The Post Office Electrical Engineers' Journal

VOL 69 PART 1 APRIL 1976

THE INSTITUTION OF POST OFFICE ELECTRICAL ENGINEERS

NIL SINE LABORE

THE POST OFFICE ELECTRICAL ENGINEERS' JOURNAL

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Contents

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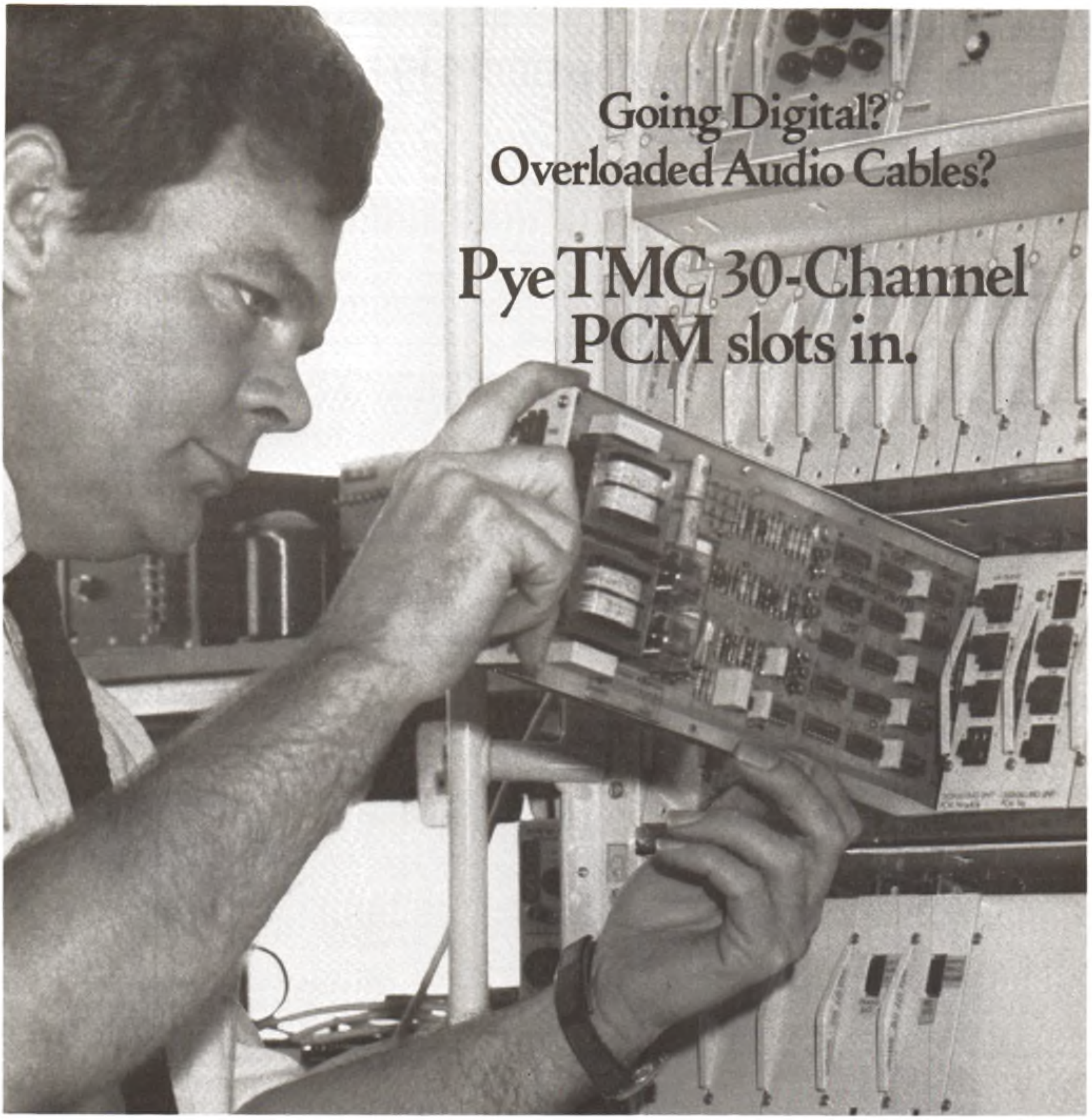

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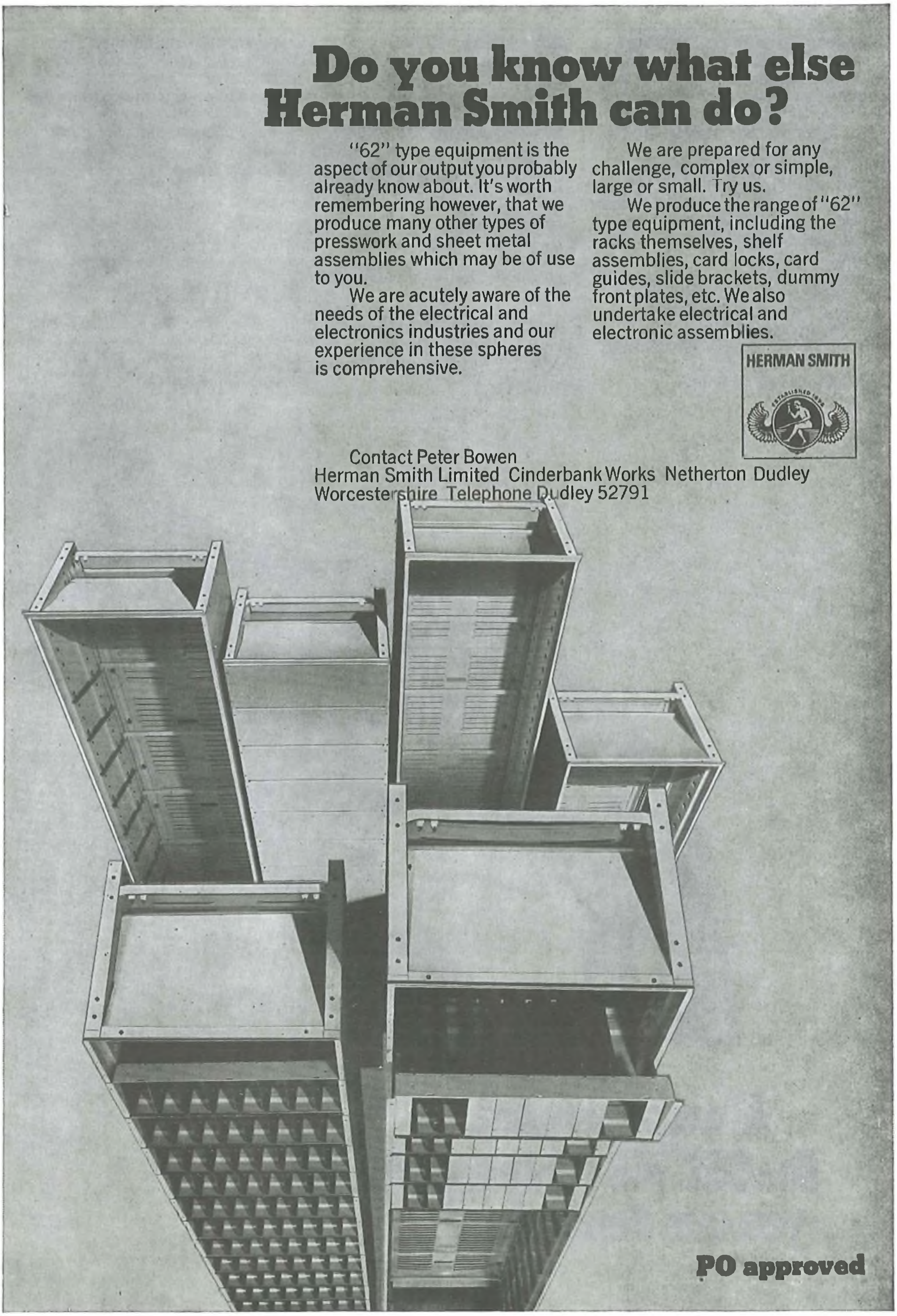
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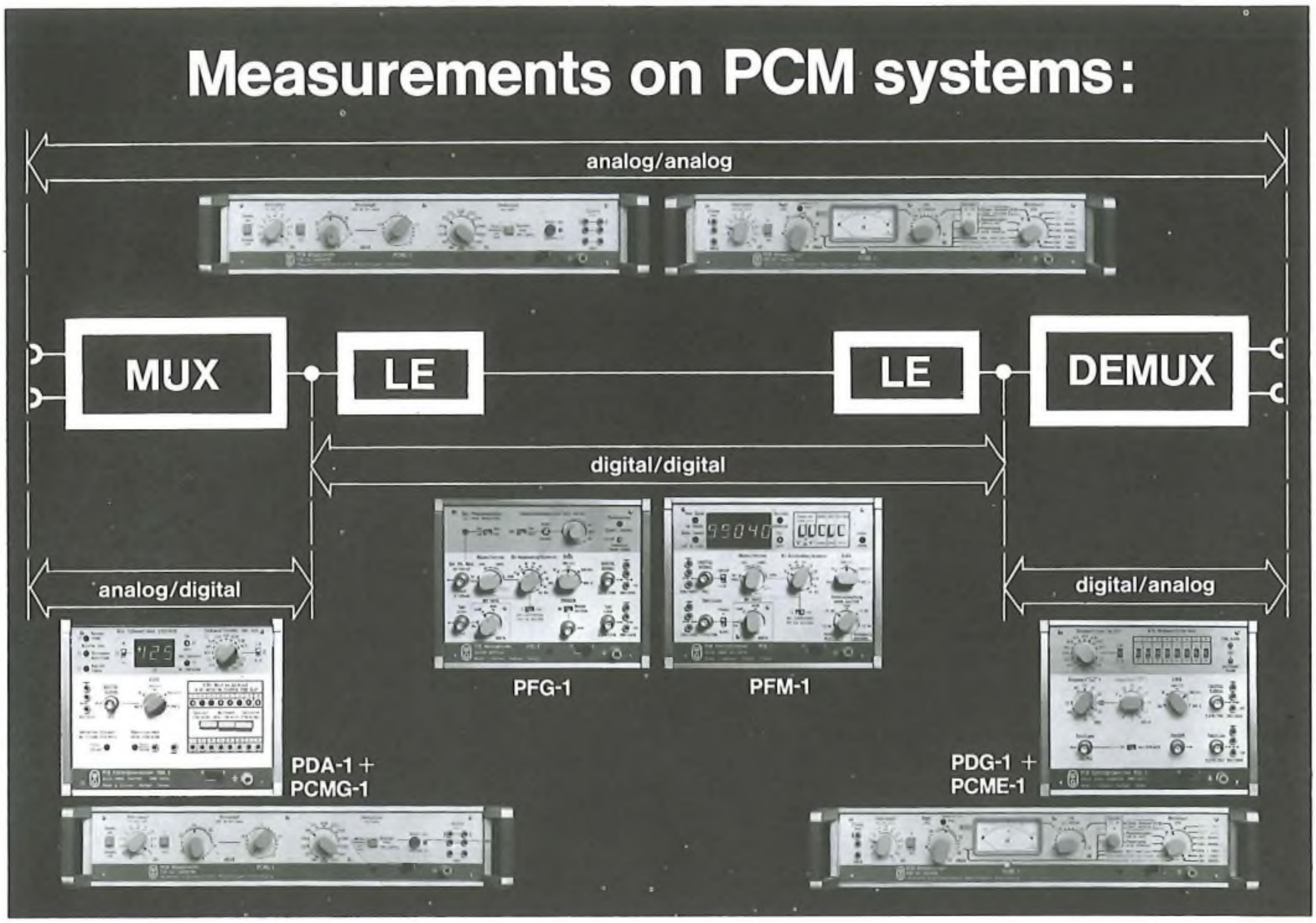

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The Post Office Electrical Engineers' Journal

EDITORIAL

On 10 March 1876, the first intelligible transmission of speech by telephone was made by Alexander Graham Bell to his assistant Thomas A. Watson in Bell's laboratory at 5 Exeter Place, Boston, USA. To mark the centenary of this great discovery, the very basis on which today's great communications industry is built, this issue of the *Journal* includes a reprint of the address given in 1928 to the London Centre of the Institution of Post Office Electrical Engineers by the then Dr. Thomas A. Watson, Bell's assistant throughout the period 1874–81. This is a first-hand account of the struggle to develop the telephone system, the difficulties encountered and overcome, and the impact of the discovery on the American public; the Address gives a vivid description of the world into which the telephone was born.

Two points in Dr. Watson's account need to be qualified in the light of information available today.* Firstly, the words actually spoken by Bell in that first telephone call were most probably "Mr. Watson, come here, I want to see you," the words "to see" having been omitted from Dr. Watson's account, given more than 50 years after the event. Secondly, Dr. Watson's account does not make it clear that, while much of the early work in Summer 1875 and most of the demonstrations described used an electromagnetic receiver and transmitter, the first intelligible telephone transmission was made using a (liquid) variable-resistance transmitter, the principle of which is shown diagrammatically on page 6 of this *Journal*.

This issue of the *Journal* also includes a brief summary of the life of Alexander Graham Bell and a description of the evolution of the United Kingdom telephone service. In contrast, the remaining articles in this issue reflect the future possibilities for the development of communications services in this country.

* BRUCE, R. V. Bell: Alexander Graham Bell & the conquest of solitude. (Victor Gollancz Ltd., London, 1973.)

Alexander Graham Bell

UDC 621.395:6(091)

Alexander Graham Bell was born in Edinburgh, Scotland, on 3 March 1847, the son of Alexander Melville Bell, a highly successful teacher of elocution and author of text books on the principles of correct speech. His mother, Eliza Grace Symonds, was a portrait painter and accomplished musician. The child was christened Alexander after his grandfather but, on his eleventh birthday, adopted the middle name Graham, from the name of one of his father's friends, Alexander Graham.

Bell's formal education was undertaken at the Royal High School in Edinburgh and, later, at University College, London, where he studied physiology and anatomy. As a young man, he became interested in, and experimented with, telegraphy. He also showed a flair for music and, for a short while, planned a musical career, but later decided to follow his father's profession in speech studies, becoming a teacher of elocution. When he was 22, his father took him into partnership in London, where he was then established.

Following the deaths of his 2 brothers from pulmonary tuberculosis, Bell's family sailed for Canada on 21 July 1870, and settled in the province of Ontario. There they bought a farmhouse on Tutelo Heights, overlooking a wide sweep of the Grand River, just outside the small town of Brantford.

Bell's parents had been concerned about Alexander's health, but it rapidly improved in his new home. Within a few months, he was once again helping his father in his studies concerning speech and ways to help the deaf and the mute, and was eagerly involved in his own experiments. In 1871, he achieved great success in Boston with his methods for teaching the deaf to speak, and a year later, opened a school of vocal physiology in Boston for the instruction of the deaf and "for the correction of stammering and other defects of utterance". This was primarily a school for teachers of the deaf, but he gave direct instruction to deaf children in order to demonstrate teaching methods. It was through his pupils that Bell met 2 other important figures in his life, who were later to become advisors and financial backers: Thomas Sanders and Gardiner Greene Hubbard. Sanders had a son who had been born deaf, and Hubbard a daughter, Mabel, who had become deaf as a result of scarlet fever. She was later to become Alexander Graham Bell's wife. In 1873, Bell became Professor of Vocal Physiology at Boston University.

The events that led to the invention of the telephone began in 1872. Bell was attempting to send several telegraph messages simultaneously over a single wire by using a number of tuning forks. This system he called the *harmonic telegraph*. It was through these experiments, plus his knowledge of music, human speech and hearing, that Bell found the way to the principle of the telephone. The idea was first formed at Bell's home in Brantford during the summer of 1874. In the following year, after further experiments, he wrote the patent specification for the telephone, but it was not until 10 March 1876, at Boston, that the telephone carried its first intelligible sentence, when Bell, speaking to his assistant, said, "Mr. Watson, come here, I want (to see) you"*. Shortly after his marriage to Mabel Hubbard in July 1877, Bell and his bride sailed for England and, during the next year, he successfully introduced the telephone to this country. Following his return to America, Bell seemed to lose interest in his invention and,

after 1881, took no active part in its development, but continued his work in the cause of the deaf.

For his invention, many great and famous universities and institutions honoured him and, in 1880, he was made an Officer of the Legion of Honour and awarded the *Volta Prix* of 50 000 francs by the French Government. With this money, Bell founded the Volta Laboratory in Washington. There he was responsible for the development of the basic method of making gramophone records on wax discs and, from the sale of the patents, Bell established the Volta Bureau to carry on his work for the deaf. He also founded the American Association to Promote the Teaching of Speech to the Deaf, and held numerous other distinguished offices.

For many years after the invention of the telephone, Bell lived a vigorous and creative life, pioneering in many fields. One of his many achievements was the development of a hydrofoil boat which, in 1919, set a world marine speed record of 114·04 km/h (70·86 miles/h). He worked on the problems of flight and, with his associates, invented the aileron, the device still used today to give lateral control to aircraft. He was also partly responsible for man's first powered flight in the British Empire, in 1909.

In 1920, Bell revisited Edinburgh to receive the freedom of the city. Two years later, on 2 August 1922, he died, a citizen of the United States of America, at his summer residence at Beinn Bhreagh, near Baddeck, Cape Breton, at the northern end of Nova Scotia.

He was buried on Friday 4 August and, for one minute during the ceremony, telephone communication was suspended throughout North America as a tribute to the inventor of the telephone. His grave is marked only by a rock, into which is set a tablet bearing Bell's name, dates and his vocation: "Inventor".

N. S. L.

* The actual phrase is disputed; see Dr. Watson's own account opposite, and the Editorial to this issue

The Birth and Babyhood of the Telephone: Dr. Watson's Address (1928)

UDC 621.395:5(091):6(091)

This address was given by Dr. T. A. Watson to the London Centre of the Institution of Post Office Electrical Engineers on 13 November 1928, and tells the enthralling story of the early history and struggles to develop the telephone system, throughout which Dr. Watson acted as Alexander Graham Bell's assistant. The address is reprinted from Volume 21 of the Journal to mark the centenary of the first intelligible transmission by telephone on 10 March 1876.

"If I could make a current of electricity vary in intensity, precisely as the air varies in density during the production of a sound, I should be able to transmit speech telegraphically." (*Alexander Graham Bell, Spring 1875*)

I am to speak to you of the birth and babyhood of the telephone, and something of the events which preceded that important occasion. These are matters that must seem to you ancient history; in fact, they seem so to me, although the events all happened in the years 1874–80.

The occurrences of which I shall speak, lie in my mind as a splendid drama, in which it was my great privilege to play a part. I shall try to put myself back into that wonderful play, and tell you its story from the same attitude of mind I had then—the point of view of a mere boy, just out of his apprenticeship as an electro-mechanician, intensely interested in his work, and full of boyish hope and enthusiasm. Therefore, as it must be largely a personal narrative, I shall ask you to excuse my many "I's" and "my's" and to be indulgent if I show how proud and glad I am that I was chosen by the fates to be the associate of Alexander Graham Bell, to work side by side with him day and night through all these wonderful happenings that have meant so much to the world.

(Photograph by courtesy of A T & T, New York, USA)

THE WILLIAMS' ELECTRICAL WORKSHOP

I realize now what a lucky boy I was, when at 13 years of age I had to leave school and go to work for my living, although I didn't think so at that time. I am not advising my young friends to leave school at this age, for they may not have the opportunity to enter college as I did at 40. There's a "tide in the affairs of men", you know, and that was the beginning of its flood in my life, for after trying several vocations—clerking, book-keeping, carpentering, etc.—and finding them all unattractive, I at last found just the job that suited me in the electrical workshop of Charles Williams, at 109, Court Street, Boston, USA—one of the best men I have ever known. Better luck couldn't befall a boy than to be brought so early in life under the influence of such a high-minded gentleman as Charles Williams.

I want to say a few words about my work there, not only to give you a picture of such a shop in the early 1870s, but also because in this shop the telephone had its birth and a good deal of its early development.

I was first set to work on a hand lathe turning binding posts for 5 dollars a week. The mechanics of today, with their automatic screw machines, hardly know what it is to turn little rough castings with a hand tool. How the hot chips used to fly into our eyes! One day I had a fine idea; I bought a pair of 25 cent goggles, thinking the others would hail me as a benefactor of mankind and adopt my plan. But they laughed at me for being such a cissy boy and public opinion forced me back to the old time-honoured plan of winking when I saw a chip coming. It was not an efficient plan, for the chip usually got there first. There was a liberal education in it for me in manual dexterity. There was no specializing in these shops at that time. Each workman built everything there was in the shop to build, and an apprentice also had a great variety of jobs, which kept him interested all the time, for his tools were poor and simple and it required lots of thought to get a job done right.

There were few books on electricity published at that time. Williams had copies of most of them in his show case, which we boys used to read noons, but the book that interested me most was Davis' Manual of Magnetism, published in 1847, a copy of which I made mine for 25 cents. If you want to get a good idea of the state of the electrical art at that time, you should read that book. I found it very stimulating and that same old copy in all the dignity of its dilapidation has a place of honour on my bookshelves today.

My promotion to higher work was rapid. Before 2 years had passed, I had tried my skill on about all the regular work of the establishment: call bells, annunciators, galvanometers, telegraph keys, sounders, relays, registers and printing telegraph instruments.

Individual initiative was the rule in Williams' shop—we all did about as we pleased. Once, I built a small steam engine for myself during working hours, when business was slack. No one objected. That steam engine, by the way, was the embryo of the biggest shipbuilding plant in the United States today, which I established some 10 years later with telephone profits, and which now employs more than 4000 men.

Such was the electrical shop of that day. Crude and small as they were, they were the forerunners of the great electrical works of today. In them were being trained the men who were among the leaders in the wonderful development of applied electricity which began soon after the time of which I am to speak. Williams, although he never had at that time more than 30 or 40 men working for him, had one of the largest and best fitted shops in the country. I think the Western Electric shop at Chicago was the only larger one. That was also undoubtedly better organized and did better work than Williams'. When a piece of machinery built by the Western Electric came into our shop for repairs, we boys always used to admire the superlative excellence of the workmanship.

EXPERIENCE WITH INVENTORS

Besides the regular work at Williams', there was a constant stream of wild-eyed inventors, with big ideas in their heads and little money in their pockets, coming to the shop to have their ideas tried out in brass and iron. Most of them had an "angel", whom they had hypnotized into paying the bills. My enthusiasm, and perhaps my sympathetic nature, made me a favourite workman with those men of visions, and in 1873–74 my work had become largely making experimental apparatus for such men. Few of their ideas ever amounted to anything, but I liked to do the work, as it kept me roaming in fresh fields and pastures new all the time. Had it not been, however, for my youthful enthusiasm—always one of my chief assets—I fear this experience would have made me so sceptical and cynical as to the value of electrical inventions that my future prospects might have been injured.

I remember one limber-tongued patriarch who had induced some men to subscribe 1000 dollars to build what he claimed to be an entirely new electric engine. I made much of it for him. There was nothing new in the engine, but he intended to generate his electric current in a series of iron tanks the size of trunks, to be filled with nitric acid with the usual zinc plates suspended therein. When the engine was finished and the acid poured into the tanks for the first time, no one waited to see the engine run, for inventor, "angel", and workmen, all tried to see who could get out of the shop quickest. I won the race as I had the best start.

I suppose there is just such a crowd of crude minds still besieging the workshops, men who seem incapable of finding out what has been already done, and so keep on year after year, threshing old straw.

THE HARMONIC TELEGRAPH

All the men I worked for at that time were not of that type. There were a very few different. Among them, dear old Moses G. Farmer, perhaps the leading practical electrician of that day. He was full of good ideas, which he was constantly bringing to Williams to have worked out. I did much of his work and learned from him more about electricity than ever before or since. He was electrician at that time for the United States Torpedo Station at Newport, Rhode Island, and in the early winter of 1874, I was making for him some experimental torpedo exploding apparatus. That apparatus will always be connected in my mind with the telephone, for one day when I

Replica of Bell's Harmonic Telegraph
(Crown Copyright. Science Museum, London)

was hard at work on it, a tall, slender, quick-motioned man with pale face, black side whiskers, and drooping moustache, big nose and high sloping forehead crowned with bushy, jet-black hair, came rushing out of the office and over to my work bench. It was Alexander Graham Bell, whom I saw then for the first time. He was bringing to me a piece of mechanism which I had made for him under instructions from the office. It had not been made as he had directed and he had broken down the rudimentary discipline of the shop in coming directly to me to get it altered. It was a receiver and a transmitter of his Harmonic Telegraph, an invention of his with which he was then endeavouring to win fame and fortune. It was a simple affair by means of which, utilizing the law of sympathetic vibration, he expected to send six or eight Morse messages on a single wire at the same time, without interference.

Although most of you are probably familiar with the device, I must, to make my story clear, give you a brief description of the instruments, for though Bell never succeeded in perfecting his telegraph, his experimenting on it led to a discovery of the highest importance.

The essential parts of both transmitter and receiver were an electromagnet and a flattened piece of steel clock spring. The spring was clamped by one end to one pole of the magnet, and had its other end free to vibrate over the other pole. The transmitter had, besides this, make-and-break points like an ordinary vibrating bell which, when the current was on, kept the spring vibrating in a sort of nasal whine, of a pitch corresponding to the pitch of the spring. When the signalling key was closed, an electrical copy of that whine passed through the wire and the distant receiver. There were, say, six transmitters with their springs tuned to six different pitches and six receivers with their springs tuned to correspond. Now, theoretically, when a transmitter sent its electrical whine into the line wire, its own faithful receiver spring at the distant station would wriggle sympathetically, but all the others on the same line would remain coldly quiescent. Even when all the transmitters were whining at once through their entire gamut, making a row as if all the miseries this world of trouble ever produced were concentrated there, each receiver spring along the line would select its own from that sea of troubles and ignore all the others. Just see what a simple, sure-to-work invention this was; for just break up those various whines into the dots and dashes of Morse messages and one wire would do the work of six, and the Duplex telegraph that had just been invented would be beaten to a frazzle. Bell's reward would be immediate and rich, for the Duplex had been bought by the Atlantic and Pacific Telegraph Company, giving them a great advantage over their only competitor, the Western Union Company, and the latter would, of course, buy Bell's invention and his financial problems would be solved.

All this was, as I have said, theoretical, and it was mighty lucky for Graham Bell that it was, for had his harmonic telegraph been a well-behaved apparatus that always did what its parent wanted it to do, the speaking telephone might never have emerged from a certain marvellous conception, that had even then been surging back of Bell's high forehead for 2 or 3 years. What that conception was, I soon learned, for he couldn't help speaking about it, although his friends tried to hush it up. They didn't like to have him get the reputation of being visionary, or something worse.

To go on with my story; after Mr. Farmer's peace-making machines were finished, I made half a dozen pairs of the harmonic instruments for Bell. He was surprised, when he tried them, to find that they didn't work as well as he expected. The cynical Watson wasn't at all surprised, for he had never seen anything electrical yet that worked at first the way the inventor thought it would. Bell wasn't discouraged in the least, and a long course of experiments followed which gave me a steady job that winter and brought me into close contact with a wonderful personality that did more to mould my life rightly than anything else that ever came into it.

I became mightily tired of those "whiners" that winter. I called them by that name, perhaps, as an inadequate expression of my disgust with their persistent perversity, the struggle with which soon began to take all the joy out of my young life, not being endowed with the power of Macbeth's weird sister to

> "Look into the seeds of time,
> And say which grain will grow and which will not."

Let me say here, that I have always had a feeling of respect for Elisha Gray, who, a few years later, made that harmonic telegraph work, and vibrate well-behaved messages, that would go where they were sent, without fooling with every receiver on the line.

Most of Bell's early experimenting on the harmonic telegraph was done in Salem, at the home of Mrs. George Sanders, where he resided for several years, having charge of the instruction of her deaf nephew. The present Y.M.C.A. building is on the site of that house. I would occasionally work with Bell there, but most of his experimenting in which I took part was done in Boston.

BELL'S THEORY OF TRANSMITTING SPEECH

Mr. Bell was very apt to do his experimenting at night, for he was busy during the day at the Boston University, where he was Professor of Vocal Physiology, especially teaching his father's system of visible speech, by which a deaf mute might learn to talk—quite significant of what Bell was soon to do in making mute metal talk. For this reason, I would often remain at the shop during the evening to help him test some improvement he had had me make on the instruments.

One evening, when we were resting from our struggles with the apparatus, Bell said to me: "Watson, I want to tell you of another idea I have, which I think will surprise you." I listened, I suspect, somewhat languidly, for I must have been working that day about 16 hours, with only a short nutritive interval; Bell had already given me, during the weeks we had worked together, more new ideas on a great variety of subjects, including visible speech, elocution and flying machines, than my brain could assimilate, but when he went on to say that he had an idea by which he believed it would be possible to talk by telegraph, my nervous system got such a shock that the tired feeling vanished. I have never forgotten his exact words; they have run in my mind ever since like a mathematical formula. "If", he said, "I could make a current of electricity vary in intensity, precisely as the air varies in density during the production of a sound, I should be able to transmit speech telegraphically." He then sketched for me an instrument that he thought would do this, and we discussed the possibility of constructing one. I did not make it; it was altogether too costly, and the chances of its working too uncertain to impress his financial backers—Mr. Gardiner G. Hubbard and Mr. Thomas Sanders—who were insisting that the wisest thing for Bell to do was to perfect the harmonic telegraph; then he would have the money and leisure enough to build air castles like the telephone.

2 JUNE 1875

I must have done other work in the shop besides Bell's during the winter and spring of 1875, but I cannot remember a single item of it. I do remember that when I was not working for Bell I was thinking of his ideas. All through my recollection of that period runs that nightmare; the harmonic telegraph, the ill working of which got on my conscience, for I blamed my lack of mechanical skill for the poor operation of an invention apparently so simple. Try our best, we could not make that thing work rightly, and Bell came as near to being discouraged as I ever knew him to be.

But this spring of 1875 was the dark hour just before the dawn.

If the exact time could be fixed, the date when the conception of the undulatory or speech-transmitting current took its perfect form in Bell's mind would be the greatest day in the history of the telephone, but certainly 2 June 1875 must always rank next; for on that day, the mocking fiend inhabiting that demoniac telegraph apparatus, just as a now-you-see-it-and-now-you-don't sort of a satanic joke, opened the curtain that hides from man great Nature's secrets and gave us a glimpse, as quick as if it were through the shutter of a snap-shot camera, into that treasury of things not yet discovered. That imp didn't do this in any kindly, helpful spirit—any inventor knows he isn't that kind of a being—he just meant to tantalize and prove that a man is too stupid to grasp a secret, even if it is revealed to him. But he hadn't properly estimated Bell, though he had probably sized me up all right. That glimpse was enough to let Bell see and seize the very thing he had been dreaming about and drag it out into the world of human affairs.

THE TELEPHONE BORN

Coming back to earth, I'll try and tell you what happened that day. In the experiments on the harmonic telegraph, Bell had found that the reason why the messages got mixed up was inaccuracy in the adjustment of the pitches of the receiver springs to those of the transmitter. Bell always had to do this tuning himself, as my sense of pitch and knowledge of music were quite lacking—a faculty (or lackulty) which you will hear later became quite useful. Mr. Bell was in the habit of observing the pitch of a spring by pressing it against his ear while the corresponding transmitter in a distant room was sending its intermittent current through the magnet of that receiver. He would then manipulate the tuning screw until that spring was tuned to accord with the pitch of the whine coming from the transmitter. All this experimenting was carried on in the upper story of the Williams' building, where we had a wire connecting two rooms perhaps 60 ft apart looking out on Court Street.

Realization

On the afternoon of 2 June 1875, we were hard at work on the same old job, testing some modification of the instruments. Things were badly out of tune that afternoon in that hot garret, not only the instruments, but, I fancy, my enthusiasm and my temper though Bell was as energetic as ever. I had charge of the transmitters as usual, setting them squealing one after the other, while Bell was retuning the receiver springs one by one, pressing them against his ear as I have described. One of the transmitter springs I was attending to stopped vibrating and I plucked it to start it again. It didn't start and I kept on plucking it, when suddenly I heard a shout from Bell in the next room, and then out he came with a rush, demanding, "What did you do then? Don't change anything. Let me see!" I showed him. It was very simple.

The contact screw was screwed down so far that it made permanent contact with the spring, so that when I snapped the spring, the circuit had remained unbroken while the strip of magnetized steel by its vibration over the pole of its magnet, was generating that marvellous conception of Bell's—a current of electricity that varied in intensity precisely as the air was varying in density within hearing distance of that spring. That undulatory current had passed through the connecting wire to the distant receiver which, fortunately, was a mechanism that could transform that current back into an extremely faint echo of the sound of the vibrating spring that had generated it. But what was still more fortunate, the right man had that mechanism at his ear during that fleeting moment, and instantly recognized the transcendent importance of that faint sound thus electrically transmitted. The shout I heard and his excited rush into my room were the result of that recognition.

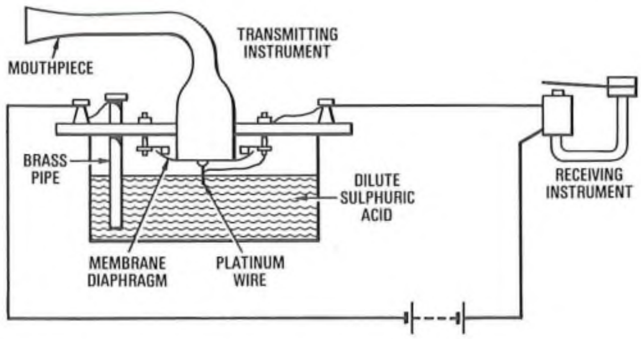
The speaking telephone was born at that moment. Bell knew perfectly well that the mechanism that could transmit all the complex vibrations of one sound could do the same for any sound, even that of speech. That experiment showed him that the complex apparatus he had thought would be needed to accomplish that long dreamed result was not at all necessary, for here was an extremely simple mechanism operating in a perfectly obvious way, that could do it perfectly. All the experimenting that followed that discovery, up to the time the telephone was put into practical use was largely a matter of working out the details.

We spent a few hours verifying the discovery, repeating it with all the differently tuned springs we had, and before we parted that night, Bell gave me directions for making the first electric speaking telephone. I was to mount a small drumhead of gold beater's skin over one of the receivers, join the centre of the drumhead to the free end of the receiver spring and arrange a mouthpiece over the drumhead to talk into. His idea was to force the steel spring to follow the vocal vibrations and generate a current of electricity that would vary in intensity as the air varies in density during the utterance of speech sounds. I followed these directions and had the instrument ready for its trial the very next day (Fig. 2(*a*), p. 13). I rushed it, for Bell's excitement and enthusiasm over the discovery had aroused mine again, which had been sadly dampened during those last few weeks by the meagre results of the harmonic experiments. I made every part of that first telephone myself, but I didn't realize while I was working on it what a tremendously important piece of work I was doing.

THE FIRST TELEPHONE LINE

The two rooms in the attic were too near together for the test, as our voices would be heard through the air, so I ran a wire especially for the trial from one of the rooms in the attic down two flights to the third floor where Williams' main shop was, ending it near my work bench at the back of the building. That was the first telephone line. You can well imagine that both our hearts were beating above the normal rate, while we were getting ready for the trial of the new instrument that evening. I got more satisfaction from the experiment than Mr. Bell did, for shout my best I could not make him hear me, but I could hear his voice and almost catch the words. I rushed upstairs and told him what I had heard. It was enough to show him that he was on the right track, and before he left that night, he gave me direction for several improvements in the telephones I was to have ready for the next trial.

I hope my pride in the fact that I made the first telephone, put up the first telephone wire and heard the first words ever uttered through a telephone, has never been too ostentatious and offensive to my friends, but I am sure that you will grant that a reasonable amount of that human weakness is excusable in me. My pride has been tempered to quite a bearable degree by my realization that the reason why I heard Bell in that first trial of the telephone and he did not hear me, was the vast superiority of his strong vibratory tones over any sound my undeveloped voice was then able to utter. My sense of hearing, however, has always been unusually acute, and that might have helped to determine this result.



Bell's variable-resistance transmitter used for the first transmission of intelligible speech (see Editorial)

The building where these first telephone experiments were made is still in existence. It is now used as a theatre. The lower stories have been much altered, but that attic is still quite unchanged and a few weeks ago I stood on the very spot where I snapped those springs and helped test the first telephone over 53 years before.

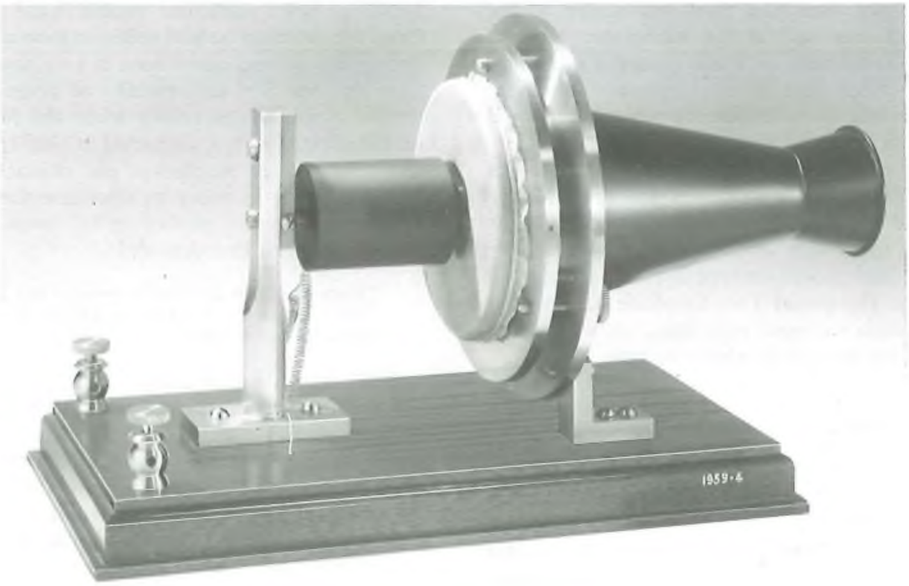
MR. WATSON HEARD THE FIRST SENTENCE EVER SPOKEN OVER THE TELEPHONE

Of course, in our struggle to expel the imps from the invention, an immense amount of experimenting had to be done, but it wasn't many days before we could talk back and forth and hear each other's voice. It is, however, hard for me to realize now that it was not until the following March that I heard a complete and intelligible sentence. It made such an impression upon me that I wrote that first sentence in a book I have always preserved. The occasion had not been arranged and rehearsed as I suspect the sending of the first message over the Morse telegraph had been years before, for instead of that noble first telegraphic message—"What hath God wrought?" the first message of the telephone was: "Mr. Watson, come here, I want you." Perhaps, if Mr. Bell had realized that he was about to make a bit of history, he would have been prepared with a more sounding and interesting sentence.

Soon after the first telephones were made, Bell hired two rooms on the top floor of an inexpensive boarding house at 5 Exeter Place, Boston, since demolished to make room for mercantile buildings. He slept in one room; the other he fitted up as a laboratory. I ran a wire for him between the two rooms and, after that time, practically all his experimenting was done there. It was there one evening when I had gone to help him test some improvement and to spend the night with him, that I heard the first complete sentence I have just told you about. Matters began to move more rapidly and, during the summer of 1876, the telephone was talking so well that one didn't have to ask the other man to say it over again more than three or four times before one could understand quite well, provided the sentences were simple.

THE CENTENNIAL EXPOSITION

This was the year of the Centennial Exposition at Philadelphia, and Bell decided to make an exhibit there. I was still working for Williams, and one of the jobs I did for Bell was to construct a telephone of each form that had been devised up to that time. These were the first nicely finished instruments that had been made. There had been no money nor time to waste on polish or non-essentials. But these Centennial tele-



Replica of Bell's Centennial Telephone transmitter
(Crown Copyright. Science Museum, London)

phones were done up in the highest style of the art. You could see your face in them. These aristocratic telephones worked finely, in spite of their glitter, when Sir William Thompson tried them at Philadelphia that summer. I was as proud as Bell himself, when I read Sir William's report, wherein he said after giving an account of the tests: "I need hardly say I was astonished and delighted, so were the others who witnessed the experiment and verified with their own ears the electric transmission of speech. This, perhaps, the greatest marvel hitherto achieved by electric telegraph, has been obtained by appliances of quite a homespun and rudimentary character." I have never forgiven Sir William for that last line. Homespun!

However, I recovered from this blow, and soon after Mr. Gardiner G. Hubbard, afterwards Mr. Bell's father-in-law, offered me an interest in Bell's patents if I would give up my work at Williams' and devote my time to the telephone. I accepted, although I wasn't altogether sure it was a wise thing to do from a financial standpoint. My contract stipulated that I was to work under Mr. Bell's directions, on the harmonic telegraph as well as on the speaking telephone, for the two men who were paying the bills still thought there was something in the former invention, although very little attention had been given to its vagaries after the 2 June discovery.

