which has an initial capacity of 8,400 lines, is located in a new building in Sedding Street, off Sloane Square. On the ground floor of this building, a temporary manual exchange of about 4,000 lines is accommodated. On the introduction of the automatic exchange it was planned to transfer these 4,000 lines together with other lines, which are at present accommodated in adjacent manual exchanges, to the new automatic exchange.

Trunking Scheme

The trunking scheme of Sloane Exchange showing the routing of local, outgoing, and incoming traffic is given in Figure 1. The numbers showing switch quantities on this diagram give some indication of the amount of equipment involved.

The fundamental trunking plan is the same as in other register systems in that the calling subscriber does not have direct control of the setting up of all the switches involved in a call, the dialed impulses being first received by the register apparatus (*A* digit selector and register-translator) and the call being then routed through the switching plant by trains of impulses sent out from that apparatus. In the London area a 7-digit dialing scheme has been adopted, the digits comprising the first three letters of the called exchange name and four numerals. The register equipment is designed to translate the first three digits into any other digits up to six in number according to the desired routing of the call. The four numerical digits are of course sent out unchanged since these operate the numerical and final selectors in the case of a call to the local or another automatic exchange and are displayed at a call-indicator *B* position in the case of a call to a manual exchange.

The arrangement of letters and figures on the dial is shown in Figure 2.

When a subscriber lifts his receiver to originate a call the line switch associated with his line is energised and hunts for a free first code selector. The *A* digit selector finder associated with this switch is then energised and connects the calling line to a free *A* digit selector from which dial tone is received. In response to the first or *A* digit dialed by the subscriber, this selector steps to the level corresponding to the numerical equivalent of the digit and hunts, in the same way as a group selector, for a free register-translator in the group associated with that digit. The second and third (or *B* and *C*) digits and the four numerical digits are received by the register-translator.

When the *B* and *C* digits have been received, the register-translator commences to send out the translated digits over a path which has been established through the *A* digit selector and

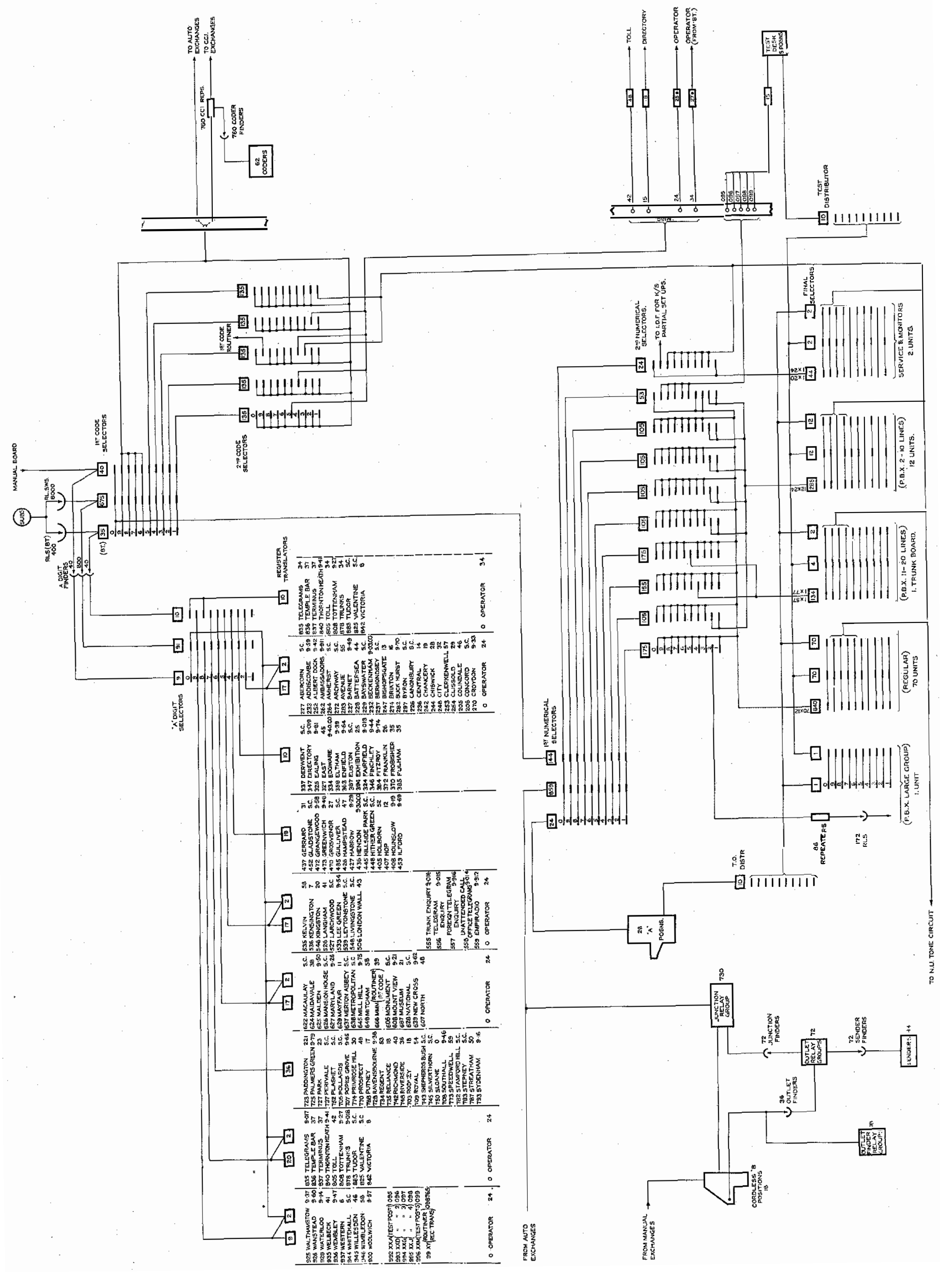


Figure 1—Switching Scheme. Sloane Exchange.

finder to the first code selector which receives the first translated code digit. This path is then extended step by step through the switching equipment, according to the digits sent out by the register-translator. When the last numerical digit has been sent out, the *A* digit selector and register-translator clear down and the calling line is switched through at the first code selector to the talking circuit which has been built up through the subsequent switches.

Figure 2—Dial.

In Figure 1, the names of London exchanges are grouped according to the *A* digit selector level from which they are reached. In order to avoid difficulties due to faulty preliminary impulses, the arrangement of the letters in the dial is such that the *A* digit is never 1, and the *A* digit selector is designed to release and restore to normal should it be stepped up to the first level by a preliminary impulse.

Level 0 of *A* digit selectors gives access to a group of special register-translators which must operate as soon as they are seized by a subscriber dialing 0. These register-translators are also made accessible from one of the later choices of other *A* digit selector levels. This is indicated in Figure 1 where the 10 zero-level register-translators are shown distributed between levels 2, 5, 6, 7 and 9. When reached via a level other than the 0 level, the zero register-translator operates as a regular switch. This is effected by means of a shunt-field relay in the register-translator, one winding of which is normally energised from the first code selector in the direction which prevents the operation of the relay. Between level 0 of *A* digit selectors and the register-translators reached from that level, the two lines are crossed so that the shunt-field relay operates as soon as the *A* digit selector cuts through.

In the list of exchange names shown in Figure 1, the numerical equivalent of the first three letters of each name is shown at the left and the translated code digits indicating the routing of traffic to that exchange are shown to the right of the name. Local traffic is routed direct to first numerical selectors from level 0 of first code selectors, the code translation for SLOane being 0. Traffic to a number of exchanges whose community of interest with Sloane is small, or which are too far from Sloane to warrant direct junctions, is routed in one block via level 9 of first code selectors to the Tandem exchange; the remaining digits of the translations operate on the selectors at Tandem to route the call to the particular exchange required.

The traffic to the three exchanges, Western, Kensington, and Victoria, is of such volume as to warrant its being trunked direct from first code selectors, and levels 6, 7, and 8 respectively are, therefore, allotted to these exchanges. The remaining five first code selector levels give access to five groups of second code selectors, each group carrying the traffic to a number of exchanges. The allocation of second selector levels to particular exchanges is indicated in the list of translations.

A subscriber wishing to make a trunk call dials the digits TRU. The translated digits 902 route the call through Tandem and connect his line to a recording position at the Trunk exchange. The final trunk connection which involves the re-call of the calling subscriber, is established via the cordless *B* board mentioned later in connection with incoming traffic from manual exchanges.

A call to any exchange reached through the London Toll exchange is made by dialing TOL. These digits are translated to 42, establishing a connection between the calling line and the Toll exchange switchboard. The Toll operator obtains particulars of the call from the subscriber and completes the connection to the called exchange.

Similarly the digits TEL are dialed when it is desired to reach an operator in the Phonograms

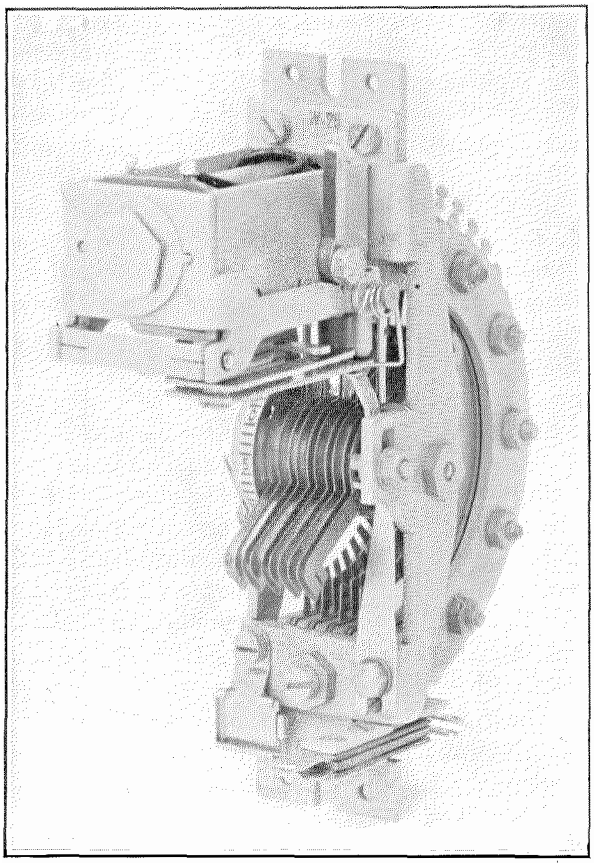


Figure 3—Subscriber's Line Switch.

Office for the transmission of a telegram by telephone and the digits DIR when any Directory service is required.

For any special services such as Enquiries, Assistance, or Information, the subscriber dials 0. This digit is received by the *A* digit selector and gives access to one of the special group of register-translators reached from the tenth level. As soon as one of these register-translators is taken from level 0 it commences sending out the translation 24, which routes the call over one of a group of lines terminating in calling equipment associated with answering jacks at the manual *A* board.

Subscribers who for any reason do not wish to have trunk service given on their lines, are connected to special groups of first code and *A* digit selectors. From levels 0 and 8 of these *A* digit selectors, access is given to a special group of register-translators which have a common translation for 0, TRU, TOL and TEL, this translation being different from those given for the corresponding calls from other subscribers. Thus a "barred trunks" subscriber calling Trunk, Toll or Telegrams, or dialing 0 for assistance, is connected via a special group of lines to an operator who deals with all such calls from these subscribers.

The call indicator method adopted by the British Post Office, for handling traffic from automatic to manual exchanges in the London area, differs from methods previously used, in that a call instead of being stored in the manual office if the operator is not ready to deal with it

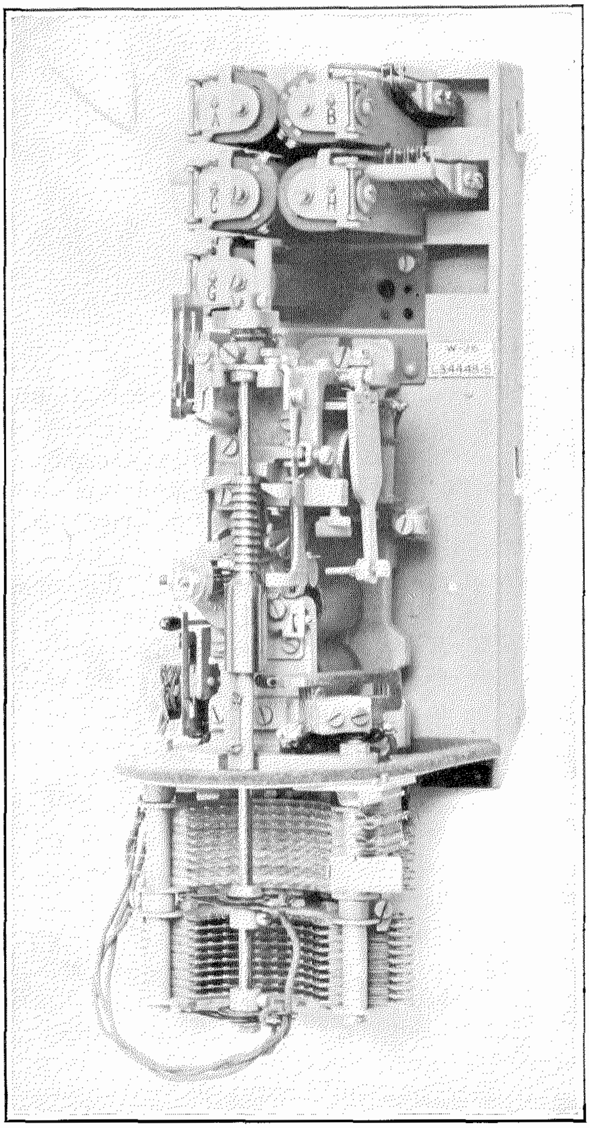


Figure 4—Group Selector.

at once, is held in the automatic exchange. This necessitates a scheme for transferring the call rapidly over the junction as soon as the position becomes free to receive the call, and has resulted in the development of the "code system," in which the call is first routed by the register-translator to a coder in the local exchange, the coder being temporarily associated with the outgoing junction by means of a repeater and coder finder. The coder receives and stores the four numerical digits and allows the register-translator to clear down in the same way as in a call to an automatic exchange. When the manual end is ready, the four digits are transferred over the junction, not as a series of step-by-step impulses, but as a code of short impulses of different polarity and strength. These impulses are received and decoded by special apparatus at the manual end, the four digits being ultimately displayed at the call indicator position. As soon as the coder is discharged it clears down and the coder call indicator repeater switches the connection through from the last code selector level to the outgoing junction.

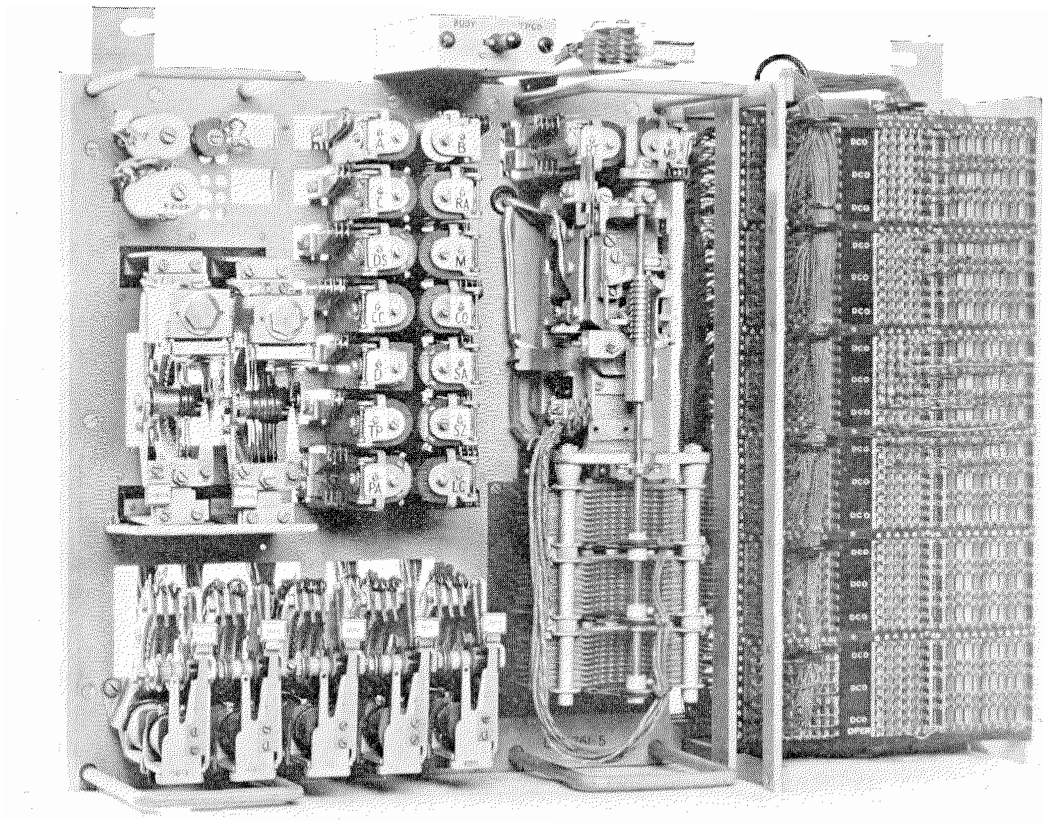


Figure 5—Register-Translator.

Incoming traffic from manual exchanges, including that from Trunk and Toll is handled on an order wire basis at a group of cordless *B* positions. Each incoming junction terminates in a junction relay group giving access to a particular selector (as indicated in Figure 1) and has associated with it at the position an assignment key, a two-position key designated "order wire emergency" in one position and "disconnect" in the second position, and a junction lamp which glows when the junction is busy. The ultimate capacity per position is 50 junctions but in the initial equipment the positions are equipped for a maximum of 40.

The position key set, used in setting up the call, consists of a strip of 10 keys of the vertical

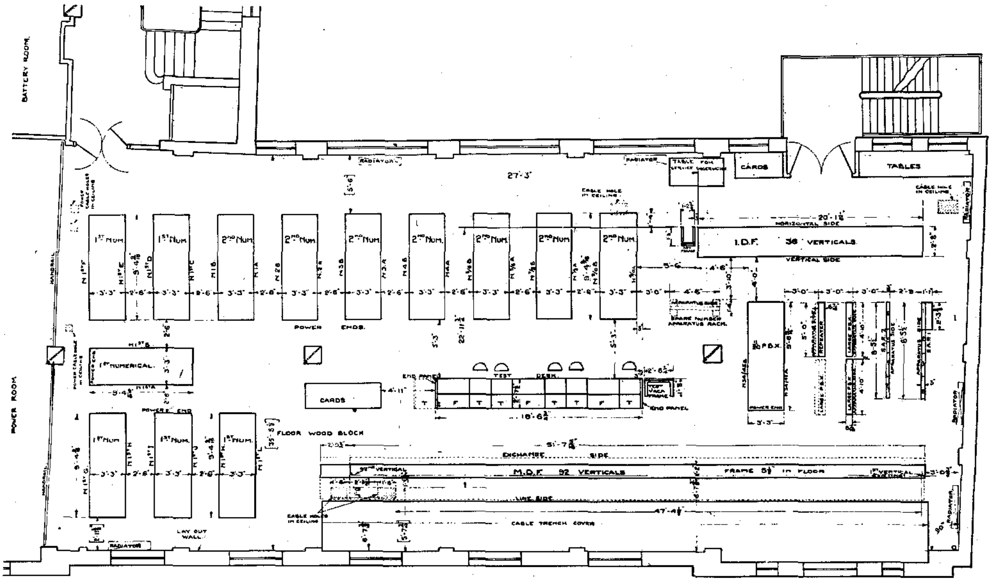


Figure 6—Floor Plan, First Floor.

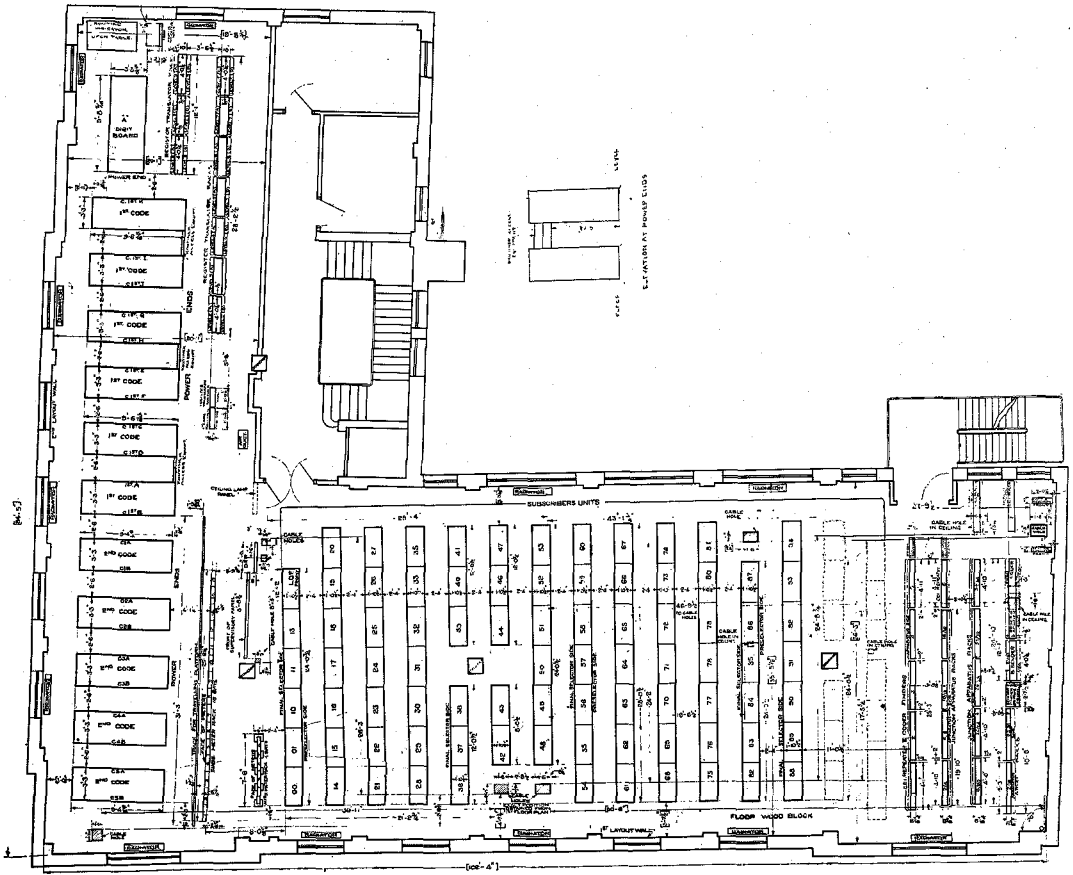


Figure 7—Floor Plan, Second Floor.

push button type numbered 1 to 9 and 0. Above these is a cancel key of the same type, by means of which the *B* operator can cancel the call, if, before completing key-sending, she realises that she has set up a wrong digit.

Two outlet finders (used on alternate days) are allotted to each position and give access to one of the four outlets allotted to a position. The change-over from one finder to the second is effected by means of a key at the position.

An outlet comprises a relay group, a sender finder and a junction finder and serves to connect the position key set to the sender, and the sender to the junction relay group and numerical selectors. Each outlet has associated with it at the position a busy key, by means of which a faulty outlet may be busied, and a lamp which glows whenever the outlet is engaged.

When a call is received on an order wire, the *B* operator allots a free junction to the *A* operator at the same time depressing the assignment key corresponding to the junction. The operation of the assignment key causes the sender finder to hunt for a free sender and the junction finder to hunt for the assigned junction relay group. When a sender is found, the digit key set is connected to it via the outlet relay group and finder and the junction lamp glows indicating to the operator that the sender is ready to receive the call. Meanwhile the *A* operator takes up the assigned junction.

Should the *A* operator take up an unassigned junction the corresponding junction lamp flickers. By operating the assignment key of this junction the *B* operator cancels the first assignment. The flicker ceases as soon as the new assignment is made and the lamp glows when a sender is found.