I moved my domicile from Salem to another room on the top floor at 5 Exeter Place, giving us the entire floor and, as Mr. Bell had lost most of his pupils by wasting so much of his time on telephones, he could devote nearly all his time to the experimenting. Then followed a period of hard and continuous work on the invention. I made telephones with every modification and combination of their essential parts that either of us could think of. I made and we tested telephones with all sizes of diaphragms made of all kinds of materials—diaphragms of boiler iron several feet in diameter, down to a miniature affair made of the bones and drum of a human ear, and found that the best results came from an iron diaphragm of about the same size and thickness as is used today. We tested electromagnets and permanent magnets, of a multitude of sizes and shapes, with long cores and short cores, fat cores and thin cores, solid cores and cores of wire, with coils of many sizes, shapes and resistances and mouthpieces of an infinite variety. Out of the hundreds of experiments, there emerged practically the same telephone you take off the hook and listen with today, although it was then transmitter as well as receiver.

TALKING FROM BOSTON TO CAMBRIDGE

Progress was rapid and, on 9 October 1876, we were ready to take the baby out of doors for the first time. We got permission from the Walworth Manufacturing Company to use their private wire running from Boston to Cambridge, about 2 miles long. I went to Cambridge that evening with one of our best telephones, and waited until Bell signalled from the Boston office on the Morse sounder. Then I cut out the sounder and connected in the telephone and listened. Not a murmur came through! Could it be that, although the thing worked all right in the house, it wouldn't work under practical line conditions? I knew that we were using the most complex and delicate electric current that had ever been employed for a practical purpose and that it was extremely "intense", for Bell had talked through the circuit composed of 20 or 30 human beings joined hand to hand. Could it be, I thought, that these high-tension vibrations, leaking off at each insulator along the line, had vanished completely before they reached the Charles river? That fear passed through my mind as I worked over the instrument, adjusting it and tightening the wires in the binding posts, without improving matters in the least. Then the thought struck me that perhaps there was another Morse sounder in some other room. I traced the wires from the place they entered the building and sure enough I found a relay with a high resistance coil in the circuit. I cut it out with a piece of wire across the binding posts and rushed back to my telephone and listened. That was the trouble. Plainly as one could wish came Bell's "ahoy".* I ahoyed back, and the first long-distance telephone conversation began.

Sceptics had been objecting that the telephone could never compete with the telegraph as its messages would not be accurate. For this reason, Bell had arranged that we should make a record of all we said and heard that night, if we succeeded in talking at all. We carried out this plan and the entire conversation was published in parallel columns in the next morning's *Advertiser*, as the latest startling scientific achievement. Infatuated with the joy of talking over an actual telegraph wire, we kept up our conversation until long after midnight. It was a very happy boy who travelled back to Boston in the small hours with the telephone under his arm

* "Ahoy!" was the telephone shout, and was used during the experiments, but "hello!" superseded it when the telephone got into practical use

done up in a newspaper. Bell had taken his record to the newspaper office and was not at the laboratory when I arrived there, but when he came in, there ensued a jubilation and war dance that elicited next morning from our landlady, who wasn't at all scientific in her tastes, the remark that we'd have to vacate if we didn't make less noise at nights.

Tests on still longer telegraph lines soon followed—the success of each experiment being in rather exact accordance with the condition of the poor, rusty-joined wires we had to use. Talk about imps that baffle inventors! There was one of an especially vicious and malignant type in every unsoldered joint of the old wires. The genial Tom Doolittle hadn't even thought of his hard-drawn copper wire then, with which he later eased the lot of the struggling telephone men.

OUR MANY VISITORS

Meanwhile, the fame of the invention had spread rapidly abroad and all sorts of people made pilgrimages to Bell's laboratory to hear the telephone talk. A list of the scientists who came to the attic of that cheap boarding house to see the telephone would read like the roster of the American Association for the Advancement of Science. My old electrical mentor, Moses G. Farmer, called one day to see the latest improvements. He told me then, with tears in his eyes, when he first read a description of Bell's telephone he couldn't sleep for a week, he was so mad with himself for not discovering the thing years before. "Watson," said he, "that thing has flaunted itself in my very face a dozen times within the last 10 years and every time I was too blind to see it. But," he continued, "if Bell had known anything about electricity he would never have invented the telephone."

Two of our regular visitors were young Japanese pupils of Professor Bell—very polite, deferential, quiet, bright-eyed little men, who saw everything and made cryptic notes. They took huge delight in proving that the telephone could talk Japanese. A curious effect of the telephone I noticed at that time was its power to paralyse the tongues of men otherwise fluent enough by nature and profession. I remember a prominent lawyer, who, when he heard my voice in the telephone making some such profound remark to him as "How do you do", could only reply, after a long pause, "Rig a jig jig and away we go".

TELEPHONE INSTALLATION

We began to get requests for telephone installations long before we were ready to supply them. In April 1877, the first outdoor telephone line was run between Mr. Williams' office at 109 Court Street, and his house in Somerville. Professor Bell and I were present and participated in the important ceremony of opening the line. and the event was a headliner in the next morning's papers.

FINANCIAL PROBLEMS

At about this time, Professor Bell's financial problems had begun to press hard for solution. We were very much disappointed because the President of the Western Union Telegraph Company had refused, somewhat contemptuously, Mr. Hubbard's offer to sell him all the Bell patents for the exhorbitant sum of 100 000 dollars. It was an especially hard blow to me for, while the negotiations were pending, I had had visions of a sumptuous office in the Western Union Building in New York which I was expecting to occupy as Superintendent of the Telephone Department of the great telegraph company. However, we recovered even from that facer. Two years later, the Western Union would gladly have bought those patents for 25 000 000 dollars.

But, before that happy time, there were lots of troubles of all the old and of several new varieties to be surmounted. Professor Bell's particular trouble in the Spring of 1877, arose from the fact that he had fallen in love with a most charming young lady. I had never been in love myself at that time and that was my first opportunity of observing what a serious matter it can be, especially when the father isn't altogether enthusiastic. I rather suspected at that time that that shrewd but kind-hearted gentleman put obstacles in the course of that true love, in order to stimulate the young man to still greater exertion in perfecting his inventions. But he might have thought as Prospero did:

> "They are both in either's power; but this swift business
> I must uneasy make, lest too light winning
> Make the prize light."

Bell's immediate financial needs were solved, however, by the demand that began at this time for public lectures by him on the telephone. It is hard to realize today what an intense and widespread interest there was then in the telephone. I don't believe any new invention could stir the public today as the telephone did then, surfeited as we are now with the wonderful things that have been invented since.

TELEPHONE LECTURES

Bell's first lecture, as I have said, was given before a well-known scientific society—the Essex Institute—at Salem, Massachusetts. They were especially interested in the telephone because Bell was living at Salem during the early telephone experiments. The first lecture was free to members of the society, but it packed the hall and created so much interest that Bell was requested to repeat it for an admission fee. This he did to an audience that again filled the house. Requests for lectures poured in upon Bell after that. Such men as Oliver Wendell Holmes and Henry W. Longfellow signed the request for the Boston lectures. The Salem lectures were soon followed by a lecture in Providence to an audience of 2000, by a course of three lectures at the largest hall in Boston—all three packed, by three in Chickering Hall, New York, and by others in most of the large cities of New England. They all took place in the Spring and early Summer of 1877, during which time there was little opportunity for experimenting for either Bell or myself, which I think now was rather a good thing, for we had become quite stale and needed a change that would give us a new influx of ideas.

My part in the lectures was important, although entirely invisible as far as the audience was concerned. I was always at the other end of the wire, generating and transmitting to the hall where Professor Bell was speaking, such telephonic phenomena as he needed to illustrate his lectures. I would have at my end circuit breakers—*rheotomes*, we called them—that would utter electric howls of various pitches, a lusty cornet player, sometimes a small brass band, and an electric organ with Edward Wilson to play on it; but the star performer was the young man who 2 years before didn't have voice enough to let Bell hear his own telephone, but in whom that 2 years of strenuous shouting into mouthpieces of various sizes and shapes had developed a voice with the carrying capacity of a steam calliope. My special function in these lectures was to show the audience that the telephone could really talk. Not only that, I had to do all the singing, too, for which my musical deficiences fitted me admirably.

My Telephone Entertainers

Professor Bell would have one telephone by his side on the stage where he was speaking, and three or four others of the big box variety we used at that time would be suspended about the hall, all connected by means of a hired telegraph wire with the place where I was stationed, from 5–25 miles away. Bell would give the audience, first, the commonplace parts of the show and then would come the thrillers of the evening; my shouts and songs. I would shout such sentences as, "How do you do", "Good evening", "What do you think of the telephone?" which they could all hear, although the words issued from the mouthpieces rather badly marred by the defective talking powers of the telephones of that date. Then I would sing "Hold the Fort", "Pull for the Shore", "Yankee Doodle", and as a delicate allusion to the Professor's nationality, "Auld Lang Syne". My sole sentimental song was "Do Not Trust Him, Gentle Lady." This repertoire always brought down the house. After every song, I would listen at my telephone for further directions from the lecturer, and always felt the artist's joy when I heard in it the long applause that followed each of my efforts. I was always encored to the limit of my repertoire, and sometimes had to sing it through twice.

I have always understood that Professor Bell was a fine platform speaker, but this is entirely hearsay on my part for, although I spoke at every one of his lectures, I have never yet had the pleasure of hearing him deliver an address.

First Sound-Proof Booth

In making the preparations for the New York lectures, I incidentally invented the sound-proof booth, but as Mr. Lockwood was not then associated with us, and for other reasons, I never patented it. It happened thus: Bell thought he would like to astonish the New Yorkers by having his lecture illustrations sent all the way from Boston. To determine whether this was practicable, he made arrangements to test the telephones a few days before on one of the Atlantic and Pacific wires. The trial was to take place at midnight. Bell was at the New York end; I was in the Boston laboratory. Having vividly in mind the strained relations already existing with our landlady, and realizing the carrying power of my voice when I really let it go, as I knew I should have to that night, I cast about for some device to deaden the noise. Time was short and appliances scarce, so the best I could do was to take the blankets off our beds and arrange them in a sort of loose tunnel, with the telephone tied up in one end and the other end open for the operator to crawl into. Thus equipped, I awaited the signal from New York announcing that Bell was ready. It came soon after midnight. Then I connected in the telephone, deposited myself in that cavity, and shouted and listened for 2 or 3 hours. It didn't work as well as it might. It is a wonder some of my remarks didn't burn holes in the blankets. We talked after a fashion, but Bell decided it wasn't safe to risk it with a New York audience. My sound-proof booth, however, was a complete success, as far as stopping the sound was concerned, for I found by cautious inquiry next day that nobody had heard my row. Later, inventors improved my booth, making it more comfortable for a pampered public, but not a bit more sound-proof.

"The Supposititious Mr. Watson"

One of those New York lectures looms large in my memory on account of a novel experience I had at my end of the wire. After hearing me sing, the manager of the lectures decided that, while I might satisfy a Boston audience, I would never do for a New York congregation; so he engaged a fine baritone soloist—a powerful negro, who was to assume the singing part of my programme. Being much better acquainted with the telephone than that manager was, I had doubts about the advisability of this change in the cast. I didn't say anything, as I didn't want to be accused of professional jealousy, and I knew my repertoire would be on the spot in case things went wrong. I was stationed that night at the telegraph office at New Brunswick, New Jersey, and I, and the rest of the usual appliances of that end of the lecture, went down in the afternoon to get things ready. I rehearsed my rival and found him a fine singer, but had difficulty in getting him to crowd his lips into the mouthpiece. He was handicapped for the telephone business by being musical, and he didn't like the sound of his voice jammed up in that way. However, he promised to do what I wanted when it came to the actual work of the evening, and I went to supper. When I returned to the telegraph office, just before eight o'clock, I found to my horror that the young lady operator had invited six or eight of her dear friends to witness the interesting proceedings. Now, besides my musical deficiencies, I had another qualification as a telephone man—I was very modest; in fact, in the presence of ladies, extremely bashful. It didn't trouble me in the least to talk or sing to a great audience, provided, of course, it was a few miles away, but when I saw those girls, the complacency with which I had been contemplating the probable failure of my fine singer was changed to painful apprehension. If he wasn't successful, a very bashful young man would have a new experience. I should be obliged to sing myself before those giggling, unscientific girls.

This world would be a better place to live in if we all tried to help our fellow-men succeed, as I tried that night, when the first song was called for, to make my musical friend achieve a lyrical triumph on the Metropolitan stage. But he sang that song for the benefit of those girls, not for Chickering Hall, and it was with a heavy heart that I listened for Bell's voice when he finished it. The blow fell. In his most delightful platform tones, Bell uttered the fatal words I had foreboded, "Mr. Watson, the audience could not hear that. Won't you please sing?" Bell was always a kind-hearted man, but he didn't know. However, I nerved myself with the thought that that New York audience, made sceptical by the failure of that song, might be thinking cynical things about my beloved leader and his telephone, so I turned my back on those girls and made that telephone rattle with the stirring strains of "Hold the Fort", as it never had before. Then I listened again, Ah, the sweetness of appreciation! That New York audience was applauding vigorously. When it stopped, the same voice came with a new note of triumph in it. "Mr. Watson, the audience heard that perfectly and call for an encore." I sang through my entire repertoire and began again on "Hold the Fort", before the audience was satisfied. That experience did me good, I have never had stage fright since. But the "supposititious Mr. Watson", as they called me then, had to do the singing at all of Bell's subsequent lectures. Nobody else had a chance at the job; one experience was enough for Mr. Bell.

My baritone had his hat on his head and a cynical expresion on his face, when I finished working on those songs. "Is that what you wanted?" he asked. "Yes." "Well, boss, I couldn't do that." Of course he couldn't.

An Exhibition in Lawrence

Another occasion is burnt into my memory that wasn't such a triumph over difficulties. In these lectures, we always had another trouble to contend with, besides the rusty joints in the wires; that was the operators cutting in, during the lectures, their highest resistance relays, which enabled them to hear some of the intermittent current effects I sent to the hall. Inductance, retardation, and all that sort of thing which you have so largely conquered since, were invented long before the telephone was, and were awaiting her on earth all ready to slam it when Bell came along.

Bell lectured at Lawrence, Massachusetts, one evening in May, and I prepared to furnish him with the usual programme from the laboratory in Boston. But the wire the company assigned us was the worst yet. It worked fairly well when we tried it in the afternoon, but in the evening every station on the line had evidently cut in its relay, and do my best I couldn't get a sound through to the hall,

The local newspaper generally sent a reporter to my end of the wire to write up the occurrences there. This is the report of such an envoy as it appeared in the Lawrence paper the morning after Bell's lecture there:

"Mr. Fisher returned this morning. He says that Watson, the organist and himself occupied the laboratory, sitting in their shirt sleeves with their collars off. Watson shouted his lungs into the telephone mouthpiece, 'Hoy! Hoy! Hoy!' and, receiving no response, inquired of Fisher if he pardoned for a little 'hamburg edging' on his language. Mr. Fisher endeavoured to transmit to his Lawrence townsmen the tune of 'Federal Street' played upon the cornet, but the air was not distinguishable here. About 10 p.m., Watson discovered the 'Northern Lights' and found his wires alive with lightning, which was not included in the original scheme of the telephone. He says the loose electricity abroad in the world was too much for him."

Waiting for Watson

The next morning a poem appeared in the Lawrence paper. The writer must have sat up all night to write it. It was entitled "Waiting for Watson," and I am very proud of the only poem I ever had written about me. I am going to ask your permission to read it. Please notice the great variety of human feeling the poet put into it. It even suggests missiles, though it flings none.

Lawrence, Massachusetts, *Daily American*, Tuesday, 29 May 1877.

WAITING FOR WATSON

To the great hall we strayed,
Fairly our fee we paid,
Seven hundred there delayed,
But, where was Watson?

Seven hundred souls were there,
Waiting with stony stare,
In that expectant air—
Waiting for Watson.

Oh, how our ears we strained,
How our hopes waxed and waned,
Patience to dregs we drained,
Yes, we did, Watson!

Give but one lusty groan,
For bread we'll take a stone,
Ring your old telephone!
Ring, brother Watson.

Doubtless 'tis very fine,
When, all along the line,
Things work most superfine—
Doubtless 'tis Watson.

We know that, every day,
Schemes laid to work and pay,
Fail and "gang aft a-gley"—
Often, friend Watson.

And we'll not curse, or fling,
But, next time, do the thing
And we'll all rise and sing,
"Bully for Watson!"

Or, by the unseen powers,
Hope in our bosom sours,
No telephone in ours—
"Please, Mr. Watson."

My Last Public Appearance

But my vacation was about over. Besides raising the wind, the lectures had stirred up a great demand for telephone lines. The public was ready for the telephone long before we were ready for the public, and this pleasant artistic interlude had to stop; I was needed in the shop to build some telephones to satisfy the insistent demand. Fred Gower, a young newspaper man of Providence, had become interested with Mr. Bell in the lecture work. He had an unique scheme for a dual lecture with my illustrations sent from a central point to halls in two cities at the same time. I think my last appearance in public was at one of these dualities. Bell lectured at New Haven and Gower gave the talk at Hartford, while I was in between at Middletown, Conn., with my apparatus, including my songs. It didn't work very well. The two lecturers didn't speak synchronously. Gower told me afterwards that I was giving him, "How do you do", when he wanted "Hold the Fort", and Bell said I made it awkward for him by singing "Do Not Trust Him, Gentle Lady", when he needed the trombone solo.

THE "GOWER-BELL" TELEPHONE

In the following August, Professor Bell married and went to England, taking with him a complete set of up-to-date telephones, with which he intended to start the trouble in that country. Fred Gower became so fascinated with lecturing on the telephone that he gave up an exclusive right Mr. Hubbard had granted him for renting telephones all over New England, for the exclusive privilege of using the telephone for lecture purposes all over the United States. But it wasn't remunerative after Bell and I gave it up. The discriminating public preferred Mr. Bell as speaker—and I always felt that the singing never reached the early heights.

Gower went to England later. There he made some small modification of Bell's telephone, called it the "Gower-Bell" telephone (see Fig. 2(*c*), p. 13), and made a fortune out of his hyphenated atrocity. Later, he married Lilian Nordica, although she soon separated from him. He became interested in ballooning. The last scene in his life before the curtain dropped showed a balloon over the waters of the English Channel. A fishing boat hails him, "Where are you bound?" Gower's voice replies, "To London." Then the balloon and its pilot drifted into the mist for ever.

DEVELOPING A CALLING APPARATUS—THE WATSON "BUZZER"

As I said, I went back to work, and my next 2 years was a continuous performance. It began to dawn on us that people engaged in getting their living in the ordinary walks of life couldn't be expected to keep the telephone at their ear all the time waiting for a call, especially as it weighed about 10 pounds then and was as big as a small packing case, so it devolved on me to get up some sort of a call signal. Williams, on his line, used to call by thumping the diaphragm through the mouthpiece with the butt of a lead pencil. If there was someone close to the telephone at the other end, and it was very still, it did pretty well, but it seriously damaged the vitals of the machine and therefore I decided it wasn't really practical for the general public; besides we might have to supply a pencil with every telephone and that would be expensive. Then, I rigged a little hammer inside the box with a button on the outside. When the button was thumped the hammer would hit the side of the diaphragm where it could not be damaged, the usual electrical transformation took place, and a much more modest, but still unmistakable, thump would issue from the telephone at the other end.

That was the first calling apparatus ever devised for use with the telephone, not counting Williams' lead pencil, and several with that attachment were put into practical use. But the exacting public wanted something better, and I devised the Watson "Buzzer"—the only practical use we ever made of the harmonic telegraph relics. Many of these were sent out. It was a vast improvement on the Watson "Thumper," but still it didn't take the popular fancy. It made a sound quite like the horseradish grater automobile signal we are so familiar with now-a-days, and aroused just the same feeling of resentment which that does. It brought me only a fleeting fame for I soon superseded it by a magneto-electric call bell that solved the problem, and was destined to make a long-suffering public turn cranks for the next 15 years or so, as it never had before, or ever will hereafter.

Perhaps I didn't have any trouble with the plaguey thing!

The generator part of it was only an adaption of a magneto shocking machine I found in Davis' Manual of Magnetism and worked well enough, but I was guilty of the jingling part of it. At any rate, I felt guilty when letters began to come from our agents reciting their woes with the thing, which they said had a trick of sticking and failing on the most important occasions to tinkle in response to the frantic crankings of the man who wanted you. But I soon got it so it behaved itself and it has been good ever since, for I have been told that nothing better has ever been invented, that they have been manufactured by the millions all over the world, and that identical jingler today does practically all the world's telephone calling.

"Williams' Coffins"

For some reason, my usual good luck I presume, the magneto call bells didn't get my name attached to them. I never regretted this, for the agents, who bought them from Williams, impressed by the long and narrow box in which the mechanism was placed, promptly christened them "Williams' Coffins". I always thought that a narrow escape for me!

The first few hundreds of these call bells were a continuous shock to me for other reasons than their failure to respond. I used on them a switch, that had to be thrown one way by hand, when the telephone was being used, and then thrown back by hand to put the bell in circuit again. But the average man or woman wouldn't do this more than half the time, and I was obliged to try a series of devices, which culminated in that remarkable achievement of the human brain—the automatic switch hook—that demanded of the public only that it should hang up the telephone after it got through talking. This the public learnt to do quite well after a few years of practice.

THE BLAKE TRANSMITTER

You wouldn't believe me if I should tell you a tithe of the difficulties we got into by flexible cords breaking inside the covering, when we first began to use hand telephones!

Then they began to clamour for switchboards for the first centrals, and individual call bells began to keep me awake at nights. The latter were very important then, for such luxuries as one-station lines were scarce. Six to twenty stations on a wire was the rule, and we were trying hard to get a signal that would call one station without disturbing the whole town. All of these and many other things had to be done at once, and, as if this was not enough, it suddenly became necessary for me to devise a battery transmitter. The Western Union people had discovered that the telephone was not such a toy as they had thought, and as our 100 000-dollar offer was no longer open for acceptance, they decided to get a share of the business for themselves, and Edison evolved for them his carbon-button transmitter. This was the hardest blow yet.

We were still using the magneto transmitter, although Bell's patent clearly covered the battery transmitter. Our transmitter was doing much to develop the American voice and lungs, making them powerful but not melodious. This was, by the way, the telephone epoch when they used to say that all the farmers waiting in a country grocery would rush out and hold their horses when they saw any one preparing to use the telephone. Edison's transmitters talked louder than the magnetos we were using and our agents began to clamour for them, and I had to work nights to get up something just as good. Fortunately for my constitution, Frank Blake came along with his transmitter. We bought it and I got a little sleep for a few days. Then our little David of a corporation sued that big Goliath, the Western Union Company, for infringing the Bell patents, and I had to devote my leisure to testifying in that suit, and making reproductions of the earliest apparatus to prove to the court that they would really talk and were not a bluff, as our opponents were asserting.

Then I put in the rest of my leisure making trips among our agents this side of the Mississippi to bring them up to date and see what the enemy were up to. I kept a diary of those trips. It reads rather funnily today, but I won't go into that. It would detract from the seriousness of this discourse.

WIRE TROUBLES

Nor must I forget an occasional diversion in the way of a sleet storm which, combining with our wires then beginning to fill the air with house-top lines and pole lines along the sidewalks, would make things extremely interesting for all concerned. I don't remember ever going out to erect new poles and run wires after such a catastrophe. I think I must have done so, but such a trifling matter naturally would have made but little impression upon me.

Is it any wonder that my memory of those 2 years seems like a combination of the Balkan war, the rush hours on the subway and a panic on the stock market?

TURNING TO OTHER ACTIVITIES

My connexion with the telephone business ceased in 1881. The strenuous years I had passed through had fixed in me a habit of not sleeping at night as much as I should, and a doctor man told me I would better go abroad for a year or two for a change. There was not the least need of this, but as it coincided exactly with my desires, and as the telephone business had become, I thought, merely a matter of routine, with nothing more to do except pay dividends and fight infringers, I resigned my position as General Inspector of the Company, and went over the ocean for the first time.

When I returned to America a year or so later, I found the telephone business had not suffered in the least from my absence, but there were so many better men doing the work that I had been doing, that I didn't care to go into it again.

I was looking for more trouble in life and so I went into shipbuilding, where I found all I needed.

Before Mr. Bell went to England on his bridal trip, we agreed that as soon as the telephone became a matter of routine business he and I would begin experimenting on flying machines, on which subject he was full of ideas at that early time. I never carried out this agreement. Bell did some notable work on airships later, but I turned my attention to battleships.

MY GREATEST PRIDE

Such is my very inadequate story of the earliest days of the telephone so far as they made part of my life. Today, when I go into a central office or talk over a long distance wire or read the annual report of the American Telephone and Telegraph Company, filled with figures up in the millions and even billions, when I think of the growth of the business, and the marvellous improvements that have been made since the day I left it, thinking there was nothing more to do but routine, I must say that all that early work I have told you about seems to shrink into a very small measure. And, proud as I always shall be, that I had the opportunity of doing some of that earliest work myself, my greatest pride is that I am one of the great army of telephone men, every one of whom has played his part in making the Telephone Service what it is today.

I thank you.

The Evolution of the United Kingdom Telephone Service

N. S. LINFORD†

UDC 621.39.001.6:6(091)

This article describes the growth of the telephone service in the UK from the time of the introduction of the telephone to this country by Alexander Graham Bell in 1877. Particular emphasis is given to the early years, when the telephone companies and the Post Office were competing to supply the telephone service.

INTRODUCTION

In Dr. Watson's address "The Birth and Babyhood of the Telephone" to the London Centre of the Institution of Post Office Electrical Engineers on 13 November 1928,* he referred to Professor Bell's visit to England in August 1877 accompanied by his bride and "taking with him a complete set of up-to-date telephones with which to start the trouble in that country". The instruments Bell brought with him were not the first of his telephones to be seen in England. In September of the previous year, 1876, Sir William Thompson, later Lord Kelvin, addressing the British Association for the Advancement of Science in Glasgow made reference to and exhibited Bell's earlier telephones. Three months previously, Sir William Thompson had been a judge at the Centennial Exposition in Philadelphia where he had met Bell and was greatly impressed by his invention. Towards the end of that year, on 9 December 1876, Bell secured patent rights for his telephone in this country, and the "trouble" was about to start. The subsequent development of the UK system, in terms of the number of telephones and the most notable events of the past 100 years, is illustrated in Fig. 1; the changing shape of the telephone instrument over this period is shown in Fig. 2. This article describes these events, with particular emphasis on the early formative years.

BRINGING THE TELEPHONE TO THE UK

During the months that followed his arrival, Bell, together with his UK representative—Colonel Reynolds, spent a great deal of his time working on public relations. He addressed many meetings, including the British Association in Plymouth

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* WATSON, T. A. The Birth and Babyhood of the Telephone. (In this issue, p. 3.)

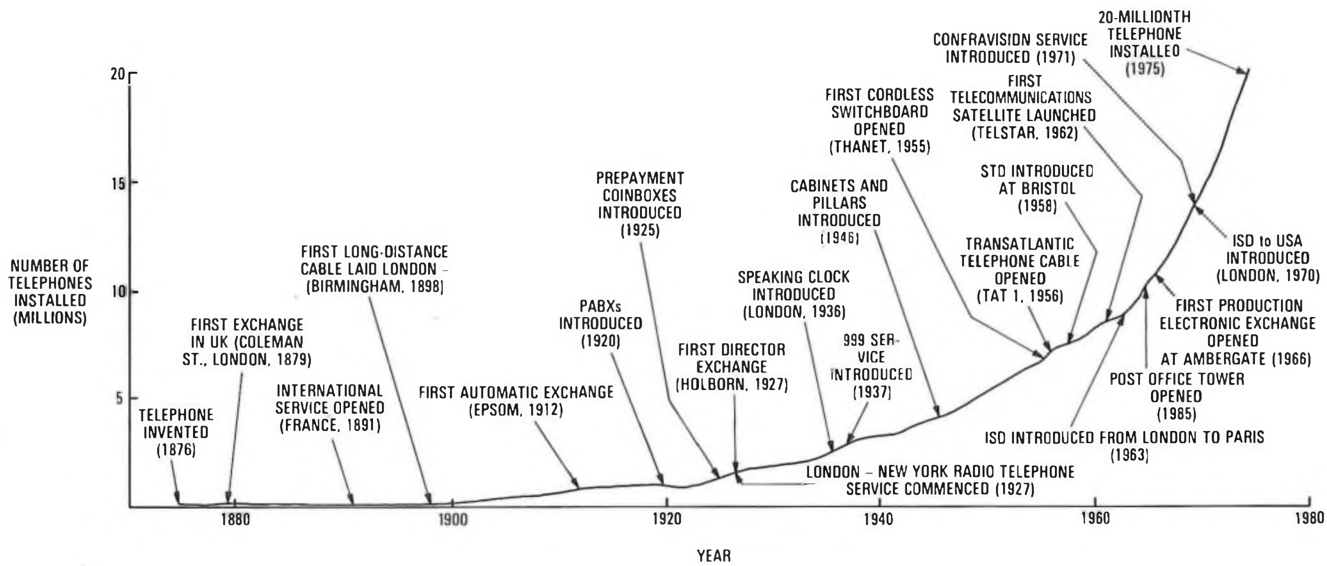
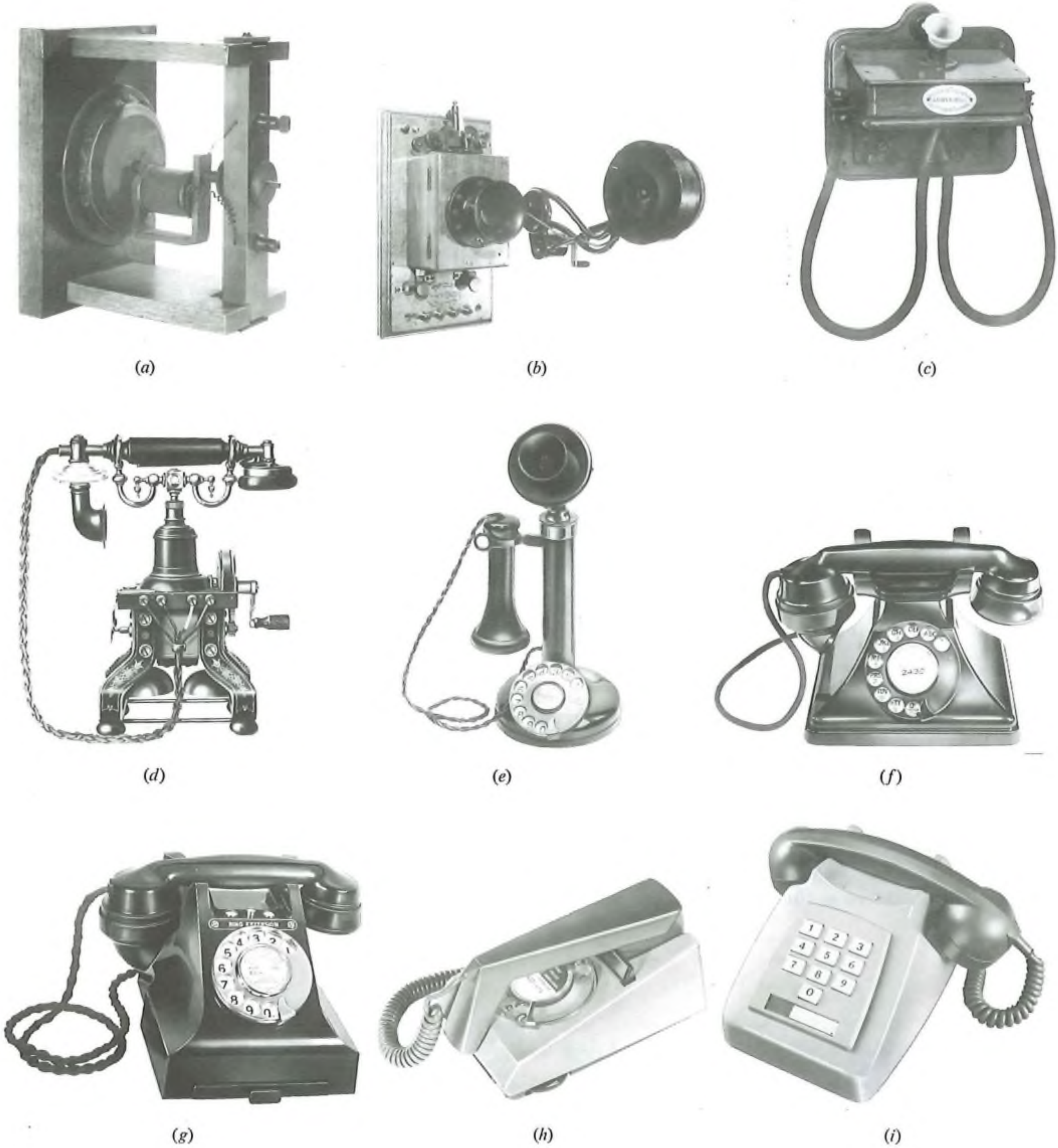


FIG. 1—Growth of telephones 1876–1975



(a) Bell's "Gallows Frame Telephone" (1875)
(b) Edison's telephone (1878)
(c) Gower-Bell loudspeaking telephone (1879)
(d) Table telephone (1895)
(e) "Candlestick" telephone (1924)
(f) Telephone Instrument No. 162 (1929)
(g) 300-type telephone instrument (1938)
(h) Trimphone (1965)
(i) Self-contained Keyphone (1975)

FIG. 2—The changing shape of the telephone instrument
(Fig. 2(a) Crown Copyright. Science Museum, London)

and the Society of Telegraph Engineers in London, and even had part of a House of Commons debate sent by telephone from the Gallery to the offices of the *Daily News* in Bouverie Street. The climax of his campaign was reached on the evening of 14 January 1878 when Professor Bell, accompanied by Reynolds, was presented to Queen Victoria at Osborne House. The new invention was demonstrated and telephonic communication was established with Osborne Cottage, the residence of Sir Thomas Biddulth, with whom Her Majesty was able to converse. Her Majesty was pleased and, a few days later, ordered her first set of telephones.

Meanwhile, Colonel Reynolds had been trying to persuade the Post Office to adopt Bell's telephone. In September 1877, he offered to exhibit the telephone, but the Engineer-in-Chief of the day, Mr. R. S. Cully, reported against the proposal observing that "his Department was in possession of full knowledge of the detail of the invention and that the possible use of the telephone was very limited". This attitude reflected the limitations of Bell's telephone at that time, but it did not stop the Colonel. He was back at the Post Office in December of that year, offering to supply telephones at rates 40% below those offered to the public. It took 9 months for the Post Office and Treasury to make up their minds to accept the offer, despite a more favourable report on the telephone from the then Chief Electrician of the Post Office, Mr. W. H. Preece, later Sir William Preece.

THE FIRST UK TELEPHONE COMPANY

By this time, on 14 June 1878, the first telephone company in the UK was formed under the title *The Telephone Company Ltd.* (*Bell's Patents*). Its purpose was to work Bell's patent with a capital of £100 000. The Company established its offices at 36 Coleman Street, London EC.

The early activities of The Telephone Company Ltd. were confined to installing instruments and private lines, which were of single wire and earth return, and one of the first private telephone lines to be installed was from the residence of a Mr. H. F. Tiarks, of Chistlehurst, to his stables.

The first commercial telephones consisted of a bell, a press-button and battery, a switchhook and 2 of Bell's telephones, one used as a receiver and the other as a transmitter.

THE FIRST UK TELEPHONE EXCHANGE

Following developments in the USA, where the first telephone exchange had been opened at New Haven, Connecticut on 28 January 1878, the Telephone Company Ltd. opened their first exchange in London, in August 1879. It was housed at their offices at 36 Coleman Street and had a capacity for 150 lines, but opened with some 7 or 8 subscribers. Fig. 3 shows this exchange and also, for comparison, a TXE4 electronic exchange. Before the end of 1879, 2 further exchanges were opened, one at 101 Leadenhall Street and the other at 3 Palace Chambers, Westminster. The telephone business had really started and, at the end of that year, there were about 200 subscribers.

THE COMPETITION TO SUPPLY TELEPHONE SERVICE

The activities of The Telephone Company Ltd. were not to remain unchallenged for long. The first sign of competition in the UK was the advent of Edison's telephone (Fig. 2(*b*)) which used a carbon transmitter and a chalk receiver. The Edison Company was floated on 2 August 1879 and quickly established exchanges in Lombard Street, Queen Victoria Street, Eastcheap and Chancery Lane, and by 1880 had 170 subscribers. Their annual tariff was £12 against £20 charged by the Bell Company.

The Government had foreseen that the growth of telephone exchanges was a direct threat to the telegraph service and its revenue. Legal advisers held the view that telephonic communications were telegrams within the meaning of the Telegraph Acts of 1863 and 1869, and in November 1879, the Attorney General, on behalf of the Crown, filed a suit against the Edison Telephone Company.

No doubt influenced by the dangers of competition, the close interest the Post Office was now paying to the development of the telephone and the forthcoming legal proceedings, the 2 companies amalgamated into the United Telephone Company on the 13 May 1880 with a capital of £500 000. Shares to the value £200 000 were allotted to the Bell Company and £115 000 to the Edison Company. Tariff differentials ceased and a rate of £20/annum was adopted.

It was not until November 1880 that the Crown action against the United Telephone Company, who were then holders of Edison's patent, came before the court. The newly formed United Telephone Company was confident of success, but in the event, judgement was given to the Crown. The High Court decision held that a telephone conversation was a "message" and therefore a telegram, and since the United Telephone Company maintained its equipment for profit, public subscribers' conversations were an infringement of the Postmaster General's monopoly. This was perhaps the most important legal event in the development of the telephone in the UK and has exercised a lasting influence.

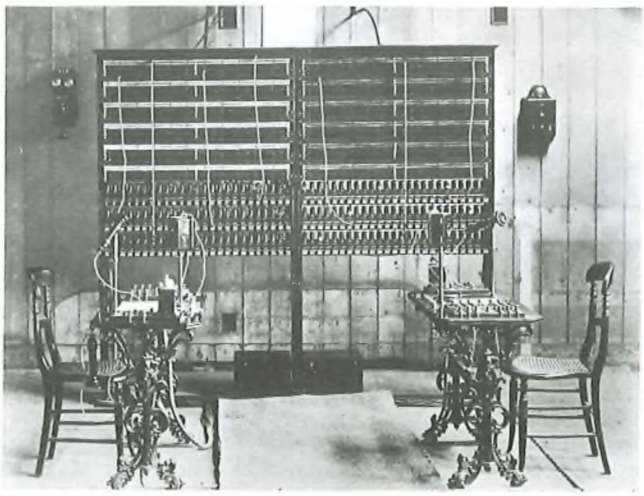


FIG. 3—The first UK public telephone exchange and a TXE4 electronic exchange.

Nevertheless, the judgement posed a major problem for the Government. What should it do with the telephone service? The alternatives were: to undertake the development of the telephone itself, to authorize approved firms to undertake the business, or to abandon the telephone completely. The third alternative was unthinkable and, as they were in no position immediately to pursue the fiist, the Government finally decided to issue licenses to private firms, allowing them to provide telephones for 10% royalty on rentals. At the same time, the Government announced that the Post Office was prepared to enter the business of supplying telephones and exchanges.

The United Telephone Company did not tamely accept the situation; after all, it held the master patent and intended vigorously to uphold its rights and threatened to take proceeding against any one who attempted infringement. On Christmas Day 1880, the *Electrician* contained 3 advertisements alongside one another which amply illustrate the unhappy and strained relations between the Post Office and the telephone companies. They read as follows.

TELEPHONE INTERCOMMUNICATION

The Post Office has for some time provided a means whereby the Renters of wires into the Postal Telegraph Offices may be placed at will in direct communication with each other. Such a system has been in operation in Newcastle-upon-Tyne, Hull, Middlesbrough, Stockton and other towns for several years.

The instrument used in these cases up to the present time has been the ABC instrument. Henceforward, in order to meet the convenience of the public, the Post Office will be prepared to provide such a system with either the ABC or the Telephone instrument.

In the case of the Telephone instrument, the annual charge to each Renter in London will be £15 if his premises be within half a mile of the Telegraph Office, £19 if they be more than half a mile, but not more than a mile distance, and at proportionate rates for greater distances.

The Renter will not only have the facility afforded them of communicating direct with each other, but they will also be enabled to send messages by wire to the Telegraph Office to be thence transmitted at ordinary charge to other towns.

Application should be made to the Secretary, General Post Office, and when several persons in any one neighbourhood have agreed to take wires, immediate steps will be taken to establish a system of intercommunication by Telephone instruments.

Signed BY ORDER OF THE POSTMASTER GENERAL
December 1880

TELEPHONES: The attention of the Director of the United Telephone Company Ltd. having been called to certain ADVERTISEMENTS by the Postmaster General offering to supply the public with Telephone instruments in connexion with private wires and upon the exchange system, NOTICE is hereby given that the patent rights in this country of Professor Graham Bell and Mr. Thomas Alva Edison are the exclusive property of the United Telephone Company (Ltd.) and that PROCEEDINGS will be TAKEN against ALL PERSONS USING ANY FORM OF CARBON TRANSMITTER, or any form of Magneto or Electro-Chemical Receiver, whether such telephones are supplied by the Postmaster General or by any other persons not authorized by the United Telephone Company (Ltd.), all such Transmitters and Receivers being infringement of the said Patent.

Signed by order of the board JAMES BRAND Chairman
36 Coleman Street, London, EC.
21 December 1880.

TELEPHONES: With reference to an advertisement, signed by the Chairman of the United Telephone Company (Ltd.) threatening legal proceedings against the users of Telephones supplied by the Postmaster General, the GOWER-BELL TELEPHONE COMPANY (Ltd.) hereby give notice:

(*i*) That HM Postmaster General has contracted with this Company for large supplies of Gower-Bell Loud-Speaking Telephones, having found this to be the only form of Telephone which has sustained the official test for efficiency, simplicity, and permanence of operation.

(*ii*) That the Telephones sold by this Company are manufactured under agreement with the United Telephone Company (Ltd.) and that that Company have been, and is directly, interested in the profits arising from such sales.

By order J A MAYS, Secretary
9 Great Winchester Street, London EC.
22 December 1880.

Meanwhile, exchanges had opened in many provincial cities. Local telephone companies were formed by enterprising individuals and the United Telephone Company had extended its activities to the provinces. Often, the opening of a new exchange was accompanied by bitter competition for business from rival companies and legal actions by the United Telephone Company for infringement of patents. Sheffield was one such city. In 1883, the National Telephone Company, which was formed in 1881 to supply telephones in Scotland and the East Midlands, sought to buy the interest of a local firm, Messrs. Taskers Sons & Company, who were successfully supplying telephones in Sheffield. Taskers refused and, in retaliation, the National Telephone Company quickly established a rival exchange. For the next 5 years, the 2 companies fought a ruthless commercial battle for telephone business in Sheffield, but eventually, the greater resources of the National Telephone Company prevailed and they took over the local firm. One amusing story is recorded during this period of intense competition. Both companies obtained wayleaves to erect a pole in the sole available position on one property. The workmen of one of the companies spent the day digging a large hole intending to erect a pole the following day. The next morning, they arrived with their pole only to find the rival company had already erected a pole in the hole they had dug the previous day.

A TYPICAL EXCHANGE

Journalists took a lively interest in the telephone, and an interesting description of Avenue Exchange (see Fig. 4) appeared in the *Pall Mall Gazette* of December 1883.

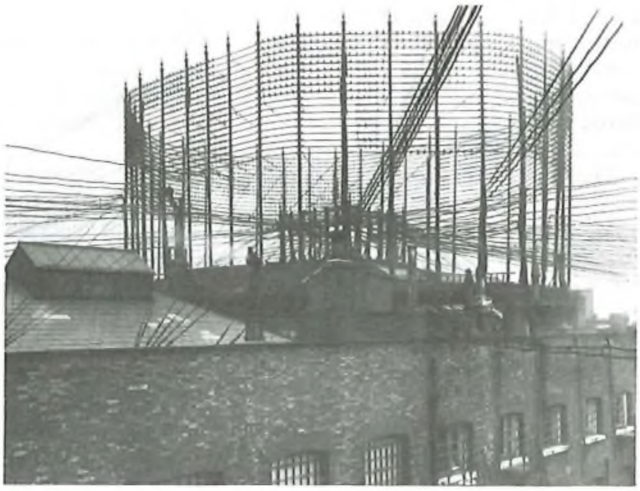


FIG. 4—Avenue telephone exchange as it was in 1907

"What then is a telephone exchange station?

We will take the East India Avenue, in the City, as an average sample. From the lofty roof of one of the houses of that sombre court rises a derrick, a square structure of wrought iron bars 30 or 40 feet high by 8 or 10 feet wide, and looking like the upper portion of a skeleton lighthouse, very rigid and very transparent. This edifice is surrounded by a lightning conductor; you ascend it by a perpendicular ladder, and, pausing on its upper storey—for it is divided into two floors—you look around from your eerie perch to find that what appears is numerable wires radiating from your transparent cage in every possible direction over the dirty housetops of the City. Most of these wires are bare and unenclosed; others are in cables containing each 20 wires. Each of them is lettered and numbered, and a cupboard on the derrick contains an apparatus for testing them.

So much for what is above the roof. Below, in the attic, is a room occupied by 11 young ladies. The 271 wires, which represent the subscribers of the East India Avenue Exchange with 46 trunk and other direct wires are guided down from the derrick above into neat mahogany cabinets or cases, in front of which the young ladies are seated. The alert dexterity with which, at the signal given by the fall of a small lid about the size of a teaspoon, the lady hitches on the applicant to the number with which he desires to talk is pleasant to watch. On the day of our visit, there had been in this one office no less than 2400 calls. Here, indeed, is an occupation to which no "heavy father" could object and the result is that a higher class of young women can be obtained for the secluded career of a telephonist as compared with that which follows the more barmaid-like occupation of a telegraph clerk".

The early years of telephony were difficult for subscribers and the telephone companies who often found themselves in financial difficulties, some even without sufficient money to pay wages. Wayleaves were difficult to obtain, and the Victorian obsession with competition caused duplication of trunk lines and rival exchanges to operate in the same territory; sometimes without intercommunication, so that people who wanted to talk to everyone on both systems needed to rent 2 telephones.

DEVELOPMENTS BEFORE THE FIRST WORLD WAR

The steady increase in applications for telephone service required improvements in the switching arrangements and, before the end of the nineteenth century, resulted in the development of multiple-position switchboards and the central-battery system, making batteries at the telephone unnecessary. Other technical achievements included the development of dry cables, but perhaps the most important invention of all was in 1889 by an undertaker, Almon B. Strowger of Kansas City, USA. It is related that Strowger suspected his calls were being diverted by the exchange to a business competitor and, in his exasperation, began to experiment with a collar box and pins to see whether calls could be linked automatically. From these quaint experiments, the history of practical mechanical telephone switching commenced.

The Post Office continued to develop its own telephone service. In 1881, the ABC telegraph sets connected to the switching system at Newcastle-on-Tyne began to be replaced by telephones and, in March 1881, a telephone exchange service was established at Swansea. During the following years, ABC telegraph sets were also replaced in other cities. The Post Office standard telephone continued to be the Gower-Bell instrument (Fig. 2(*c*)).

The 1890s saw the first efforts to unify telephone service in the UK. On 1 May 1889, The United Telephone Company and the Lancashire and Cheshire Company amalgamated with the National Telephone Company, serving a total of 25 585 telephones, and in 1896, the Post Office took over the trunk system which then consisted of 29 000 miles of wire.

The Telegraph Act of 1899 was the result of agitation against the services and alleged high charges of the National Telephone Company. It provided a sum of £2M to allow the Post Office to compete in the provision of telephones and to establish exchanges in London. Local authorities were empowered to establish exchanges financed by borrowing against rates, and the Act restricted the activities of private companies to those areas where they had already established exchange services.

Up to this time, the Post Office had not vigorously competed with the private companies and, in January 1901, still served only 2026 exchange lines from 112 exchanges. Most of them were very small with only 2 or 3 lines. Twenty-five of the 112 had only one connexion and could hardly be called exchanges. In comparison, 2 years earlier, the National Telephone Company reported that their system had grown to 853 exchanges, serving 120 144 lines.

Following the Act of 1899, Post Office activity in the provision of telephones greatly increased, not only in London, but also in the rural areas which had largely been ignored by the private companies; by 1911, the Post Office had established 1033 provincial exchanges serving 25 681 subscribers, in addition to 27 exchanges with over 47 000 subscribers in London.

The provision of telephones by local authorities was not a great success. Only 6 authorities actually provided service, these being Tunbridge Wells, Glasgow, Brighton, Hull, Swansea and Portsmouth. The undertakings did not survive for long, although Portsmouth successfully operated for 11 years. Eventually, they were all taken over by the Post Office or The National Telephone Company, with the single exception of Hull which still provides telephone service today.

Overseas trunk telephony had commenced in 1891 when the first telephone cable, laid by HMTS *Monarch* between England and France, enabled telephone conversations to be made between London and Paris.

On 1 January 1912, the Postmaster General took over the assets of the National Telephone Company and, for the first time, a unified telephone system was available throughout most of the UK. For a sum of about £12·5M the Post Office obtained 1565 exchanges, 561 738 telephone stations and 1·5 million miles of wire.

There followed a period of rapid expansion and, during the next 3 years, no fewer than 450 new exchanges were opened. On 18 May 1912, the Post Office opened the UK's first public automatic telephone exchange in Epsom.

A few months after the opening of Epsom, a second automatic exchange was brought into service at the General Post Office, London. This equipment served officials of the Post Office as a private branch exchange and was known as the *Official Switch*. It was equipped for 900 lines and had an ultimate capacity of 1500. Both exchanges were supplied by the Automatic Telephone Manufacturing Company Ltd. of Liverpool, who were the first firm to undertake the manufacture of automatic telephone equipment in this country.

DEVELOPMENTS BETWEEN THE WARS

Progress during the 1914–18 War was slow, but, by 1918, some 13 automatic exchanges of several different types had been brought into service; these included Leeds, which was the largest of its kind in Europe, being equipped for 6600 lines with an ultimate capacity of 15 000 lines, and opened for service on 18 May 1918. After a series of full-scale experiments, the Post Office decided to adopt the Strowger system as its standard. It had been thought that there might be difficulties using this system in very large cities such as London, but this problem was solved when the Automatic Telephone Manufacturing Company Ltd. of Liverpool, working in conjunction with Post Office engineers, developed the director system; the first director exchange was brought into use at Holborn, London in 1927.

The complicated job of planning the automatic system for London included the selection of suitable names for exchanges. It was not practicable to use 2 identical letter combinations for any 2 exchanges; hence Hammersmith became RIVerside leaving HAM for Hampstead. The automation of rural areas was achieved by small-scale exchanges which could be installed in cheap and quickly-erected buildings. Although only 9 of these exchanges had been completed by 1929, 5 years later, over 1100 were in use.

The steady automation and expansion of the UK telephone system continued throughout the 1930s. On-demand trunk service was introduced and also the cheap shilling night trunk call as a part of the plan, initiated by Sir Kingsley Wood, the then Postmaster General, for advertising and

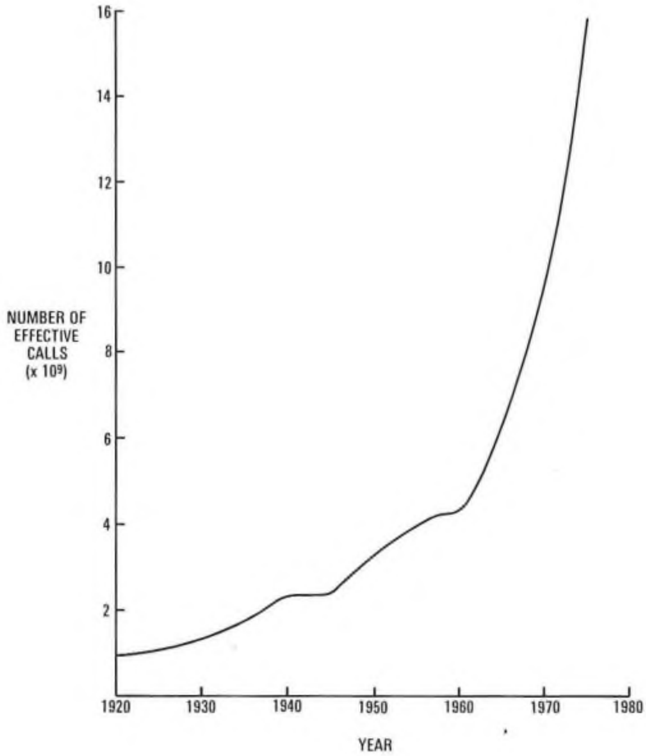
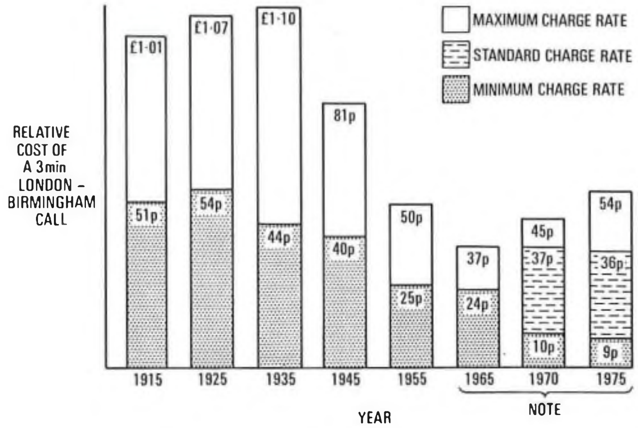


FIG. 5—Growth of telephone calls 1920–75



Note: Direct-dialled calls

FIG. 6—Relative cost of a 3 min London–Birmingham call 1915–75 (expressed at October 1975 prices)

increasing the popularity of the telephone. The number of stations grew from 1 284 901 in 1925 to 2 387 808 in 1935. In the same period, calls increased from 929 million/annum to 1680 million/annum.

Following the introduction of the first radio telephone service between the UK and the USA in January 1927, overseas telephone service was progressively extended to other countries throughout the world.

The 1930s saw the introduction of 12-channel carrier systems and, in 1936, the Post Office laid the world's first coaxial cable between London and Birmingham.

Telephone instruments were improved. The development of the immersed-electrode principle in transmitter design and advances in plastics technology made it possible for the Post Office to introduce a new telephone with a plastics case and a handset suitable for all types of exchanges. This telephone was known as the *Telephone No. 162* (Fig. 2(*f*)) and was further improved by the introduction of an anti-sidetone induction coil in 1932. A new combined telephone set, the shape of which originated from Sweden, was introduced in 1938 and was known as the 300-type telephone (Fig. 2(*g*)). A valuable feature of this design was the 3 push-button keys that could be fitted to it for auxiliary purposes in extension working.

The expansion and automation of the system virtually ceased during the 1939–45 War and telecommunications became a vital factor in the nation's war effort. The importance of the telephone and the achievements of Post Office people who provided and maintained essential communications during this period is another story.

POST-WAR DEVELOPMENTS

The immediate post-war years saw the gradual re-opening of continental overseas telephone services and the continuation of the development of the telephone system following its war-time stagnation.

The story of the last 30 years is one of unprecedented growth and achievement. New technologies have been exploited to improve existing services and make possible the introduction of new ones. Electronic exchanges, subscriber

1870				1976		2000+
Telegraphy	Telephony Telegraphy	Telex Telephony Telegraphy	Radiophone Datel Telex Facsimile Telephony Telegraphy	Radiopaging Confravision Telemetry Radiophone Datel Telex Facsimile Telephony Telegraphy	Viewphone Viewdata Telecommand Radiopaging Confravision Telemetry Radiophone Datel Telex Facsimile Telephony Telegraphy	Telemail Home Newspapers Viewphone Viewdata Telecommand Radiopaging Confravision Telemetry Radiophone Datel Telex Facsimile Telephony Telegraphy

FIG. 7—Growth of services

dialling of inland and overseas calls, satellite communication to many parts of the world through the Post Office earth station at Goonhilly Downs, the Post Office Tower carrying aerials for a nationwide microwave network, Confravision and Datel Services are only a few of the many achievements during this period, most of which have been fully described in previous issues of this *Journal*.

CONCLUSION

The invention of the telephone is now 100 years old. In the beginning, it would have required a man of great vision to foresee its development and growth over the first 100 years. From its slow and faltering start in the UK, the telephone service has continuously improved, the number of telephones has steadily increased and, only in the last decade, reached the zenith of its growth rate. There are now over 20 million telephones in service and the subscriber of 1976 is a member of a worldwide telephone club with over 350 million other members. The number of calls made by users in this country has multiplied many times since the Coleman Street exchange first opened in 1879. Inland and overseas calls now exceed 16 000 million/annum (see Fig. 5), and most are dialled direct by the user. Advances in technology, the use of new materials plus efficient management have generally cheapened the real cost of calls, as illustrated by the example shown in Fig. 6. A variety of telephone instruments and other terminal apparatus is now available to customers, including push-button telephones (Fig. 2(*i*)) which will gradually replace dial telephones. Many new facilities and services have sprung from Bell's invention. Over the years, these have been developed and, today, customers' needs can be met from a comprehensive range of services and facilities. Fig. 7 shows the growth of telecommunication services and applications from the late nineteenth century to the present and indicates some possible services of the future.

What of the future? Trying to forecast the shape and scope of the telephone service for the next 100 years is as difficult today as it was for those pioneers of the telephone in the late nineteenth century. One thing is certain, however, the telephone and its offspring will continue to develop and grow, and new technologies will make possible many of today's communication dreams. Our hopes must be that our successors in 2076, reviewing progress and developments over the second century of the telephone, will be able to pay tribute to the inventiveness, vision and achievements of the men and women involved, as we do in 1976 to Alexander Graham Bell and the many people who improved and extended his original invention during the past 100 years.

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Book Review

Microwave Mobile Communications. Editor: W. C. Jakes. John Wiley & Sons Ltd. ix + 642 pp. 320 ills. £15·50.

This book, by 5 authors from Bell Telephone Laboratories, is a leader in the field of mobile telephony. The preface implies that it represents the summation of 10 years of study, undertaken to impart reality to an American dream of a radio-telephone in every car. The magnitude of the dream is indicated by an example given in the final chapter which supposes an average distance between such cars of about 30 m for each direction of traffic in every street in a city centre, and that an attempt to use each of the radio-telephones is made, on average, every 50 min. According to the authors, the solution lies in use of frequency-modulated channels in the 800–1000 MHz band, organized into a small-cell scheme. Radiotelephone system designers with lesser aspirations will still find the book highly instructive, even if they find the solutions proposed inappropriate to their needs.

The first 3 chapters of the book are a study of the radio field as affected by multiple-path effects, vehicular movement, urban and geographical features, and the aerials employed. Much of the theoretical work is new and these chapters are highly recommended reading.

The fourth chapter deals excellently with frequency-modulated channels with respect to co-channel and adjacent-channel interference and background noise. Amplitude-modulated and single-sideband channels are curtly dismissed, and it is disappointing to see no study of very narrow channel spacing, or of methods analogous to the Lincompex system. The large section on digital modulation is admitted to be irrelevant for civilian purposes. The section on man-made noise is useful only for its comprehensive list of references.

The fifth and sixth chapters deal very thoroughly with diversity reception, which the authors clearly regard as highly important at frequencies above 800 MHz. The overall impression is that use of this band is going to be expensive in terms of production of the mobile sets unless they are produced in quantities that warrant the effective use of large-scale integrated circuitry.

The final chapter, on the use of small-cell systems as a means of spectral conservation, is less convincing than the others, mainly because it relies heavily on Monte-Carlo-type studies performed with hypothetical, and not particularly onerous, traffic situations. The high cost of the fixed equipment needed for small-cell systems is obvious but not studied, and the necessity for such systems ought to have been more rigorously demonstrated.

Throughout the book, wherever possible, the treatment is deeply mathematical and, to obtain full benefit, the reader will need to have a radio-communication background and a knowledge of random-signal and communication theory. The diagrams are numerous, well chosen and very clear. There are 352 numbered references, but some of these are duplicated, and others are to unpublished work or even private communications.

The overall impression is that the studies have been conducted on the basis that performance is more important than implementation costs, but this does not detract from the brilliance of the studies, and the book is highly recommended for critical reading by all engaged in the mobile-radio field.

R. H. T.

A Review of Data Transmission in the United Kingdom

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This article has been adapted from "Data Transmission—A Post Office Review" by J. F. P. Thomas, Director of Network Planning, and falls into 3 broad parts. The first part deals with the Datel services, the second with future demand forecasts and network options to meet the demand, and the third with the British Post Office experimental packet-switched data service and the proposed digital data services.

THE DATEL SERVICES: INTRODUCTION

Within the UK, British Post Office (BPO) Datel services offer data transmission facilities over the public switched telephone network (PSTN), the Telex network and private circuits. In the case of the BPO international services, the term *Datel* relates only to data transmission services over the public telephone or Telex networks. BPO Datel services include the provision and maintenance of any necessary modems[1,2,3] and data control equipment to interface customers' data terminal equipment, and BPO lines. Customers may, on private circuits, use proprietary modems if they are of a type approved for attachment, but the BPO will not normally permit the use of proprietary modems on the PSTN. Proprietary modems are not maintained by the BPO. Data transmission facilities provided by proprietary modems, or over international leased circuits, are covered by the general title *data services*, rather than Datel services.

INLAND DATEL SERVICES

The first BPO Datel service was Datel 100, introduced in 1964 to provide data transmission up to 50 bit/s over the Telex network, and up to 110 bit/s over private telegraph circuits. Customers' data terminal equipment can be provided and maintained by the BPO or may, if approved, be supplied by a commercial contractor. Modems are not required for these services, but data control equipment supplied by the BPO must be used to interface any customer-provided data terminal equipment connected to the public switched Telex network.

The first Datel service using the analogue telephone network, and therefore requiring modems, was Datel 600, introduced in 1965. The facilities provided by this service were dictated by

(*a*) customers' needs, although these could not be specified beyond a general requirement for data transmission rates higher than those available through the Datel 100 service,

(*b*) technical limitations of the existing PSTN,

(*c*) available modem designs, and

(*d*) the availability of an International Telegraph and Telephone Consultative Committee (CCITT) recommendation for service at 600 bit/s or 1·2 kbit/s. The dual-bit-rate standard was necessitated by the characteristics of some of the older types of telephony line plant which, although affecting only a small proportion of calls, precluded an assured 1·2 kbit/s switched service being offered universally.

At the present time, the major banks are the principal users of the Datel 600 service and their use is confined to private circuits.

As the number of users increased and more experience was gained, the need for new services became apparent. The emergence of computer bureaux, with on-line access from simple terminals, pointed to the need for a lower-bit-rate service and, to meet this, Datel 200 was launched in 1967. This service originally offered asynchronous transmission at up to 200 bit/s, but rates up to 300 bit/s, although not assured, are now permissible. At about the same time as Datel 200 was introduced, there was increasing evidence of the need for transmission rates higher than those provided by the Datel 600 service. This led to the introduction in 1968 of the Datel 2400 service, offering 2·4 kbit/s synchronous duplex transmission over 4-wire private circuits.

By 1970, it was realized that there would be a requirement for high-speed data links between computers, although there was no real evidence as to the data signalling rates needed, or how the system would be used. The BPO did, however, co-operate with a manufacturer in developing a 48 kbit/s modem[4] for use on private point-to-point circuits. At about this time, an experimental 48 kbit/s manually-switched service[5] was opened between London, Birmingham and Manchester. In the event, only one customer used the switched service and it was abandoned in 1972. Demand for 48 kbit/s point-to-point service was also lower than expected, but has, since 1974, shown encouraging growth.

The progressive modernization of PSTN line plant and increasing experience in the design of modems enabled the BPO to introduce the Datel 2400 Dial-up service in 1972. This service offers 1·2 kbit/s or 2·4 kbit/s synchronous half-duplex transmission over the PSTN, and is used primarily by customers for remote job entry from batch terminals.

All of these Datel services were introduced to meet the identified needs of customers using commercially-available data terminal equipment. All have been successful in marketing terms; even the 48 kbit/s Datel service, which still has relatively few users, is meeting the needs of these customers and is paving the way for a wider market.

What then of the relatively unsuccessful Datel services that the BPO has introduced, or considered introducing? In 1968, in response to the views of some customers and parts of the data-processing industry, the BPO took the first steps to launch a low-cost data-collection system, to be known as *Datel 300*. However, when the trial equipment was available, there was no support from terminal-equipment manufacturers. In addition, customers' systems for data collection were not sufficiently developed to make use of such a system.

The Datel 400 service was introduced in 1973, largely as a

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result of representations made over a number of years by a research authority who claimed that they had detected a considerable "ground-swell of demand" for a telemetry modem to be provided by the BPO. In the event, demand has been very low and the service is no longer being offered. A similar project to provide a 3-channel analogue modem for use by the medical profession to monitor, for example, heartbeats and pulse rates, had to be abandoned because of lack of support.

Table 1 shows existing and planned inland Datel services.

INTERNATIONAL DATEL SERVICES

International Datel services are available in one form or another to 22 countries and demand for the services continues to grow. Customers whose needs cannot be met by the current range of Datel switched services use international leased circuits and the current annual growth rate is 15%. However, this may fall as the range of international Datel services is extended to cover more countries and higher speeds.

Table 2 lists existing and planned international Datel services.

TABLE 1
Existing and Planned Inland Datel Services

Datel Service	Date of Introduction	Type of Circuit	Maximum Data Signalling Rate (bit/s)	Terminal Operating Mode	Remarks
100	1964	PC (telegraph) Telex	110 50	Asynchronous	Duplex or half-duplex
200	1967	PC (2-wire) PSTN	300 300	Asynchronous	Duplex or half-duplex; transmission up to 200 bit/s assured
600	1965	PC (2-wire) PC (4-wire) PSTN	1 200 1 200 1 200	Asynchronous Asynchronous Asynchronous	Half-duplex Duplex Half-duplex; transmission up to 600 bit/s assured
2400	1968	PC (4-wire)	2 400	Synchronous	Duplex; PSTN stand-by at 600 bit/s or 1·2 kbit/s half-duplex
2400 Dial-up	1972	PSTN	2 400	Synchronous	Half-duplex; fall back to 600 bit/s or 1·2 kbit/s
2412	1976 (planned)	PC (4-wire) PSTN	2 400 2 400	Synchronous Synchronous	Duplex; fall back to 1·2 kbit/s, PSTN stand-by at 2·4 kbit/s or 1·2 kbit/s half-duplex Half-duplex; fall back to 1·2 kbit/s
4800	1977 (planned)	PC (4-wire) PSTN	4 800 4 800	Synchronous Synchronous	Duplex; fall back to 2·4 kbit/s, PSTN stand-by at 4·8 kbit/s or 2·4 kbit/s half-duplex Half-duplex; fall back to 2·4 kbit/s
48k	1970	PC (4-wire)	50 000	Synchronous	Duplex

PC—private circuit, PSTN—public switched telephone network
Asynchronous mode—each character or block of characters is preceded and followed by *start* and *stop* signals respectively, to control the receiving equipment
Synchronous mode—transmitting and receiving equipment are maintained in synchronism by electronic clocking devices
Duplex—simultaneous transmission of data in both directions
Half-duplex—transmission of data in each direction, but not simultaneously

TABLE 2
Existing and Planned International Switched Datel Services

Datel Service	Date of Introduction	Maximum Data Signalling Rate (bit/s)	Terminal Operating Mode	Remarks
100	1968	50	Asynchronous	Uses the Telex network
200	1969	300	Asynchronous	Duplex; transmission up to 200 bit/s assured
600	1965	1200	Asynchronous	Half-duplex; transmission up to 600 bit/s assured
2400	1976 (Note)	2400	Synchronous	Half-duplex; fall back to 1·2 kbit/s

Note: Until this service is available, the BPO will permit the use of proprietary modems that conform to CCITT Recommendation V26 (Alternative B) on the PSTN for international 2·4 kbit/s transmissions, where there are no technical or operational constraints, and subject to the agreement of the overseas administrations (or recognized private operating agencies) concerned

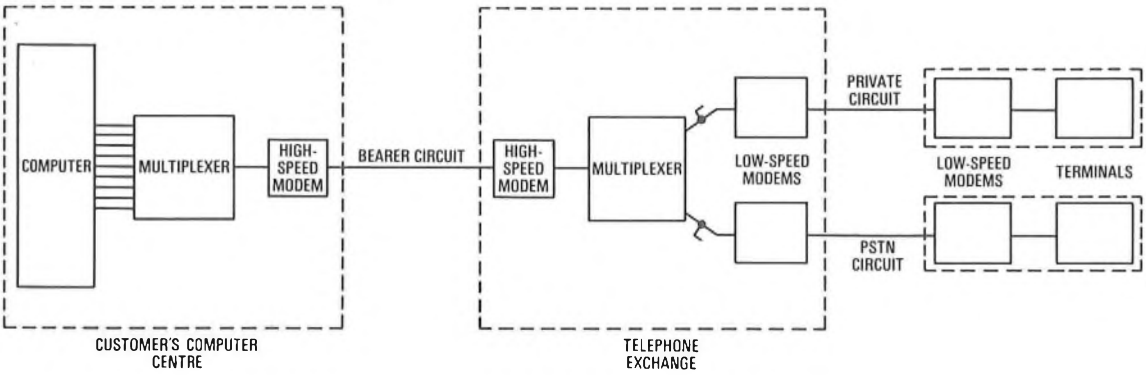


FIG. 1—Typical Dataplex application

ADDITIONAL FACILITIES

Apart from straightforward data transmission facilities provided by Datel services, the BPO provides a number of services, outlined below, to meet particular needs.

Dataplex

The Dataplex service is provided for the exclusive use of a single customer and his clients. It offers data transmission users lower costs by sharing one private circuit between a number of remote terminals requiring to communicate simultaneously with a computer centre. A Dataplex system comprises multiplexers, exchange lines and/or private circuits and modems. A typical application is to enable a computer bureau to offer remotely-located groups of customers access to a central computer at local-call charges, as shown in Fig. 1.

Dataplex facilities were originally provided by frequency-division multiplexing (FDM). This service was known as *Dataplex 1/240F* and was adapted from multi-channel voice-frequency telegraphy equipment, allowing data from 12 low-speed lines to be multiplexed and transmitted over a single bearer circuit. This service provided only limited facilities for customers, and was superseded in 1971 by systems using time-division multiplexing (TDM). Two versions of TDM have been used for Dataplex services, both based on proprietary equipment. The current version, Dataplex TDM2A, allows up to 64 low-bit-rate asynchronous inputs to be multiplexed over a single bearer circuit operating at 2·4 kbit/s or 4·8 kbit/s.

Midnight Line

For a fixed annual rental, the Midnight Line allows a customer an unlimited number of directly-dialled inland calls between midnight and 06.00 hours. The service, which may be used for data transmission or speech, was introduced as a result of pressure from some customers; it was also an attempt to move a significant volume of data traffic from busy periods to the night hours. Despite the potential financial savings, demand for the Midnight Line service has been negligible, and customers have obviously been unwilling to change their present working habits.

Automatic Calling and Answering

These facilities allow a customer's data-terminal equipment automatically to establish and receive data calls over the PSTN or Telex network. For PSTN calls, automatic calling is provided by Data Control Equipment No. 1[6], and facilities for the automatic answering of inland calls are now incorporated in BPO modems. A Data Control Equipment No. 2[6] is necessary to provide automatic answering of

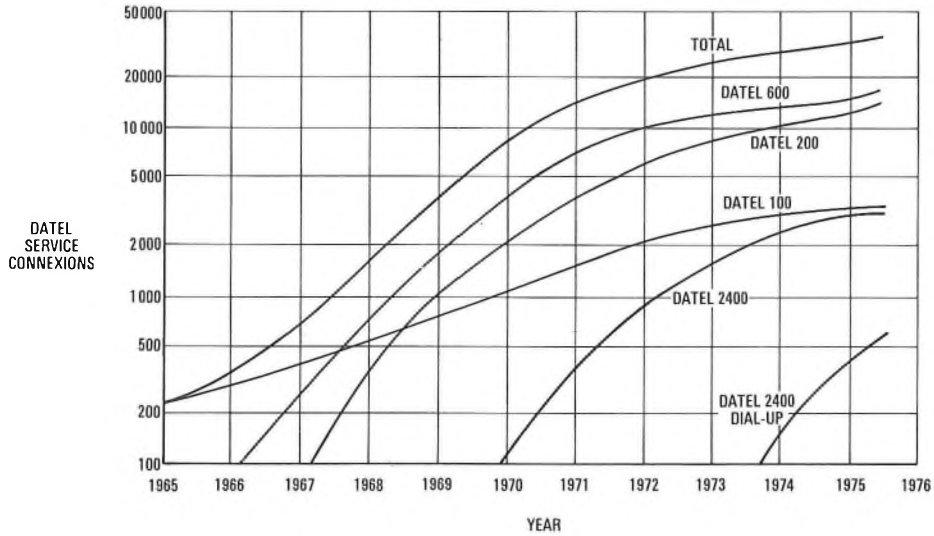


FIG. 2—Growth of Datel connexions

international Datel calls. This equipment is also needed to disable any echo-suppressors on circuits over which duplex transmission is required.

Where a computer is required to originate or answer calls automatically on the Telex network, the provision of a BPO supplied Data Control Equipment No. 3[7] is mandatory. In these circumstances, no Telex terminal is necessary.

Control Systems

These systems provide a convenient and efficient means of controlling and testing Datel equipment in customers' premises. The modems, control units, interface connexions and circuit terminations are housed on a rack, together with the necessary power unit, alarm lamps and telephone unit.

DATEL GROWTH TO DATE

Fig. 2 shows the growth of inland Datel services since 1965. It can be seen that, after the introduction of a service, there is generally a period of rapid growth, followed by less rapid and more stable growth after a few years. The demand for Datel services has, in the past, not been seriously affected by fluctuations in the economy, but is, nevertheless, difficult to predict. Datel services generally form a relatively small, albeit vital, part of customers' total data-processing systems; demand is, therefore, largely outside BPO control, being dependent on the policies and plans of computer and terminal manufacturers and suppliers.

A further complication arises because BPO Datel services, particularly over private circuits, are in direct competition with outside suppliers of data transmission services; it is thus difficult to assess the extent to which the total market will be met by BPO services. At September 1975, the total of 38 250 BPO Datel connexions included approximately 34 150 modems. At that date, it is estimated that there were some 20 000 proprietary modems, mostly on private circuits, and 3000 acoustic couplers for data transmission over the PSTN.

Table 3 shows the data connexions* in a number of Western European countries, based on the latest information available. It will be seen that the UK continues to be the leading data transmission user in Western Europe. In general, the UK provides a wider range of data transmission services than other European Administrations. However, in some countries (for example, West Germany) the Telex network is used more extensively than in the UK for the transmission of low-speed data.

TABLE 3

Data Connexions in the UK and Other Western European Countries

Country	Data Connexions	Date
Austria	1 029	Dec. 1974
Belgium	3 729	Dec. 1975
Denmark	3 213	Dec. 1974
Eire	363	Dec. 1975
Finland	2 311	Dec. 1975
France	15 222	Dec. 1974
West Germany	17 826	Dec. 1974
Greece	150	Dec. 1974
Italy	19 143	Dec. 1975
Luxembourg	25	Dec. 1973
Netherlands	6 100	Dec. 1975
Norway	1 475	Dec. 1974
Portugal	480	Dec. 1974
Spain	9 217	Dec. 1975
Sweden	6 722	June 1975
Switzerland	4 351	Dec. 1975
UK	55 968	Dec. 1975
Total	147 324	—

* A data connexion is a connexion to public switched networks (PSTN and Telex), or to leased private circuits, for the purpose of transmitting or receiving data, irrespective of whether BPO-supplied or privately-owned modems or telegraph terminating equipments are used

FUTURE DATEL DEVELOPMENT

The lack of customer interest in the Datel 400 service and the 48 kbit/s manually-switched network clearly demonstrates that availability of a service does not create demand. Unless a broad base of users and the data-processing industry have reason to support a service, it will fail and, when the BPO has acted on the strength of narrow-based demands, the service has enjoyed negligible success. If scarce and valuable development resources are not to be misdirected, new services should be introduced only if market studies indicate a broad-based need. The present range of Datel services meets the needs of most customers for this type of service, but data communication is a market where changes in technology, application and attitude occur over very short timescales. Thus, it is necessary to monitor constantly for changes in existing trends and for the emergence of new trends, by improved market-analysis and forecasting techniques.

To remain competitive, the BPO must keep pace with technological progress and ensure that the equipment it offers to customers is as compact and attractively styled as possible. This necessitates a continuing development programme. A recent addition to the range of BPO Datel Modems is the Modem No. 20 which supersedes Modem No. 1 for certain applications in the Datel 600 service. Modem No. 20 is an interim model, requiring less rack space than the Modem No. 1, and will, in turn, be superseded by a new generation modem (Modem No. 22) in 1978.

Another recent addition to the BPO range is Modem No. 13—a restricted-facility, call-only modem for the Datel 200 service. It consists of a single circuit card, mounted in a plan-set fitted under the base of a 700-type telephone, and is designed for use at out-stations in conjunction with remote computer terminals. A new generation modem (Modem No. 21) is planned to be introduced in 1978 to supersede the existing full-facility Modem No. 2 in the Datel 200 service. A new modem (Modem No. 12) has been developed for use with the proposed Datel 2412 service, which should be launched in late-1976. Unlike the Modem No. 7, used in the existing Datel 2400 services, the Modem No. 12 will fully conform to the now accepted CCITT recommendations and thus be suitable for international Datel service.

There has been increasing evidence of the need for data transmission over the PSTN at rates higher than the 2·4 kbit/s provided by the Datel 2400 and 2412 services. A new modem (Modem No. 11) is being developed to provide full-duplex data transmission at 4·8 kbit/s over 4-wire private circuits or half duplex over the PSTN and, if work proceeds satisfactorily, could be available in 1977. Preliminary work is now starting on a 9·6 kbit/s modem, in anticipation of a demand for this higher rate.

Although the digital data services described later in this article are designed to meet users' needs for more sophisticated data transmission services, they cannot be made available economically on a national scale from the outset; as a result, they will be introduced at a small number of centres initially and gradually extended. Datel services will, therefore, continue to be required for many years.

FORECAST DEMAND FOR DATA TRANSMISSION SERVICES

The difference between telephony services and data transmission services gives rise to problems in forecasting demand. With telephony, the BPO usually provides the complete system or, as a minimum, controls the design of the terminal equipment. With data communications, the terminal equipment is supplied by the computer industry. The terminal equipment includes the input and output devices, and could also include call-initiating and terminating equipment, as well as the central processing unit itself. Data transmission constitutes only one component, albeit a vital one, of a complete data-processing system.

There are fundamental differences between telephone traffic and data traffic. Telephone traffic has a degree of homogeniety, which enables the forecaster to make useful postulations about the average telephone call; but data-traffic call holding times have a much wider range than telephony, varying from a few seconds to several hours,[8] even on the same time-sharing system. Data signalling rates range from 50 bit/s to 48 kbit/s, and it is difficult to forecast the growth rate of traffic at individual speeds within this range.

The forecaster must research customers' needs, technological trends, equipment manufacturers' plans, and social and business habits—all of which are changing; these must then be blended into a medium-term view that will be accurate enough to enable decisions to be taken on what services and facilities should be provided, when, where, and in what quantities.

Compared with telephony, data communication is in its infancy, and there is limited historical information from which to work. As yet, there is no discernible correlation between the demand for data communication and national economic indexes. Almost any market, at the start of its growth, is volatile; a change in plans by one of the major banks can have a significant effect on total demand within the planning period. For this reason, one of the major forecasting aids is market intelligence. There are a number of sources:

(*a*) formal market studies undertaken either by the BPO or by consultants; for example, the SCICON[9] and EURODATA Reports,[10]

(*b*) formal meetings with representative bodies such as the Electronic Engineering Association, the Institute of Administrative Management, the Computer Services Association and the Interbank Research Organization,

(*c*) formal meetings with customers and manufacturers, and discussions at seminars and training courses, and

(*d*) published material in, for example, the trade press, national and international journals and CCITT papers.

The current BPO forecast of data connexions for planning purposes, based on all the available sources of information, is shown in Fig. 3. It is a mean forecast, and the range of values from which it was derived deviate from the mean by ±15% at 1980 and ±30% at 1985. BPO planning is based on the upper limit.

For comparison purposes, Fig. 3 also shows the SCICON forecast and the EURODATA forecast adjusted to bring them to a common base; that is, data connexions. The SCICON report also gave high and low forecasts and, for 1983, the last year of the forecast, the range is ±20% of the mean. The EURODATA curve in Fig. 3 has been derived from the Study Report Data-Terminal Forecast, for which upper and lower limits are not given. The data-terminal forecast is, however, derived from a total-traffic forecast, for which "likelihood limits" are given. Applying these limits to the EURODATA curve in Fig. 3 would give a range for 1985 of +100% to −50%.

For planning work, a forecast in terms of speed ranges is necessary and the BPO figures, derived from the forecast of total data connexions shown in Fig. 3, are shown in Table 4 for the base dates 1980 and 1985. The limits of accuracy for the 1985 figures are ±30%.