The four digits of the required number are set up in the sender by the successive operation of the corresponding four digit keys at the position. When the last key has been operated the outlet finder steps on to the next outlet, allowing the operator to proceed with another call while the sender automatically sends out, to the numerical

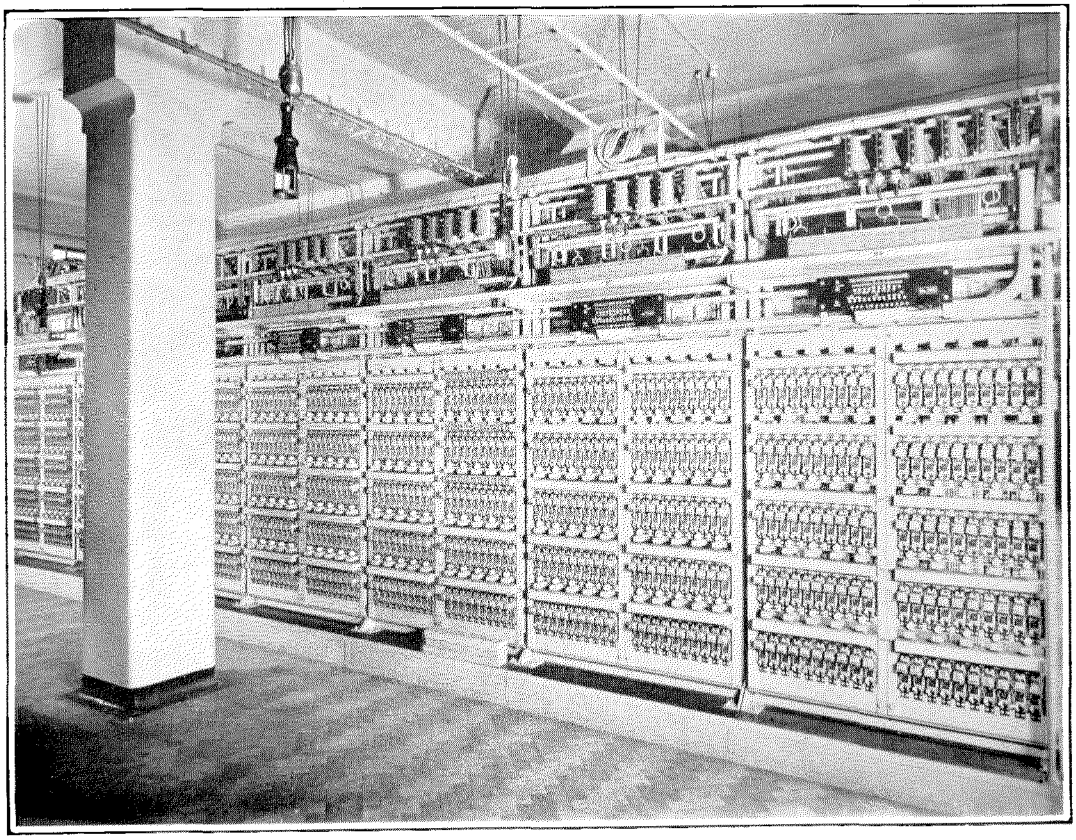


Figure 8—Suite of Line and Final Units—Line Switch Side.

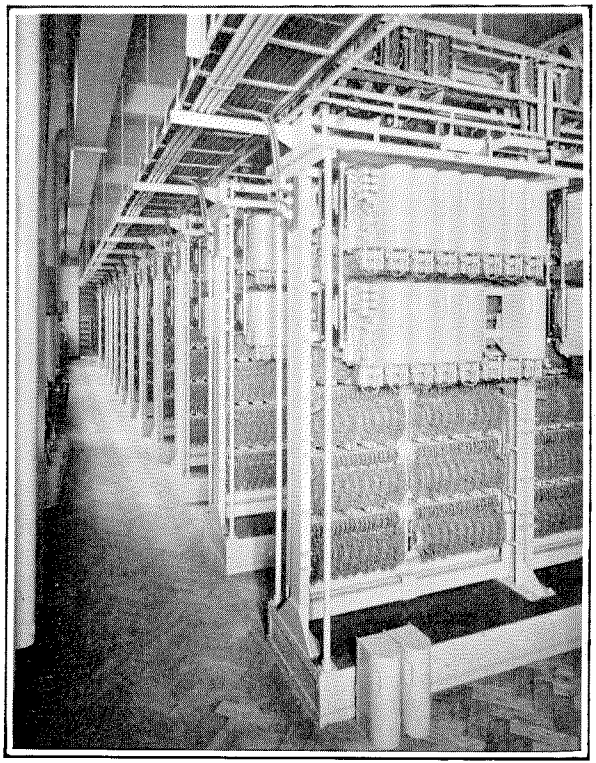


Figure 9—Line and Final Units—Final Selector Side.

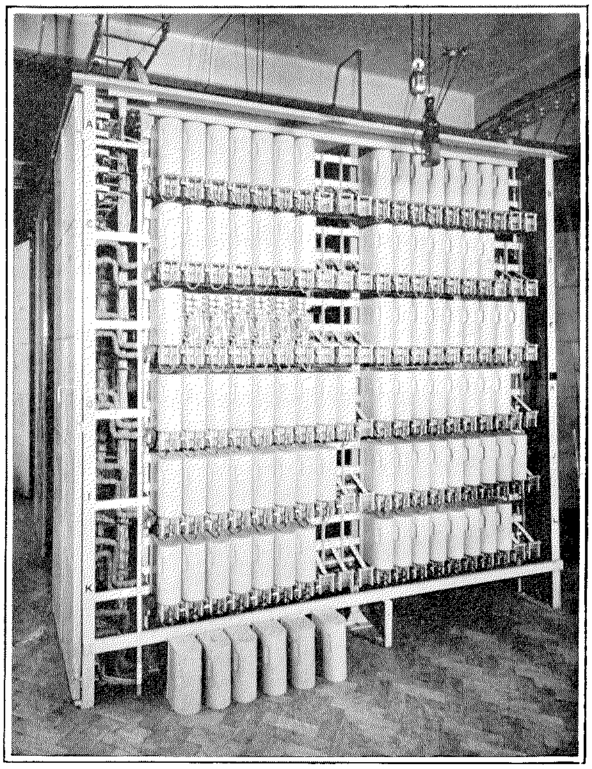


Figure 10—First Numerical Selector Board.

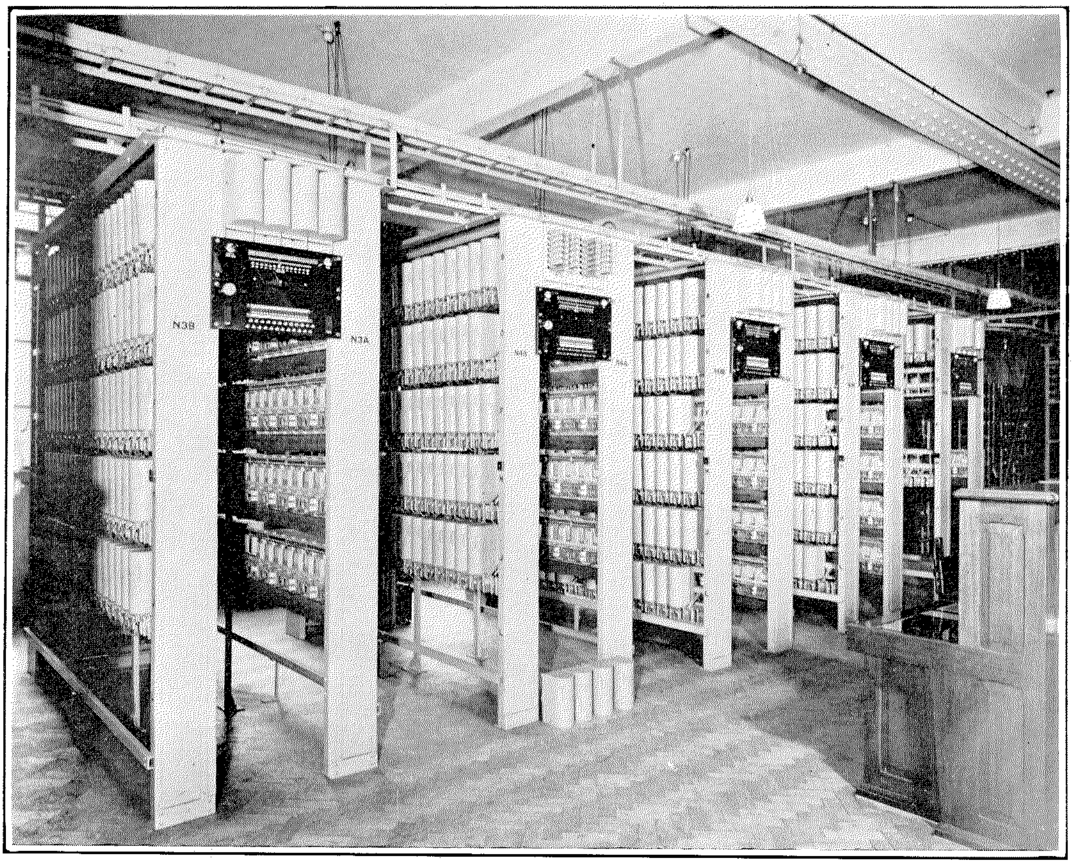


Figure 11—Second Numerical Selector Boards—Power Ends.

and final selectors, the four trains of impulses corresponding to the four digits which have been set up. When sending is complete the sender clears down and the junction relay group switches the connection through from the *B* position to the selectors, while the common apparatus is released and becomes free for another call.

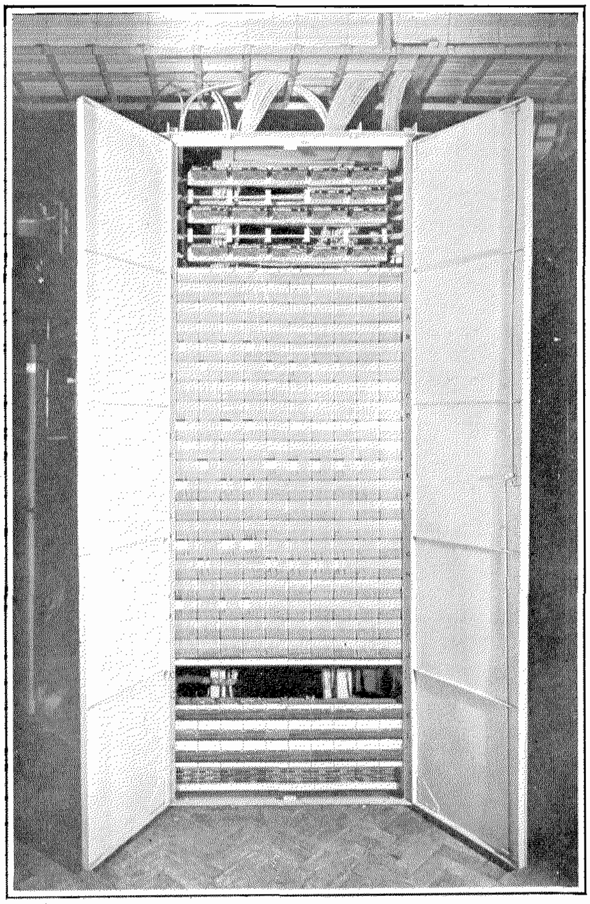


Figure 12—Grading on First Numerical Selector Board Terminal Assembly.

Supervision is left entirely to the *A* operator; the junction lamp at the *B* position is extinguished, and the apparatus set up in the automatic exchange is released when that operator withdraws the plug from the outgoing junction.

In the event of the called subscriber being engaged or of an eleventh step busy on a numerical selector, the busy signal is passed back to the *A* operator and to the calling subscriber by the automatic apparatus.

The disconnect key associated with the junction is used to disconnect, and prevent the use of, any junction if a call is not in progress. With the key in the "disconnect" position the junction lamp glows indicating that the junction is not to be used. The key is thrown when tests are being made on relays in the junction relay group, or if the junction or relay group is faulty.

A faulty order wire is disconnected by means of an order wire disconnect key at the *B* position and by throwing a junction key to the "order wire emergency" position that junction may be used as an order wire.

Since there is a transmission bridge in the first code selector as well as in the final selector there is no need for impulse repeaters on lines outgoing to automatic exchanges. The CCI repeaters in lines to manual exchanges are required for connecting the coder to the junction and provide no transmission feed when the final connection is established.