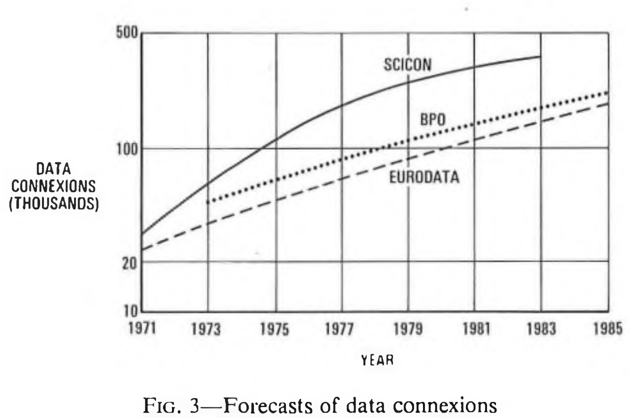


FIG. 3—Forecasts of data connexions

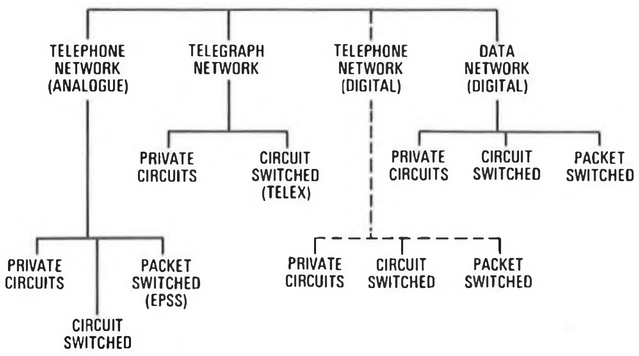
NETWORK OPTIONS TO MEET FORECAST DEMANDS

Technically, it is now possible to provide, by means of digital transmission and switching, a common network for telephony, Telex, data, television and many other services. However, to establish an all-embracing network of this kind quickly would require massive investment, beyond the present resources of the nation and, furthermore, with little chance of achieving a satisfactory return on the capital invested. To be economically viable, a comprehensive digital telecommunications network must be established on a stage-by-stage basis, with efficient utilization of plant at each stage. The established networks for speech, Telex and television will have to continue their separate existence in the shorter term and, in the medium term, an interim period of coexistence with the emerging digital telecommunications network will also be necessary. It is generally agreed that the advantages of economies of scale dictate that any interim arrangements must take account of the longer-term objective of maximum commonality of plant for all telecommunications services.

The network options that are available for the provision of data facilities are shown in Fig. 4. The Datel services are carried by the established analogue telephone and telegraph networks, and enjoy wide geographical coverage and the economic advantages of almost complete commonality of plant. Analogue networks are not ideally suited to data transmission, and this has led to the proposed use of dedicated digital transmission and switching facilities for data. A dedicated digital data network introduces a dilemma in that, to establish wide geographical coverage, a substantial invest-

TABLE 4
Mean Forecast Demand of Data Connexions by Speed Range

Speed Range (Data Signalling Rate) (bit/s)	Data Connexions	
	1980	1985
0–300	56 500	78 000
301–1200	24 000	32 500
1201–2400	22 000	39 000
2401–4800	6 300	11 800
4801–9600	520	1 000
9601–48 000	175	350
> 48 000	15	30
Total	109 510	162 680



EPSS—Experimental Packet-Switched Service

FIG. 4—Network options for data transmission

ment is required that, when translated into charges, tends to cancel the advantages of digital working over analogue working. If, on the other hand, the investment is contained by restricting the geographical coverage of the network, then again the attractiveness of digital working diminishes.

The dilemma would not have arisen had it been possible for the telephony and Telex networks to have developed in a digital mode from an early stage; data services would then have been provided digitally from the outset. The bridge between the present conflicting requirements is the introduction of digital techniques into the telephony network, and it is worthwhile briefly reviewing the achievements and prospects in this area.

For many links over 10 km in length, digital transmission is now the most economic form of provision of telephone services, and digital switching is expected to be significantly lower in cost than space switching at points in the network where traffic levels are high.

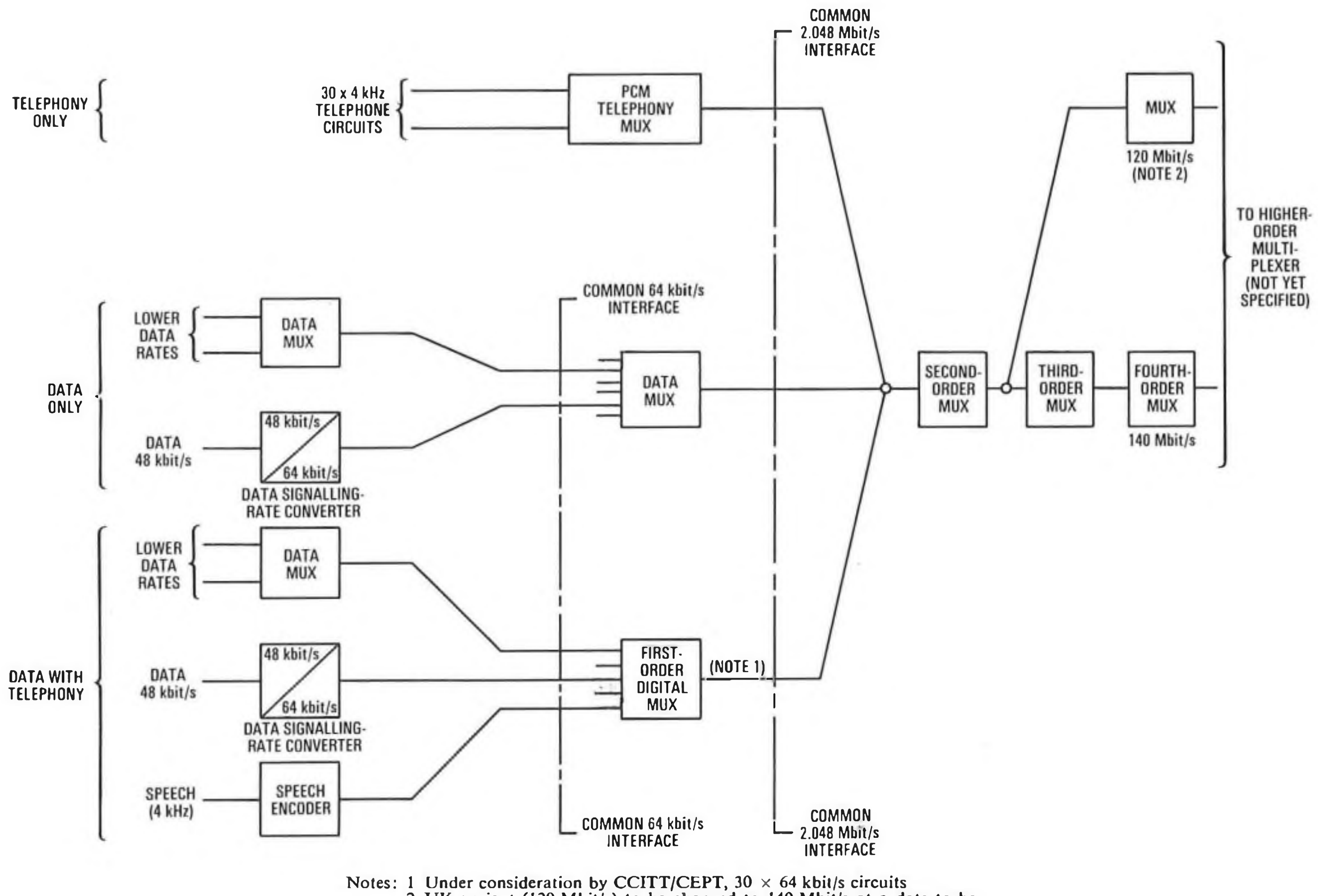
The BPO is now installing approximately 1000 short-haul pulse-code-modulation (PCM) systems each year and, with over 4000 systems installed and commissioned, the practical problems associated with interfacing these systems with analogue plant have been solved.

Ordering of the BPO 24-channel systems will be superseded in 1976 by orders for the CCITT-recommended 30-channel system, operating at 2·048 Mbit/s. Assembled from 32 basic time slots, each having 64 kbit/s capacity suitable for data or speech, the 2·048 Mbit/s module will form the primary level of an internationally-agreed digital hierarchy.

High-capacity line and radio systems at 120/140 Mbit/s and their associated multiplexing equipment are now on field trial, and device technology is opening the way to similar systems at around 500 Mbit/s. At the top end of the scale, a digital waveguide system is under field trial and digital glass fibre techniques have made progress that few would have forecast a few years ago. Designs have also been requested for 8 Mbit/s systems to upgrade the existing paired carrier cables at present carrying 24-circuit FDM systems.

In addition, the BPO has favourable experience of digital switching from the prototype digital tandem exchanges at Empress and Moorgate.

The general picture is that, above the first level of switching, the network will progressively contain a higher proportion of digital plant. Digital plant will be provided in large quantities and at relatively low cost for telephony, most of



Notes: 1 Under consideration by CCITT/CEPT, 30 × 64 kbit/s circuits
2 UK variant (120 Mbit/s) to be changed to 140 Mbit/s at a date to be determined
MUX—Multiplexer

FIG. 5—Proposed multiplexing structure for data and telephony

which will be equally applicable to data. Maximum commonality between data and telephony in this area will help lead to digital data services that are attractively priced compared with the existing Datel services for a high proportion of users. At, and below, the first level of switching the penetration of digital techniques for telephony is likely to be significantly slower and, here, dedicated equipment for digital data will be required.

The proposed general hierarchical structure for telephone and data multiplexing up to 2·048 Mbit/s and beyond is shown in Fig. 5, and an indication of how the various network options could be directed to an all-embracing network is shown in Fig. 6.

EXPERIMENTAL PACKET-SWITCHED SERVICE

In August 1973, the BPO confirmed its intention to establish an Experimental Packet-Switched Service (EPSS). The opening of the service is being phased over the period late-1975–mid-1976. The EPSS has been described in some detail in previous issues of the *Journal*[11,12,13,14] and will, therefore, be covered only briefly here.

The main aims of the service can be summarized as follows:

(*a*) to provide a packet-switched service of sufficient flexibility and geographical extent to establish the usefulness of such a service to customers, and to enable them to assess the overall technical and economic viability of packet switching in relation to their own data-processing systems,

(*b*) to enable a decision to be made regarding the inclusion or exclusion of packet-switching facilities in future digital data services, and

(*c*) to provide an indication of the future demand for a packet-switched service to assist in formulating tariff and traffic-design principles.

The packet mode of working could offer advantages in

(*a*) circuit utilization,

(*b*) error protection,

(*c*) interworking between terminals operating at different data signalling rates,

(*d*) automatic alternative routing for each packet, and

(*e*) customer use of a single high-speed link to the exchange, carrying many simultaneous calls.

The project will enable these potential advantages to be assessed.

The following basic types of customers' data terminal equipment can be connected to the EPSS packet-switching exchange (PSE).

(*a*) *Packet terminals* The data terminal equipment assembles data into specified packet formats before transmission in a synchronous mode to the PSE.

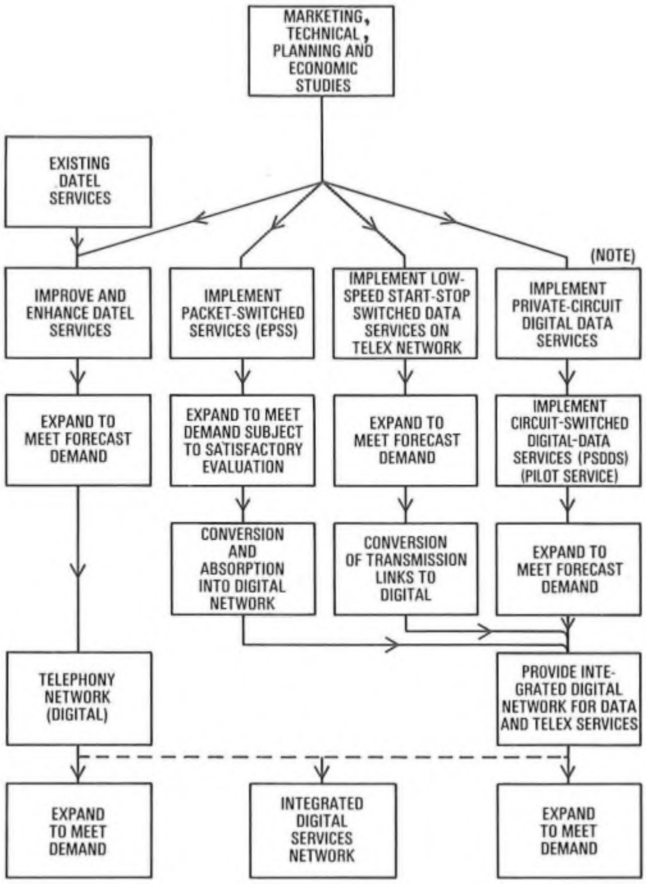
(*b*) *Character terminals* The data terminal equipment transmits data to the PSE character by character; the PSE then assembles data into packets for onward transmission.

Packet terminals will operate at 2·4 kbit/s, 4·8 kbit/s and 48 kbit/s, and will be connected to the PSE by direct circuits. Character terminals will operate at 110 bit/s and 300 bit/s and will be connected to a PSE by direct circuits or via the PSTN. PSEs will be installed at London, Manchester and Glasgow.

In the past 2–3 years, there has been a growing interest in the packet mode of working in many countries, including the UK, by private as well as public organizations. The BPO is therefore closely observing developments in general in the packet-switching field.

In addition, the BPO is collaborating in the setting-up of the European Informatics Network[15,16] and Euronet,[17] and is in discussion with all UK organizations known to have an interest in implementing private packet-switched networks.

The variety of packet networks emerging indicates the very real need for standardization, both nationally and internationally. The BPO is very actively involved with CCITT, CEPT and the International Standards Organization to this end. Standardization would allow private networks to be easily incorporated into a national packet-switched network, should this prove to be desirable, by using the closed-user-group facility that would be available. There would also be considerable economies to manufacturers of data terminal equipment, and consequently to customers, in having to consider only one standard.



Note: This stage in the provision of digital data services will not be implemented unless studies show that private-circuit services are economically viable

FIG. 6—Possible progression towards integrated switched-services network

TELEX EXCHANGE MODERNIZATION

A number of countries are replacing, or planning to replace progressively, their existing Telex exchanges by stored-programme-controlled (SPC) exchanges. These countries will then be able to provide improved and additional facilities for their 50 baud Telex service, and offer circuit-switched data services, generally the lower-speed start-stop services; for example, 110 bit/s, 200 bit/s and 300 bit/s. Four European countries, Belgium, France, West Germany and Italy, already offer low-speed data services nationally on their existing Telex networks, and intend to interwork with each other.

An international SPC TDM Telex exchange is in the course of installation in London, and is planned to be operational during 1976. In 1977, in addition to 50 baud capacity, it will have the capability of interworking with the low-speed data services offered by the European systems and such services as may be offered in other countries. Plans to modernize the inland Telex network by this type of switching equipment are under consideration; should these plans be implemented, it would enable both national and international circuit-switched low-speed data services to be established if required.

DIGITAL DATA SERVICES

The direct use of digital transmission plant to carry digital data signals avoids the need to provide costly analogue-digital conversion equipment and, furthermore, by digital multiplexing, the capacity of transmission bearers can be efficiently shared among a number of lower-speed digital sources.

As indicated earlier, the strategic approach to digital data services must, necessarily, be closely related to arrangements being planned for digital telephony. The main and junction digital transmission plant, based on a 2·048 Mbit/s transmission rate, will terminate at digital main network switching centres (DMNSCs)—digital replacements for group switching centres—and telephone circuits will be switched as 64 kbit/s time slots.

In order that these arrangements are used as effectively as possible for digital data services, the maximum degree of commonality between a DMNSC and a data switching exchange (DSE) is required. Digital exchanges for various applications will be configured from a family of subsystems, so that it will be necessary to develop additionally for a DSE only those subsystems that will have a dedicated role to play in the data-switching function. It is expected that the processor utility subsystem and digital-switch subsystem will be common items to both telephony and data applications.

Although 2·048 Mbit/s common bearer transmission plant would be used in the provision of digital data services, in the main and junction networks, dedicated data equipment would be required to facilitate access to this plant using wire pairs in the local network; some dedicated equipment would also be required at the DSE location. In addition, a network terminating unit would be required at the user's premises.

Studies are currently being undertaken to determine the optimum form of this dedicated digital data equipment, bearing in mind emerging international recommendations on digital-data-network structures and that the DSE is based on the DMNSC development. A further aspect of the studies will be to consider whether appropriate items of the dedicated equipment, which will be optimized for circuit-switched services, could be used on a stand-alone basis to provide economically attractive private-circuit services. Budgetary quotations were obtained for the component items of one design of transmission network, but it was found that the overall cost of this design did not permit the provision of private-circuit services that were economically attractive compared with the existing Datel services.

In the first instance, the studies mentioned above are likely to lead to the provision of a geographically-restricted pilot Public Switched Digital Data Service (PSDDS), operating at the synchronous user rates of 600 bit/s, 2·4 kbit/s, 9·6 kbit/s and 48 kbit/s in the circuit-switched mode. Build-up of the service and extension of facilities would follow evaluation of the information provided by the pilot service in the technical, economic and traffic fields.

The work described above is essentially an approach to the provision of circuit-switched digital data services based on the BPO strategy for the development of its digital telephone exchanges, often referred to as *System X*.

In the shorter term, the 2·048 Mbit/s digital transmission plant, referred to earlier, may be used in the provision of Datel-type private-circuit services. Studies are proceeding in this area and, if these prove to be successful, an alternative means of provision of Datel private circuits would be available as a planning option. In essence, this would involve access to 64 kbit/s digital time slots, together with some submultiplexing and the use of digital modems.

SUMMARY OF PLANS FOR DATA SERVICES

BPO plans for data services are now based on the following staged implementation programme.

Stage 1

Datel services will continue to be improved and enhanced, as required to meet forecast demands. These services will continue to be provided in parallel with new services.

Stage 2

The EPSS will be fully operational by mid-1976 and, if it is shown to be a practicable and economically-viable service, it will be extended and enhanced as required; it will then be absorbed as one of the services provided as part of the long-term plan for switched digital data services. The need for international packet-switched connexions is likely to arise.

Stage 3

In 1977, a new Telex switching system for international services will provide a capability for switching low-speed start-stop services (up to 300 bit/s). Plans to modernize the inland Telex network using this type of switching equipment are under consideration.

Stage 4

A pilot circuit-switched synchronous PSDDS is likely to be introduced to determine the demand for such services and to study traffic patterns.

Stage 5

A private-circuit digital data service, using the transmission equipment provided for pilot PSDDS (Stage 4) in advance of the commencement of PSDDS, will be offered if studies show that an economically viable service is practicable.

ACKNOWLEDGEMENT

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Local Distribution—An Assessment for Future System Development

Part 2—Systems Examples and Longer-Term Proposals

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UDC 621.395.743:654.15

The first part of this 2-part article reviewed briefly the evolving pattern of UK telecommunications service demand, together with its network implications. Local-line options that were open for system development in the short and medium terms suggested the use of combined or dual-cable schemes. In this second part, examples of such schemes are described, together with proposals for the longer term. Prospects for alternative transmission media are also considered. It is noted that the future technological strategy for the local-line network will be significantly influenced by policy decisions on the provision of wideband services, and on the timing of the provision of any new generation of electronic digital exchanges.

INTRODUCTION

In the first part of this 2-part article, it was noted that the evolving pattern of service demand in the UK telecommunications system would be likely to result in a requirement for transmission capability in the local-line network considerably greater than could be provided by the existing balanced-pair medium. The advantages to be gained from the introduction of an alternative medium were discussed, emphasis being placed on coaxial cables. Partly through an ability to effect changes at the flexibility points, the planner could then choose from a number of options in local-line system development.

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Two examples of multi-service system implementation are discussed below: one involves a dual-cable main network with balanced-pair distribution; the other applies a dual-cable concept of provision.

SYSTEM DEVELOPMENT IN THE MEDIUM TO LONG TERM

Dual-Cable Main Network: Balanced-Pair Distribution

In this scheme, shown in Fig. 7, the main network [exchange–primary cross-connexion point (PCCP)] would continue to be provided with existing-type balanced pairs for telephony and other public-switched-telephone-network (PSTN) services,

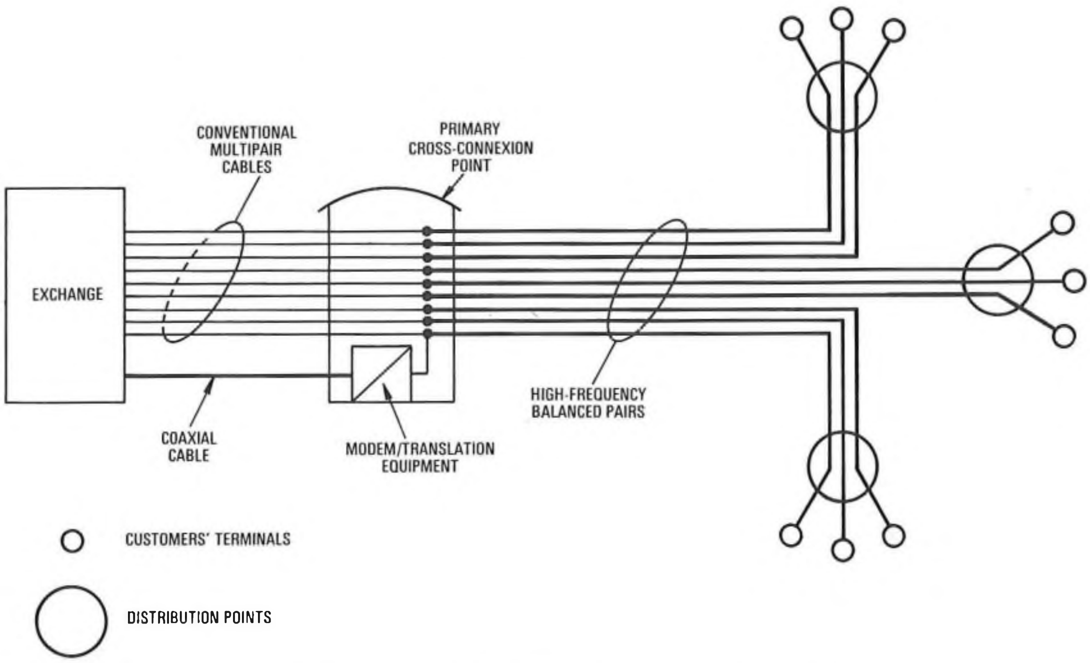

FIG. 7—Combined system with dual-cable main network and balanced-pair distribution

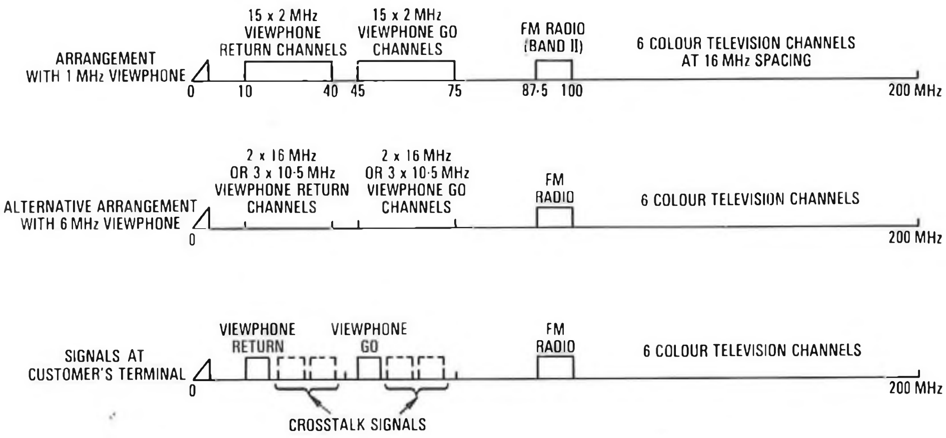

FIG. 8—Frequency allocation for balanced-pair distribution

whilst co-located coaxial cables would be laid in this section to carry, in suitable multiplexes, the wideband services. In the distribution network (PCCP–customer), individual balanced pairs of improved high-frequency (HF) performance would be laid instead of existing small-gauge types of pair cable. Telephony, and similar narrow-band traffic, would be carried throughout the system at baseband on the individual pairs, whilst the wideband services would be assembled in frequency-division multiplex (FDM) on the coaxial main cables and translated, as necessary, into an appropriate part of the frequency spectrum to suit the balanced-pair tail cables. A typical frequency-spectrum arrangement might be as shown in Fig. 8. The system would make provision for up to 6 television channels, frequency-modulated radio transmissions in the very-high-frequency (VHF) band (band II), and some penetration of Viewphone. Variants of the latter are shown for 2 different Viewphone standards; that is, for required bandwidths of either 1 MHz or 6 MHz.

The system has some attraction for new estate developments because a limited amount of forward provision for wideband services can be made at a minimum cost and with the burden of spare plant on initial installation being avoided. The traditional type of telephone provision is made; the coaxial main network with multiplexed wideband services effects a move towards efficient utilization of this medium, and the dedicated HF pairs on the distribution section need associated wideband plant only when required for such services. Resulting capital outlay is thereby minimized.

However, as previously discussed, systems of this type are essentially limited by the characteristics of the balanced-pair cable medium. In particular, although the problem of interfering crosstalk (cross-view) on the Viewphone channels is reduced by staggering the channel carriers within the groups permitted for this service provision, privacy could never be offered with confidence. Penetration of the 2-way vision services would, of course, be severely restricted, although this might be permissible in relatively short-term planning. The effect of multiple crosstalk paths between a number of adjacent pairs carrying the same group of broadcast vision service frequencies might also produce impairment difficulties.

If the final section of distribution (that is, distribution point (DP)–customer feeds) were to be provided in overhead distribution, use of HF balanced-pair cables could lead to radiation and pick-up hazards in certain parts of the frequency spectrum.

The significance of the difficulties outlined above will be more fully apparent only when more comprehensive measurement data is available on balanced-pair cable performance in the HF/VHF spectrum, in this type of environment.

Variants on the above type of scheme include the extension of the dual-cable section nearer to the customer (for example, moving the PCCP towards the DP), so reducing the length of section of HF pair cabling. However, although schemes using HF balanced pairs at the local-distribution remote ends offer some potential wideband service capability, they appear to be limited to use in certain new development situations and also leave little scope for future manoeuvre.

Dual-Cable Systems

Systems of this type provide 2 electrically separate networks, but share common route topology and plant. Typically, one network would be of conventional multipair distribution, similar to present telephone system provision, and capable of exploitation up to about 100 kHz in favourable environments. The other network would be for wideband services, using coaxial cables arranged to provide a number of service options.

An early development of this type of scheme is shown in Fig. 9. Between exchange and PCCP, the large-capacity multipair telephone cables and the coaxial cable share common ducting. This sharing continues through to the DP, using the underground system of ducts and joint boxes, with the pair-type cable progressively reducing in size. In the arrangement shown, a teed form of distribution is used for the wideband services, the coaxial feeds being co-located with the individual pairs for each customer's telephone. The wideband services are supported by amplifiers, suitably housed in the cabinets and joint boxes; FDM methods are used to provide the service channels, any necessary frequency translation being made at intermediate wideband distribution points (cabinets).

Early versions of this scheme are already in use in several new town developments for the distribution of entertainment television.[7,8] They differ mainly in the manner in which the final feed is effected.

The basic system principle offers all the facilities provided by balanced-pair systems, together with much greater potential for the longer term. Its implementation is not difficult technically. It allows continuance of the present telephone network arrangements and medium-term development of the system for other facilities. It permits introduction of wideband facilities on a comprehensive scale, provided certain topological criteria are observed. It is not likely to be constrained in the foreseeable future by any limitations of the transmission media. Capital outlay is not excessive and is recoverable from services with higher penetrations. A dual-cable network can allow sufficient flexibility in planning to enable more advanced system technology to be incorporated in the longer term.

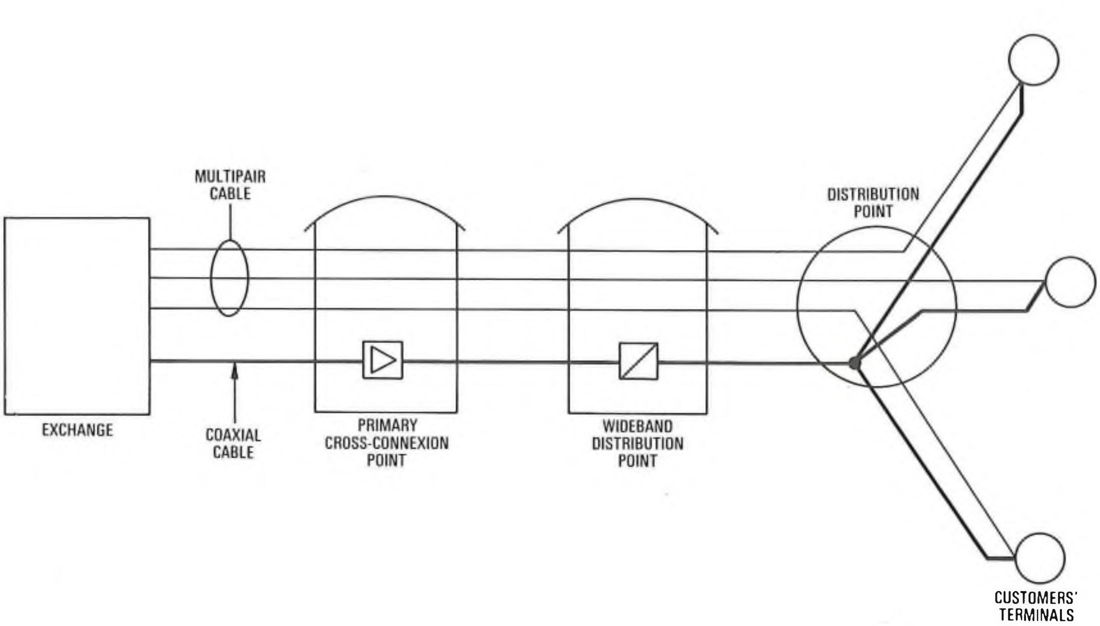

FIG. 9—Dual-cable system

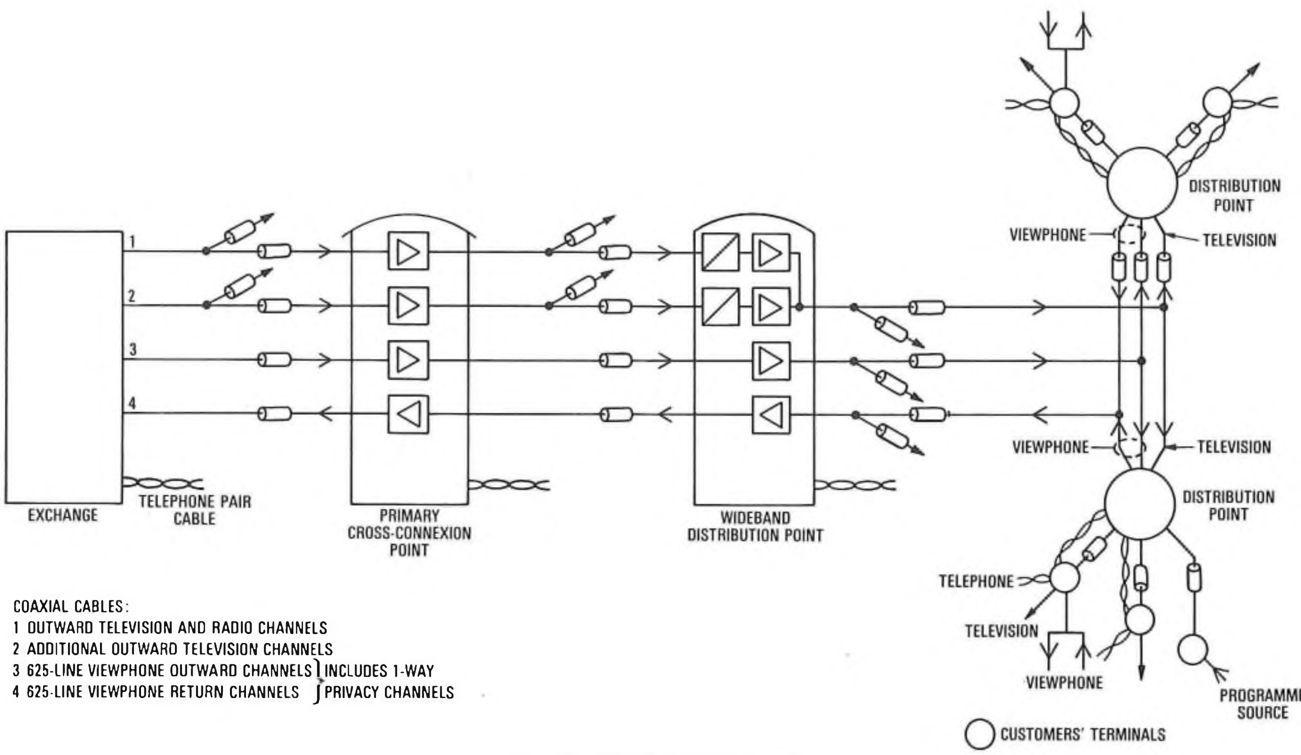

FIG. 10—Total-system concept

Considerations such as these lead to the conclusion that the dual-cable concept at present offers the best compromise for all new installation work. However, in allowing for development of future wideband services, the topology of the network must be carefully planned. The feeding arrangement adopted at the DP exemplifies this aspect. For a wideband service such as cable television, the tree-type configuration in final distribution is adequate; some degree of "upstream" circuit provision can also be made. However, where switched wideband services are required, individual access back to the exchange is necessary and the customer must be fed on a separate channel basis. A radial topology then has to be adopted at the DP, or further back, such that a separate coaxial cable is provided in the final feed. Appropriate wideband channel availability is also needed at the nearest multiplex; a wideband translation point positioned between the PCCP and the DP usually meets this requirement.

The development of a forward provisioning plan in a new area, using the dual-cable principle, is influenced by factors such as the type of area served, proportions of residential or business populations, and the penetration and growth probabilities of the various wideband services. Recognition of these factors has led to the study of the feasibility of applying a *total-system concept*, in which service facilities are built up, as demand arises, from a basic dual-cable layout. A fully-developed system could then take the form shown in Fig. 10. Provision is made for basic television and radio channels, additional outward television channels which

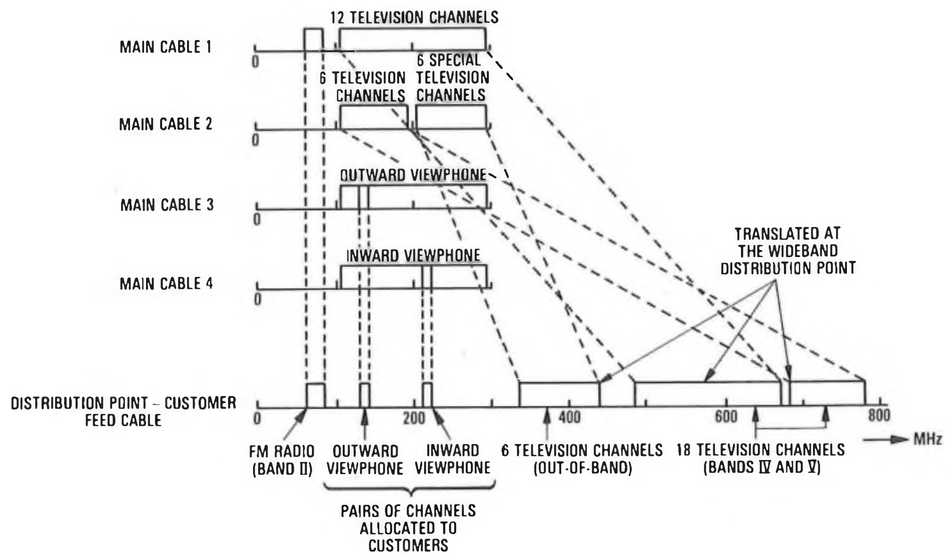

FIG. 11—Typical frequency plan for total-system concept

could be on a premium basis, return channels, and 2-way 625-line standard Viewphone. Fig. 11 shows a typical frequency plan.

The dual-cable system principle is clearly applicable in the short term with existing technology. It is also capable of evolution to satisfy forward demand, certainly in the medium term and possibly in the longer term, since it offers the potential to accommodate new system arrangements.

Wideband Service Provision in Existing Networks

The foregoing comment has referred to the options open for the provision of comprehensive services in new property developments. The most difficult problem in local-plant provision arises, however, in planning measures to meet the possibility of demand for such services arising in established areas.

Accepting that the capability of current pair-type distribution is essentially limited in its capacity to carry wideband services, a programme of progressive overlay or replacement of part of the network has to be considered. It is in this respect that the nodal points in the local-line system (that is, the CCPs and DPs) achieve particular significance, because these flexibility points offer the potential for making progressive changes in specific sections of the network. Since the main network and much of the distribution network is already ducted, the latter in many cases out to the DP,† the possibility exists for the addition of coaxial line plant in these sections. The dual-cable-system approach can, therefore, be developed to meet the situation requirement.

However, the most awkward part of the line plant to augment or replace is that of the feed section between DP and customer. Here, the feed is on an individual-pair basis. Territorial environments differ widely: the geographical situation, the nature and density of property, and the method originally adopted for telephone provision (for example, overhead or directly-buried cabling); all these factors contribute toward a cost burden on new provision that can vary widely, but in most cases is likely to be heavy. A recent cost study in the British Post Office (BPO) Telecommunications Systems Strategy Department (TSSD) of alternative methods of wideband provision in the DP–customer part of the network shows a typical variation in rental capital cost per customer's line of from £17 (providing a coaxial feed in an existing duct) and £28 (providing composite overhead drop-wire to replace existing drop-wire) to £95 (providing a new underground lead-in).

The choice of a provisioning method, based on acceptable cost, is complicated by other factors. It would, for example, be relatively cheap to produce a composite balanced-pair/coaxial-pair drop-wire feed. In existing overhead provision areas, this could be used as a direct replacement for existing drop-wire and would be convenient to install. It would, however, have somewhat greater bulk and the degree of objection likely on environmental grounds is unknown. Clearly, in situations such as this, a compromise would be necessary, balancing cost against amenity values.

In all new basic telephone service installation work, provision of a duct between the customer and the DP to carry the telephone pair is highly desirable if an option is to be kept open for the future addition of a wideband cable feed with the minimum of disturbance and cost.

CABLE SYSTEMS IN THE LONGER TERM

The cable-system principles described enable short-term and medium-term development to meet demands for comprehensive services, and also achieve a measure of plant integration in the local-line network. The technology is available and no radical change is necessary as implementation proceeds. It is, however, relevant to question whether schemes based on these principles could meet the long-term requirements of the telecommunications service; also whether the system technology thereby adopted for the local network would be compatible with the overall evolutionary transmission and switching progress that will occur, as previously outlined, in the UK inland main network toward the turn of the century. Dual-cable schemes, for example, achieve a useful degree of constructional integration, but they do not set out to attain full electrical integration of the system; they are aimed to allow continuance of individual pair-type telephony distribution within a changing service environment.

One clear objective for feasibility study would be to develop, for implementation in the long term, a local network exploiting digital technology as an aid to integration of the transmission and switching functions, and as a means of providing all services on a single medium. The preference for a system, in which all the switched services and their control and routing arrangements are handled by digital methods and assembled in a time-division multiplex, arises

† Approximately 77% of customers' lines are ducted down to the DP (1974 assessment)

from factors similar to those bringing changes in the main network. These include compatibility with micro-electronic technology, potential for cost and bulk reductions, and speed and reliability of operation. The alternative of analogue signal-handling techniques offers little future scope for the reduction of filtration and modem complexities.

A number of studies have been made in this area, and commonly involve providing access to a broadband highway. Assumptions are usually made on the availability of fast processor control at the near-by switching centre, and the adoption on the highway of time-division methods of switching and sharing.

Consideration of the organizational problems of bi-directional traffic sharing on a highway could lead to a preference for the concept of a closed ring, on which the traffic moved unidirectionally and where the utilization could be very high. However, the simple ring system has certain basic drawbacks: one on grounds of security and another on complexity of individual-customers' terminal equipment. A development of this type of scheme, and one which avoids these objections, has been proposed in the BPO Research Department,[9,10] and a laboratory model has been in successful operation for some time.

The scheme, which represents a radical departure from present distribution methods, is illustrated in Fig. 12. Coaxial ring highways are laid from cabinet flexibility points to serve areas of distribution. Traffic from the rings is assembled and conveyed to the nearest digital exchange that has access to the network control system. Traffic (for example, telephone, data, facsimile or Viewphone) circulates unidirectionally around the ring in the form of coded digital signals in time slots which are offered by the control system. Access to the highway is gained at a number of points, called *accessors*, located conveniently for serving small groups (10–20) of customers via short spur feeds. Typically, these accessors would be small micro-electronic device assemblies sited in roadside footway boxes and would carry out the first stage of traffic arrangement. The bandwidth of the highway, upwards of 300 MHz, would also enable broadband services, such as entertainment and educational television, to be carried.

If a local distribution system of this type were to be integrated, via time-division switches, with the future digital main network, stable and low transmission losses, and freedom from noise and crosstalk could be achieved. A preliminary cost study has already indicated that this system, installed as part of an overall digital system, could be a cheaper way of providing even the basic telephone service than the present arrangement of individual pairs and space-division switches.

Methods of introducing digital technology into the local-line network have particular significance in the longer term and will influence future local network strategy. The system described is one of several alternatives currently receiving detailed study in TSSD.

OTHER TRANSMISSION MEDIA

In the assessment of the potential capability of transmission media for future use in the local-line network, interest must remain primarily directed towards the application of cables with metallic conductors. This is largely because of their known capabilities, state of development and availability. However, in the longer term, the feasibility of use of at least 2 other media—radio propagation and guided waves—could be increasingly relevant.

Radio Propagation

There are interesting technical grounds for suggesting the application of millimetric radio techniques for fixed local-distribution service. One attraction is the possibility of avoiding problems associated with new cabling; use of radio could facilitate speed and flexibility in provision. Another is the potential for exploiting these higher-frequency regions, which offer prospects for reduction in component and sub-system (for example, aerial) sizes. There is also the feasibility of defining specific service areas by the utilization of the

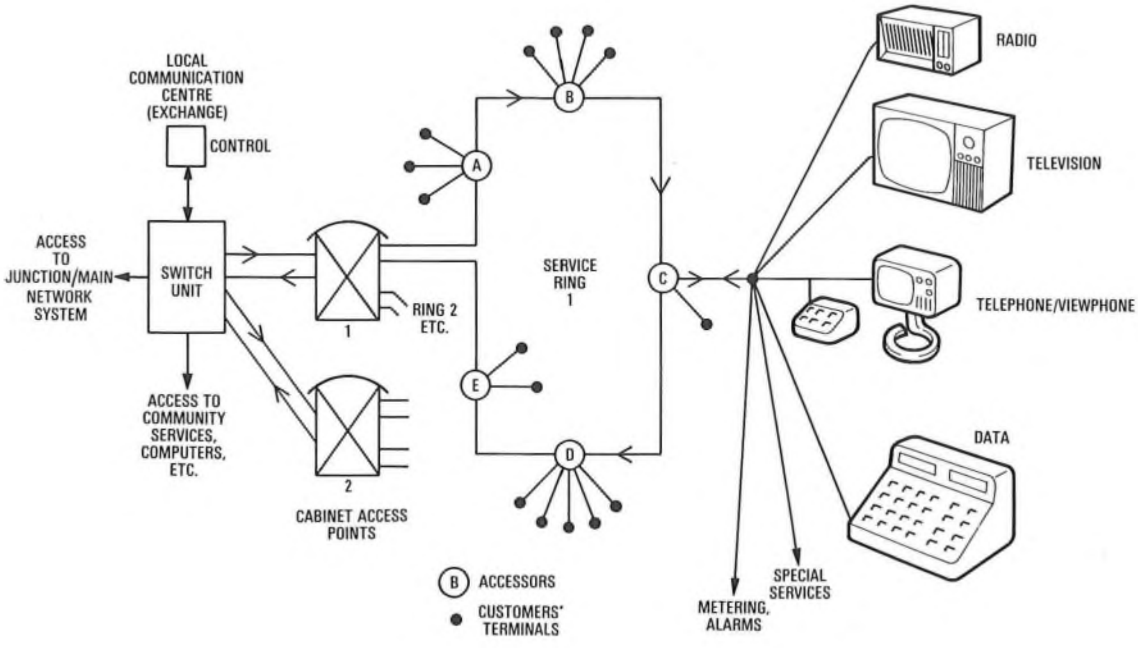

FIG. 12—Multi-purpose local-distribution system using ring highways

cut-off properties in propagation characteristics that occur over part of the suggested frequency spectrum.

Millimetric radio might be used either as the sole transmission medium or, possibly, in association with cable schemes. At precisely which hierarchical or system level, or over what area of coverage, radio transmission could be used does, however, raise many questions, both in areas of signal propagation and in the organization of appropriate nodal switching.

The propagation aspect (suitable frequency, size of coverage area and reliability of the medium, for example, interruption of service under adverse weather conditions) is already being explored in the BPO Research Department and at the Appleton Laboratory, Slough, as part of a broader study programme. The screening effect on signal propagation, for example, of large buildings, is a potentially serious hazard in area coverage. The degree to which this could be overcome, for example, by multiple transmitters sited on the fringes of the service area, is also the subject of study.

In the component development field, solid-state devices, with output powers that would permit distribution of a variety of customer services on an exchange-area basis, are likely to be commercially available within the next few years.

However, it is clear that substantial equipment provision would have to be made, not only for transmitters, receivers and aerials, but also for the complex signalling, switching, control and multiplexing equipment that would be necessary. The extent of the bandwidth requirement, and problems associated with switching organization, are aspects which cast doubt on the use of the medium at this hierarchical level and need very careful examination to assess system viability.

But it may be possible to use very-short-range low-power millimetric radio for the final feeds from the network to the customer (for example, 100 GHz radio links at the DP) where rapid installation or temporary service requirements arise, or where local cabling becomes extremely difficult and costly. There is also a possible application in rural communities for a longer-reach point-to-point system, operating at frequencies around 20 GHz, to provide line-of-sight linkage for main routes in the local system in sparsely-populated or isolated environments.

Development of the technology for applications of the type mentioned above is at a relatively early stage and, at present, costs are likely to be greater than for an equivalent cable facility. However, in the longer term, potential exists for considerable cost reduction in radio system technology, an aspect which merits regular review.

Radio Communication by Satellite

Satellite communication technology has become well established at national and continental levels of coverage. Its relevance to local-network application is, however, more obscure. Satellite methods could be applied to the distribution of certain wideband services in at least 2 ways: direct from satellite to customer, or via receivers situated at suitable nodal points and then into a local-cable system.

The first method has the serious objection that each customer would require a properly oriented aerial on a line-of-sight path to the satellite. This could be costly and may not be physically possible in some applications. The second method would pose problems in traffic organization and it is difficult to visualize any real advantage being gained. If all towns of 10 000 or more inhabitants were to be served in this way, for a number of common vision broadcast services, it has been calculated that approximately 700 nodal points would be needed in the UK for a service area coverage in excess of 90%. A considerably greater number of nodes would be required to access directly local areas of distribution at, say, the PCCP level.

Organizationally, there would be very severe traffic assembly and processing problems for any type of service other than simple broadcast.

Guided-Wave Media

There are 2 broad areas in which there is considerable research interest in the quest for new wideband transmission media. The first of these is, however, in meeting requirements for heavily-loaded inland trunk routes and is unlikely to be directly relevant to local-network use. The 50 mm waveguide, at present in an advanced state of development in the BPO Research Department for use in the 30–110 GHz frequency band, illustrates this aspect.[11] The constraints on laying and the large guide size do not conveniently lend themselves to use in local distribution. It is, nevertheless, possible that a flexible dielectric guide of small diameter could offer the possibility of longer-term use for main routes in the local network.

The second of the areas into which increasing research effort is being devoted is in the development of optical-fibre systems.[12] The optical fibre is a dielectric waveguide driven at optical frequencies. To constrain the light passing along the glass-fibre transmission path, an outer cladding glass of a slightly different refractive index is needed. Two types of system are emerging, based on the 2 main transmission modes in which the fibres can be used.

Firstly, in the high-capacity system, light travels in a single mode of transmission (monomode) along a very small diameter (for example, 2 μm) core, or in a number of modes having equal group velocity in a fibre of graded-index† construction.[13] A coherent light source, typically a solid-state laser, is used; the information-carrying capacity is large (of the order of several hundreds of megabits per second) and the potential application is more likely to be of interest on heavily-loaded trunk routes, However, there is clearly potential for use in a local system, possibly initially on the main highways. A system of this type would be of particular interest in the longer term if integration of all services, and transmission in the digital mode, were to be adopted as a basis for network organization.

The second type of fibre system uses multimode transmission, and aims to avoid the practical difficulties associated with the very small core of the monomode system. The larger core diameter (for example, 50 μm) permits less intense light-emitting devices, such as diodes, to launch sufficient power into the system. Because of multiple-path and material-dispersion effects, the bandwidth capacity of the system is much less than for the monomode system. However, the capacity, typically tens of megabits per second or about 10 MHz for analogue transmission, could be potentially very useful in local-line-system applications.

The significance of optical-fibre cable technology is that the fibres are extremely small and flexible, and use essentially cheap materials that are freely available. These factors taken together could ultimately revolutionize system thinking in the local-line network.

CONCLUDING COMMENT

In the UK, the increasing share of business and household expenditure being used for telecommunications and the growing size of the information-handling sector enable a steadily rising service demand to be safely predicted for the next 30 years. Although the telephone is likely to remain dominant over much of this period, there will be widespread demand for new services, including visual services.

Within the local-line network, there are very real incentives, in economic terms, to use the existing pair-type conductor cables for narrow-bandwidth and medium-bandwidth services; it may be possible to utilize the final feeds to the customer for certain visual-signal transmission purposes. In the setting-up

† The refractive index of the material is a smooth or continuous function of the radial distance from the fibre axis

of a Viewphone service, for example, it appears technically possible to provide for low penetration of a nominal 1 MHz bandwidth system over existing telephone pairs, at moderate cost. However, any significant expansion of this type of service, or any real penetration of cable television or similar 625-line standard services, would demand a new local network of wideband capability. But the cost of line-plant provision of a 625-line (6 MHz) Viewphone service, compared with a 1 MHz Viewphone service, could be expected to rise by a factor of the order of 10, because wideband feeding must be installed specifically for the 6 MHz service.

One of the main difficulties in making wideband provision where telephone service is already arranged, lies in the differences in the types of existing plant layout, particularly in the final feed between DP and customer. In such circumstances, the cost of a specific wideband service can vary by a factor of 4 or more; a critical feature is whether or not a duct already exists and can be utilized. In all forward provisioning, it is therefore highly desirable, in order to keep future options open, to make such duct provision initially, if the costs incurred can be accepted.

For the medium term, analogue-mode dual-cable schemes using both balanced and coaxial pairs offer substantial opportunities for cost saving by sharing local-line plant between the various services. If such schemes are designed in accordance with an overall system concept, the services can be accommodated efficiently as demand arises and worthwhile economies achieved from the shared plant. This approach probably offers the best compromise at present available and it has the merit that, if certain topological arrangements are made in cabling, the options for alternative future system technologies are kept open for the longer term.

These, typically, are the prospects offered in the medium term for development from the existing single-pair-type network to one using a dual-cable concept in an essentially analogue system environment.

However, reference was made earlier in this article to the general trends towards digital transmission and switching in the UK main network, and the desirability of rational system integration. The local network must move towards compatibility with this environment, seeking to gain similar advantages in the use of common technology. The longer term, therefore, offers the challenge of the development of local-line systems, which provide multi-purpose facilities within a TDM-switched hierarchy. Digital schemes of the type mentioned earlier offer the prospect of a move away from the constraints of the existing network towards this objective.

But, clearly, the present heavy local-plant commitment, which is inherited, cannot be ignored; any programme of plant provision will need very careful phasing to allow for both a changing and uncertain customer demand pattern, and for the evolution of new technology. It is particularly important to build into any system a high degree of flexibility to meet aspects such as these. It is also very relevant to identify action that must be taken early to avoid closing any future options; for example, ducting policy for providing customer feeds. Such action becomes highly appropriate when the possibility for the introduction into the local network of radically new transmission media, such as glass fibres, is contemplated. And in this context, it is becoming increasingly clear that, with its compatibility with advanced solid-state and digital technologies, the optical fibre might well offer the ultimate solution to the problem of providing comprehensive multi-purpose transmission facilities.

The future technological strategy for the local-line network is significantly dependent on whether or not large-scale provision is to be made for wideband services. One critical factor is the policy to be pursued on cable television; another is the rate at which demand develops for switched vision services and whether this will be met by channel bandwidths of, say, 1 MHz or 6 MHz. A third is in the timing of the provision of any new generation of electronic digital exchanges, with appropriate switching capability and with potential for fast common control of a local digital system. And, overall, there must remain the fundamental necessity for any proposals for large changes in the network to take heed of the prevalent economic climate.

There appear to be essentially 2 alternatives which will determine future local-network strategy. One would be based on the decision to restrict future services to those capable of being provided by the existing pair-type system (for example, PSTN-type services); this implies curtailment of any real wideband service prospects. The other alternative would arise from an acceptance that pressures for the faster transfer of information will increase, and to aim to meet the resulting far-reaching demands on the network by the forward provision of an appropriately evolutionary system, rationally developed and progressively integrated.

Some engineers feel that the local network has for long been the Cinderella in the telecommunications picture. Perhaps, despite, or even because of, the present economic climate, it is time that Cinderella found her slipper. Alternatively, perhaps she might have to be patient until a new pair is made—from glass?

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The Millimetric Waveguide System: The Current Situation

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A new type of transmission system must be able to cater satisfactorily for a wide diversity of present and future services and offer a cost-effective solution to the transmission problem, particularly when there are possible competitive systems at various stages of development. A system, which is currently in the field-trial stage and which appears to meet these conditions, uses millimetric waveguide as the transmission medium. It is a broadband system for the transmission of digital signals and operates in the frequency band 30–110 GHz; when fully loaded, it has a traffic capacity of almost half a million simultaneous 2-way telephone circuits, or the equivalent in other services.

In this and following issues of the Journal, articles will be presented that cover the history, design, development, field trial and future prospects of such a system based on the work undertaken and managed at the British Post Office Research Centre. The first article is an introduction to the series, and outlines briefly what a waveguide system is and how it operates in general terms; subsequent articles will treat various major aspects of the system in more detail.

INTRODUCTION

As the need for greater communication capacity increases, transmission systems are developed which have their own particular advantages in different circumstances. Thus, in the past, coaxial cables, radio, submarine cables and satellite systems have been developed, and each has a specific complementary role to play in the overall communication scheme. Much of the future communication traffic—telephony, television and other video services—will be in digital form, so that systems being developed now must be capable of carrying any or all of these services.

The inland main-network communications routes offer economies of scale from the use of very-high-capacity broadband transmission systems. Millimetric waveguide is a medium particularly suited to carrying digital signals, and is capable of meeting, over a single highway, all foreseeable needs for even the densest traffic route. It can also cope with any mixture of services ranging from low-speed telemetry to high-definition colour television.

It is therefore not surprising that interest in millimetric waveguides is high, both in the UK and internationally. The British Post Office (BPO) Research Centre has been working on the development of millimetric waveguide systems for many years in close collaboration with UK industry, and other Administrations are actively engaged on similar work, notable among them being the USA, Japan, France, Germany and Italy. These various developments do not necessarily result in systems identical to that proposed for the UK, and some of the more significant differences will be mentioned in later articles.

BACKGROUND

Rectangular-section waveguides are probably familiar in the form of the "plumbing" associated with radar and microwave-radio equipment. Such waveguides are relatively narrow-band devices so that a range of sizes is required for different operating frequencies, which can range from 1–40 GHz, or more. Their losses are low compared with typical cables at these frequencies, but they are not negligible.

For wideband telecommunication highways, interest is centred on circular waveguide in the form of a hollow tube of conducting material. It has been known for a long time that, theoretically, such guides are capable of propagating specific patterns (known as *modes*) of electromagnetic waves, and that one mode in particular appeared to have a very small loss that decreased with increasing frequency; this is contrary to the situation in cables, for example, where loss increases as the frequency increases.

Practical confirmation that satisfactory circular waveguides could be made, and that they behaved in this surprising way, awaited the availability of electronic tubes operating at millimetric wavelengths (specifically, in the frequency range 30 GHz upwards) in the late 1950s. But these early tubes were costly and unreliable and, although it was possible to confirm the promise of low-loss performance of circular waveguides, the potentially large traffic capacity offered was not needed at that time. It was also not known definitely whether the traffic carried in the future would be in analogue or digital form and so, for these and other reasons, further work was deferred.

However, much had still to be learnt. The early and simplified theory of waveguides assumed straight and uniform guides with perfectly conducting walls; also, it was still necessary to determine how practical waveguides would behave when made under factory production conditions to reasonable tolerances, and subsequently laid in ducts.

The situation today is very different. Because of the significant traffic requirements predicted for the last quarter of this century, a comprehensive UK programme of research and development on millimetric waveguide systems was started in the late 1960s, co-ordinated and predominantly financed by the BPO in close co-operation with UK industry. This work has resulted in a field trial which is now in operation. This demonstrates that such a system is technically and operationally feasible, and that it is economically attractive compared with existing and developing competitive systems for broadband digital transmission.

To describe this waveguide system and its prospects for future operational use, it is desirable to consider briefly some

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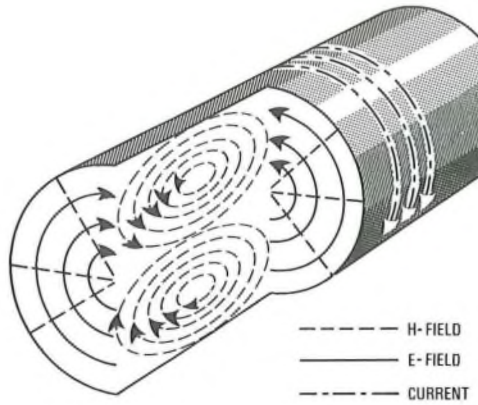


FIG. 1—TE_{01} mode in a circular waveguide

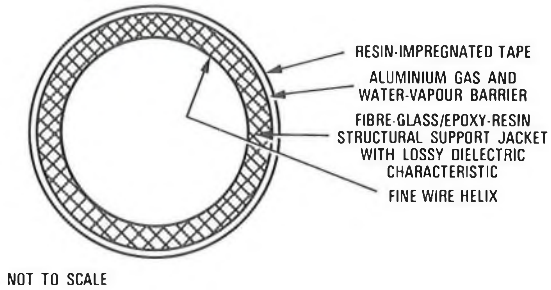


FIG. 2—Cross-section of helix waveguide

of its main aspects and components. A simple explanation of electromagnetic wave propagation in circular waveguide now follows, before waveguide construction and installation, and terminals and repeaters are considered.

PROPAGATION IN WAVEGUIDES

The concept of transmission by waveguide is basically quite simple. That electromagnetic waves can propagate along metallic conductors and through space (as radio waves) is generally well known, and waveguide transmission can be considered as very-high-frequency radio waves guided within a hollow cylindrical conductor.

Whatever the medium of transmission, the electrical energy is in the form of electric and magnetic waves bearing a distinct relationship to each other and to the medium concerned; the particular patterns, or arrangements, of the electric and magnetic field lines are known as *modes*.

It is well known that in, for example, open-wire lines, the electric field lines and the magnetic field loops extend theoretically to infinity, whereas in coaxial lines, these fields are constrained within the outer conductor. Also, the electric and magnetic field lines are normal to each other, while at a conducting surface, the electric field must be normal to it or zero, and the magnetic field must be parallel to it or zero.

These constraints and relationships also apply to the fields in circular waveguide and, surprisingly, there is a large number of modes that are possible; these are designated for convenience as either *TE* (*transverse electric*) modes or *TM* (*transverse magnetic*) modes with a double suffix which derives from mathematical equations for specific identification. Thus, there are such modes as TE_{11} and TM_{12}, but the mode of particular interest is the TE_{01} mode shown in Fig. 1.

In this mode, the electric field is theoretically zero at the (inner) surface of the waveguide, and the energy is sensibly transmitted in the space within the waveguide and not in the conducting surface, so that the loss tends to be very small.

However, the problem is that in such a conducting cylinder (circular waveguide), many modes can exist simultaneously; indeed energy can change from one mode to another if there are surface imperfections or directional irregularities, and full advantage of the low-loss TE_{01} mode cannot be taken. Consequently, the waveguide has to be designed to prevent, or at least minimize, the propagation of all modes other than the wanted mode.

TYPES OF CIRCULAR WAVEGUIDE

It is a property of circular waveguides that the modes that can be present at a particular frequency are a function of the ratio of the wavelength to the waveguide diameter, the latter being 50 mm for the BPO waveguide. As ordinary copper tube is unsuitable because it has no mode-suppression properties, the 2 most popular waveguide structures that are considered acceptable are the copper-helix waveguide and the dielectric-lined copper waveguide.

Helix Waveguide

After a considerable amount of research and development effort, a jointly-funded BPO/BICC Ltd. factory has been set up to produce helix waveguide, illustrated in Fig. 2. The waveguide consists of a precision helix of fine copper wire in a structural jacket of glass-reinforced lossy epoxy-resin plastics. This jacket is surrounded by an aluminium gas and water-vapour barrier which, in turn, is covered by a resin-coated tape to prevent scuffing.

The wanted TE_{01} mode induces only circumferential currents in the waveguide, while most other modes induce both axial and circumferential currents. Thus, a helix waveguide, backed by a lossy jacket, passes the TE_{01} mode with virtually the same performance as plain copper waveguide, but the transmission properties of the other modes are modified. In general, the attenuation coefficient of the spurious modes is increased.

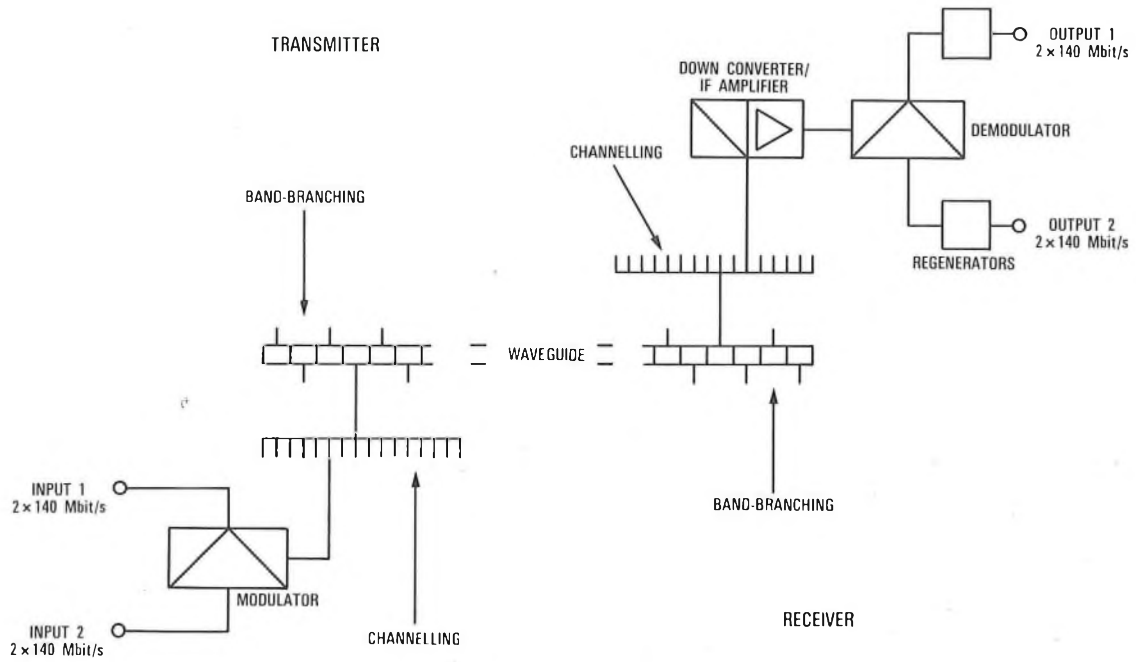
This form of waveguide is preferred on the grounds of economics and general transmission performance (low signal distortion and low attenuation), even though it has a slightly higher basic attenuation than dielectric-lined waveguide. Roughly speaking, it has a basic loss of less than 2 dB/km over a bandwidth of about 80 GHz, which will allow repeater spacings of up to 30 km. The waveguide is manufactured in 3 m lengths on precision stainless-steel mandrels, and jointed in the factory into 9 m lengths for delivery to site.

Dielectric-Lined Circular Waveguide

By lining a precision-bore copper tube with a fine layer of suitable dielectric, a waveguide is produced which relies on the difference in the phase velocities of the various modes to keep the power in the wanted low-loss TE_{01} mode. The basic loss of such a waveguide can be very low even when the guide is bent into curvatures of about 50 m radius. However, any imperfections in the waveguide can cause conversion into the unwanted (higher-loss) modes, and these would not be suppressed except by the introduction of sections of helix waveguides or mode filters. There are also constructional difficulties with this form of waveguide so that the BPO favour the helix waveguide, although the dielectric-lined guide is used in the USA and Japan.

DUCT AND WAVEGUIDE INSTALLATION

To provide mechanical protection and to decouple the waveguide from subsequent earth movement, it is BPO practice to install the waveguide within an accurately laid steel duct of 100 mm inside diameter. Large radius curves (say greater than 100 m radius) can be accommodated without difficulty, but



IF—intermediate frequency

FIG. 3—Simplified block diagram of waveguide interface with repeater equipment

it is desirable that the installed waveguide should be reasonably straight to minimize additional attenuation caused by spurious modes. Sharp bends of about 2 m radius have been developed in reduced-diameter dielectric-lined waveguide for tight situations. Further work is in hand to produce a modified form of helix waveguide that will be satisfactory for bends below 100 m radius.

The duct is laid either by lowering jointed lengths into a prepared trench with about 0·6 m cover or, in cross-country situations, by mole-ploughing lengths of several hundred metres at a time into the ground at a depth of about 1·2 m. The waveguide is subsequently installed on a length-by-length basis from above ground, and rests on the jointing sleeves and intermediate support collars at 1 m intervals.

When completely installed, the waveguide is pressurized with pure dry nitrogen to eliminate a resonance caused by oxygen which creates a loss peak at a frequency near 60 GHz; the duct is pressurized with dry air.

TERMINALS AND REPEATERS

It is expected that the waveguide terminal stations will interface with other digital communication systems at traffic bit rates of 140 Mbit/s. For transmission over the waveguide, these 140 Mbit/s inputs will be multiplexed to 280 Mbit/s or 560 Mbit/s, coded and augmented by system-monitoring digits as necessary for eventual modulation at about 300 Mbit/s on radio-frequency (RF) carriers. This modulation may be at an intermediate frequency of about 1·4 GHz with subsequent frequency up-conversion, or directly at the millimetric wave frequency. At the repeater or receiving terminal, demodulation takes place at the intermediate frequency prior to regeneration of the digital signals.

A simplified outline of the waveguide interface with the repeater equipment and the digital signals is given in Fig. 3. The similarity with conventional microwave radio systems can be seen.

Each millimetric wave carrier will accommodate two

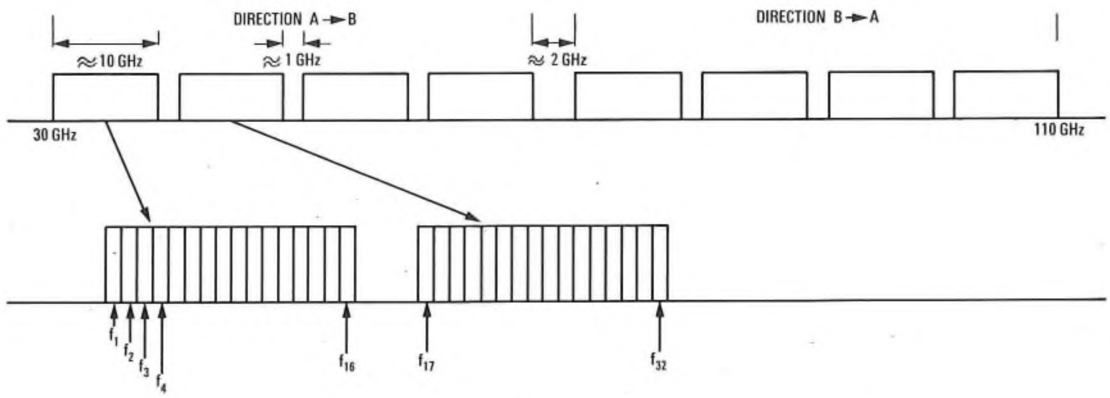


FIG. 4—Provisional channelling plan

300 Mbit/s streams and, typically, such carriers spaced at about 560 MHz intervals will be multiplexed into groups of 16, occupying a band of about 10 GHz. By subsequent multiplexing of these 10 GHz bands throughout the band, spaced by suitable guard bands of about 1 GHz, it is possible to build up a provisional channelling plan as indicated in Fig. 4. The band-branching and carrier-separating functions are all achieved in passive waveguide networks, which are produced by precision electro-forming and numerically-controlled machining techniques.

WAVEGUIDE SYSTEM FIELD TRIAL

To demonstrate the feasibility of a practical waveguide transmission system and to compare and evaluate various technical options, a field-trial system is in operation between the BPO Research Centre at Martlesham and a repeater/terminal at Wickham Market, a distance of 14·2 km. The field-trial route was chosen to provide representative problems of laying duct and installing waveguide along trunk and minor roads, through suburban areas and across country. Detailed planning involved a careful survey to determine an optimum line, generally avoiding obvious obstacles. As a result, over most of the route, bends are greater than 300 m radius, but some are as low as 100 m. Near Wickham Market, 3 deliberate sharp corners have been introduced for negotiation by mirror corners or reduced-sized waveguide. For comparison purposes, an alternative duct route, 1·5 km long, has been laid, bypassing these sharp bends. In addition to the normal hazards, the duct had to be laid over a river using a special bridge, below a stream at another point, and through a marsh 200 m wide.

With the duct work completed and with manholes spaced at about 500 m intervals, the 9 m lengths of waveguide delivered to site were jointed together in special caravans and installed length-by-length from above ground, through surface-to-manhole lead-in ducts. The waveguide was then tensioned to ensure adequate straightness and to overcome any expansion or contraction effects due to temperature changes.

While this external duct and waveguide work was being carried out, the components and subsystems of the repeaters and terminal equipments were being assembled and checked at the BPO Research Centre, Martlesham. Individual and back-to-back tests of the repeaters preceded their transfer to a terminal station at Wickham Market in October 1975, when the installation of the waveguide in the duct had been completed.

With regard to the transmitting terminal and the repeaters, 2-level and 4-level phase-shift modulation can be demonstrated, by both direct and indirect modulation, to enable a direct comparison to be made. Modulation of the digital signals directly onto the millimetric wave carrier is particularly attractive because there is little RF power loss, whereas with modulation of an intermediate frequency and subsequent frequency up-conversion via a non-linear process, the RF power loss is quite significant and additional filtering is necessary to remove unwanted intermodulation products. At the receiver, frequency down-conversion to an intermediate frequency takes place, and the signal is amplified and demodulated. Experiments on the field-trial system have included comparison between coherent and differential coherent demodulation systems. While coherent demodulation requires some 2 dB lower carrier-to-noise ratio for comparable performance, it is more complex technically than differential detection, particularly as regards accurate carrier recovery. In differential detection, it is necessary to compare only the carrier phase between adjacent bits to determine whether a change has occurred, but there are quite stringent demands on circuit stability.

The demodulated signal, after suitable amplification, is regenerated in units which work on the sample-and-decision principle; timing information is obtained from the demodulated signal and a phase-locked loop is used to achieve a stable clock reference, substantially free of jitter.

Tests so far have shown that an error rate of 1 part in 10^9 per repeater section is obtainable with a carrier-to-noise ratio of 20 dB at the demodulator input. A satisfactory transmission performance is also achieved when the signal is relayed serially through the waveguide several times, using a different RF carrier for each transmission.

FUTURE PROSPECTS

From the field trial results so far, it is possible, with confidence, to look towards the future and the possible implementation of operational waveguide systems in the major arteries of the telephone network.

The inherent capacity of the system is 64 bothway carriers, each with 560 Mbit/s of digital traffic, equivalent to 491 520 2-way telephone circuits. From a knowledge of various system parameters (for example, available transmitter power, waveguide attenuation and receiver noise factor), the relationship between this total capacity and the necessary repeater spacing is as shown in Fig. 5, where a spacing of over 20 km is suggested.

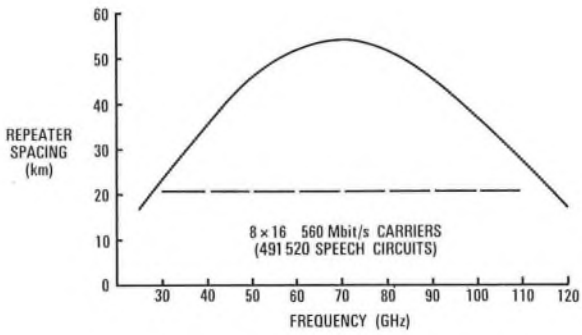


FIG. 5—Repeater spacing and band allocations

Economic factors obviously come into play in deciding how an operational system would best be implemented; is a system with reduced capacity, but widely-spaced repeaters, more cost-effective than a large-capacity system with repeaters closer together, and how do these alternatives compare with other high-capacity systems in terms of cost and flexibility? At present, the indications are that waveguides will be the only high-capacity digital system available in the early 1980s that is cost effective, and tentative proposals have been made for the implementation of the initial systems.

These proposals are based on the fact that the traffic requirements of the routes under consideration, though substantial, could be met until the early 1990s by a waveguide system using only the first two 10 GHz frequency bands of Fig. 4 (with the bands working in opposite directions), until such time as growth requires additional bands to be brought into use. The subsequent logical evolution of a waveguide-system frequency plan will be discussed in a later article, but this arrangement has the attraction that the system is essentially demonstrated now in the field trial, together with much of the equipment and facilities needed to exploit the higher frequency bands for later systems. Where minor additional research and development work is necessary, it could then be phased in during the later years as required, rather than be progressed at present when manpower and capital resources are limited.

Single-Channel-per-Carrier Digital Transmissions by Satellite

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UDC 621.394.4:681.327.8:621.396.946:629.783

International data transmission is becoming almost an everyday requirement and is expected to grow rapidly over the next few years. Communication-satellite systems can provide an efficient media for such transmissions. This article discusses the recent practical participation by the UK in the development of facilities for the provision of data services by satellite.

INTRODUCTION

The advent of satellite communications on the international scene, some 10 years ago, greatly increased the scope and range of new types of services that could be provided between almost any parts of the world. In particular, by the very nature of its relatively extensive wideband facilities, it provided the opportunity for the expansion of international data traffic, especially at the higher speeds.

The introduction of the single-channel-per-carrier, pulse-code-modulation, multiple-access, demand assignment equipment (SPADE)[1] about 4 years ago, with its inherent 64 kbit/s digital transmission paths, provided the opportunity to increase further the efficiency of data transmission by satellite. Already, there are several full-time 48–50 kbit/s links in operation using the 64 kbit/s single-channel-per-carrier (SCPC) facilities associated with the SPADE system. In addition, an experimental programme was recently conducted to investigate the possibility of combining low-speed and medium-speed data streams to facilitate the sharing of a single 64 kbit/s satellite transmission path, thereby increasing the channel utilization efficiency even further. The British Post Office (BPO), through its earth station at Goonhilly Downs in Cornwall, has been fully involved in the initial testing of these facilities, using Aerial No. 3[2] and an Atlantic region INTELSAT IV satellite.[3]

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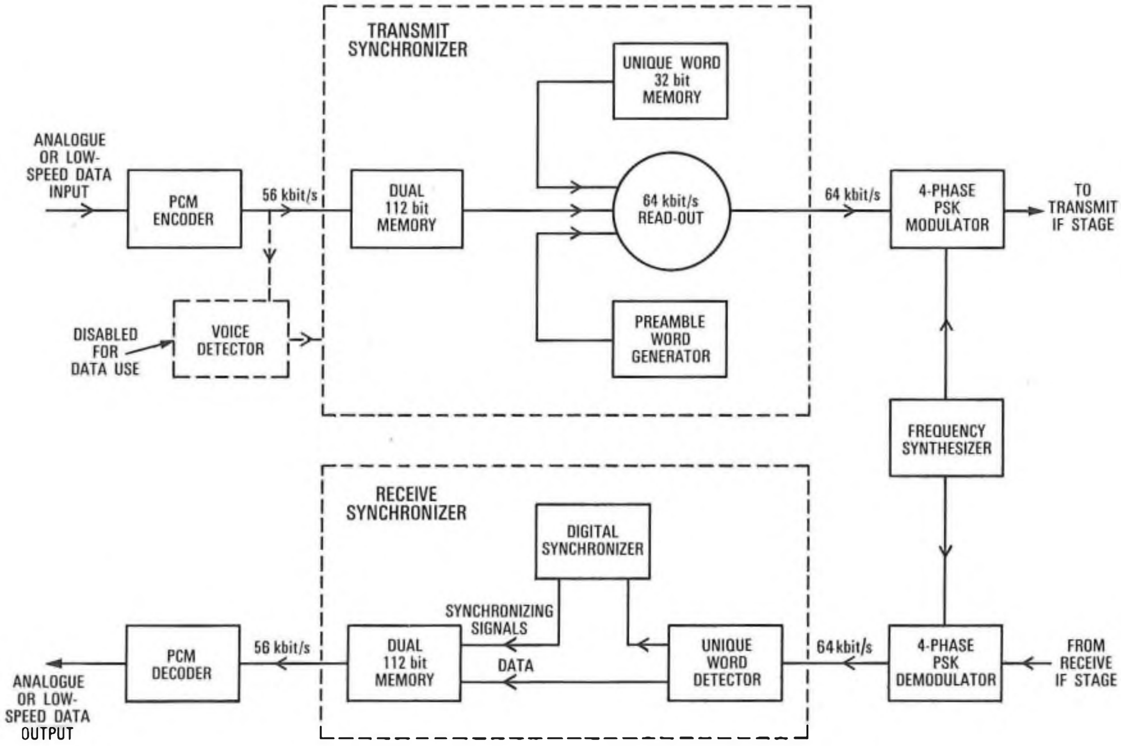


PSK—Phase-shift keyed
PCM—Pulse-code modulation
IF—Intermediate frequency

FIG. 1—Simplified block diagram of the basic channel unit for voice and low-speed data

LOW-SPEED (NARROW-BAND) DATA TRANSMISSIONS

In the SPADE system, the analogue voice transmission is converted into a 56 kbit/s pulse-code-modulated (PCM) digital signal in the SPADE channel unit, and addition of the necessary synchronizing information increases the bit rate to 64 kbit/s for final transmission. Low-speed data transmissions that would normally be transmitted over voice-channel bandwidths, such as 1·2 kbit/s, 2·4 kbit/s and 4·8 kbit/s, can be processed directly by the SPADE channel unit. These low-speed digital signals are treated in the same way as analogue voice signals, except that, for data transmissions, the voice detector is usually disabled to provide continuous transmissions. There is no evident degradation introduced as a result of the PCM encoder–decoder action on the digital signal. Since the analogue voice and low-speed data transmissions are processed in exactly the same manner, these circuits can also be used for alternate voice/data transmissions and as multi-channel voice-frequency telegraph bearers. Fig. 1 is a simplified block diagram of the basic SPADE channel unit that would be used for these low-speed data applications.

MEDIUM-SPEED (WIDEBAND) DATA TRANSMISSIONS

To maintain, as far as possible, the same basic overall configuration and transmission parameters within the SCPC system, whether providing voice or data services, it was necessary to develop medium-speed data channel units that were compatible with the existing SPADE system. There are 2 data-channel-unit configurations of interest that meet this requirement, both of which use the convolutional-encoding technique. One of these channel-unit concepts also retains the bit-stuffing activity of the basic SPADE channel unit for medium-speed data transmissions. For comparison, these 2 functions are briefly described below.

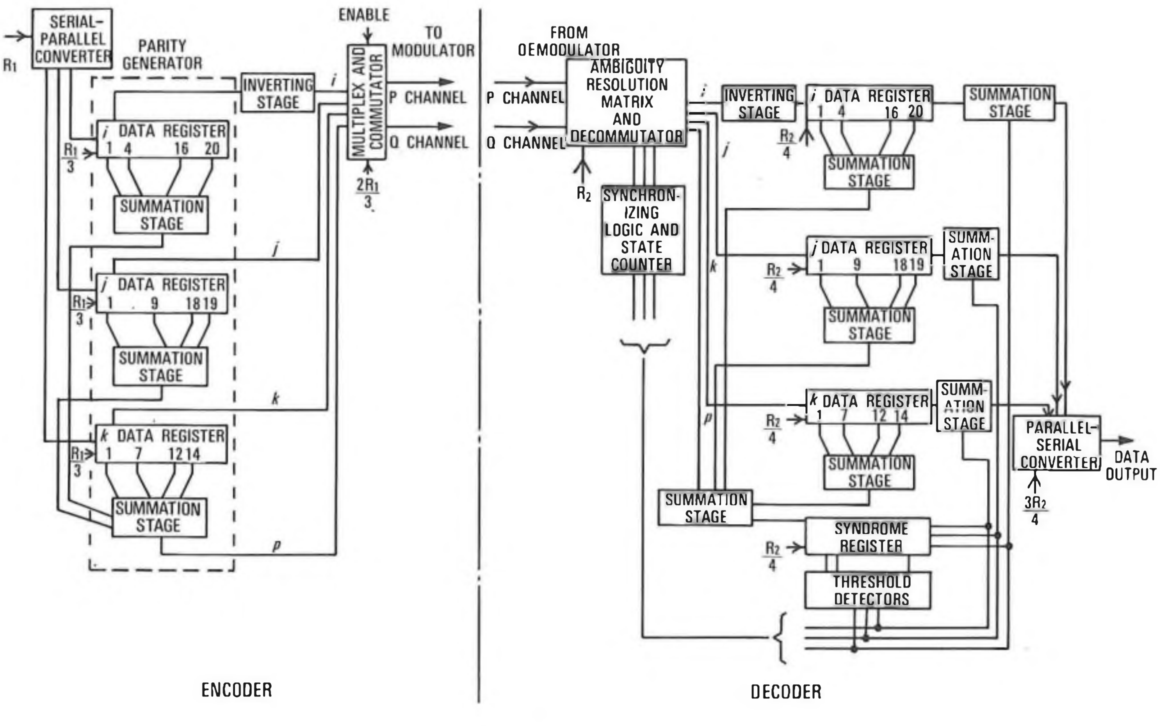
Bit Stuffing

This process is used in the synchronizer of the SPADE channel unit to bring the 56 kbit/s output of the PCM encoder up to the 64 kbit/s final transmission rate. The incoming bit stream is fed into a store or memory device and held until read out again at the desired higher bit rate. Additional blocks of *preamble* and *start-of-message* bits are inserted into the gaps created in the bit stream by the delaying action of the memory device, to produce a continuous bit stream at the higher bit rate. In the SPADE channel unit, the additional bits that are inserted, or stuffed, into the bit stream are extracted and used for synchronizing purposes in the receiver; for example, carrier and bit-timing recovery, and phase-ambiguity resolution. The remaining data bits are passed into a store in the receiver, which is basically the reciprocal of the memory device in the transmit synchronizer, and read out again at the original 56 kbit/s rate for supplying the input to the PCM decoder.