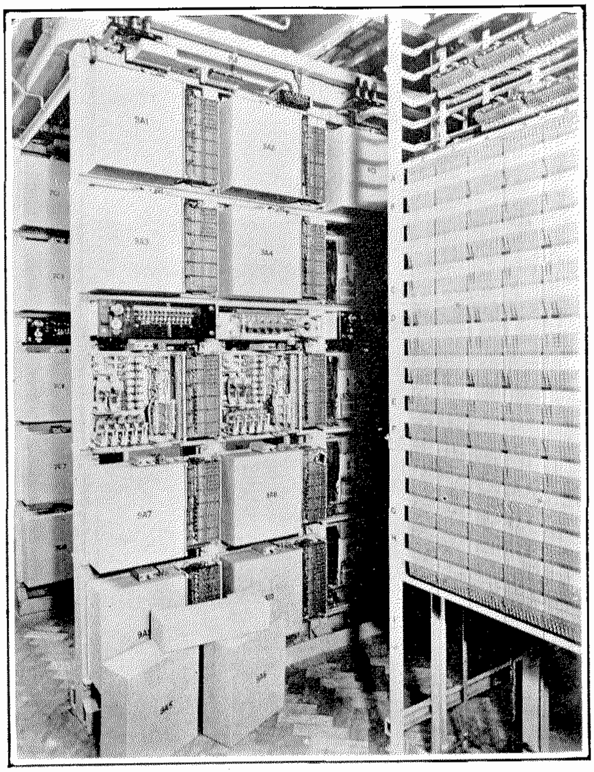


Figure 13—Register-Translator Rack and *A* Digit Selector Board Terminal Assembly.

The local switch train in a call to automatic or manual exchanges is held by the first code selector. In a call incoming from an automatic exchange, the incoming switch train is held by the final selector and in a call from a manual exchange a transmission bridge in the junction relay group is under the control of the *A* operator at the manual exchange and provides a loop forward to the final selector which holds the first and second numerical selectors over the release trunk.

The relay groups provided in the lines to special services (directory and assistance) are required to provide signaling facilities.

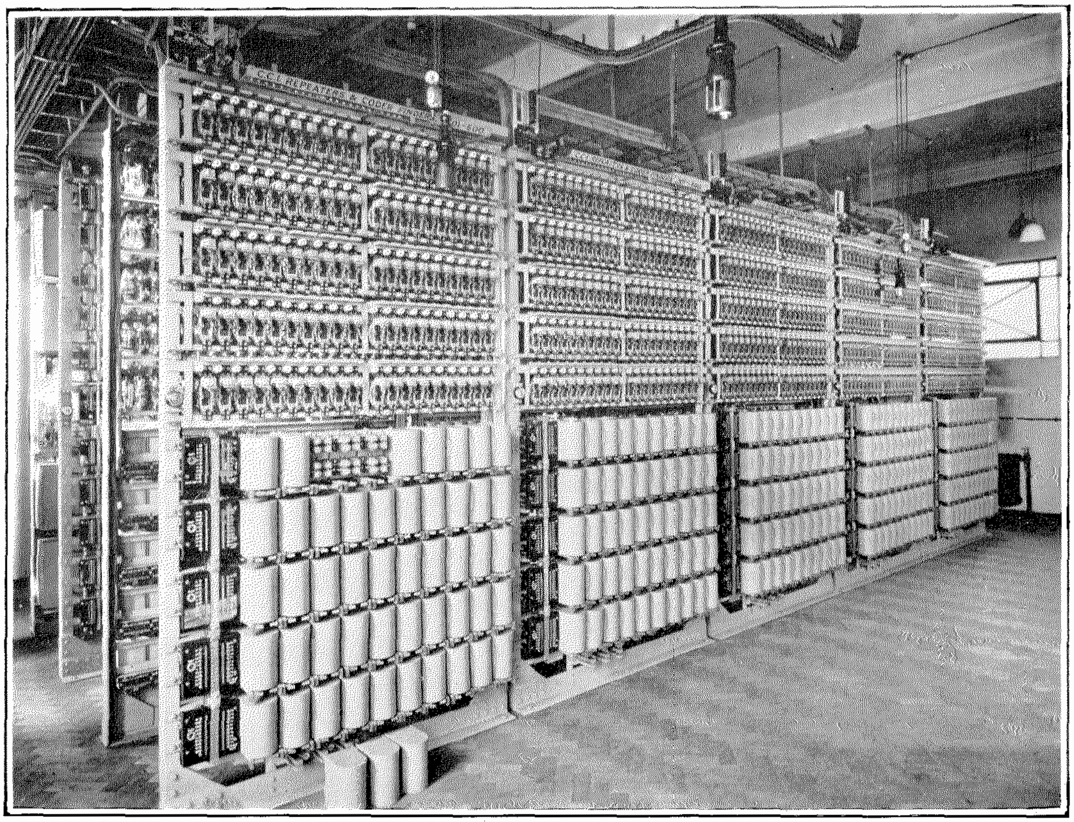


Figure 14—CCI Repeater and Coder Finder Racks.

Apparatus

In order to comply with British Post Office requirements, the register-translator system has been built up on the general type of apparatus which has become practically standard in Step-by-Step systems. Typical switches as used in the Sloane equipment are shown in Figures 3 and 4, and with the exception of the minor switches used in the register-translator, the whole of the switching plant, including the larger switch units such as register-translator, sender and coder, is built up on these two types of switches. The arrangement of apparatus in the register-translator assembly is shown in Figure 5.

The subscriber's line switch and the various finder switches indicated in the switching scheme diagram are of the type shown in Figure 3. Since the outlets from the banks of line switches, *A* digit selector finders and coder finders are graded, these switches are of the homing type, so that only 24 of the 25 points are utilised, the wipers resting in the home position on the first set of contacts. The junction finder is equipped with a double bank and two sets of single-ended wipers in the manner normally adopted to provide a 50-point switch.

All code, numerical and final selectors in the Sloane equipment, with the exception of the final selector for large P.B.X. groups, are of the type shown in Figure 4. Group selectors arranged to hunt over 20 outlets in one level are not installed, though these are being adopted in later exchanges which are being installed in the London area by Standard Telephones and Cables, Ltd.

Small P.B.X.'s with not more than 10 exchange lines are reached through final selectors which are designed to commence hunting over the P.B.X group if the first line reached by dialing is found busy. If all lines are busy, the wipers stand on the last line without being electrically connected to it, while the "busy" signal is sent back. The switch is also designed to give access to individual lines so that, if desired, both P.B.X. and individual lines may be accommodated on the same level, as long as the lines to one P.B.X. are consecutive.

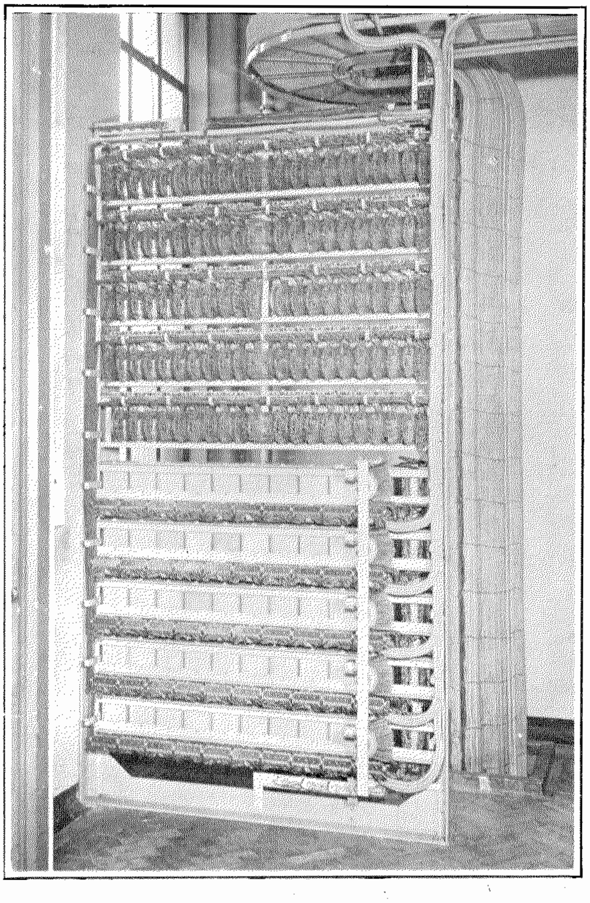


Figure 15—CCI Repeater and Coder Finder Rack—Rear View.

The 11–20 line P.B.X final selector is constructed on the lines of the 20-group selector. The P.B.X. group is reached when the tens digit of the directory number is dialed and the switch then automatically hunts over the P.B.X. group testing two lines in each position.

In the initial equipment of Sloane exchange there is only one P.B.X. having more than 20 lines. The final selector giving access to this P.B.X. consists of two 50-point rotary switches and an associated relay group. In the Sloane switching scheme the P.B.X. is reached when the hundreds digit has been dialed. Hunting is delayed until the tens digit has been received, after which one of the switches commences to hunt over 49 lines and if it fails to find a free outlet, the second switch hunts over the remaining lines in the group. If all lines are engaged, the "busy" signal is returned from the last point of the second switch. A final selector of this type gives access to a maximum of 97 lines.

Figure 16—Coder Racks and Junction Apparatus Racks.

With the trunking arrangement used in Sloane, the large group P.B.X. takes up 100 numbers in the exchange numbering scheme. In later exchanges, where the number of large group P.B.X.'s would involve the suppression of an abnormally large number of directory numbers, an additional switching stage is introduced, the P.B.X. final selector being reached from a third numerical selector.

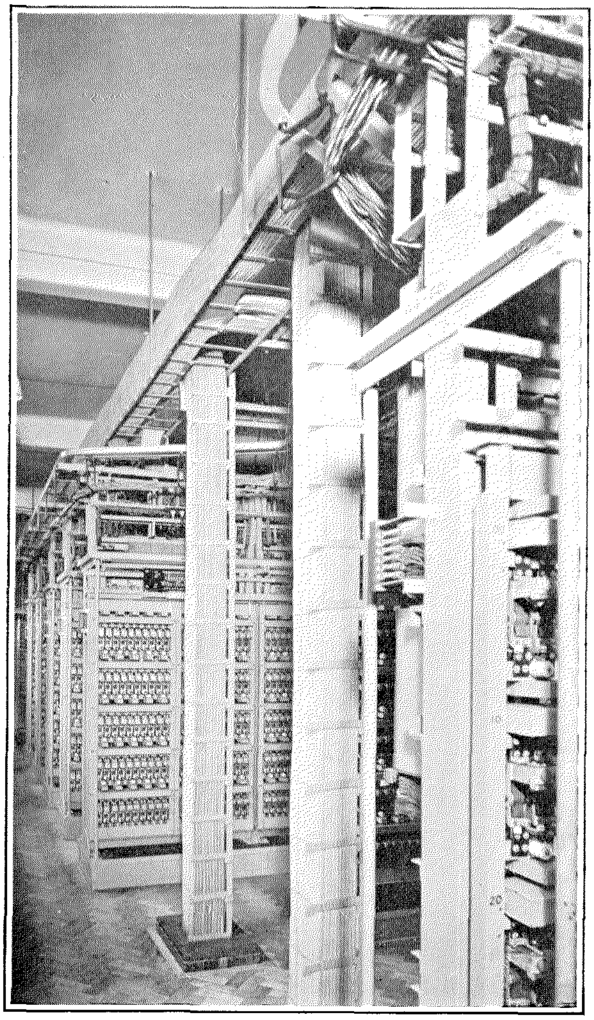


Figure 17—Cabling from MDF to Line and Final Units.

The various relay groups, such as junction relay groups, CCI repeaters, etc., are mounted one or two circuits per base on standard base plates. Figures 14 and 16 show some typical groups.

Equipment

The layout of the automatic equipment on the first and second floors is shown in Figures 6 and 7, and some typical views showing methods of mounting apparatus are given in Figures 8 to 16. Figure 8 shows the line switch side of a suite of seven line and final units, the line switches and associated line and cutoff relays being mounted 100 per unit on two gates carrying 50 each. The arrangement of the final selector side of the rack is seen in Figure 9.

Double-sided racks of the type shown in Figure 10, are used for mounting all code and group selectors, *A* digit selectors and 11–20 P.B.X. final selectors. In Figure 11 a view is given of the power ends of a number of second numerical selector boards.