Convolutional Encoding

This is a process whereby the incoming bit rate can be matched to the required 64 kbit/s final transmission rate, while also providing a forward-acting error-correction facility.

Basically, the encoder, which has a correction-code ratio dependent upon the incoming and outgoing bit rates, consists of 3 main sections: a serial–parallel converter, a parity generator, and a multiplex-and-commutator output combination. In the case of a rate-$\frac{3}{4}$ encoder, which is shown in block diagram form in Fig. 2, the incoming data stream is converted into 3 equal parallel bit streams, designated *i*, *j*, and *k*, which are then passed to the multiplex-and-commutator unit. At the same time, an arithmetical operation is performed on the 3 parallel bit streams from which the parity generator produces an appropriately-related fourth bit stream,



i, *j* and *k* are original data bit stream and *p* represents generated parity bit stream

FIG. 2—Block diagram of the rate-$\frac{3}{4}$ codec

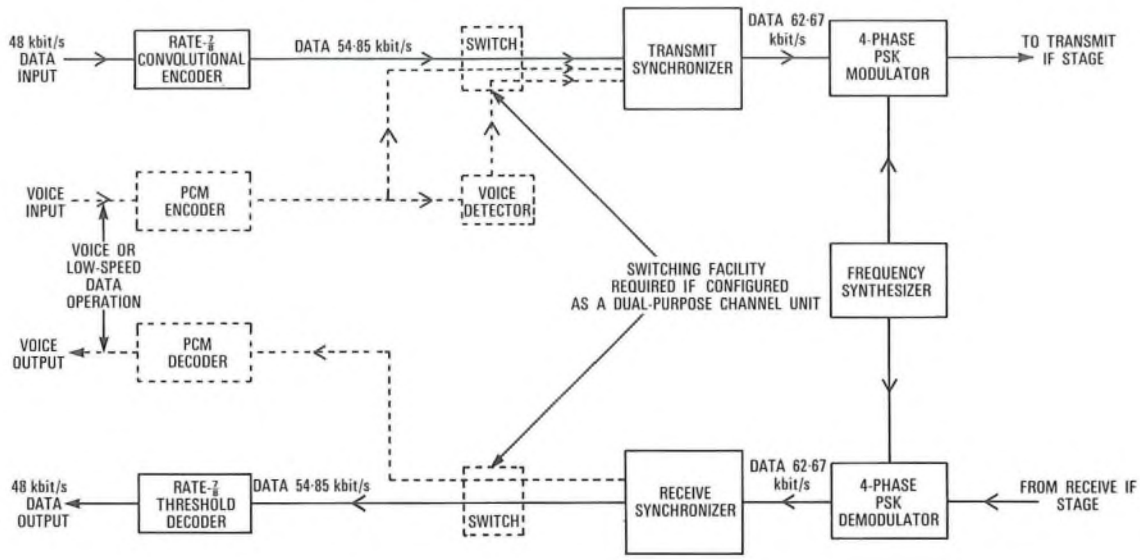


FIG. 3—Simplified block diagram of a SPADE channel unit modified for medium-speed data transmissions

designated *p*, which is also passed on to the multiplex-and-commutator unit. The 4 bit streams are combined at the multiplexer in the required sequence, and connected via the commutator to the 4-phase, phase-shift-keyed (PSK) modulator at the final transmission rate. At the decoder in the receiver, the 3 original parallel data bit streams, *i*, *j* and *k*, are separated out from the incoming signal and passed to a parity-bit generator identical to that used in the encoder. The parity bits produced locally in the decoder are compared with those received in the incoming signal from the distant encoder, and any necessary error-correction activity is thus determined and effected.

The same process would apply for any correction-code ratio, except that the relationship between the converted parallel data bit streams and the parity bit stream would be different. In particular, for the rate-$\frac{7}{8}$ encoder, there will be one parity bit generated for each 7 converted parallel data bits. In the case of the rate-$\frac{3}{4}$ coder/decoder (codec), the decoder is capable of correcting transmission errors of less than 2 bits among 80 continuous signal bits (that is, 60 data bits plus 20 parity bits) using the convolutional error-correction code. This improves the basic bit error rate from the 1 in 10^4 performance of the SCPC system at threshold, to a data-signal bit error rate of about 1 in 10^7, or better, at threshold. The convolutional-encoding process also provides the necessary phase-ambiguity resolution for data transmissions, which the synchronizer in the SPADE channel unit provides for voice transmissions.

MODIFIED SPADE CHANNEL-UNIT CONCEPT

One concept for medium-speed data transmission, which was originally proposed for small-earth-station operation,[4] was based on modifying the existing SPADE channel-unit configuration. Basically, this involved replacing the PCM codec with a convolutional codec, thereby retaining a major part of the basic SPADE channel-unit configuration for the medium-speed data mode of operation.

The output of the PCM codec in the SPADE channel unit interfaces with the synchronizer at 56 kbit/s. Therefore, for a 48 kbit/s data transmission, the convolutional encoder must match the 48 kbit/s input signal to the 56 kbit/s rate required to interface with the synchronizer in the SPADE channel unit. This can be done by using a rate-$\frac{7}{8}$ convolutional encoder to provide a 54·85 kbit/s output. This signal, comprising both data and error code, is then subjected to bit stuffing in the channel synchronizer (also at a $\frac{7}{8}$ rate) to produce a final output transmission rate of 62·67 kbit/s. Although this is slightly less than the standard SPADE transmission rate of 64 kbit/s, it is sufficiently close to the designed operating frequency of the modem, and within the design tolerances of the system, that it functions quite satisfactorily.

The same rate-$\frac{7}{8}$ convolutional encoder could be used for a 50 kbit/s input signal, in which case the final transmission rate would be slightly higher than the nominal 64 kbit/s at 65·25 kbit/s.

In the case of a 40·8 kbit/s input signal, a rate-$\frac{3}{4}$ convolutional encoder would be required. This would result in a codec output rate, comprising the data and error code, of 54·4 kbit/s and a final transmission rate of 62·17 kbit/s.

One possible advantage of this approach, particularly for the small user, is that by providing both a PCM codec and a data (convolutional) codec in a single channel unit installation, together with the necessary switching facilities, a relatively simple dual-purpose channel unit can be provided at reasonable cost. Such a channel unit could be used to meet the requirement for a part-time medium-speed data service during a specified period, and then be switched at a predetermined time to provide a voice service, or to augment an existing voice service, during peak telephony traffic hours. Fig. 3 is a simplified block diagram of a SPADE channel unit, modified for medium-speed data transmissions; also indicated are the original channel-unit elements for the voice-mode operation.

BASIC CONCEPT FOR A MEDIUM-SPEED DATA CHANNEL UNIT

Although the concept of the modified SPADE channel unit for medium-speed data transmission is technically feasible, it does not take full advantage of the available digital capacity of the basic SCPC facility to maximize either the error-correcting functions or the efficient transmission of data information. The higher the data information rate that can be transmitted over the 64 kbit/s SCPC digital highway, the more efficient that transmission is; for example, the 48 kbit/s and 50 kbit/s transmissions are more efficient than the 40·8 kbit/s transmissions. Furthermore, the indications are that future requirements will be for the higher-bit-rate services rather than for the lower-rate 40·8 kbit/s service. However, in the modified SPADE channel-unit concept, the

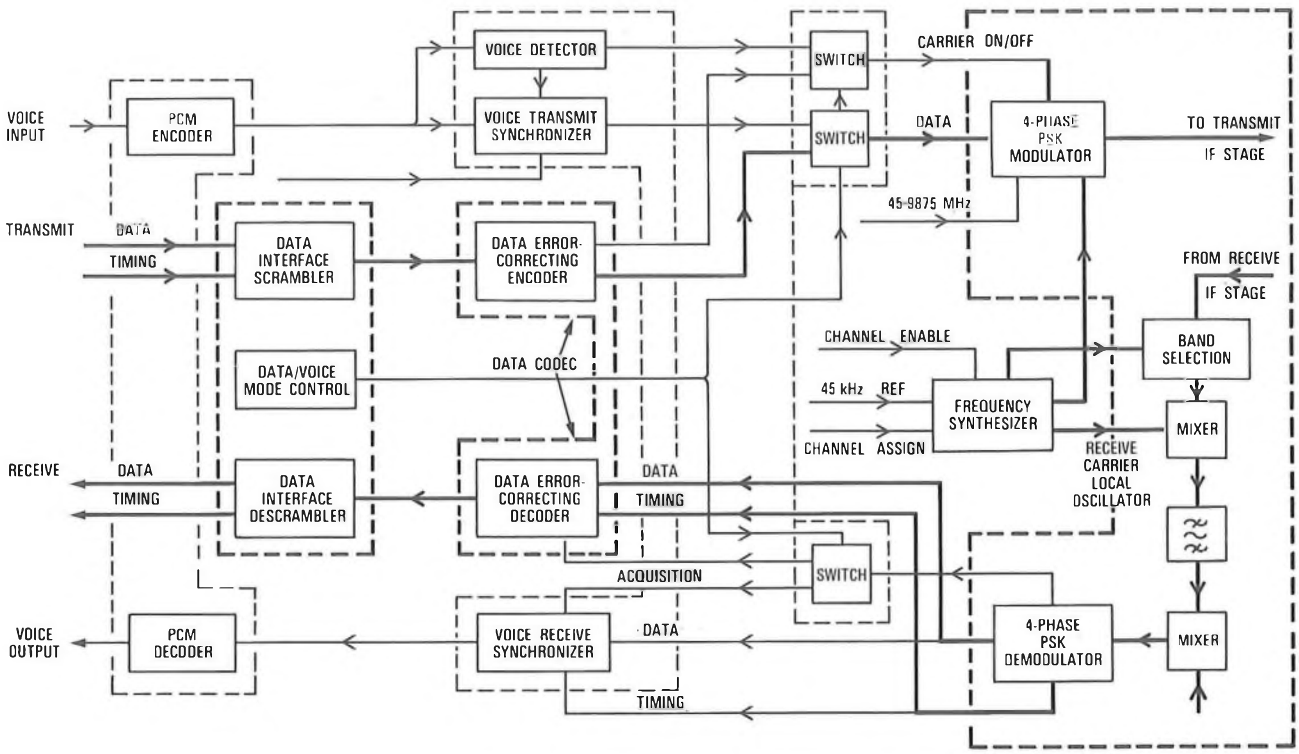


FIG. 4—Block diagram of medium-speed channel unit with alternate voice transmission facility

40·8 kbit/s transmissions are associated with the more effective rate-$\frac{3}{4}$ error-correction code, while the more efficient 48 kbit/s and 50 kbit/s transmissions use the $\frac{7}{8}$-rate error-correction code. In addition, the transmission of a 56 kbit/s data rate is not catered for, and could be accommodated only if transmitted without the insertion of an error-correction code which would result in an unacceptable bit error rate. Also, while this particular concept does have the advantage of facilitating a relatively simple dual-purpose channel unit, the larger users are primarily more interested in providing a reliable and efficient medium-speed digital transmission facility, rather than a dual-purpose voice/medium-speed-data facility. The basic concept for a medium-speed data channel unit is, therefore, based primarily on efficiently meeting the required SCPC medium-speed digital-system performance specification,[5] rather than on considerations of adaptability for multiple-purpose use, although this facility can be provided if required.

Much of the synchronizing information provided by the SPADE channel-unit synchronizer, and retained in the modified SPADE channel-unit concept for medium-speed data transmission, is associated with the burst-mode operation of the basic SPADE voice-activated speech transmissions. Since medium-speed data transmissions will always be pre-assigned with continuous carrier transmission, most of this information is redundant and could, therefore, be omitted; the remaining function associated with the phase-ambiguity resolution of the bit stream itself can be incorporated in the data (convolutional) codec operation. The bit-stuffing function in the SPADE channel unit can then be dispensed with, and the digital capacity thus saved can be used to better advantage.

This is achieved by using a rate-$\frac{3}{4}$ convolutional encoder for 48 kbit/s data inputs, thereby providing a more effective error-correction-code ratio than in the modified SPADE channel-unit concept which uses a $\frac{7}{8}$-rate code. The output of the rate-$\frac{3}{4}$ convolutional encoder is, conveniently, at the final transmission rate of 64 kbit/s for supplying the input to the 4-phase PSK modem. To guard against possible malfunction of the PSK modem and/or data codec when certain data patterns are being transmitted, a scrambler/descrambler device is used in front of the data codec. The same rate-$\frac{3}{4}$ data codec would be used for 50 kbit/s input data rates, in which case the final transmission rate would be slightly higher than the nominal 64 kbit/s at 66·67 kbit/s. For 56 kbit/s data transmissions, a rate-$\frac{7}{8}$ convolutional encoder would be used, resulting in a final transmitted rate of the nominal 64 kbit/s.

Although the requirement for an alternate voice/medium-speed-data service is not expected to be a real consideration, a dual-purpose channel unit can be provided. However, it does require the provision of a PCM codec, a voice detector, transmit and receive synchronizers, and the associated switching facilities, in addition to the basic requirements for the medium-speed data channel unit.

Fig. 4 shows a block diagram of the medium-speed data channel unit, including the facility for alternate voice transmission. If required for data transmission only, as is the more usual case, the circuits and switching associated with voice transmissions would be omitted.

MEDIUM-SPEED DATA CHANNEL-UNIT TESTS

A programme of initial tests was carried out at the UK earth station at Goonhilly, and between Goonhilly and the USA earth station at Etam, on a prototype model of the medium-speed data channel unit during October and November 1973. These tests were conducted to confirm the operational performance of the data channel units, primarily in respect of bit error rate, error-correcting performance and compatibility with existing interfacing equipment. In addition, the test results would provide an assessment of the proposed operating parameters and indicate any technical modifications that might be necessary for the production models. All the tests were carried out using a 48 kbit/s channel unit and a rate-$\frac{3}{4}$ codec, and included testing in the following 4 modes:

(*a*) circuit looped at the channel unit,

(*b*) circuit looped at intermediate frequency, (*c*) Goonhilly–satellite–Goonhilly circuit loop, and

(*d*) a complete Goonhilly–satellite–Etam–satellite–Goonhilly circuit loop.

Brief Summary of Test Results

Bit Error Rate and Error-Correction Performance

The bit error rate of the channel unit without error correction, at the threshold level of an energy-to-noise-density ratio of approximately 11 dB, corresponding to a carrier-to-noise ratio of approximately 14 dB, met the requirement of 1 in 10^4 for all the test conditions. With error correction incorporated, the bit error rate improved at threshold by a factor of 10^3, to meet the required specification of 1 in 10^7. The addition of BPO modems at the input and output of the data loop produced little degradation, requiring an increase in the energy-to-noise-density ratio of 0·2 dB to maintain the same bit error rate. The nominal threshold carrier-to-noise ratio, in a bandwidth equal to the symbol rate under these operational conditions, was therefore determined to be 14·2 dB.

Compatibility

The BPO terrestrial modems and the medium-speed data channel units were fully compatible, and the requirements of the International Telegraph and Telephone Consultative Committee (CCITT) Recommendation V35 were met at the interface. However, it was established that the basic data channel unit could not accept repetitive data patterns; for example, continuous 1 or 101010 patterns. Therefore, to avoid restriction on the data format, subsequent production models of the medium-speed data channel units include a data scrambler/descrambler at the input/output of the codec, as already indicated above.

MULTIPLEXED LOW-SPEED AND MEDIUM-SPEED DATA TRANSMISSIONS

The transmission of medium-speed data services (48 kbit/s, 50 kbit/s and 56 kbit/s) and of low-speed data services (1·2 kbit/s, 2·4 kbit/s and 4·8 kbit/s) can conveniently be provided over the 64 kbit/s SCPC system by using the appropriate channel-unit configuration. Not included in these channel-unit configurations is the capability to handle the 9·6 kbit/s and 19·2 kbit/s medium-speed data transmission rates.

Another characteristic of the low-speed data services needing consideration is the rather inefficient use made of the digital capacity of the 64 kbit/s SCPC facility when a number of such services originate from the same earth-station terminal. One 64 kbit/s channel has the capacity to handle a combination of several low-speed and/or medium-speed data transmissions to improve the utilization efficiency of the channel. This concept of combining several lower-speed data transmissions into one higher-speed digital transmission can be realized in practice by using a digital multiplexer and a 50 kbit/s medium-speed data channel unit.

The Time-Division Multiplexer

A typical synchronous time-division multiplexer (TDM) provides for 20–60 input channels of synchronous low-speed and medium-speed digital streams, with an aggregate high-speed output digital bit rate of 48–250 kbit/s. In addition to the original input data, the high-speed digital output stream contains about 2 kbit/s, or typically 3–4% of the output capacity, for "housekeeping" purposes; for example, synchronizing, channel control and framing bits. The high-speed aggregate output is a bit-interleaved, serial, synchronous, isochronous (all bits of equal interval) stream, containing up to 2 kbit/frame with the frame speed being dependent on the number and combination of types of inputs. For use with the satellite SCPC 64 kbit/s system, the TDM would be configured for up to 20 input channels of any combination of 2·4 kbit/s, 4·8 kbit/s, 9·6 kbit/s and 19·2 kbit/s data streams, to give an aggregated output digital rate of 50 kbit/s with 48 kbit/s of data information and 2 kbit/s of housekeeping information.

A basic TDM configuration is shown in Fig. 5, and consists of a clock generator unit, a common transmit unit, a common receive unit, a high-speed interface unit, and one synchronous channel card for each full-duplex line connected. Additionally, it will be provided with the necessary power-supply units, and may also include common alarm units and other control and diagnostic facilities.

Basic Operation of the TDM

Incoming synchronous data is clocked into the appropriate synchronous channel unit and passed through elastic buffers for jitter compensation. Since all the incoming channels are synchronized to a common clock, provided either from the TDM or some other external source, the sequence and timing of data received from the incoming channels is predetermined. The elastic buffers are, therefore, of only a few bits capacity, and compensate for any slight misalignment (jitter) that may result from causes external to the multiplexer, such as varying conditions on the access lines.

The data are passed from the various channel cards to the common transmit unit, in accordance with a channel-data select signal provided directly to the channel card by the common transmit unit. The channel select times are determined by programming in the common transmit unit, and are dependent on the number, type and mix of synchronous channel inputs. The data-frame time-slot generator is driven by the high-speed aggregate transmit clock and the frame is made up of an appropriate number of bits from each incoming channel, in accordance with the relative channel bit rates; for example, in the ratio of 1 : 2 : 4 : 8 for incoming channel rates of 2·4 kbit/s, 4·8 kbit/s, 9·6 kbit/s and 19·2 kbit/s respectively.

Various programmable channel-status control data, including channel alarm and remote loop-back test command, can also be provided to the common transmit unit each time a channel control select signal is sent to a channel card. These control data effectively validate the onward transmission of the channel data for the channels concerned, and some are retained throughout the process for frame-control purposes.

After the interleaving of the data from all the incoming channels with the test and control data, the common transmit unit generates a programmable frame-synchronization word and the channel-data selection sequence (frame) is repeated. The aggregate transmit clock, supplied by the high-speed modem (or by the high-speed interface unit), clocks the aggregate data stream out of the TDM via the high-speed interface unit and the modem to line. Since each frame follows immediately on from the previous frame, and the aggregate data stream in each frame is sequential and continuous, each frame in the transmitted aggregate data stream is preceded and followed by the frame-synchronization word.

At the remote TDM, the high-speed modem receive clock transfers aggregate received data into the high-speed interface unit and synchronizes all clock-generator frequencies. Aggregate data is clocked into the common receive unit which detects the frame-synchronization word. If the TDM is in synchronism, the received channel and control data are distributed to the respective channel cards at synchronous channel data select times, these being determined by programming in the common receive unit identical to the programming in the distant common transmit unit. If the

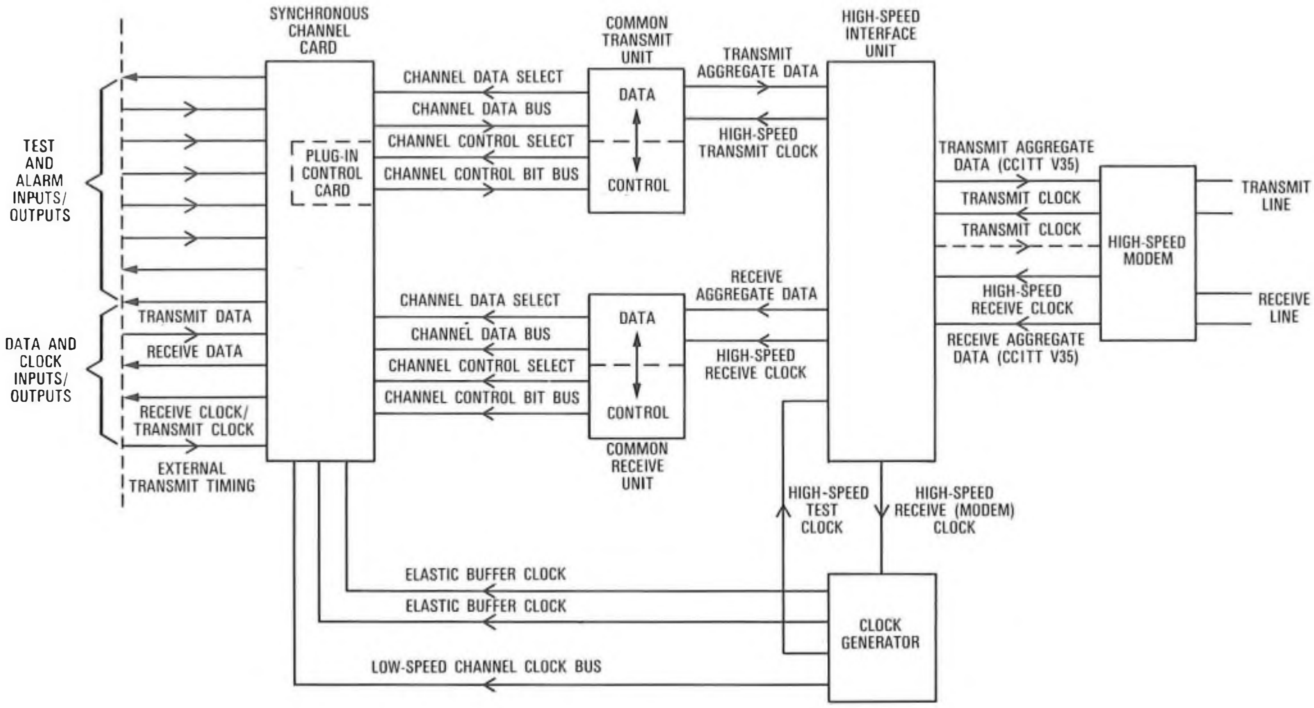


FIG. 5—Simplified block diagram of typical digital multiplexer

TDM is out of synchronism, data is not distributed to the channels, which retain a *space* or *mark* hold depending upon programming.

DIGISAT TESTS

A programme of digital transmission tests, using digital multiplexing techniques, was carried out between the UK and the USA in December 1974. The TDMs were located at the Goonhilly and Etam earth stations. The objects of the tests were

(*a*) to check the performance of a typical digital multiplexer when operated in the satellite environment,

(*b*) to determine the feasibility of multiplexing low-speed synchronous data traffic into composite 50 kbit/s streams for transmission over the SCPC satellite paths,

(*c*) to obtain initial indications of the desirable features of a multiplexer for this type of application, and

(*d*) to develop ideas on how the performance of such a service could be specified.

For ease of reference, and for commercial recognition purposes, the name under which the USA entity will market any service based on this concept is DIGISAT. Fig. 6 is a block diagram showing a typical equipment arrangement for the tests and Fig. 7 is a photograph of the equipment in use at Goonhilly.

Summary of DIGISAT Test Results

SCPC Link

The initial phase of the test was to verify the characteristics of the SCPC transmission and to establish that the 50 kbit/s channel unit was functioning correctly. The results confirmed that, at the normal operating point of carrier-to-noise ratio of 15·5–16 dB with error correction (convolutional encoding) and data scrambling in circuit, the specified random bit-error-rate performance would be exceeded, the actual bit error rate measured being about 1 in 10^9.

TDM Aggregate Receive-Clock Jitter

Small variations in the position of a geographically-stationary satellite cause corresponding changes in the length of the transmission path between any 2 earth stations. It was expected that this might change the phase relationship between the aggregate transmit clock and the aggregate receive clock. The variation in the position of the satellite is the result of a longitudinal drift, on which is superimposed a diurnal variation; it has been predicted that, for some satellites, these variations may result in phase differences of up to 40 bit/day (diurnal) and up to 100 bit during the lifetime of the satellite (drift).[6] It was therefore expected that the jitter would be a composite of 3 factors:

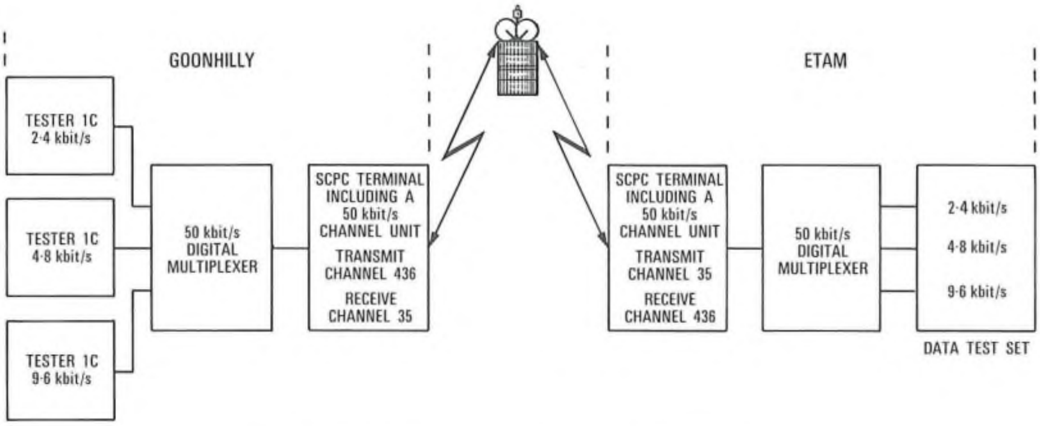
(*a*) the normal phase jitter of a few per cent of element length that would be expected from any regenerated clock,

(*b*) a gradual drift in frequency about a mean (diurnal), and

(*c*) a long-term drift of the mean.

The results of the measurements taken showed a phase jitter of about 10%, which would normally be handled by the multiplexer without difficulty. This indicated that jitter due to drift of the satellite was less than expected; consequently, at no time during the tests, which lasted for periods of several hours at a time, did the multiplexer lose synchronism due to overflow of the aggregate receive buffer. This demonstrated that the receive buffer, which was of 16 bit capacity, was sufficient to contain any phase jitter and drift that was present during the test periods.

Subsequent examination of the published satellite orbital parameters for the time-frame concerned indicated that the maximum rate of change of path delay on the Etam–Goonhilly link would have been 0·15 μs/h due to longitudinal drift, 12 μs/h for orbit inclination and 12 μs/h for eccentricity, with the 2 latter effects exhibiting peak-to-peak changes of about 100 μs in 12 h. Even in the worst case of these 2 effects being additive, the maximum path delay change during the test periods would not have exceeded the 320 μs duration of the 16 bit aggregate receive buffer. However, this favourable situation would not necessarily always exist, and



Notes: Test sets transmit CCITT 511 bit pseudo-random pattern
Transmit and receive clocks derived from multiplexer

FIG. 6—Simplified block diagram of digital multiplexer tests by satellite

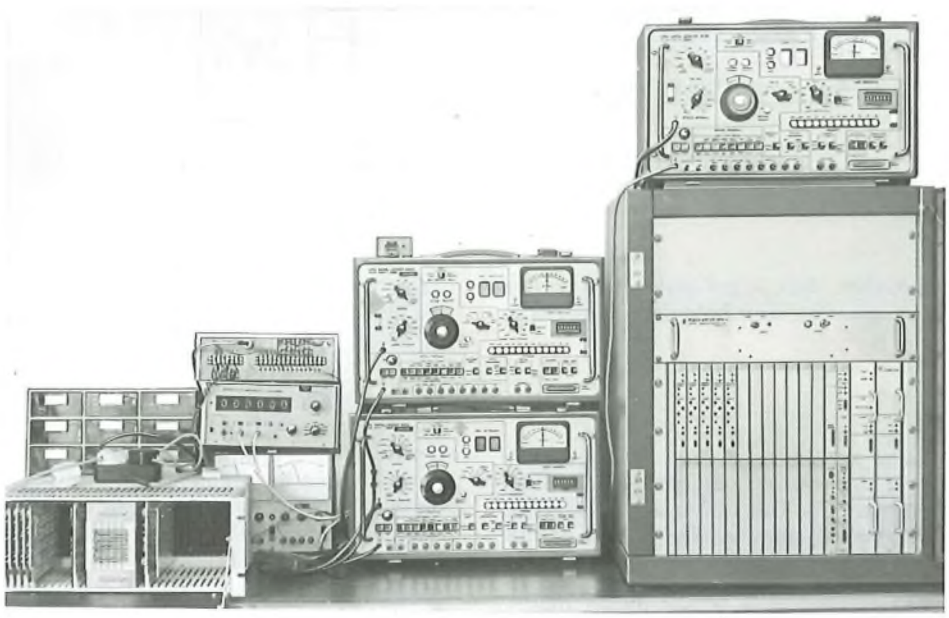


FIG. 7—Multiplexer and Testers 1C in use at Goonhilly

circumstances could arise where the 16 bit receive buffer would be inadequate. Furthermore, in cases where the corresponding earth stations are located relatively close to each other or in a north–south plane (for example, within Europe or the Americas), the satellite drift becomes more significant since the resulting changes in path lengths become additive, rather than tending to cancel out as in the case of an east–west link such as the Goonhilly–Etam link.

Measurement of Control-Function Loop Delay

So that prospective customers can programme their communications processors, they must be given an indication of the time taken by data or control functions to pass through the system to the distant end and back again. This time, or *loop delay* as it is known, has 2 components: the propagation time of the satellite circuit which is sensibly fixed, and the delay through the multiplexers which is variable.

Twenty measurements were taken which indicate propagation times varying between 562–574 ms, with an average loop delay of 568·8 ms. This means that, if the response time of the called terminal is neglected, the maximum time between putting up the *request-to-send* signal and receiving the *receive line signal detect* could be about 574 ms.

Error Performance of Individual Synchronous Multiplexed Channels

The purpose of this test was to determine the error performance of individual low-speed synchronous data channels when using data multiplexers over the SCPC system. The test results were obtained over a total of about 17 h during a period of 5 d. The test results indicated that the element error rate for carrier-to-noise ratios of greater than 14·5 dB was negligible during the time the system was available. An indication of the individual channel performance when operating below threshold, is given by the results for a carrier-to-noise ratio of 12 dB, when the error rates obtained were 1 in 2×10^6 at 2·4 kbit/s and 1 in 3×10^6 at 9·6 kbit/s. However, under normal operating conditions, the carrier-to-noise ratio is approximately 16 dB, and values below this figure, or even as low as 14·5 dB, are likely to be met only under very adverse conditions.

It was noted during the tests that the main interruptions to transmission appeared to be caused by various factors adversely affecting the SCPC system rather than the TDM, and sometimes even by unassociated actions such as equipment activation and change-overs. The errors thus resulting tended to arrive in bursts rather than at random. It was

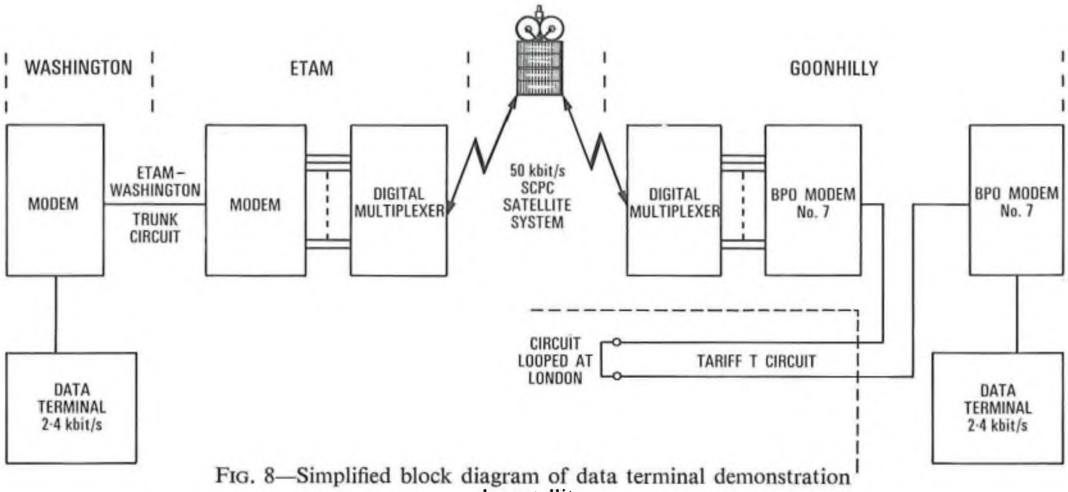


FIG. 8—Simplified block diagram of data terminal demonstration by satellite

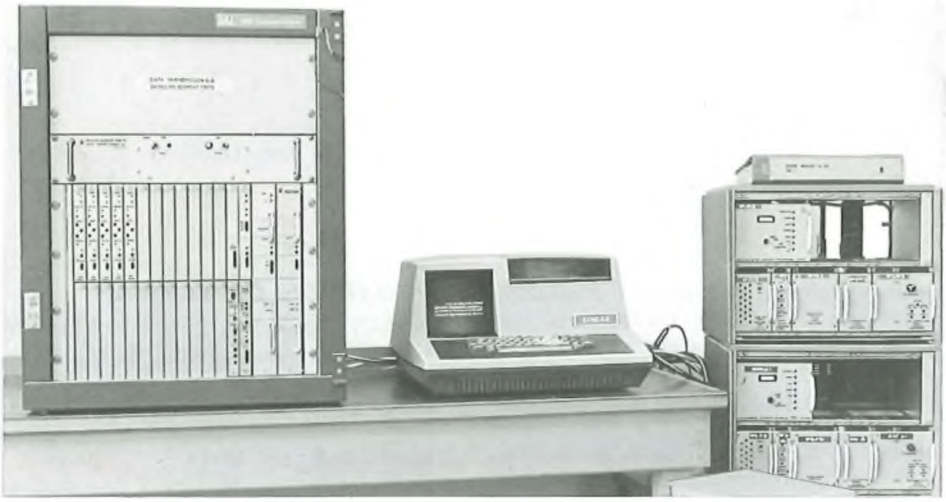


FIG. 9—Multiplexer and data terminal in use at Goonhilly

subsequently considered that it would be more meaningful to express the error performance in terms of *percentage availability* and *percentage error-free seconds*, rather than simply as bit error rate.[7] The results showed that, in approximate terms, the percentage availability ranged from 98·3–100% over 5 different test periods, and the percentage error-free seconds was better than 99·9%. However, in all cases, the tests were not specifically designed with this form of presentation in mind; consequently, the results are not fully conclusive, and further tests must be conducted over longer test periods for more definite results.

Addition of Modem Local Ends to the Multiplexer Link

The purpose of this test was to simulate the circuit performance achievable on a typical customer–customer route. This was simulated by the addition of inland tails to the multiplexer terminals. In the UK, the 2·4 kbit/s port of the multiplexer was extended using Modems No. 7 to London, where it was looped back to Goonhilly. Similarly, in the USA, the corresponding port was extended to the Communications Satellite Corporation (COMSAT) headquarters in Washington, DC. During the course of a 15 min test, using a 511 bit pseudo-random pattern, there were no errors in the Washington–Goonhilly direction.

DIGISAT MARKETING DEMONSTRATION AT COMSAT HEADQUARTERS

The BPO gave full co-operation in the setting-up and conducting of marketing demonstrations at the COMSAT headquarters. This phase of the programme lasted for a period of 5 d (16–20 December 1974), and consisted of 3 demonstrations.

(*a*) *Digital Facsimile Demonstration at 9·6 kbit/s*

Two facsimile transceiver units were located adjacent to each other in the COMSAT Headquarters. These units operated at a data speed of 9·6 kbit/s. For the demonstration, they were interconnected by a terrestrial link to the TDM at Etam and then over a double-hop satellite circuit looped at Goonhilly.

(*b*) *Graphic Display Demonstration at 4·8 kbit/s*

A graphic display unit located at the COMSAT Headquarters was connected to the TDM at Etam by terrestrial facilities, then routed over a double-hop satellite circuit looped through Goonhilly back to Etam and extended by terrestrial facilities to a computer at the COMSAT laboratories in Clarkesburg, Maryland.

(*c*) *Interconnexion of Data Terminals at 2·4 kbit/s*

Two data terminals were used for this demonstration, one being located at Goonhilly and the other at the COMSAT Headquarters. These terminals permit data to be entered using a keyboard into a tape cassette in the unit, where the data are stored until ready for batch transmission to the other terminal. A small cathode-ray tube on the terminal permits monitoring of the data being received or transmitted. A series of questions and answers, pre-written on the cassette

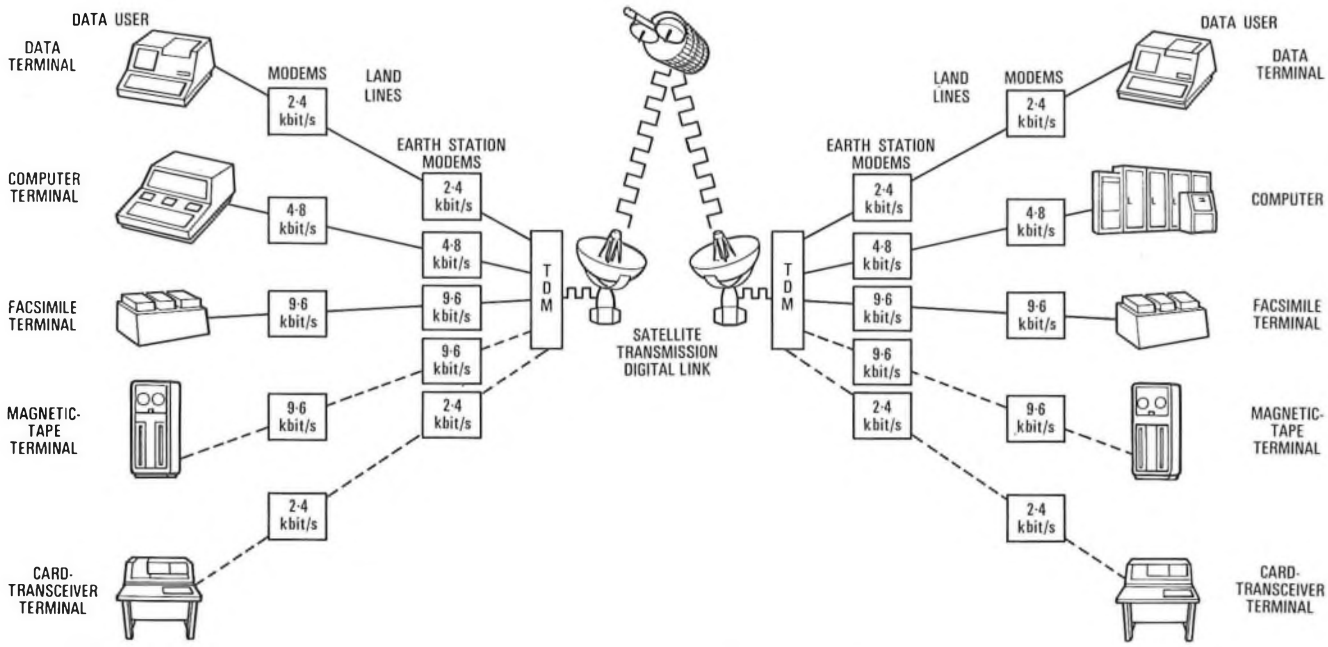


FIG. 10—Typical commercial applications of the DIGISAT system

tapes, was used to demonstrate the data-transfer capability. The terminal located at the COMSAT Headquarters was connected to the TDM at Etam using a terrestrial circuit, while the terminal at Goonhilly was connected to the TDM by a terrestrial circuit looped in London. This demonstration was conducted at a data rate of 2·4 kbit/s. Fig. 8 is a block diagram of the equipment arrangement for this demonstration and Fig. 9 shows the multiplexer and data terminal in use at Goonhilly.