The grading between selector stages is carried out on terminal assemblies located at the end of the selector boards. A typical example of this grading is shown in Figure 12. The selector banks are multipled in half shelves of 10, the multiple from the bank of each half shelf of selectors (designated A, B, C, D, etc., on each side of the board, as shown in Figure 10) is brought out to the terminal assembly, the 10 outlets from each of the 10 levels (numbered 1 to 9 and 0 in Figure 12) being arranged in one horizontal row. In the example shown in Figure 12, only 10 half shelves per side are equipped. The grading of the outlets from each level is then carried out by commoning up with lengths of bare cadmium copper wire.

Figure 13 indicates the method of mounting register-translators, 10 on each side of the rack.

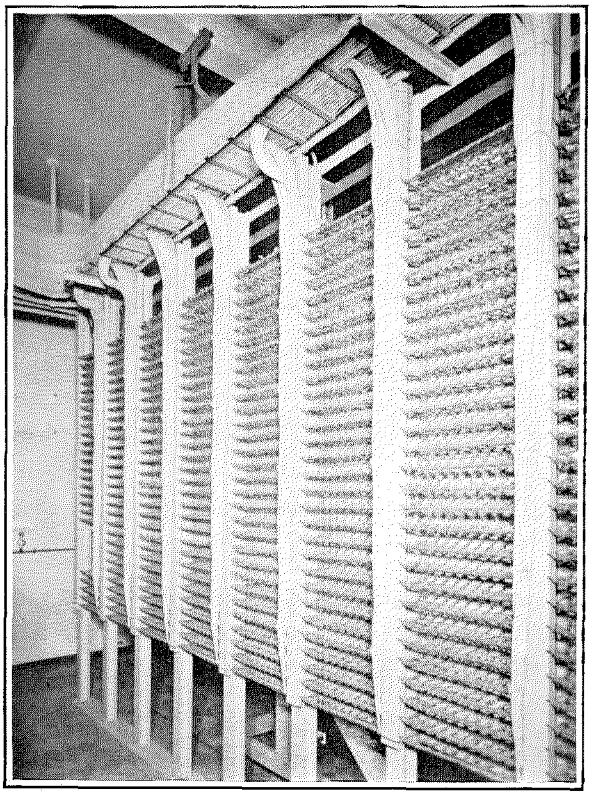


Figure 18—Subscribers' Meter Rack—Rear View.

In order to facilitate the replacement of a faulty register-translator panel, the panels are arranged to jack into position on the rack and are secured by wing nuts which are easily accessible. The impulse machine which operates the interrupter springs associated with all the register-translators on one side of the rack, jacks into position alongside the fuse panel. The machine consists of a small motor, which by means of an eccentric on its shaft, imparts a reciprocating motion to the common rod controlling the moving spring of each springset. To ensure that the impulse speed for all machines shall be the same, the motors are all driven from a common motor alternator, the speed of which is controlled within limits of ± 2 percent.

On the right of Figure 13 a portion of the terminal assembly end of the *A* digit selector board is seen, the doors being removed to show the grading between *A* digit selectors and register-translators.

Figure 14 shows a suite of 5 CCI repeater and coder finder racks. Each relay panel mounts the apparatus for two repeater circuits, the complete rack capacity consisting of 100 repeater circuits and 100 finders. A rear view of the CCI repeater rack showing wiring and routiner access equipment is given in Figure 15.

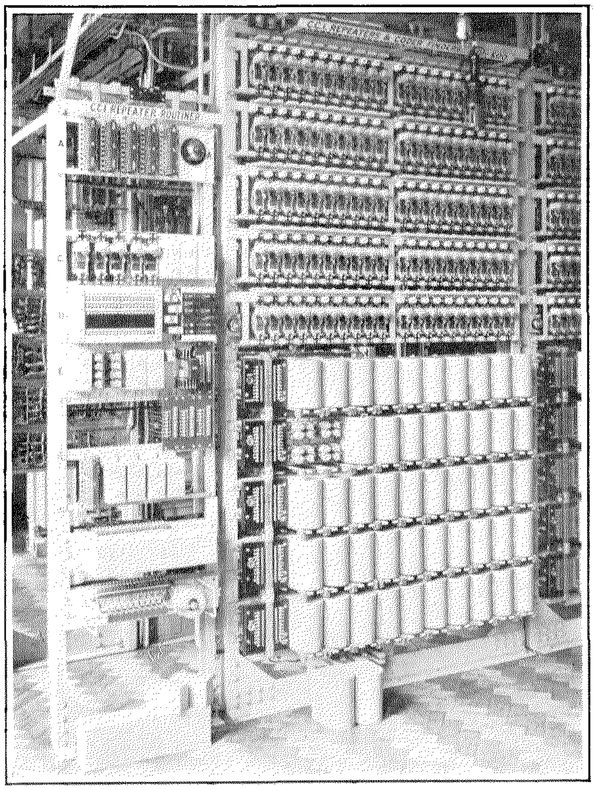


Figure 19—CCI Repeater Routiner.

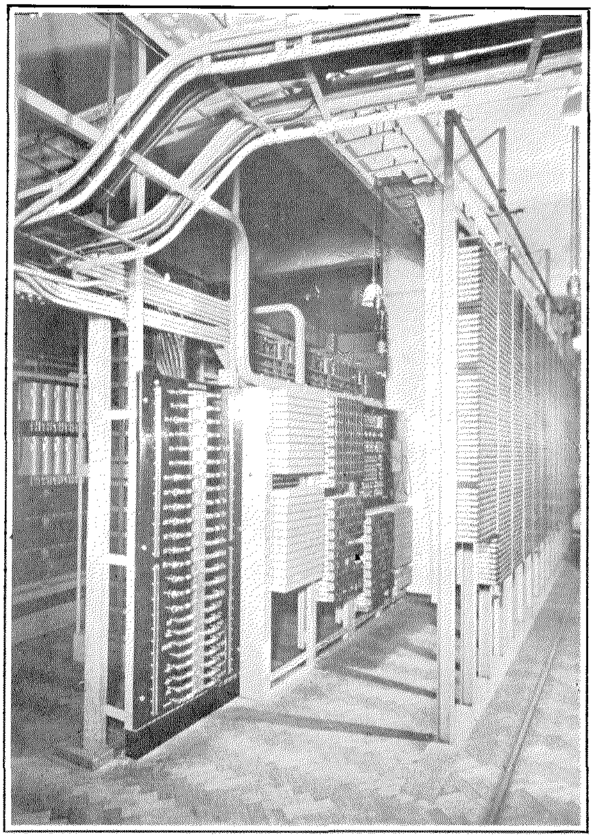


Figure 20—Distribution Fuse Panel (Second Floor), Power Supervisory Apparatus and Subscribers' Meter Rack.

The coder rack (Figure 16) is of the same type as the register-translator rack. Two coders are mounted as one unit which jacks into position on the rack and the complete rack equipment consists of 40 coders. One impulse machine, with motor, is mounted on each side of the rack.

Figure 16 also shows a suite of junction apparatus racks. Each rack is designed to carry the junction relay groups for two cordless *B* positions, the present equipment being 80 circuits and the ultimate capacity 100. This rack also mounts the 8 junction finders associated with the two positions. Outlet racks each designed to carry the equipment for ten positions are used to mount the remainder of the outlet apparatus.

Two typical cabling views are given in Figures 17 and 18. The former shows the cabling from the M.D.F. on the first floor to the line and final units on the second floor. The other shows the cabling at the rear of the subscribers' meter rack.

Maintenance and Testing

The maintenance and routine testing of a large register-translator installation constitutes a formidable task. This has, however, been simplified by the introduction of automatic routiner equipment which is being specified by the British Post Office for all such exchanges.

This equipment is designed to carry out a series of routine tests on each of a particular group of circuits, the tests proceeding from circuit to circuit automatically, until the whole group has been tested or until a fault is found. The nature of the particular fault is indicated by one of a series of lamps. These automatic routiners are provided for register-translators, first code selectors, CCI repeaters, coders, junction relay groups, senders, 11–20 and 21–97 P.B.X. final

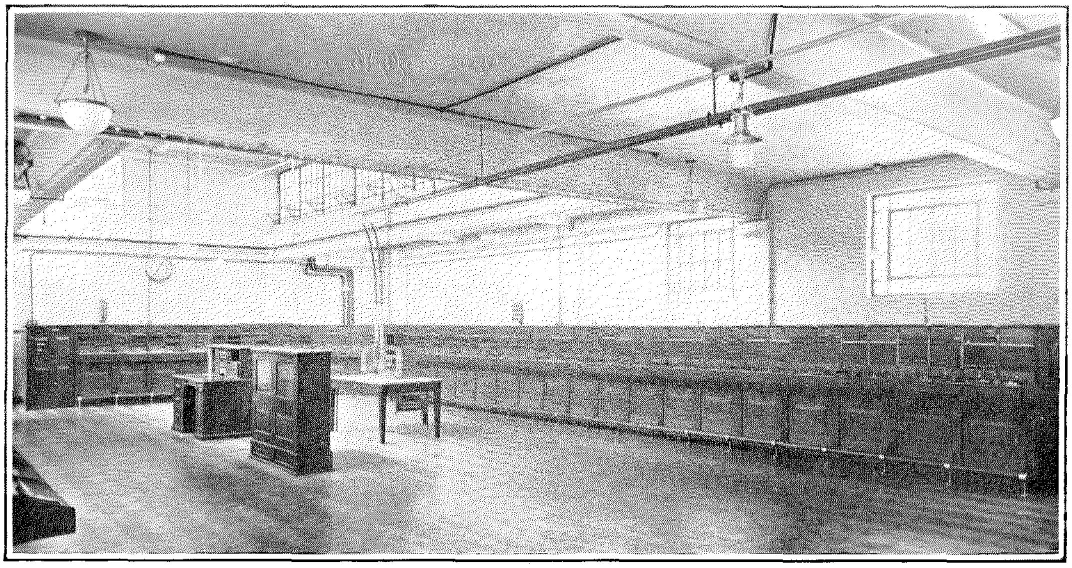


Figure 21—Manual Operating Room—*A* Positions.

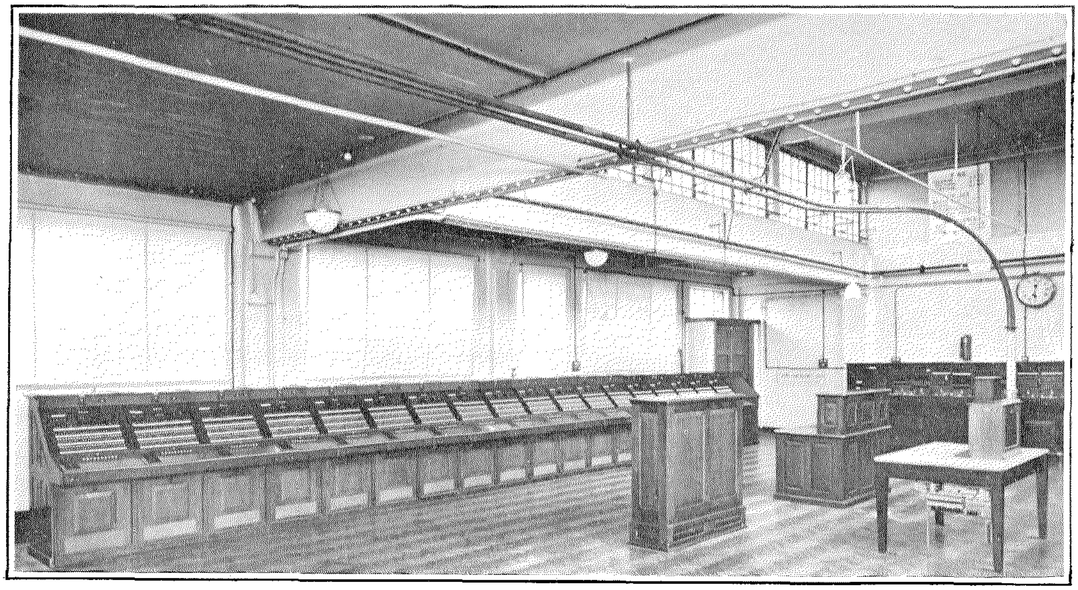


Figure 22—Manual Operating Room—Cordless *B* Positions.

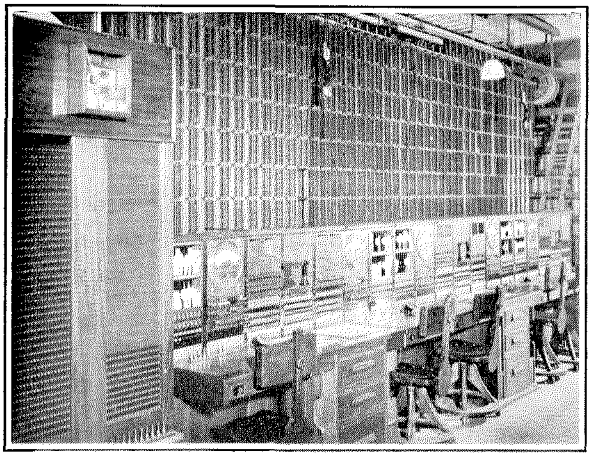


Figure 23—Test Desk and MDF.

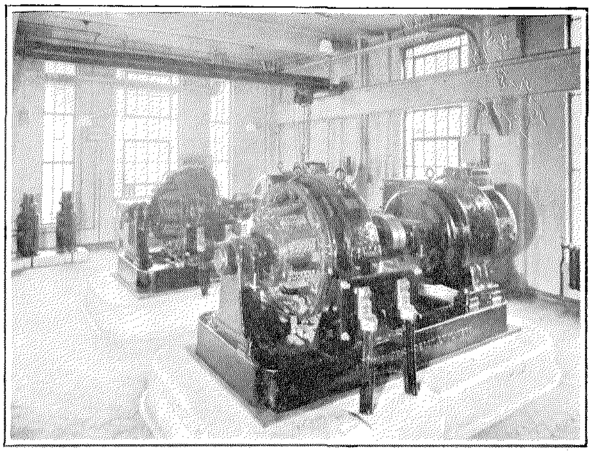


Figure 24—Machines.

selectors. The CCI repeater routiner is shown in Figure 19. To connect the routiners to the apparatus under test, access equipment is provided at the apparatus racks. The routiner access equipment for CCI repeaters is shown in Figure 15. This method of mounting the access equipment will only be used at Sloane, where the routiner equipment was ordered after installation of automatic equipment had commenced.

The common supervisory and alarm apparatus for the automatic and power equipment, including time alarm relays used on delayed alarm circuits and ceiling lamp relays, is mounted on the supervisory panel, shown in Figure 20. The supervisory apparatus particular to a unit is mounted at the unit. In the case of the selector board, for example, this apparatus is mounted above the fuse panel, as shown on Figure 11. The supervisory scheme provides for an alarm being given in the apparatus room by a ceiling lamp and a bell during the day; at night the alarm is extended to the manual board, rings a night alarm bell and lights an urgent or non-urgent supervisory lamp according to the nature of the fault.

The fuse panel on the third bay of the supervisory panel mounts the fuses for supervisory apparatus, ringing, ringing return, and busy tone circuits and circuits distributing 3-phase current to the interrupter motors on register-translator, sender and coder racks.

On the upper part of the fourth bay is mounted a fault localisation jack panel, associated with the busy and N.U. tone circuits. The busy tone lead to each line and final unit and to each side of a selector board passes through a break jack on this panel. Should a partial earth fault occur in any of the tone distribution leads, the fault may be localised by plugging a telephone set into the listening jack beside the jack panel, and listening to the tone received through each jack, when tested by the plug and cord seen in the photograph. The effect of a partial earth fault on any lead is to weaken the tone on all leads. When the listening plug is inserted in the jack associated with the faulty lead, the fault is cut off and the normal tone is heard, while in all other jacks a weak tone is heard. To facilitate testing, a group test is provided by means of a number of master jacks, so that a group of leads including the faulty lead may first be located, and then the actual lead found by testing the individual jacks in the group.

Manual Board Equipment

The *A* board in Sloane exchange (Figure 21) consists of a suite of twenty-eight positions including one service P.B.X. position, two supervisors' positions and twenty-five positions for assistance, interception and coin box service. The switchboard sections are similar to those of the standard No. 10 board but have no subscribers' multiple.

A group of twenty-four circuits to first numerical selectors is multipled over the *A* board, for completing local connections, and a similar group of 30 lines to first code selectors is provided for outgoing calls requiring the use of a register-translator.

The cordless *B* suite (Figure 22) consists of eighteen positions. The main features of these positions have been described in connection with the method of handling traffic from manual exchanges.

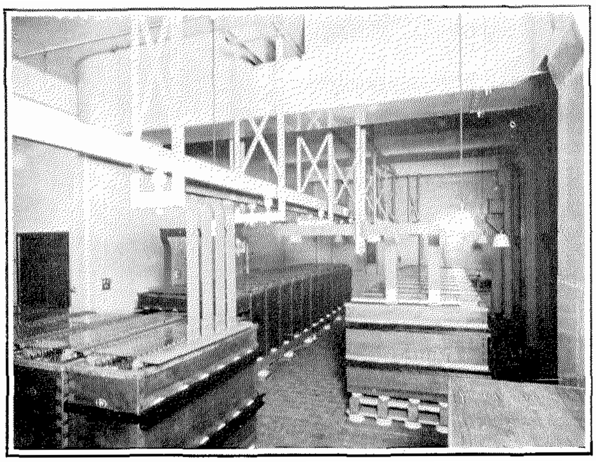


Figure 25—Battery Room.

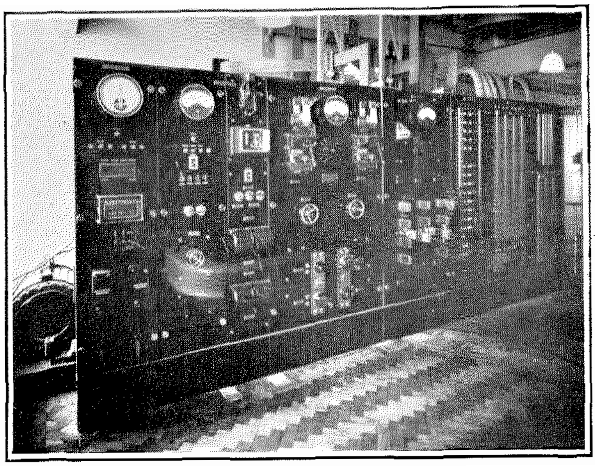


Figure 26—Power Board, D.F.P. (First Floor) and Manual Fuse Panel.

The 5-position test desk is shown in Figure 23 with the test jack frame, used for testing outgoing junctions, mounted alongside. Each outgoing junction passes to the M.D.F. via one of the jacks on this frame. By means of a circuit which terminates in a plug at the test jack frame and in a multiple jack at the test desk, any junction can be extended to the desk for testing purposes. The pendulum of the dial speed tester is mounted on the panel above the test jack frame.

Power Equipment

The capacity of the power plant of a register-translator exchange, such as Sloane, is necessarily much greater than is commonly provided in telephone exchanges, since it is estimated that the peak load reached during the busy hour will be of the order of 1,200 amperes.

The two charging sets shown in Figure 24 have each an output of 1,200 amperes at 57 volts, with regulation between 50 and 68 volts. Generators of the telephone type are used so that, if required, they may carry part of the load during busy periods. The motors are 400 volt shunt wound D.C. machines designed to run at a speed of 600 r.p.m.

The two motor-alternators, controlling the interrupter motors for register-translators, senders and coders, are seen in the background of Figure 24. The two sets are driven from the 50 volt battery supply and each supplies alternating current at a frequency of 40 cycles for coders and 20 cycles for register-translators and senders. Provision is made for automatically switching in either set in the event of a failure in the supply from the other set.

The two 25-cell batteries have each an ultimate capacity of 7,496 ampere-hours at a 9 hour rate and are equipped initially with plates for an output of 6,460 ampere-hours. One counter-E.M.F. battery of 7 cells is provided for P.B.X. power supply. A view in the battery room is given in Figure 25.

The main discharge circuits are connected to the power board, on the negative side, through circuit breakers mounted in the power room, on the dividing wall between the battery and power rooms. The positive discharge leads are connected to a common earth bar supported on the wall behind the power board.

Connections are run from the power board to the distributing bars on the distribution fuse panels on both floors and, from the main earth bar, to auxiliary earth bars, one mounted at the rear of the distribution fuse panel on the first floor, and one mounted above the fuse panel on the second floor. Owing to the voltage limits of 46 to 52 volts at the D.F.P.'s, which must be maintained under all load conditions and also on account of the size of the maximum discharge current, the conductors between batteries and D.F.P.'s must be of considerable cross-section. Consequently hard drawn copper bars, supported on porcelain insulators, have been used. The negative conductors are insulated throughout by strips made of an asbestos compound.

The distribution from fuse panels to apparatus racks is effected by means of V.I.R. cables, run in cable racks. The cross-section area of these leads is such as to ensure correct operation of switches and absence of crosstalk.

The power board is shown in Figure 26. The three panels on the left are equipped with the automatic change-over switches for the two motor-alternators and the two ringing machines. On the main power panels are mounted the overload and reverse circuit breakers and field regulators for the two charging machines, together with the voltmeter, plug bus bars and switches. The arrangement of the plug bus bars and switches is such that either machine may be used to charge, or to share the load with, either battery.

The distribution fuse panel for the equipment on the first floor, the manual fuse panel supplying manual board circuits and the panel supplying ringing current and 30 volt direct current to P.B.X.'s are mounted to the right of the power board.

The distribution fuse panel serving the second floor is shown in Figure 20. In this view the guard has been removed to show the positive bus bar coming up through the floor.

Acknowledgment

The writer desires to express his thanks to the Engineer-in-Chief of the British Post Office for permission to publish this article and the accompanying illustrations.

An Artificial Traffic Machine for Automatic Telephone Studies

By E. A. ELLIMAN and R. W. FRASER

Engineering Department Standard Telephones and Cables, Ltd.

DESIGNERS of automatic telephone exchange equipments have at all times felt the need for positive data to enable them to provide the most economical, yet adequate, quantities of equipment for efficient service. Consequently close attention has been given to the theory of probability by means of which fundamental formulæ and curves have been devised, enabling the equipment engineer to determine readily the equipment quantities required to carry any known traffic with a particular switching arrangement and a specified grade of service. Various investigators engaged in probability research have produced basic formulæ, which, while being approximately in agreement for general traffic conditions, are nevertheless at variance in certain respects owing, in some cases, to the different physical assumptions made, and in other cases, to the different methods of interpreting these assumptions in developing formulæ. Each has in turn resorted to experiment to justify assumptions and to obviate laborious or impracticable mathematical work. In these experiments different methods have been employed to reproduce physically a sequence of events governed by the laws of pure chance and analogous to those obtaining in telephone traffic. So far as the writers of this article are aware, all the methods hitherto adopted required a long period of time for one experiment, and involved careful plotting on graphs of a very large number of points. As a test, the method often adopted, of obtaining from a telephone directory a random series of four-digit numbers representing the times of call originations in ten-thousandths of the busy hour, was tried and it was found that with two men employed on the work there was an average interval of 20 seconds between the recording of two successive call originations on a graph. In this method each originating call is assumed to continue for a constant holding time—usually 2 minutes— and the number of simultaneous calls in progress at any interval is indicated as shown in Figure 1. If ten switches are being considered, any call arriving whilst ten simultaneous calls are in progress is lost. This condition is reached at points "X" marked on the graph. To obtain reliable results the experiment should be continued until about 20 lost calls are recorded so that to verify conditions with a grade of service of 1 in 1,000 ($P = 0.001$) it would be necessary to record 20,000 calls on the graph. This, at the rate indicated, would occupy 222 man-hours and even if by practice this time could be reduced it will be seen that one experiment involves a considerable amount of labour and time.

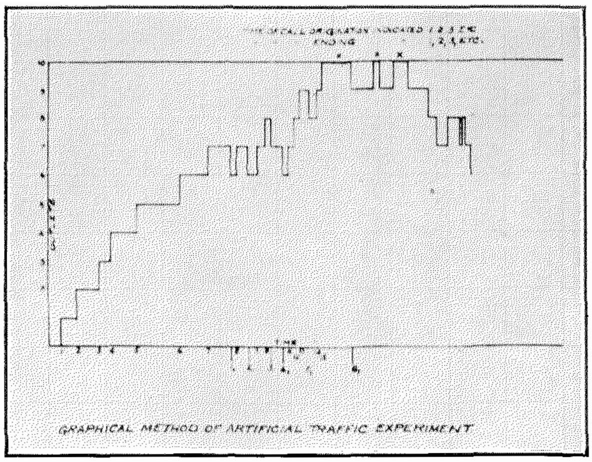


Figure 1—Simultaneous Calls in Progress at Any Interval.