The marketing demonstration was judged to be most successful and fully displayed the potentialities of the DIGISAT system. Fig. 10 is a pictorial diagram depicting typical commercial applications of the DIGISAT system.

GENERAL CONSIDERATIONS OF A TDM FOR THE DIGISAT SYSTEM

With the proposals as they now stand, the DIGISAT system, if offered as a service, contains no redundancy on the high-speed link and there will be only one operational multiplexer for each SCPC circuit. It is, therefore, essential that the multiplexer used should be both reliable and, in the event of a TDM fault, easy to repair or replace. Also, in this type of system, the multiplexer provides a useful point from which to find faults on the associated circuits, but this is possible only if the multiplexer is equipped with the necessary diagnostic and test facilities.

In general terms, therefore, a suitable multiplexer for the DIGISAT service should have a bit-rate capability of 50 kbit/s and be able to support 20 inputs at 2·4 kbit/s or the equivalent in higher-rate multiples of 2·4 kbit/s. It should also have a minimum of one duplex control function and, to meet the possibility of common use on other types of service in the future, it would be useful if it had the capability of increasing both the maximum bit rate and the number of inputs. To facilitate fault finding, the multiplexer should provide various visual indicators for loss of synchronism and equipment malfunctions, and also, where appropriate, local and remote loopback indicators and common alarms.

These are very tentative basic requirements and may be modified or extended when the details for an operational system configuration have been determined.

PROVISION OF SERVICE

No SCPC low-speed data service has been established by the UK so far, but several SCPC voice-frequency-telegraph bearers are currently in operation in the INTELSAT system, including several via Goonhilly earth station.

Medium-Speed Data

Following the testing of the prototype data channel units in December 1973, 6 fully-engineered production models were provided at Goonhilly in the third quarter of 1974, one of which was used for the DIGISAT tests. The first commercial SCPC 50 kbit/s service, established between the UK and the USA, commenced during the first quarter of 1975. By the third quarter of 1975, 4 such circuits had been provided in the INTELSAT system, 2 each in the Atlantic and Pacific regions. The current indications are that further services will be initiated, including some via Goonhilly, in the not too distant future.

DIGISAT Service

The DIGISAT tests and demonstrations, carried out so far, indicate that this is a viable means of passing a number of low-speed and medium-speed synchronous data streams between earth stations using the SCPC system. On the basis of these and further tests carried out by the USA earth-station entity, a DIGISAT service is now being offered between the USA west coast earth station in California and the USA earth station in Hawaii. However, in the UK, additional tests are planned for late-1975–early-1976, to determine the feasibility of providing such a service with the TDM located remotely from the earth station at an international switching centre in London, the connexion to the earth station being made by a 50 kbit/s terrestrial (group link) circuit. These tests will also provide the necessary additional information required to develop more detailed system parameters and service specifications.

OTHER DATA SERVICES UNDER CONSIDERATION

The DIGISAT system facilitates the sharing of one relatively high-speed digital channel by several lower-speed data transmissions, by means of a multiplexing process using bit-interleaving techniques. Inherently, therefore, this system cannot accommodate data transmissions that exceed or even approach the bit rate of the high-speed digital channel. Also, access to the high-speed channel is both predetermined and pre-assigned, irrespective of the actual use of the lower-speed data channels.

An alternative method by which several low-speed or medium-speed and/or low-utilization data channels can share one high-speed digital channel or highway, is the data packet-switching technique. This concept is already being employed nationally in the UK, using terrestrial transmission facilities, in the Experimental Packet-Switched Service.[8] A similar terrestrial system, commissioned in 1969 by the Advanced Research Projects Agency of the United States Department of Defence, is currently operational in the USA.[9]

SCPC DATA PACKET-SWITCHING TEST BY SATELLITE

The UK earth station at Goonhilly is currently participating in a 2-year experimental test programme with the appropriate US entities, to determine the feasibility of extending the packet-switching concept internationally over the satellite system. These tests, which commenced in September 1975, involve the use of one multi-destination 64 kbit/s SCPC satellite highway, with access from several earth stations (2 or more) on a time-shared basis, over which packets are transmitted by all of the participating earth stations. Control of access to the single 1-way satellite channel by the participating earth stations can range from being purely random to fully programmed. Each earth station in the network receives all packets transmitted from the satellite, and extracts those packets addressed to destinations served by that earth station. Processing at the earth station involves interfacing the satellite formats to the terrestrial formats and this function, together with the channel-access control, is accomplished by a satellite interface message processor which is located at the earth stations. A full description of the experimental satellite packet-switched system is beyond the scope of this article, but this brief outline is included to indicate the further possible use of the satellite SCPC system for digital transmission.

CONCLUSION

International data transmission has, in the past, generally been limited to the lower-speed services, basically because of the absence of an economically viable transmission facility for the medium-speed and higher-speed data rates. Already, through the satellite SCPC facility, the provision of an efficient medium-speed international digital service up to 56 kbit/s is a reality. Furthermore, transmission of the lower-speed services in the 1·2–19·2 kbit/s range can be efficiently accommodated by the satellite system using the techniques discussed in this article. Undoubtedly, the lack of suitable transmission facilities has conditioned the demand for international data services in the past and this, together with the present rapid growth in the use of computers and other digitally-based communications systems, makes it difficult to forecast possible future demand. However, various studies and forecasts have been made, some recently, which consider both future international data requirements that may be carried specifically by satellite[10] and the total international data requirements for given regions of the world.[11] The indications from these studies are that international data traffic requirements will certainly grow in the future, probably at rates ranging from 15–60% per annum. One reason for the seemingly wide range of these forecast growth rates is the difficulty of determining whether forecasts should be expressed in terms of equivalant circuits of a specific digital rate or purely in terms of bit rate. Nevertheless, it is apparent that there is a future demand for such services, and that the satellite system has a significant part to play in providing the required international transmission facilities.

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The Development of Dual-Cable Systems for New Towns

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This article brings up to date the British Post Office activities in providing cable television and integrated local services in new towns. Subsequent articles will describe, in more detail, the systems and the equipment used.

INTRODUCTION

This article brings up to date the published articles on British Post Office (BPO) involvement in cable television and integrated local services,[1] and provides the background information for other more detailed articles on the subject in this,[2] and later, issues of the *Journal.*

In the early 1960s, BPO engineers looking into the future envisaged, perhaps 30 years ahead, a single comprehensive local network providing homes and businesses with all their telecommunication facilities, including entertainment television and sound broadcasts. They imagined only one cable, probably a coaxial cable, feeding into each home.

It was recognized that probably the greatest difficulty in realizing such a system was in moving from the current situation to this ultimate system, while maintaining all existing services. As a first step, it was decided in 1966 to provide a comprehensive communications system in the new town of Washington, County Durham.[3] In the residential areas, it was decided to install a community-antenna-television (CATV) system on a coaxial-cable network, and a normal balanced-pair local telephone cable network, both wholly underground and using the same underground plant, such as ducts, jointing chambers and access to houses. If the necessary device and system technology had been available then, it is possible that a single-cable network would have been installed for all purposes. Nevertheless, the frequency spectrum used for the cable-television system was chosen so that, ultimately, the cables and equipment could form a major part of a comprehensive single-cable system. One of the declared objects of this first installation was to gain practical experience of broadband systems in the local network, as regards planning, installation, commissioning, maintenance and administration, using as far as possible the normal local telephone staff and organization.

Since that time, the involvement of the BPO in such schemes and the CATV facilities provided have gradually increased; there are now dual-cable schemes in the new towns of Washington, Irvine, Craigavon and Milton Keynes, and in a few smaller places. The total number of CATV customers in these 4 towns is only 20 000, but the planned rate of building will give 30 000 by 1980, 70 000 by 1990 and, ultimately, 160 000.

The BPO has been prepared to provide such dual-cable schemes in any large new housing development at the request of the local town authority concerned. The legal position of the BPO in this respect is worth noting. The Post Office Act 1969 continued the General Post Office monopoly for all telecommunication facilities between different parties, except those covered by broadcasting authorities' charters. The BPO provides most of such services itself on a countrywide basis, but it licenses other commercial organizations to provide CATV in specific areas. In a new town, therefore, although the telephone service is always provided by the BPO, the CATV service could be provided by one of the CATV companies. The BPO has said that in new towns it will, if the local authority wishes, tender competitively with other CATV companies and not withhold a licence from another successful tenderer. The contract to provide the CATV service in Milton Keynes was obtained by the BPO on this basis. A further legal point to be noted is that all CATV systems in the UK, including the BPO ones, are controlled by the Department of Industry (DOI), in respect of minimum technical standards and the programmes that can be distributed; at present, only those receivable off-air are permitted.

The dual-cable type local-distribution system was started as an interim solution to the problem of providing a comprehensive local communication network at a time when the potential market for visual communication was considered very large. In this article, it is suggested that the dual-cable scheme might be a suitable long-term solution, when account is taken of revised views of the probable demand for visual telephone services and the ever-increasing penetration of the balanced-pair cable network.

DESCRIPTION OF NEW TOWN LOCAL NETWORKS

General

In new towns, no overhead plant is permitted except for essential items approved by the town planning authority; for example, a CATV aerial mast. There is also an attempt to co-ordinate the works of all the various authorities who place plant underground, particularly in the final connexions to houses, where most of the money is spent.

The BPO, therefore, provides cable duct routes to all parts of the new town according to its normal standards, but the building contractor provides, for the BPO, the final plastics ducts into each building, often separately to each residence, and internal cable ways. The building contractor also fits, into walls and porches, the boxes required for housing such items as amplifiers and splitters.

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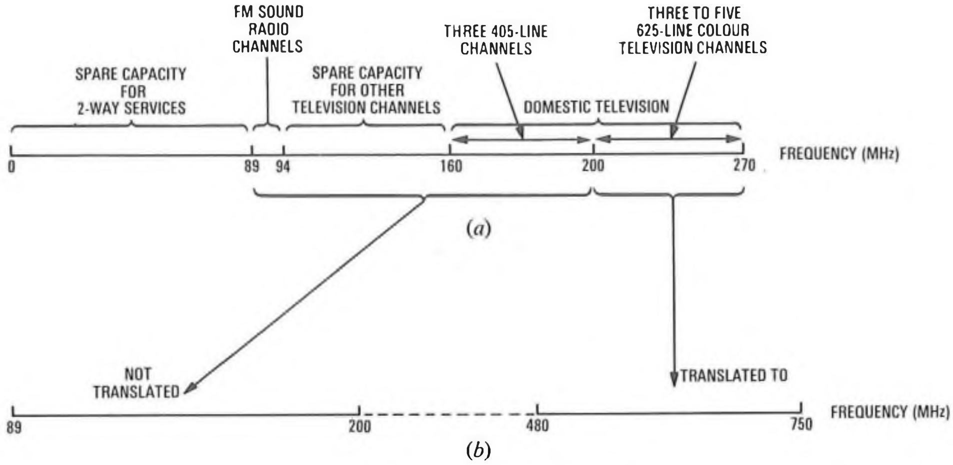

FIG. 1—Frequency spectra

The Telephone Network

The telephone network is a normal one, consisting of fairly large unit-twin cables to flexibility points in street cabinets and smaller pair cables to every tenancy, usually one pair per tenancy.

The CATV Network

The type of CATV network described is that of Milton Keynes, since this is becoming the standard to which the earlier new town systems will ultimately be converted.

In its final form, in the completed town of about 250 000 inhabitants, the system will consist of

(*a*) a master aerial and head-end equipment housed near the centre of the city, the head-end equipment bringing all channels to frequencies shown in Fig. 1 (*a*),

(*b*) cable links up to about 12 km long between the head-end and main distribution centres,

(*c*) main distribution centres,

(*d*) main distribution highways up to 7 km long, using the spectrum shown in Fig. 1 (*a*),

(*e*) frequency translators in street cabinets to change the spectrum from that of Fig. 1 (*a*) to that shown in Fig. 1 (*b*), a spectrum suitable for all receivers in general use, and

(*f*) final distribution to houses.

Since, as a matter of policy, the BPO does not provide television receivers, the signals for final distribution to houses must be suitable for all commonly available domestic receivers. The signals provided are therefore

(*a*) up to 5 stereo sound channels in the frequency range 88–94 MHz,

(*b*) two or three 405-line monochrome television channels in the band 160–200 MHz, and

(*c*) three to five 625-line colour television channels in the band 480–750 MHz.

The number of channels provided depends on the number of off-air channels available in the locality, since these are all that are, at present, permitted by the DOI.

Despite the apparently generous bandwidths available for the television channels, it can be quite difficult to find suitable channel allocations for each new town. The restrictions are that

(*a*) since receiver screening is generally poor, the channels in use locally for off-air reception cannot be used on the system because of the possibility of ghost signals,

(*b*) receiver selectivity does not permit adjacent channels to be used, and

(*c*) channels 40 MHz apart cannot be used owing to receiver local-oscillator interaction.

The continuing requirement to provide 405-line monochrome very-high-frequency (VHF) channels is a further complication. This was the original television standard set in 1936 and used for all off-air transmissions until 1964. According to a recent report,[4] such transmissions are expected to continue into the 1980s.

Unfortunately, new towns do not develop in the way most suited to the telecommunications engineer. Most of the towns in which the BPO is providing CATV service have started as isolated groups of houses, often near the periphery of the new town area. It has, therefore, been necessary to set up a number of temporary head-ends isolated from each other. In Milton Keynes in January 1976, over 3 years after the service started, there are about 6700 customers. The master aerial and head-end equipment and the cable links to the main distribution centres do not exist; in the main distribution centre positions are 5 temporary head-ends serving about a thousand customers each.

The plant used is in many respects typical CATV plant, and will be described in other articles; so a summary is given here of only the more important points.

The cable used is semi-airspaced, of 3 different sizes as shown in Table 1. The 2 larger sizes are used underground, and have a moisture barrier of aluminium foil between the outer conductor and polyethylene sheath. The smallest size is used for internal work with a PVC sheath.

TABLE 1

Cable Sizes Used

Inner-Conductor Diameter (mm)	Outer-Conductor Internal Diameter (mm)	Overall Diameter (mm)	Loss at 200 MHz (dB/km)
2·6	11·2	16·5	38
1·7	7·3	12·5	57
1·3	5·6	9·0	73

The VHF amplifiers for the main distribution highways are housed underground in standard footway boxes in such a way as to minimize the risk of their complete immersion in water. Typical gain is 20 dB at a frequency of 270 MHz, the maximum number normally permitted in tandem being 14.

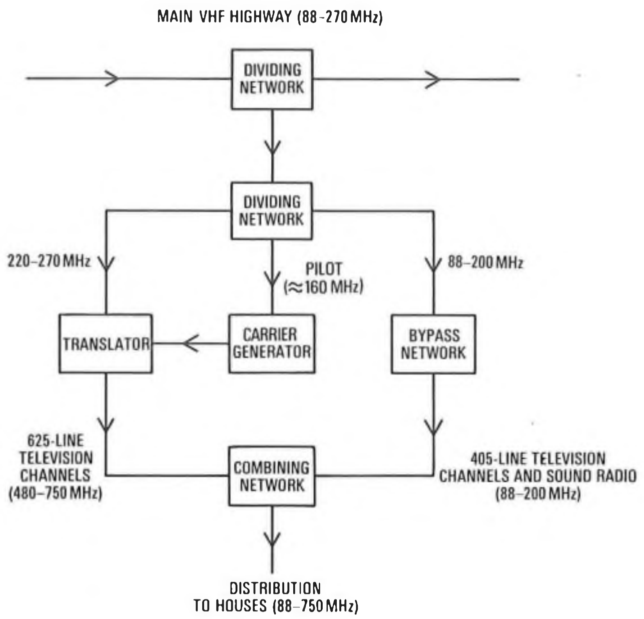

FIG. 2—Simplified block diagram of translation arrangements for distribution to houses

Block or channelized translators are used for the frequency translators in cabinets. The channelized translator for new work is described elsewhere in this issue of the *Journal*.[2] It caters for three, four or five 625-line television channels but could provide more; 405-line channels and VHF stereo sound channels are bypassed (see Fig. 2). The use of such translators is an alternative to the use of "set-top" convertors for each customer. At present, each translator serves about 200 customers and can, therefore, be designed to have a significantly better performance than can usually be afforded for set-top convertors. The optimum placing of the translator, between the limits of one for all customers (as part of the head-end) and one for each customer (a set-top convertor), varies with the changing relative costs and attainable performance of cable and amplifiers, but the need for firm planning rules necessitates a compromise solution that is rarely changed.

For final distribution into the houses, ultra-high frequency (UHF) amplifiers covering the band 80–750 MHz are required, the number in tandem being limited to 3.

Line amplifiers, both VHF and UHF, are fed with power over the coaxial cable, either from the head-end or from one of the cabinets housing the translators. A constant direct-voltage supply is connected between inner and outer conductors, the inner conductor being positive. When necessary, the amplifiers incorporate power regulators, so that the tree-type network can be added to without any adjustment to the power-feeding arrangements.

The planning of allowable signal impairments in the system is still evolving, but, generally, there is the usual aim to limit impairments in the relatively few main cable links to the minimum, to allow maximum impairment in the many more numerous distribution feeds.

Quality of Signals Delivered to Customers

In general, the BPO system is designed to ensure that the technical requirements of the DOI are met under the most adverse circumstances. At present, the BPO, the DOI and the UK CATV industry are co-operating through the British Standards Institution to set new national standards that will conform to international standards to be set by the International Electrotechnical Commission. Present BPO systems are designed to meet the following limits at customer's outlets.

Signal Level

Television channels: maximum r.m.s. carrier level 1–3 mV.
Sound channels: maximum r.m.s. carrier level 0·5–5 mV.

Frequency Response

The spread over any television channel must not exceed 4 dB and over any sound channel 1 dB.

Noise

Maximum r.m.s.-carrier-to-unweighted-r.m.s.-noise ratio must not be less than 45 dB.

Intermodulation

Products resulting in vision crosstalk must be at least 52 dB below the signal level.

Echoes

The signal-to-echo ratio must not be less than 28 dB for echoes with a delay of greater than 1 μs.

ADDITIONAL SERVICES ALLOWED FOR IN PLANNING THE SYSTEM

In the frequency spectrum for the VHF main distribution highways of the system, frequencies up to 80 MHz were allocated for 2-way services, many of which it was expected would be digital. The frequency band 100–160 MHz was reserved for non-entertainment television channels. Except in one case, where an entertainment channel has had to be placed at 145 MHz to cater for English and Welsh language transmissions, no use is yet made of these bands. Some television services have been provided in a group of educational establishments in Milton Keynes, but the particular requirements are such that there is no advantage in using the CATV system, except for outwards (downstream) distribution of programmes at frequencies that can be received by standard commercial colour receivers.

FUTURE POSSIBILITIES

In considering the future of local distribution networks and the possibilities for additional services on coaxial CATV and telephone cable networks, it is useful to bear in mind the following 2 points.

(*a*) It is the business customer rather than the residential customer who is likely to want, and be willing to pay for, 2-way visual services, high-speed data, and complex visual information-retrieval systems.

(*b*) The residential customers, more of whom will have telephones than CATV, are likely to want services that can be provided economically on the telephone cable network by slow-speed signalling (data transmission) systems on their telephone pairs; for example, fire, intruder and assistance alarms, remote meter reading, remote control of domestic appliances, and response to television advertising.

It could be, therefore, that dual-cable systems similar to that described could satisfy all residential and most business requirements for some time to come. The tree-type 1-way CATV network is appropriate for television services when each channel is viewed by large numbers of people; for example, entertainment and educational television, and commonly required visual information services. The local telephone cable network is appropriate for individual services, particularly those requiring a measure of secrecy or security, and those requiring a similar but narrow bandwidth in each direction. The switched telephone service itself can already provide medium-speed data and slow facsimile facilities.

Using frequencies above the audio range, additional narrow-band systems can provide the slow-speed signalling systems mentioned above.

For some services, the 2 cable systems could be used together. An example would be the provision of individually demanded visual information, the demand being made on the slow-speed data channel working on the telephone pair, and the visual information being provided on the CATV system.

The requirement for services needing a wider bandwidth than normal telephone pairs can readily provide (for example, high-speed data, high-definition video telephones, television circuits for national and local programme sources, and police, traffic and industrial surveillance) is likely to be confined in the short and medium term to relatively few localities. Rather than make any provision for them over a wide area, it may well be better to provide special cables as required.

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Translation Equipment for British Post Office Local-Line Wideband Systems

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The introduction of television receivers, capable of receiving only ultra-high-frequency (UHF) transmissions, made it necessary to translate the very-high-frequency (VHF) signals on a cable-television system to UHF. The Equipment Translator LWB 2A, which is the subject of this article, can translate up to 7 VHF channels to UHF. The article begins with the constraints on translator design and follows with a description of the equipment.

INTRODUCTION

The very-high-frequency (VHF)/ultra-high-frequency (UHF) hybrid cable-television system which the British Post Office (BPO) is installing has been described in a previous article.[1]

In this system, an important part is played by the equipment that translates the 625-line television signals from VHF to UHF, and bypasses the frequency-modulated (FM) sound and 405-line television signals. The equipment is situated at a point in the network where it can, typically, serve 200 customers, and is readily accessible for maintenance.

No suitable translation equipment was commercially available and so the BPO decided to design and develop its own, described below, and shown in Fig. 1 mounted in a cross-connexion cabinet at Milton Keynes.

OPERATIONAL REQUIREMENTS

The operational requirements of the translator are listed below.

(*a*) It must be capable of translating up to seven 625-line

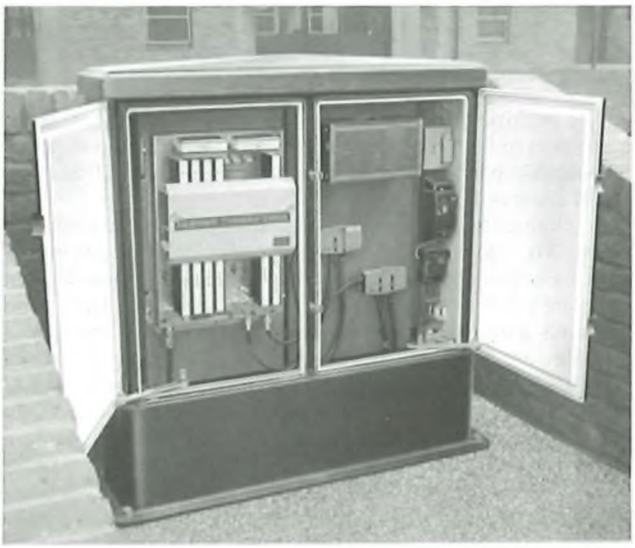

Fig. 1—A translator mounted in a cross-connexion cabinet at Milton Keynes

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television channels in the frequency range 40–300 MHz to the UHF bands IV and V (470–860 MHz).

(*b*) It must provide an untranslated path for 405-line television channels and band II FM sound services.

(*c*) The nominal input and output impedances must be 75 Ω and have return losses in excess of 10 dB.

(*d*) It must be capable of working with an input level of not less than +10 dB relative to 1 mV (dBmV), and delivering 2 outputs in the UHF bands of not less than +40 dBmV.

(*e*) The interchannel cross-modulation ratio for translated channels must be greater than 90 dB.

(*f*) The International Electrotechnical Commission (IEC) 3-signal intermodulation ratio[2] for any translated channel must be greater than 54 dB.

(*g*) The noise figure must be less than 15 dB.

(*h*) The required performance must be attained over an ambient temperature range of −10 to +60°C.

(*i*) It must have facilities for power feeding line amplifiers in both the forward and reverse directions.

(*j*) It must be easy to install and maintain inside a telephone cross-connexion cabinet.

DESIGN CONSIDERATIONS

There are 2 ways of translating a group of channels from the VHF band to UHF. One way is to translate all channels with one mixer, known as a *block* translator; the other way is to translate each channel separately with its own mixer, termed a *channelized* translator.

A block translator is cheap and easy to build; television set-top translators are often of this type. However, there are a number of disadvantages to this type of translator: translation of all channels in one mixer gives rise to problems with interchannel cross-modulation; the wide bandwidth translated (40–300 MHz) means that many intermodulation products fall inside the output bandwidth and cannot, therefore, be removed by filtering; all channels are translated with the same local-oscillator frequency.

A channelized translator is, by comparison, more complicated and expensive, as it requires narrow-band filtering to separate the channels before translation. The advantages of channelized translators are as follows:

(*a*) interchannel cross-modulation can be reduced to an arbitrarily low level,

(*b*) the intermodulation products can be filtered out from the output signal,

(*c*) different local-oscillator frequencies can be used to translate each channel or group of channels, thereby allowing greater flexibility in system frequency planning, and

(*d*) a higher output level is available from narrow-band channel amplifiers than from wideband multichannel amplifiers.

The performance of a channelized translator enables many customers to be served from its output. Thus, its cost is not an insuperable barrier to its use, and the Equipment Translator LWB 2A is of this type.

A channelized translator has many frequency-selective parts. To allow for variations in channel allocations on systems in different geographical areas, all frequency-selective parts are made as plug-in modules. This enables all translators to be made up from a common chassis, into which pre-aligned modules are plugged for the channel allocations concerned (see Fig. 2). Only those channels that are immediately required need to be provided; other channels can be provided as the need arises, without interrupting service. Field maintenance is made easier by this approach as a faulty module can be quickly replaced, thereby restoring service; the faulty module can then be sent off to a repair centre. The local-oscillator signals for translation are obtained by doubling and tripling the frequency of a pilot signal. This method has advantages over using free-running oscillators; one accurate oscillator,

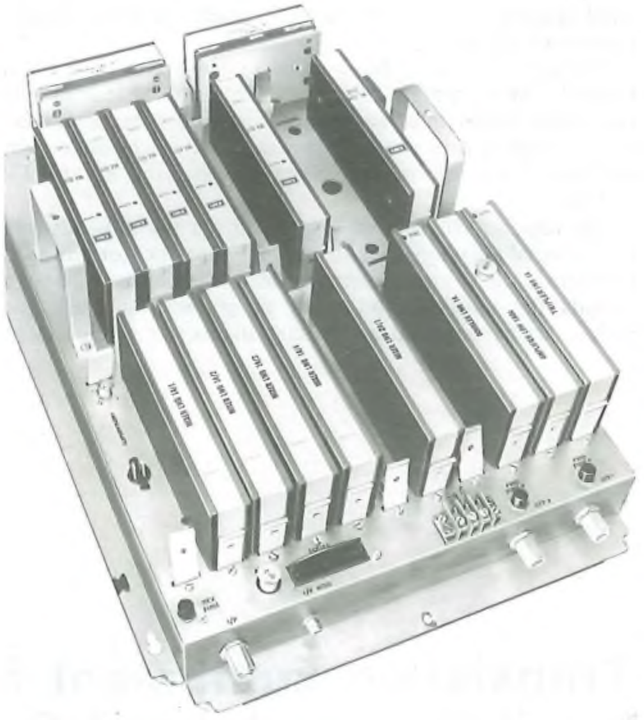


FIG. 2—Modules plugged into main chassis of translator

situated at the head-end of the system, ensures that the frequencies at all the translators in a system are accurate. If a crystal oscillator were to be used in each translator, it would be necessary to use high-order multiplying circuits to obtain the required frequencies. Such a process gives rise to additional frequencies that are difficult to suppress and are troublesome on a system.

FREQUENCY ALLOCATIONS FOR THE CHANNELIZED FREQUENCY TRANSLATOR

The channel frequencies are chosen according to the geographical area in which the translator is used such that the UHF channels at the output of the translator fulfil the following 2 main requirements.

(*a*) They shall not coincide with strong off-air signals in the area. If they do, interference is likely to occur in the form of ghost pictures, because the television receivers on the system have limited immunity to off-air signals and there is also the possibility of pick-up in leads.

(*b*) No use shall be made of a channel that is 5 channels above another being used. This is necessary to avoid interference on a television receiver tuned to the higher channel from the local oscillator of a receiver tuned to the lower channel. Local-oscillator frequencies are present at the input of television receivers and thus exist as unwanted signals on a system.

The description given in this article is based on the frequency plan that is, at present, most extensively used. However, other frequency plans have been considered and it is believed that most requirements can be met. These other frequency plans depend upon the flexibility inherent in making changes to the positions of the 625-line television channels in the VHF input spectrum, and on slightly changing the pilot frequency.

DESCRIPTION OF THE TRANSLATOR

A block diagram of the translator is shown in Fig. 3. The main functions of the equipment are described below in con-

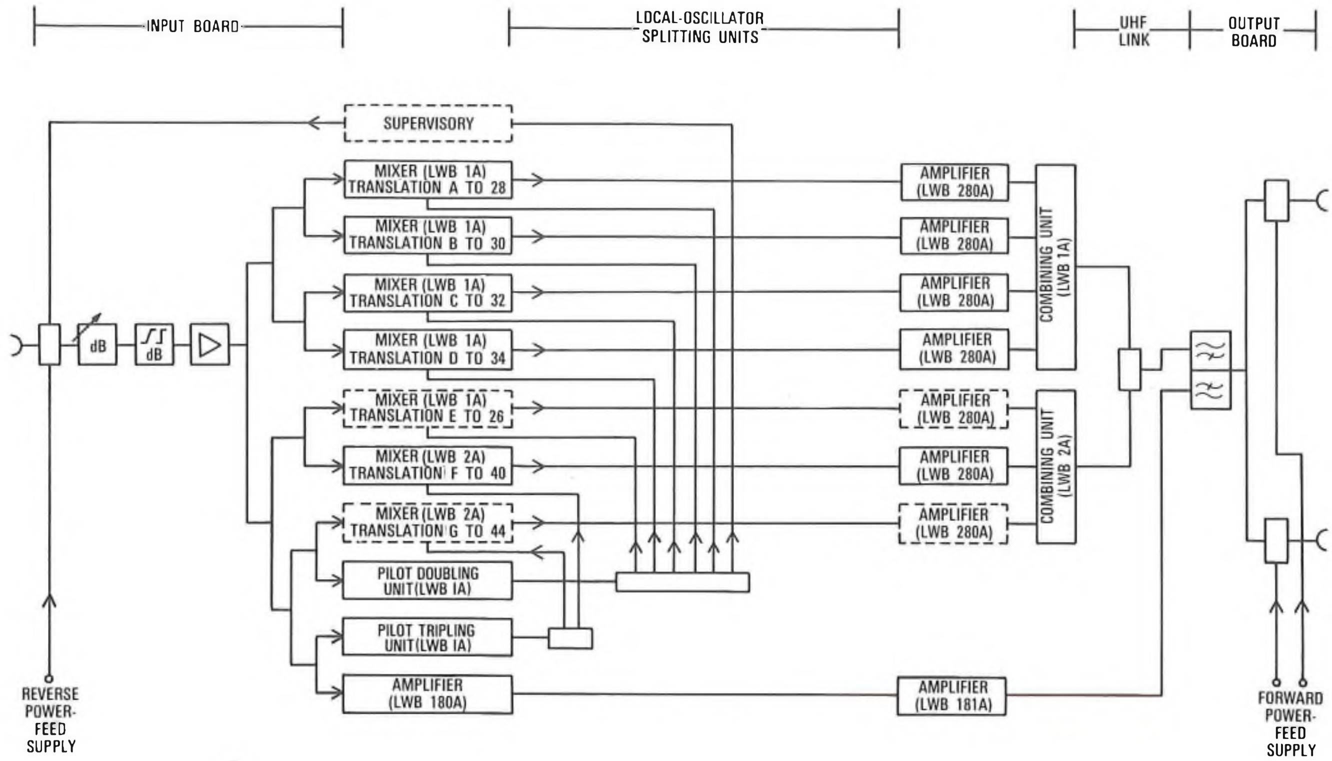


FIG. 3—Block diagram of translator

junction with the frequency allocation plan, shown in Fig. 4, which is, at present, in most extensive use. The translator input is fed from the preceding VHF main highway which, in many cases, has amplifiers that are dependent upon the translator for their d.c. power. For this reason, a d.c. reverse power-feeding connexion appears across the radio-frequency (RF) signal input of the equipment. From the input, the RF signals in the frequency range 80–270 MHz (Fig. 4) are passed through an attenuator and equalizer, enabling variations of incoming signal level to be absorbed and the preceding cable-section response to be equalized. The signals are then fed to a 10-way transformer splitting network via a 15 dB gain wideband amplifier. Without this amplifier, the translator input noise figure would be unacceptably worsened. The outputs of the splitting network are connected to the inputs of the mixers, and frequency multiplying and VHF bypass modules. These units are thus presented with all the signals on the VHF highway.

The 159·625 MHz pilot carrier is selected by the frequency-doubling module (Pilot Doubler LWB 1A), which produces

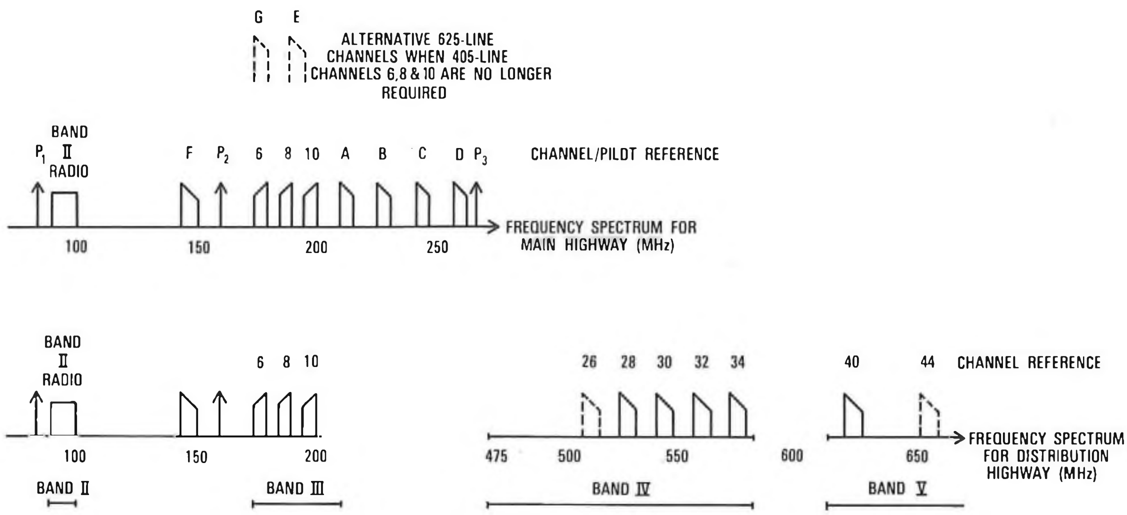


FIG. 4—Frequency plan

a high-level signal at a frequency of 319·25 MHz. This signal is distributed by a resistive splitting network to the local-oscillator inputs of 5 mixers LWB 1A, and to the supervisory module. The frequency-tripling module (Pilot Tripler LWB 1A) also selects the 159·625 MHz pilot carrier, and develops at its output a 478·875 MHz signal which is fed to the local-oscillator inputs of the 2 mixers LWB 2A.

Fig. 4 shows that the VHF 625-line channels A, B, C and D require, respectively, translation to channels 28, 30, 32 and 34 in broadcast band IV. To meet this requirement, 4 mixers LWB 1A are used, each selecting the appropriate channel. The 319·25 MHz signal at the local-oscillator inputs of these mixers produces the desired translation.

Channel F is translated to channel 40 in broadcast band V using a mixer LWB 2A which selects the wanted input channel in the normal way, but is designed to accept the 478·875 MHz local-oscillator signal.

The VHF 625-line channels E and G can be introduced on the system only when the decision is taken to remove the 405-line channels 6, 8 and 10. When this decision is taken, translation of channels E and G to channels 26 and 44 will be obtained using mixers LWB 1A and 2A respectively.

The output of each mixer is fed to a channelized amplifier which has a gain of 40 dB. The amplified UHF channels are then combined using 2 narrow-band filter combining units, which provide outputs of 3 and 4 channels. These outputs are again combined, forming a common UHF path carrying up to 7 translated channels.

The FM sound services in broadcast band II and the 405-line television channels in band III are fed via the VHF bypass network without translation. The VHF bypass network consists of an amplifier LWB 180A which selects and amplifies signals on the VHF highway below 200 MHz, and an amplifier LWB 181A which provides a further 24 dB of gain.

The VHF bypass path is combined with the common UHF path using a diplexer. A final splitting network provides 2 translator outputs, each with its own d.c. forward power-feeding connexions. The RF signal level at each output is +40 dBmV.

Fig. 4 shows that the channels are assembled in a manner suitable for forward transmission over the distribution highway and subsequent reception by standard broadcast receivers.

Mixer Modules

A mixer module (Fig. 5) selects a single VHF 625-line television channel and translates it to a standard UHF broadcast channel. Mixer LWB 1A accepts a local-oscillator signal of 319·25 MHz which restricts output channels to band IV. Applying the tripled pilot (478·875 MHz) to a Mixer LWB 2A permits translation to band V, in addition to band IV. A block diagram of the mixer module is shown in Fig. 6.

The band-pass filter at the input of each mixer selects the appropriate channel required for translation. Its selectivity must be sufficient to reduce interchannel cross-modulation to a low order in subsequent stages. These stages have an inter-channel cross-modulation figure of 50 dB, which must be improved by a further 40 dB to meet operational requirement (*e*). This 40 dB improvement can be achieved if the input filter reduces the level of the adjacent-channel signals by 20 dB. The 3-section bandpass filter used provides more adjacent-channel rejection than is required, but a 2-section filter would have been inadequate.

The filter is of the coupled-resonator type, and the initial design was obtained using the BPO computer programme CUPRES. The programme assumes ideal components and, at these frequencies, the computed values are extremely small and of a similar order to the stray values. Thus, for consistent performance, very-low-value stable components were required, together with a printed-circuit layout that minimized the effect of stray components. The circuit and the printed-circuit-board layout are shown in Fig. 7 (*a*) and (*b*). The single-turn inductors have been printed on the board to obtain repeatable results, and any parallel stray capacitance is absorbed by the tuning capacitors. The inter-section coupling-capacitor values obtained by experiment were found to be higher than the computed values. This was due to stray inductive coupling between the tuning coils. Stray capacitance also exists across the coupling capacitors, and its value is dependent on the dielectric constant of the printed-circuit-board material. This parameter is not tightly controlled in low-cost printed-circuit boards, with the result that the coupling, and thus the filter bandwidth, can vary. To overcome this problem, an earthed strip was printed between the coupling-capacitor leads, and this is arrowed on Fig. 7 (*b*). The strip reduces the stray coupling capacitance at the expense of increasing the capacitance to earth, but the latter is in parallel with the tuning capacitors and is absorbed. The changes in filter performance due to component tolerance and temperature effects were evaluated using a circuit-analysis computer programme. The results enabled components to be chosen so that, under worst-case conditions, the performance of the filter was not seriously degraded.