The object of this article is to outline a development which has been undertaken with a view to producing a machine for the production, distribution and analysis of artificial traffic so that experiments may be carried out within a reasonably short period of time and with a considerable reduction of the tiresome work involved in graphical methods. Whilst the design of the machine described here is limited to the study of the comparatively simple trunking arrangement known as two-group grading, the principle involved readily admits of an extension of its application to more general cases.

Two main requirements have to be met in the machine:

1. It must produce a random time distribution of originated calls.
2. It must give facilities for applying the traffic so produced to particular switching arrangements, in such a manner that the traffic distribution through the system is readily obtained.

Production of Artificial Traffic

The time distribution of call originations is arranged to satisfy the following conditions:

1. Calls must originate in a purely chance manner.
2. The calling rate taken over a long period must be uniform.
3. A large number of call originations per holding time must be possible. This means that the traffic must represent that which would originate from a large number of subscribers.

To obtain numerical results readily, steel balls such as are used in ball bearings are utilised to represent calls, thereby giving each originated call a physical identity. The random traffic distribution is obtained (Figures 2 and 3) by directing a stream of balls from a funnel on to a large steel ball placed above the centre of a wire grid which supports a small number of funnels connected to rubber tubes leading to the lower part of the machine. The balls, after striking the deflecting ball, are scattered in a random manner over the grid as indicated in Figure 2 and a small proportion at chance intervals enters one or other of the funnels, which are spaced irregularly over the grid. These balls now represent originated calls, and the remainder which have fallen through the grid are directed by means of an inclined plane to a container fixed on the outside of the cabinet. The balls collected in this container are regularly transferred to the main supply at the top of the cabinet. The box containing the supply of balls is provided with an inclined glass-lined base so that an even flow of balls is supplied to the funnel. The funnel adopted, after several experiments with different shapes and types, consists of a loud-speaker horn which is hinged to the supply box so that the slope may be adjusted to the best value for an even flow. A baffle plate is fitted at the outlet from the funnel, and is operated by means of a shaft terminating in a milled nut at the side of the cabinet. This baffle plate serves to direct the stream of balls on to the deflector. The deflector is provided with both horizontal and vertical adjustments. The distribution of the balls can

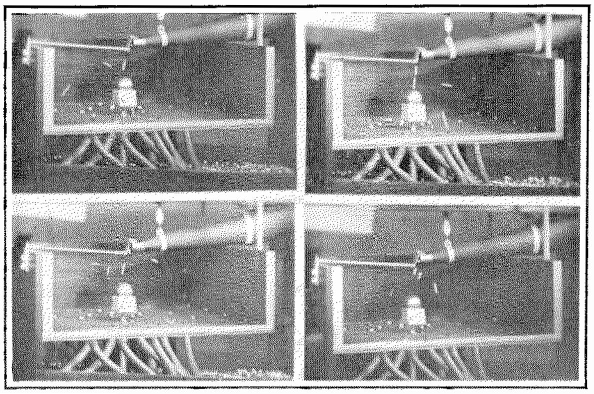


Figure 2—Random Traffic Distribution Illustrating Stream of Balls, Large Steel Deflecting Ball, Wire Grid and Rubber Tubes Leading to Lower Part of Machine.

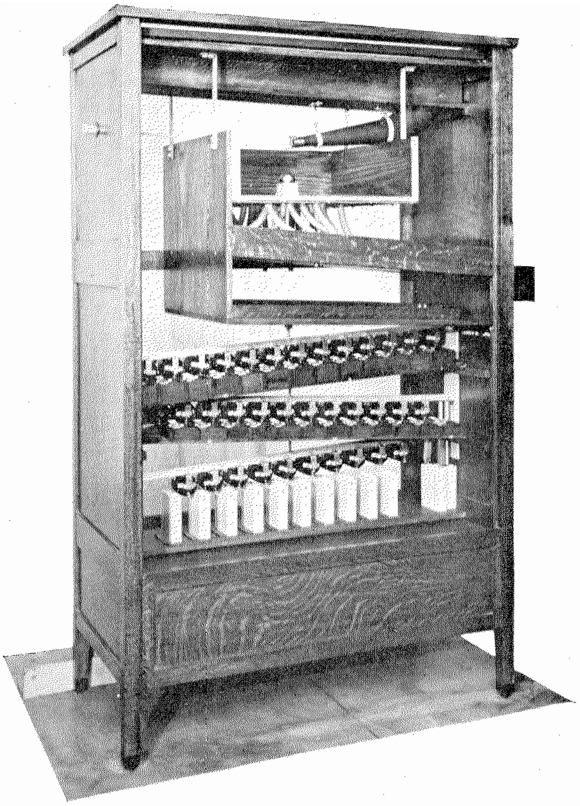


Figure 3—Artificial Traffic Machine. Lower part of mechanism represents switching equipment.

therefore be adjusted to cover the whole area of the grid over which they are scattered.

Method of Setting up Switch Arrangements

The balls which enter the rubber tubes are led through the inclined plane on which the other balls fall. They then drop into a wooden runway which directs them to the lower part of the machine representing the switching equipment. The original design represented two switching stages—a 24- or 25-point line switch stage followed by a 10-point selector stage. The arrangement is shown in Figure 3, and although this has been modified in the later design it is described here to indicate the facilities which may be provided.

In Figure 3 the multipled 25 outlets from a group of line switches is represented by an inclined aluminium runway with 25 holes, each hole being provided with a "busying" device arranged to close it for a period equal to a call holding time whenever a ball drops into it. A ball starting from the beginning of the runway proceeds along it, passes all busy outlets and enters the first free one, thus giving a mechanical representation of a call hunting by means of a line switch for a free outlet. Before they enter the line switch runway, the balls from the wooden runway pass through a separating device which ensures a certain time interval between the arrival of two balls in the line switch runway. This is done to prevent the mechanical equivalent of a double connection, which would otherwise occur in the machine more frequently than in actual practice. A ball which finds all line switch outlets engaged falls through a hole at the end of the runway into a tube leading to an overflow bin. This represents a call which has failed to find a free outlet on the first half-revolution of a line switch; but since a line switch continues to hunt till a free outlet is found, this ball must immediately be transferred to the beginning of the line switch runway and must be allowed to hunt again.

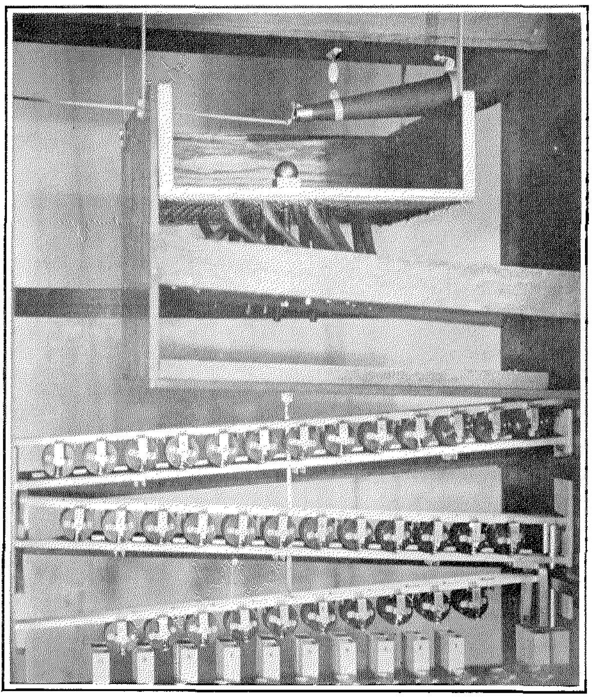


Figure 4—Artificial Traffic Machine. First three outlets shown engaged by means of "busying" device.

For convenience in designing the cabinet, the 25 outlets representing the line switch multiple are arranged in two groups, one of 13 and one of 12—the upper two runways in Figure 3. If it is desired to represent the 24-point multiple of the homing line switch, one of the 25 outlets is permanently "busied."

The outlet "busying" device shown in Figure 3 consists of an ebonite roller mounted below the outlet. Attached to the side of the roller is a short glass tube the bore of which is slightly greater than 5/16". A 5/16" diameter steel ball is enclosed in the tube; the remaining space is completely filled with a mixture of glycerine and water, and both ends of the tube are sealed. In the free condition, the tube takes up a vertical position due to the weight of the steel ball, and in this position the roller presents a pocket to the outlet in the runway. A steel ball on reaching a free outlet, drops into the pocket, turns the roller over and drops into a runway below, parallel to the first, and leading to the next switching stage. Meanwhile the roller having been turned over is prevented from returning to the normal position by a pin which engages a pawl, the arrangement being such that the roller can rotate in one direction only. In the locked position, the roller closes the runway outlet while the glycerine tube is held in a position slightly inclined to the horizontal. In Figure 4 the first three outlets are shown engaged. The ball enclosed in the tube rolls slowly down, the motion being restricted by the glycerine. When the ball has passed the centre of the tube its weight turns the roller over to a second normal position 180° removed from the first. In this position a second pocket is presented to the outlet which is, therefore, free again. The time taken for the roller to leave one normal position and restore to the second represents the holding time of the call. The average value of this time should be the same for all rollers to reproduce conditions corresponding to those assumed in theory.

In the original design, a ball having taken a line switch outlet is carried by means of the runway below the rollers to the top of a similar runway equipped with 10 outlets representing the multipled outlets from one level of a group of selectors. The delay between the seizure of a free line switch outlet and the subsequent seizure of a selector outlet is somewhat longer in the traffic machine than in actual automatic switching. The runways are, however, arranged so that the time between the commencement of hunting at the line switch stage and the commencement of hunting at the selector stage is the same for all calls. Thus the slower hunting speed and delay between stages does not affect the traffic distribution.

Since the traffic from subscribers' line switches is not all routed over the same level of first selectors, the artificial traffic machine must be arranged to satisfy this condition. For the purpose of traffic experiments it is not necessary to study more than one level; traffic to the other levels need not be analysed. A mixture of two sizes of balls is, therefore, used and, after leaving the line switch runway, the balls pass a separating device which routes the larger size to the selector runway and the smaller size, representing traffic to other levels, to an analysis bin. The mixture of the two sizes thus controls the average value of the fraction of the total traffic routed over the level which is being studied.

The outlets in the selector runway are tested in turn in exactly the same manner as already indicated, and when a free outlet is found, the ball, having turned the roller over, is dropped into an analysis bin placed below the roller. If all 10 outlets are busy the ball drops through a hole at the end of the runway into a separate bin. Thus the number of calls received by any one outlet or the number of lost calls is given by the number of balls found in the corresponding bin at the end of the test.

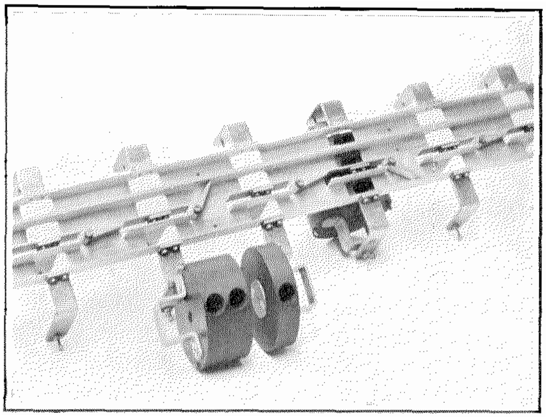


Figure 5—Double Runway Provided for Two-group Grading.

In order to carry out tests on the distribution of traffic at the line switch stage, two sets of analysis bins, corresponding to the two halves of the line switch runway, are provided. These analysis bins can be seen in Figure 3, numbered 1, 5, 10, 15, 20 and 25. When these bins are placed in position alongside the runways, the balls which take line switch outlets drop into short channels each leading to a bin corresponding to a particular outlet.

Facilities for two-group grading are provided by duplicating the whole of the mechanism representing the switching arrangements as described above. The rubber tubes from the wire grid are divided into two groups leading to two wooden runways which serve the two sets of line switch and selector runways. Each of the duplicate line switch and selector runways consists of two channels fitted close together and equipped with one set of rollers double the width of the first rollers so that the two outlets controlled by one roller may be "busied" by a ball from either channel. The double runway is mounted alongside the first, and the partition between the single runway and the adjacent channel of the double runway is provided with a series of gates, one between each pair of outlets. The arrangement is shown in Figure 5. At the beginning of the line switch or selector runways, the balls enter the two outer of the three channels so that if it is desired to run the two groups of outlets with no grading, the centre channel is not used. If some of the outlets in the two groups are to be graded, the gate before the first graded outlet is thrown across the single runway, so that a ball finding the individual outlets in that runway engaged, is deflected into the centre channel and proceeds to test the outlets which are also being tested by balls in the outer channel of the double runway. A trunking arrangement with individual outlets following graded outlets (called "reversed grading" by the British Post Office) can be provided by setting the gate after the last graded outlet across the centre channel, so that a ball which finds the graded outlets in the centre channel engaged, is returned to the single runway to test the last group of individual outlets.

Arrangements are also provided in the machine for enabling a call to be routed from either of the two line switch multiples to either of the two selector groups. Thus, a ball having taken a particular line switch outlet, may either drop into the channel immediately below it and leading to one selector runway, or, by means of a deflector which clips on to the channel below the roller, the ball on falling out of the roller may be deflected to the runway which leads to the other selector group.

The trunking scheme of the machine as described above is shown in Figure 6.

It was proved that with the design of "busying" device described above, owing to the difficulty of adjusting all rollers to have the same average holding time, it was not possible to obtain any accurate results from tests. This difficulty was caused by the slight differences in the several timing devices and the individual adjustments which were necessary for each. It was, therefore, decided to introduce a timing device with a common control, the arrangement being such as to utilise the first model as far as possible.

The timing arrangement adopted is shown in Figure 7, and consists of a series of shafts, one running below each set of rollers, and all shafts being driven through gearing from a small electric motor fitted inside the cabinet. Each shaft carries a number of wheels (one per roller) which are driven through a friction clutch. The glycerine tubes are removed from the rollers, and one of the two pockets is filled in to load the roller, so that normally it takes up a position with the other pocket open to the runway. In this free position, the corresponding wheel on the rotating shaft is prevented from turning by means of a pawl which engages with a notch in the wheel. When the outlet is taken, the roller turns over as before, and in doing so, a pin, fitted in the side, strikes the pawl, and raises it out of the notch in the wheel, which immediately moves away from the normal position. The ball having dropped out of the roller, the latter tends to return to normal, but is prevented by the pawl, which now rests on the rim of the wheel against which it is forced, both by its own weight and by the roller. The outlet is thus held "busy" until the notch in the wheel has made a complete revolution, when the pawl drops in and releases the roller, and at the same time locks the wheel again.

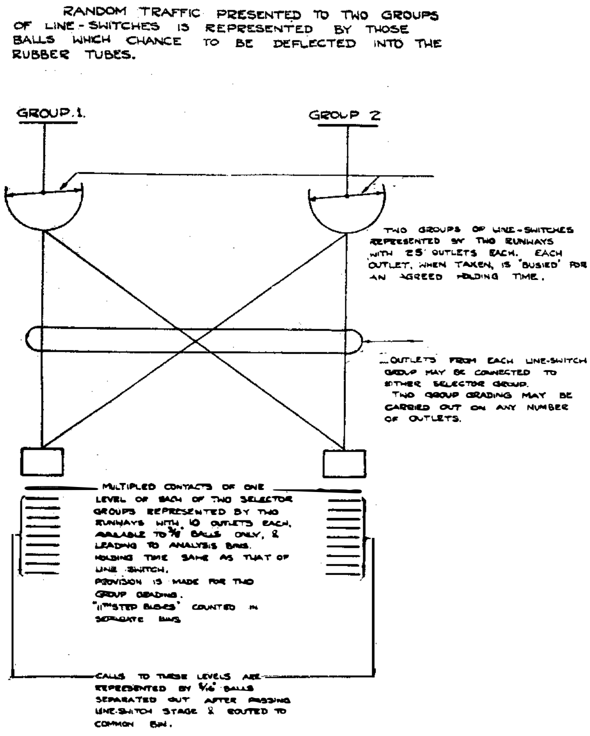


Figure 6—Trunking Scheme of Artificial Traffic Machine

One complete turn of the shaft, therefore, represents a call holding time, and since all shafts are controlled by the same motor, the holding time of all outlets is the same. By varying the speed of the motor, the holding time may be adjusted within limits to any desired value.

The introduction of this type of "busying" device in the original model permits the use of only 23 of the 25 outlets in each line switch group (in Figure 7: outlets 12, 13 and 25 are shown permanently "busied"). The capacity of the machine is, therefore, reduced for the present to one switching stage with facilities for studying the traffic distribution in two groups of outlets, each group consisting of any number of outlets up to 22. The arrangements for direct or reversed grading between these groups remain unchanged.

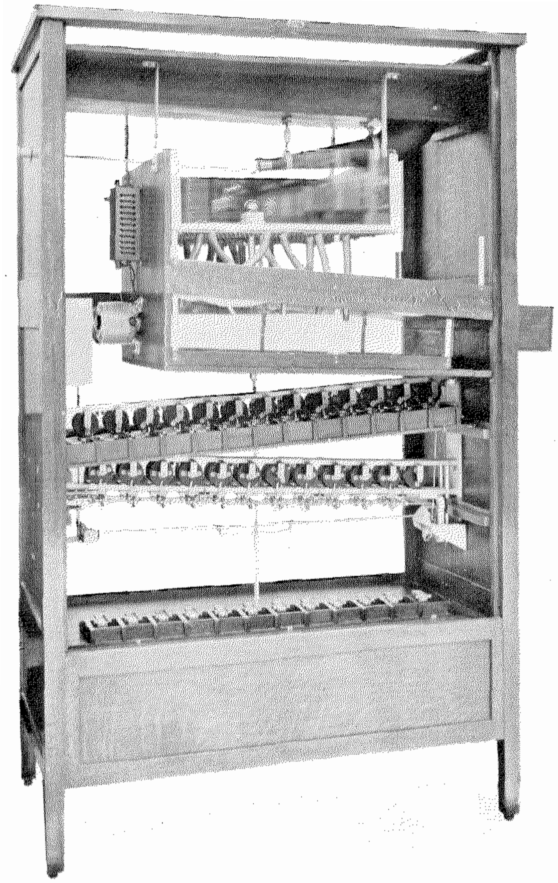


Figure 7—Artificial Traffic Machine with Common Control "Busying" Device.

Although the reduction to one switching stage reduces the scope of the machine, it is possible with the single stage to study problems associated with the standard 10-group selector or with the 20-group selector. In this way the accuracy of the underlying principle of the machine may be tested and the machine may then be applied to the solution of problems such as arise, for example, with reversed grading. If required, arrangements can be made for adding the second stage.

Method of Making Tests

Before a test is run on the machine, a preliminary experiment must be made to ascertain that a satisfactory volume of traffic is being obtained. The balls are allowed to run from the funnel, and the baffle plate and deflecting ball are adjusted to give a satisfactory distribution over the grid. The wooden runways leading to the lower part of the machine are closed to prevent the balls from proceeding further, and the time taken for a number of calls to originate is measured. From this the number of calls per holding time—i.e., the traffic—is obtained, and if any change is required to the value given, this can be effected either by adjusting the number of rubber tubes or by altering the position of some of them on the grid.

To commence a test on both line switch and selector stages, the required grading and cross-connecting arrangements are made, and the balls are allowed to run through the machine until a number of calls are in progress. During the preliminary run all the balls are collected in a common bin placed below the selector runways. These calls do not count in the test. The test interval commences from the time when all the analysis bins, mounted on a platform at the bottom of the machine, are pushed forward into position below the rollers.

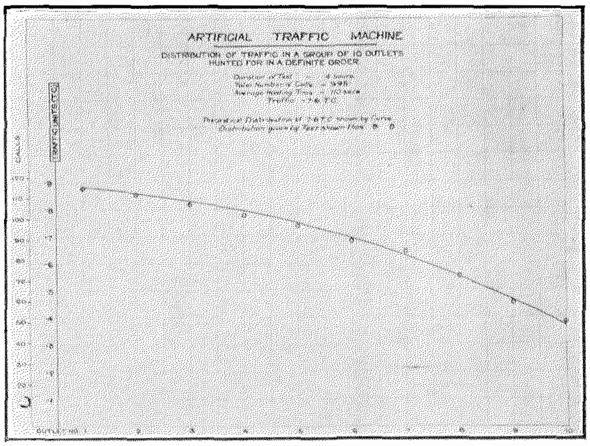


Figure 8.

At the end of the test period, the platform with the analysis bins is withdrawn and the common bin is replaced. The aperture between the baffle plate and the funnel mouth is then closed to stop the flow of balls.

A test on the line switch stage only, is carried out in the same manner except that during the preliminary run the balls are allowed to proceed to the selector stage, or in the present model, to a common starting bin. The test period commences when the group of wooden analysis bins is placed up against the runway and ends when these bins are withdrawn.

Results of Tests

The machine in its modified form has been employed to determine the distribution of traffic in certain simple cases where the solution can also be derived mathematically. Results of such experiments are reproduced in graphical form in Figures 8 and 9 and in tabular form in Tables I and II. It will be seen that in Figure 8 the mechanical analysis closely approximates to that deduced by theory; the machine, therefore, furnishes a direct means of solution for the complex cases where precise mathematical solutions are too laborious or are impossible.

TABLE I

Test of Distribution of Traffic in a Group of Ten Outlets Hunted for in a Definite Order

Summary of Results

Duration of Test	4 hours
Total Number of Originated Calls	995
Average Holding Time of Calls	110 seconds
Traffic (a)	7.6 T.C.

Distribution

Outlet No. (r)	Calls	Traffic Units (T.C.)		Calls	
		Test	Theoretical (a_r)	Test	Theoretical
1	115	.879	.884	115	115.6
2	112	.856	.860	112	112.5
3	107	.817	.828	107	108.3
4	102	.779	.796	102	104.3
5	96	.734	.748	96	98.0
6	89	.680	.692	89	90.6
7	84	.641	.625	84	81.8
8	72	.550	.548	72	71.8
9	59	.451	.461	59	60.4
10	50	.382	.369	50	48.3
O/F	109	.833	.789	109	103.1
Totals...	995	7.602	7.600	995	994.7

TABLE II

Test of Distribution of Traffic in a Two-Group Grading with Two Individual and Nine Common Outlets

Summary of Results

Duration of Test	5 hours
Number of Calls to Group 1	475
Number of Calls to Group 2	971
Total Number of Calls	1,446
Average Holding Time of Calls	104.6 seconds
Traffic to Group 1	2.82 T.C.
Traffic to Group 2	5.78 T.C.
Total Traffic	8.6 T.C.

Distribution

Outlet No.	Calls	Traffic Units (T.C.)		Calls	
		Test	Theoretical	Test	Theoretical
1 Grp. 1	124	.737	.739	124	124.1
1 " 2	146	.868	.852	146	143.1
2	145	.862	.869	145	146.0
3	142	.844	.838	142	140.9
4	137	.815	.803	137	135.0
5	128	.761	.761	128	128.0
6	124	.737	.708	124	119.0
7	113	.672	.643	113	108.0
8	99	.589	.570	99	95.8
9	83	.493	.490	83	82.4
10	67	.398	.400	67	67.3
O/F	138	.821	.927	138	155.9
Totals...	1,446	8.597	8.600	1,446	1,445.5

The points through which the theoretical curve in Figure 8 is drawn are those given in column 4 of Table I and are derived from the formula:

$$a_r = \frac{\dfrac{a^{r-1}}{r-1!}}{1 + a + \dfrac{a^2}{2!} + \ldots + \dfrac{a^{r-1}}{r-1!}} - \frac{\dfrac{a^r}{r!}}{1 + a + \dfrac{a^2}{2!} + \ldots + \dfrac{a^r}{r!}}$$

where a_r = traffic carried by the rth choice switch of a fully available group hunted for in a definite order, and

a = total traffic approaching the group.

The expression:

$$\frac{\dfrac{a^r}{r!}}{1 + a + \dfrac{a^2}{2!} + \ldots + \dfrac{a^r}{r!}}$$

represents the probability that a group of r

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