When the wanted input channel has been selected and amplified, it is applied to the double-balanced diode mixer. This type of mixer was chosen because a largely resistive impedance is presented at all ports. This factor immensely

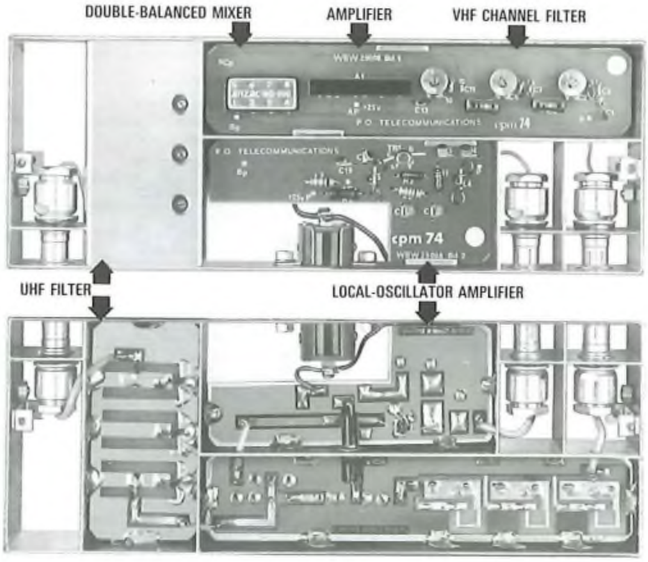


FIG. 5—Internal construction of mixer module

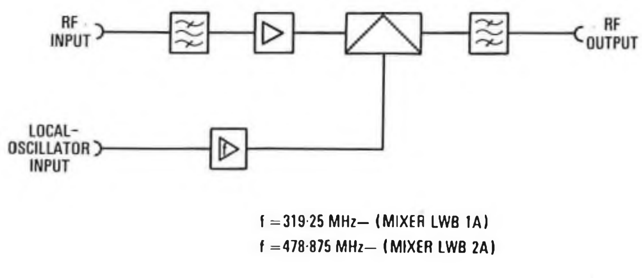
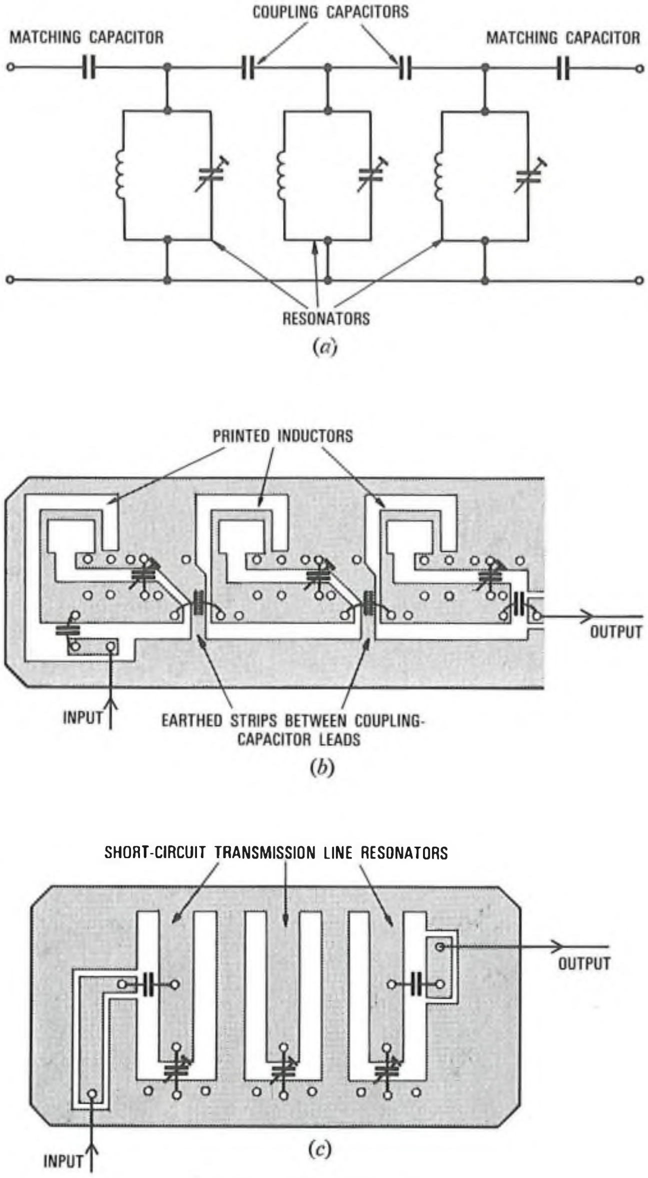


FIG. 6—Block diagram of mixer module



(*a*) General circuit diagram
(*b*) VHF channel filter layout
(*c*) UHF channel filter layout

FIG. 7—Coupled-resonator type filter

simplifies the problem of matching filters and amplifiers to the device. The mixer also offers good cross-modulation performance and suppression of both the input and local-oscillator signals.

When development first started, a low-cost transistor mixer was tried because such a design offered conversion gain and a low oscillator-level requirement. However, the input and output impedances of a transistor are not only different, but also vary with frequency; this meant that filters had to be designed both for different channels and to work between the different impedances. Because a transistor is to some extent transparent, adjustment to one filter affects others also connected to the device, and this makes alignment very difficult. Inexpensive transistors with useful gain at UHF were, at that time, not highly stable and, with certain combinations of source and load impedances, would oscillate without external feedback. These fundamental problems led to the adoption of the passive diode mixer with its more predictable performance.

It is essential that spurious modulated signals are prevented from appearing at the local-oscillator port of the diode mixer, or cross-modulation with the wanted output channel will

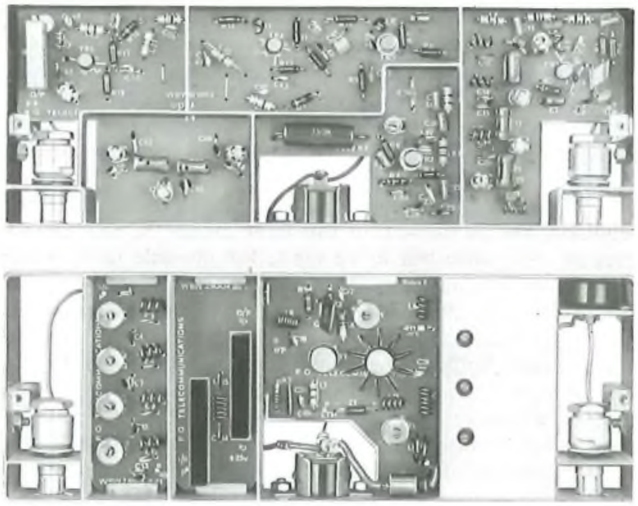


FIG. 8—Frequency-doubling (top) and tripling (bottom) units

occur. An amplifier is, therefore, included in the local-oscillator input of each mixer to isolate the units from the common local-oscillator splitting-unit circuitry. Separate designs were developed to amplify the doubled and tripled pilot carriers. Both amplifiers use a single tuned transistor stage and have a gain of 10 dB, which permits a corresponding reduction to be made in the gain of the frequency multipliers.

When the appropriate local-oscillator signal, f_{LO}, and the selected input channel, f_I, are both applied to the diode mixer, the wanted second-order intermodulation product $(f_I + f_{LO})$ appears at the output. Unfortunately, numerous other second and higher-order products are also produced, from which the wanted product must be separated. This is achieved using a 3-section band-pass filter, with the same circuit configuration as the VHF channel filter (Fig. 7(*a*)). Although the circuits are the same, the realization of the UHF filter is quite different from its VHF counterpart, as can be seen in Fig. 7(*c*). In the VHF filter, earthed strips were used to reduce the stray capacitance across the primary coupling components, but in the UHF filter, this stray capacitance becomes the primary coupling element and its value is optimized by controlling the width of the earthed line. The circuit resonators are short-circuit printed transmission lines, which are tuned using trimming capacitors. The board (substrate) which carries the printed lines must be suspended between ground planes, and so it was soldered into a trough-section box, with the copper-lined mixer-unit lid completing the earth-plane circuit. The geometry and internal surface finish of the box are important parameters in the overall design. This suspended-substrate form of construction provides a low-cost filter which has repeatable performance and requires only simple tuning adjustments.

Both types of mixer module have an overall bandwidth of 10 MHz. A gain of 5 dB in the passband is obtained when the applied local-oscillator level is +44 dBmV. The units have a noise figure of 11 dB and an IEC 3-signal intermodulation ratio of 92 dB at the normal output level of +18 dBmV.

Frequency-Multiplying Modules

The frequency-multiplying modules, one doubling and one tripling unit, provide the local-oscillator signals for translation (see Fig. 8). They select the 159·625 MHz pilot signal, multiply its frequency and amplify it to provide sufficient output to drive the mixer modules. If there is any modulation present on the local-oscillator signal, it will be impressed on the translated signal and appear as cross-modulation. Thus, modulation at the outputs of the frequency-multiplying units must be minimized to avoid worsening the cross-modulation figure of the whole translator.

Multiplying the frequency of a signal involves the use of non-linear processes, which also cause cross-modulation. To prevent any cross-modulation on the local-oscillator signals, all signals other than the 159·625 MHz pilot must be removed before any frequency multiplication takes place. A sharp cut-off band-pass filter, tuned to 159·625 MHz, is therefore required. The bandwidth of this filter cannot be too narrow because allowance has to be made for possible drift in the filter tuning and in the pilot frequency. Also, decreasing the bandwidth of a filter increases the pass-band insertion loss because of the finite Q-factor of the components used for its construction. Sufficient selectivity has been obtained from a 4-section filter with 5 MHz bandwidth. This filter is also of the coupled-resonator type, designed using CUPRES. The same construction problems were met and overcome, but wound wire coils are used for the inductors because a higher inductance is required and they are smaller than printed coils.

Each mixer module requires a local-oscillator signal input level of +44 dBmV. The frequency-doubling-unit output is distributed to 5 mixers and the supervisory module through a 6-way resistive splitting unit, having 16 dB loss to each outlet. Therefore, an output level of +60 dBmV is required from the doubling unit. A 2-way resistive splitting unit, with 6 dB loss, distributes the frequency-tripling-unit output to 2 mixers. An output level of +50 dBmV is, therefore, required from the frequency-tripling unit.

The frequency multiplication in both the doubling and tripling modules is achieved by overdriving a transistor amplifier stage. This produces a multitude of harmonics of the input frequency, the appropriate one being filtered out.

In the frequency-doubling unit, the 159·625 MHz pilot signal is selected and amplified by 2 tuned amplifier stages separated by the 4-section filter. Each amplifier stage consists of a single transistor, with matching networks that provide the optimum source and load impedances for stable gain, and were designed using 2 BPO computer programmes. The second stage produces sufficient output to drive the frequency-doubling stage that follows. The output from the frequency-doubling stage is amplified by a single transistor stage and filtered by a 3-section coupled-resonator type filter. This filter also uses printed inductors. A final amplifier stage then brings the doubled signal to the required output level; a simple potentiometer attenuator at the output provides continuous adjustment of the output level.

The 4-section coupled-resonator type filter in the frequency-tripling module is at the input, which makes it easier to align. The 159·625 MHz pilot signal is then amplified by 2 commercial thick-film amplifiers in tandem, followed by a single transistor amplifier stage. The signal is then applied to the frequency-tripling stage which produces sufficient third harmonic such that no further amplification is necessary. The third harmonic is selected by the output tuning of the frequency-tripling stage and a filter which is of the same type as the UHF filter of the mixer module. As with the frequency-doubling unit, a simple potentiometer attentuator is included at the output.

Limiting occurs in the input amplifiers of both frequency-multiplying modules with the normal input signal level. This forms a type of automatic gain control, and gives a constant output level for a range of input levels.

Amplifier LWB 180A

This amplifier module allows the 405-line television and band II FM sound services to pass through the translator unchanged. To do this, it selects and amplifies all frequencies below 200 MHz. The module consists of a single transistor amplifier stage, sandwiched between 2 m-derived low-pass filters. Both of these filters have a cut-off frequency of 202 MHz. The overall gain is 8 dB over the frequency range 40–200 MHz. A plug-in attenuator is incorporated so that the output level can be adjusted.

Amplifiers LWB 280A and 181A

Both types of amplifier are proprietary items. The UHF channelized Amplifiers LWB 280A have a nominal gain of 40 dB and an accessible 15 dB gain control. An IEC 3-signal intermodulation ratio of 86 dB is obtained at the normal output level of +48 dBmV. The amplifiers' input and output circuits are adjusted during manufacture for optimum return loss over the designated channel. Amplifier LWB 181A is a wideband module with a bandwidth of 40–230 MHz and a nominal gain of 24 dB. This is used in the VHF bypass path of the translator.

Combining Units

The 4-way and 3-way UHF channelized combining units (Combiner LWB 1A and 2A) both use a proprietary 4-way filter combining/splitting unit. Each unit is soft-soldered into a BPO designed framework, which adapts the item for plug-in use on the translator main chassis. The combining unit consists of 4 band-pass filters, each tuned to the desired channel. The individual 2-section filters are of trough-line type and are fabricated such that the 4-output connexions can be coupled to a common point. Each filter has a bandwidth of 15 MHz and an insertion loss of 3 dB.

Supervisory Module

The d.c. power-feeding circuits of the VHF routes can be used to transmit low frequencies back to the head-end of the system from the translators to provide supervisory signals. A particular translator can be identified by the frequency that it transmits. The frequencies must be below 500 kHz.

The supervisory module contains an amplifier which amplifies the 319·25 MHz signal applied to its input from the frequency-doubling unit. From this, a direct voltage is obtained by rectification and is used to control the power supply to a low-frequency oscillator. If the 319·25 MHz output from the frequency-doubling unit fails for any reason (such as the failure of the 159·625 MHz pilot to the input of the translator) then the low-frequency oscillator stops oscillating. This ceasing of the low-frequency signal can be detected at the head-end of the system, and so constitute a supervisory signal.

At present, only a small number of supervisory units has been made for experimental purposes. Uncertainties exist about the extent to which a supervisory system is required.

Main Chassis

The chassis is fabricated from sheet steel, which is coated with a hot-tin dipped finish to provide good RF conductivity and protection against corrosion. The input board, local-oscillator splitting units, UHF link and output board are mounted on the underside of the chassis, which is not normally accessible. The wideband input amplifier is the only active device mounted on these boards and, as all the other components are passive, good reliability is expected.

The plug-in modules are mounted on the top surface of the chassis. Signal connexions to the plug-in modules are made using push-fit BNC connectors. Chassis-mounted clips ensure that each module is guided accurately onto both the push-fit RF and d.c. power connectors. A number of these chassis-mounted BNC connectors locate directly with the circuit track of the local-oscillator splitting-unit and UHF link board, while very short wire links are used for connexion to the input board. The signal path between the modules is completed using coaxial cable links terminated with crimped chassis-mounted push-fit BNC connectors.

Two-pin push-fit connectors are used to feed the 24 V d.c. supply to the modules. The main chassis carries all the necessary d.c. wiring and fuses, as well as the forward and reverse power-feeding facilities.

Two handles, which also provide a mounting position for a small retaining lid, are fixed to the top side of the chassis. The printed-circuit boards on the underside of the chassis are protected by a steel base plate, which is simply located by 4 metal clips.

PERFORMANCE

The noise and cross-modulation performance are probably the most significant parameters in cable-television system planning.

The overall translator noise figure is 13 dB, which is within the 15 dB limit specified.

A more complicated situation exists with the cross-modulation performance. The wideband amplifier in the translator input stage passes all signals on the VHF highway and has a 2-channel cross-modulation figure of 90 dB. This is 20 dB better than the worst-case result for the preceding VHF route and thus has a negligible effect on system performance. The channelized paths which follow the input stage have sufficient selectivity to reduce cross-modulation between adjacent channels and the wanted channel to a very low order. With 16 MHz channel spacing, the closest interfering carrier appears 10 MHz from the wanted signals and, at this frequency difference, the 2-channel cross-modulation ratio is 105 dB.

The vision, sound and colour sub-carrier of a single 625-line television channel can beat together, producing an in-channel product close to the vision carrier. An IEC 3-signal measurement method simulates these signal conditions and, for impairment-free picture quality, an intermodulation ratio of greater than 54 dB must be achieved. The channelized paths from the mixer inputs to the translator output yield a result 30 dB better than the minimum figure of 54 dB.

The 2-channel cross-modulation performance of the VHF bypass section does not have to meet the 90 dB figure obtained in the wideband input stage. This is because only 3 television channels are transmitted and these channels are fed along the subsequent distribution highway at a level 6 dB lower than the 625-line UHF channels. A figure of 70 dB is therefore adequate. The measured 2-channel cross-modulation figure for the VHF bypass path, excluding the wideband input stage, is 73 dB at a translator output level of +34 dBmV.

CONCLUSION

Equipment Translator LWB 2A can translate up to 7 channels from VHF to UHF on a channelized basis. Accurate translation frequencies are obtained by having a common pilot signal on the system, this being doubled and trebled at the translator. The frequency translation is achieved with no significant non-linear degradation to the signals.

At the time of writing, 80 translators have been manufactured, half of which have been installed, and a further 200 units are currently under construction. All of these translators are equipped to provide 4 translated channels. However, plans for adding a fifth channel are at an advanced stage.

ACKNOWLEDGEMENTS

The authors wish to thank their colleagues in Line and Radio Systems Division, Telecommunications Development Department for their assistance in developing the equipment, and also Telecommunications Division, EMI Sound and Vision Equipment Limited for the helpful co-operation received during the manufacture of the equipment.

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Book Review

Transmission and Display of Pictorial Information. D. E. Pearson, PH.D., D.I.C. Pentech Press. 224 pp. 95 ills. £5·95.

There are now many books dealing with television; they commonly start with an outline of a complete television system and, then, develop their theme by analysis and description of modern practice in those parts of the system being covered. Dr. Pearson, in his new book, adopts a quite different approach. In it, he concentrates on the basic fundamentals, and makes reference to current practice only as an example of their application. One result of this approach is that much of the material presented is relevant not only to broadcast television, but also to other visual communications systems, such as videotelephones, facsimile and computer-generated displays. Another result is that the book will not become out of date, due to changes in practice, almost as soon as it is published, as sometimes happens.

The main topics covered are the mathematics of image analysis and the theory of scanning, the properties of the eye, the display of monochrome and colour pictures, the transmission of monochrome and colour signals, and the subjective assessment of picture quality. The most extensive treatment is given to well-established, though not well-understood, topics, such as scanning theory and colourimetry applied to television systems. Topics that are the subject of active research, and are therefore changing rapidly, such as digital coding and subjective testing, receive shorter treatments in the form of balanced reviews concentrating on the fundamental aspects.

The treatment is generally clear and concise, using mathematics freely. However, the mathematics is not burdened by rigorous proofs, and is supported by many excellent illustrations that aid the reader to an understanding. Considerable emphasis is placed on the Fourier transform, including its less familiar 2-dimensional and 3-dimensional forms, and it is used as the unifying principal throughout most sections of the book. While this approach leads to an elegant and coherent theory, the reviewer feels that the author has done less than justice to the alternative space-domain/time-domain approach which simplifies some of the problems. The limitations of the frequency-domain approach perhaps account for the rather inadequate treatments of bandwidth and transmission impairments, of which one of the most important in practice (line-time waveform distortion) is not even mentioned.

Notwithstanding these comments, the book is thoroughly recommended. It is well produced, well illustrated and contains a 10-page list of references. It has evolved from a course of post-graduate lectures given by the author at the University of Essex and is, therefore, particularly suitable for students at advanced undergraduate, or post-graduate, level, but will also be a valuable work of reference for practising engineers requiring information about visual communication theory.

I. F. M.

Regional Notes

SOUTH EASTERN REGION

Second Telex Exchange in Guildford Telephone Area

Demand for the Telex service in the Guildford Telephone Area continues to grow, and the existing Telex exchange at Guildford, with a capacity of 600 lines, became exhausted in 1974. Extension of the exchange was not possible because of lack of space, but, as the equipment still had several years of life, it was decided to install a second exchange rather than replace the existing one. With Aldershot, Basingstoke and Camberley becoming the fastest developing communities in the area, it was logical to provide the second exchange at Aldershot, where suitable accommodation existed. The location chosen allowed the shortening of local ends, and the opportunity was taken to improve the maintenance arrangements by providing additional testing facilities at the new exchange.

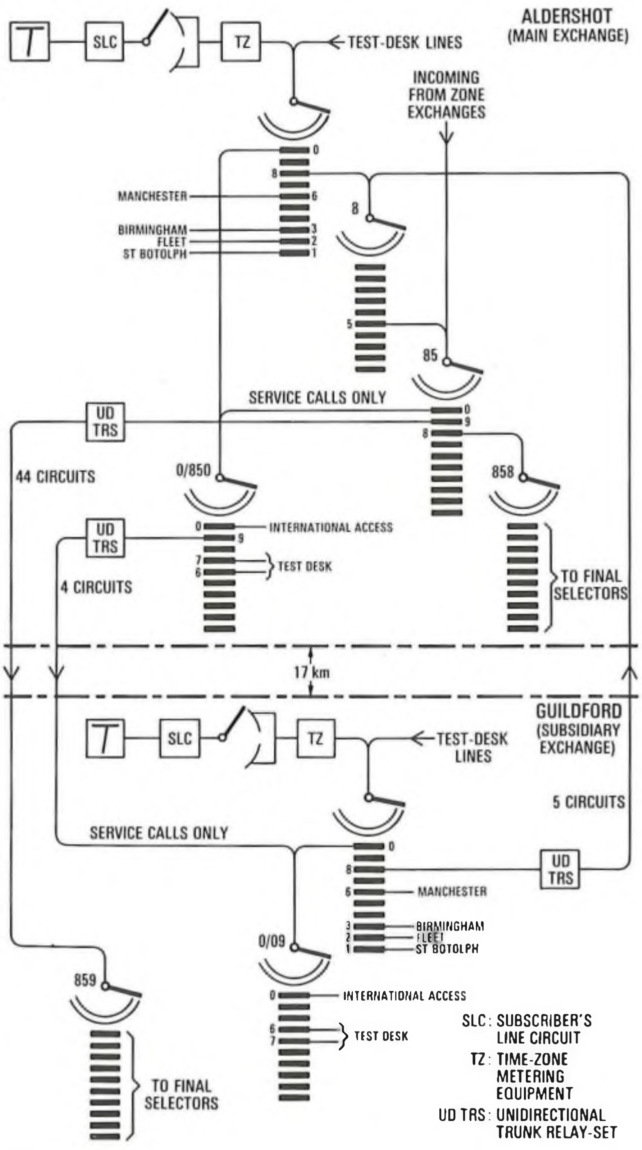
The installation of the new 800-line exchange, by Standard Telephones and Cables Ltd., after many difficulties and delays, took 16 months. During this period, existing Telex subscribers were given 6-digit numbers. Subscribers destined to become dependent on Aldershot exchange were given numbers in the series 858*XXX*, and those destined to remain connected to Guildford exchange after the opening of Aldershot were given numbers in the series 859*XXX*. This allowed the eventual transfer to take place without the complication of numbering changes.

The transfer of 320 subscribers from Guildford exchange to Aldershot was carried out without incident on 6 September 1975, and involved staff simultaneously switching voice-frequency-bearer and physical circuits at 9 remote locations. Finally, on 1 October 1975, 65 customers, who had been given service on out-of-area lines from Reading exchange during the period between the exhaustion of Guildford and the opening of Aldershot, were all transferred to Aldershot.

All incoming zone-exchange traffic is routed initially to Aldershot, which is designated the main exchange. An unusual feature of the trunking arrangements is the provision of 53 circuits, each approximately 17 km long, between selector levels, as shown in the simplified trunking diagram.

The installation of Aldershot Telex exchange has provided sufficient capacity to meet the growth requirements of the Guildford Telephone Area, on present trends, for the next 4 years.

F. D. Noble



Simplified trunking diagram for Aldershot and Guildford Telex exchanges

WALES AND THE MARCHES

Storm Damage at Barmouth, 2 January 1976

During the evening and night of 2 January 1976, severe storms caused considerable damage to British Post Office plant in and around the Shrewsbury Telephone Area. High tides and storm-force winds caused the erosion and subsequent collapse of some 20 m of the sea front at the northern end of Barmouth, Gwynedd.

This resulted in considerable flood damage to a housing estate, and a single duct track along the sea front, containing 2 major junction cables and a 100-pair local cable, was also damaged.

The 2 junction cables were the Machynlleth–Portmadoc Nos. 1 and 2 cables, of 104 pairs and 182 pairs respectively. In the case of the No. 1 cable, only superficial damage to the lead sheath occurred, and this was easily repaired. The No. 2 cable, however, was severely damaged in 2 places about 1 m apart, and sea water had completely soaked the conductors for a distance of some 2 m.

Because of the weather and tide, it was impossible to reach the point of damage for some 12 h, and, by this time, it was not practicable to dry out the conductors to effect a temporary repair of the No. 2 cable. A 3 m length of 182-pair cable was inserted to make a temporary repair, and jointers worked through the night of 3 January to restore full service.

The collapsed sea front at Barmouth

The exposed cables, showing the 3 m length of temporary repair cable jointed in

During the disruption, Llanbedr and Dyffryn, 2 unit automatic exchanges dependent on the damaged junction cables for access to their parent group switching centre at Machynlleth, had severely restricted service. All circuits between Machynlleth and Portmadoc exchanges, and between Dolgellau and Portmadoc, were lost.

G. F. Arnold

LONDON TELECOMMUNICATIONS REGION

Bond Street Station

In 1971, the Centre Telephone Area of the London Telecommunications Region was informed by the London Transport Executive (LTE) that it was their intention to reconstruct Bond Street underground station. This was to be done as part of the construction of a new underground line, to be known as the *Fleet Line*. The new line will run from Trafalgar Square (called Charing Cross), via Green Park and Bond Street, to Baker Street station, and thence on existing Bakerloo Line track to Stanmore.

Bond Street station is at an intersection in Oxford Street, midway between Oxford Circus and Marble Arch. This is one of the most congested areas in London in terms of both the volume of pedestrian and vehicular traffic on the surface and the multitude of services below ground, such as telephone plant, gas, water and electricity mains, sewers, and the tunnels of the London underground railway.

To allow free traffic flow, and permit construction work to progress continuously, an elevated road-deck was constructed over the whole work site, approximately 900 mm above road level, with ramps down to each of the 5 roads forming the intersection. Fig. 1 is a map of the site, showing the existing plant and the position of the elevated road-deck.

The LTE's contractors excavated across the whole width of the roads, exposing all the services, most of which were then temporarily diverted clear of the working area by raising and attaching them to the underside of the road-deck. As the cost of temporarily diverting the telephone plant in this manner would have been of the order of £50 000, it was agreed that the cables should remain suspended from the road-deck in their existing positions, and the new station constructed around them, until such time as they could be diverted into permanent alternative routes. The ducts and cables, and the large concrete blocks in which they were embedded, presented a weight problem. The ducts and the concrete were therefore broken away, protection for the cables being given by boxing them in with timber.

The new station roof was constructed with the main beams in line with Oxford Street, the spaces between them being available for the various services. One space was allocated to the British Post Office, and this was filled with 60 PVC ducts laid in concrete between manholes on the existing duct routes on each side of the station. This work was complicated by the fact that the Oxford Street pavements had recently been doubled in width, reducing vehicular traffic to a single line; any excavation in the carriageway would have stopped traffic completely. It was, therefore, necessary to ask Westminster City Council to reduce the pavements to their original widths so that vehicles could pass the excavations. This was agreed and, following completion of the ductwork, the cables routed east–west along Oxford Street were diverted to the new route.

The diversion of the cables routed via Oxford Street and South Molton Street presented a much more difficult problem. No ground was available over the main beams of the station, and there was no space available between the side of the station and the adjacent buildings through which a duct route of the required size could be laid. Consequently, it was necessary to find an alternative route away from the vicinity of the station. This plan was complicated by a proposed large property development involving the closure of several streets in the vicinity and an extensive duct requirement for a new telephone exchange on a site close to the station. After numerous discussions, surveys, negotiations, and trial excavations, a new route, varying in size between 36–60 ways, was established. The route is approximately

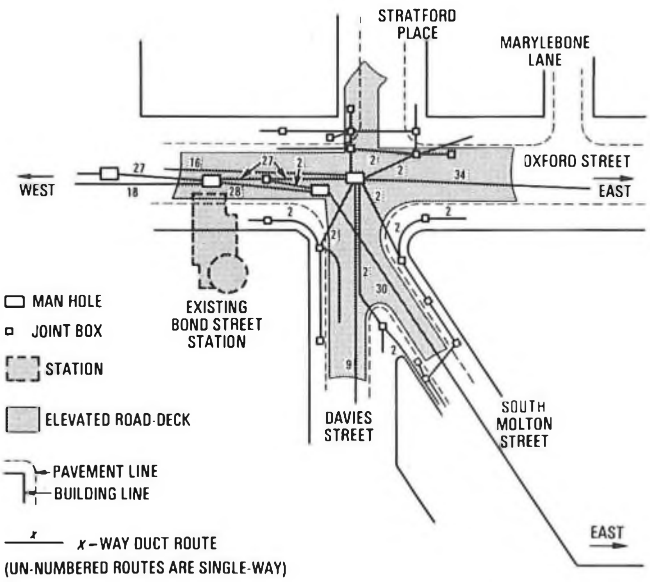


Fig. 1—The site prior to reconstruction

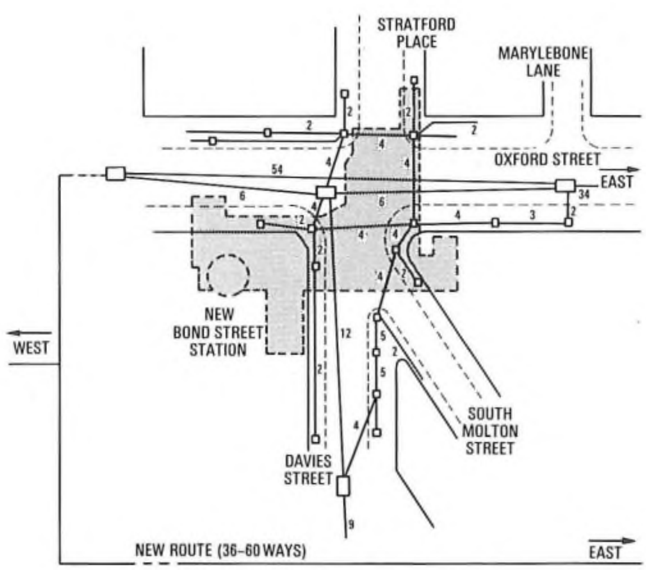


Fig. 2—The site after reconstruction

750 m in length and has 8 non-standard manholes, 3 of which are on 2 levels with loading coils and capacitor pots being housed in the upper levels and the cables routed through the lower. The route chosen passed several embassies and crossed Grosvenor Square: favourite areas for protest marches and demonstrations. All construction was, therefore, in tunnelling, mainly in timbered headings, but, due to earth pressure, one 70 m section was constructed using a 1·5 m diameter driving shield and concrete-segment tunnel lining. All spoil from the work had to be removed from the site, so as not to provide ammunition should there have been any violent demonstrations.

A further route that had to be provided was from Oxford Street southwards down Davies Street. This had to be constructed along the side of the station and past many other services. In the event, it was found possible to get only 12 ducts through, although more would have been desirable.

In addition to the main routes, local duct and cable had to be rerouted in the immediate vicinity of the station. It was decided that 4 ducts should be laid around the station with a joint box on each corner. This had to be done under the restricted clearance of the road-deck, where much of the ground had been excavated. Joint boxes were built initially only up to duct level, and were completed when the road-deck was removed.

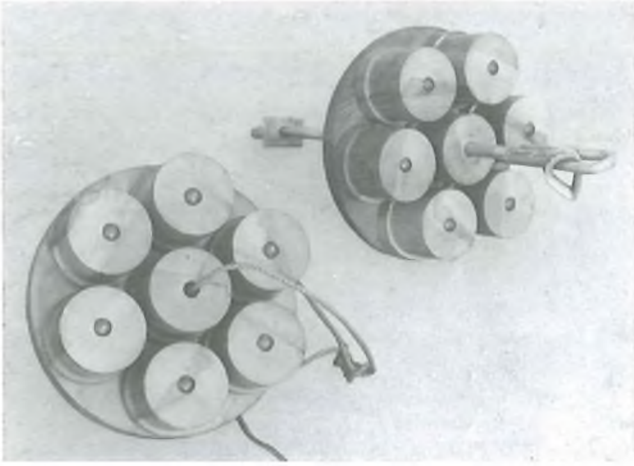
All ducts and cables were finally diverted clear of the station by the required date of August 1975. The final layout of plant around the station is shown in Fig. 2. Thirty-one junction cables and 9 local cables were rerouted, and 50·2 km of duct and 16·861 km of cable were used. The final cost to the LTE was approximately £600 000.

E. J. LODDY

The 60 MHz Gas Pipe

The duct route between Uxbridge and Denham for a section of the London–Birmingham 60 MHz cable crosses the carriageway at the intersection with the M40 at Denham roundabout. During the planning of the route, it was anticipated that the ducts would have to be laid in a tunnel under this carriageway.

However, trial holes, dug at each side of the carriageway, revealed an uncharted 457 mm diameter metal pipe, crossing the road exactly along the line of the proposed tunnel. Tests made on the site by the Gas Board confirmed that the pipe was a derelict 394 mm bore gas main.



The rear and front wooden formers, showing the pulling rod through the front former

A section was removed, and the bore of the 60 m long pipe was inspected by closed-circuit television. No faults or serious joint misalignments were found, and it was decided to attempt to draw lengths of PVC duct (Duct No. 57A) into the pipe. Six ducts were required over this section, and consideration was given to drawing these into the gas pipe one at a time. Using this method, 5 ducts could be provided fairly easily, but there were doubts about whether they would retain their correct formation inside the pipe, and also whether there would be sufficient space left for the sixth duct. To be reasonably certain of successfully installing 6 ducts, it would be necessary to pull them all into the pipe in one operation. Following experiments, it was decided it would be easier to pull in 7 ducts arranged in a star formation. This gives a stable formation with a maximum diameter of only 356 mm, assuming that the duct joints are staggered.

A wooden test mandrel, 356 mm in diameter and 610 mm long, was constructed and successfully pulled through the gas pipe, proving that it could be used to house the required number of ducts. Negotiations were started with the Gas

The gas pipe and duct-entry pit

Fitting the front former to the ducts

The assembled duct nest being drawn down the ramp to the gas pipe

Board, and an acceptable purchase price for the pipe was eventually agreed.

The next major problem was how to manoeuvre the nest of ducts into the pipe. The 7 lengths of duct together weighed 1 t, and the gas pipe was over 2 m deep at its shallower end. This end was chosen as the duct-entry point, and a timber-lined ramp was constructed, commencing 1 m below the end of the pipe and rising to surface level 14 m away. A further 60 m of 457 mm wide level timber track was constructed at the higher end of the ramp. On this level section of track, the ducts were jointed into 7 lengths, each 60 m long, and assembled into a star formation on trolleys. The trolleys used were deep-level-tunnel cabling trolleys, modified to support and cradle the lowest 2 ducts of the formation.

Turned wooden formers, 356 mm in diameter, were used at the front and rear of the ducts to ensure that the correct formation was maintained, and that the insides of the ducts were kept free of grit. A section of stay rod, 457 mm long and 19 mm in diameter, was passed through the centre of the front former, and a cabling eye welded to each end of it to form a floating pulling bolt. A similar stay rod was also passed through the centre of the rear former, its threaded portion, lengthened to 1 m, protruding to the rear.

During the assembly of the duct nest, a steel hawser was drawn into the centre duct, threaded through the eyes of both front and rear rods, and passed back through the centre duct. Its 2 ends were then clamped together using an aerial-cable suspension-wire clamp. As a safeguard, a second steel hawser was provided in a similar way.

When all 7 ducts were assembled on the trolleys, they were bound together in star formation using flat plastics tape. The bindings were repeated at 1 m intervals throughout the whole duct length.

At this stage, the rear former was removed and the ducts trimmed to exactly the same length. The former was then replaced, and the hawsers in the centre duct were tensioned by tightening the nut on the rear stay rod. This secured the whole assembly into a solid formation ready for pulling into the gas pipe.

At the receiving end of the pipe, a timber-lined pit had been excavated to a depth of 4 m, approximately 500 mm lower than the base of the gas pipe. A heavy-duty cabling boom was lowered into the pit and wedged firmly in position, with the cabling rope aligned with the pipe's centre. Radio contact was established between staff at each end of the pipe so that the operations could be effectively controlled.

The cabling equipment was used to draw a lubricating brush through the pipe. The brush used was the original test mandrel with 3 layers of 406 mm diameter 19 mm thick polyurethane foam sandwiched between the original face plate and an additional one. The foam was soaked in medicinal paraffin prior to its use.

The rope of the cabling equipment was then connected to the pulling eye on the front former of the duct nest, and the ducts were pulled steadily down the ramp and into the pipe. The cabling trollies dropped from the duct nest into the pit below the pipe as the ducts entered the pipe. The drawing-in was completed within a few minutes without hindrance.

This method of providing the ducts saved £5000 over the cost of providing 6 ducts in a tunnel. Contractors were employed to dig the pits, joint the ducts and construct the wooden runway.

Thanks are due to the British Post Office staff who constructed all the special equipment required and assembled the duct nest on site, and also for the loan of the Regional television camera and crew, and the heavy-duty cabling equipment.

E. S. WHITEHORN

SOUTH WESTERN POSTAL REGION

New Offices for Supplies Division

A new office block for staff of the Supplies Division, Purchasing and Supply Department, Telecommunications Headquarters (THQ), has just been completed at Swindon in only 58 weeks from the start of the contract. The accommodation has a total floor area of 4200 m^2, and is on 3 floors. The project was on a design-and-construct basis, using an industrialized building system.

The new office block, Swindon

Because of the proximity of residential property, particular attention had to be paid to possible noise problems from the boiler plant. Consequently, the boiler fans and gas boosters have been fitted with silencers, and first indications are that these measures have been successful.

The Property Services Agency of the Department of the Environment was responsible for the construction and external works. The South Western Postal Region acted as agents for THQ, and were responsible for the electrical services, heating, ventilation, the hot-and-cold water supplies and internal drainage. The main contractor was George Wimpey & Co. Ltd.

R. L. STICHBURY

Associate Section Notes

Aberdeen Centre

The 1975–76 session commenced in September 1975 with a visit to CS *Monarch*, under construction at a Dundee shipyard.

On 30 October, a team of members took part in a quiz, competing against the Inverness Centre. Inverness won by 31 points to Aberdeen's 24 points.

On 20 November, Mr. D. Morris of the North of Scotland Hydro-electric Board gave a short lecture on the oil-fired power station under construction at Boddam, near Peterhead.

The December meeting was given a lecture by Mr. A. M. Scott of IBM (UK) Ltd., entitled *Computerized PABXs*. In January one of our own members, Mr. W. Watson, gave a talk entitled *Crossbar Switching*.

I. Booth

Dundee Centre

At the time of writing, we can look back on 4 very successful visits, and forward into 1976 to 2 talks and perhaps another visit, yet to be arranged.

Following our visit to a cable ship in September, 16 members descended into the depths of Comrie Colliery, in Fife, and rode on a conveyor belt to, and from, the coal face. An anonymous comment was, "It's better than Blackpool, and free, too."

On 19 November, 14 of us were enthralled by a lecture on the meteorological-satellite ground station—the only one in Britain—at Dundee university. The visit was timed to coincide with a pass by the satellite, and we witnessed the recording of the data and saw the resulting weather picture.

Despite the wintry weather, a visit to a cold-storage plant took place in December; a shattering experience at −6° C, but most interesting.

R. T. Lumsden

Edinburgh Centre

On 14 October, the Centre listened to a talk from Mr. A. M. Scott, of IBM (UK) Ltd., entitled *Computerized PABXs*. This very informative talk was attended by 13 members, who were left wondering if IBM's PABX 3750 was designed for telephone use or as an office computer.

The main attraction of the PABX 3750 appeared to be that the customer could instantaneously select almost all of the enormous range of facilities with no British Post Office involvement. This was a most interesting talk by a speaker with obvious faith in the PABX 3750, and who passed this feeling on to those members present.

The Glenkinchie distillery at Pencaitland was the venue for 19 members on Wednesday 12 November. This visit was thoroughly enjoyed by all who attended, and concluded with a tasting session that was an obvious success for the firm's product.

J. L. M. Alexander

Exeter Centre

At the annual general meeting, held on 25 March 1975, the following officers and committee were elected for the 1975–76 session. The President, Mr. E. A. Boothroyd, Head of Installation and Maintenance Division, kindly accepted office for the second year.

Chairman: Mr. J. J. F. Anning.
Vice-Chairman: Mr. C. K. Sanders.
Secretary: Mr. J. W. Clark.
Assistant Secretary: Mr. M. Durrant.
Treasurer: Mr. W. F. Lambert.
Librarian: Mr. G. W. W. Abbott.
Committee: Messrs. J. Brown, I. G. Elston, G. Tout, J. Grimes, C. Reynolds, E. Soper, T. Pool and D. Miller.

Our summer programme began with 2 evening visits to Burrington Radar Station, on 21 and 28 May, both of which were well attended.

The next visit, on 18 August, was to the Sir Norman Lockyer Observatory at Sidmouth, where we were the guests of the Sidmouth and District Astronomical Society. The Society presented a talk, illustrated by slides and followed by a question time, and we then had the opportunity to inspect the various telescopes on the site. Unfortunately, we were unable to view the moon because of poor weather conditions and low cloud, but it was a very interesting evening.

The final outing of the summer programme, on 30 September, was in 2 parts. In the morning, we visited the Post Office Museum at Taunton Telephone Exchange, which contains exhibits illustrating the development of the telecommunications industry from the late 1800s to modern times. After lunch, we visited Harvey's wine vaults at Bristol. This visit started with a tour of the vaults, which have been converted into a museum and include a very fine collection of drinking glasses, followed by an unofficial sherry tasting. The latter was very well conducted, with the finer points of the various sherries being explained to our members.

Our winter programme started on 20 October with a disappointing attendance of only 32 for a lecture entitled *Forestry and Conservation*, given by Mr. E. A. Keen, District Officer for Devon District Forestry Commission. This was a very interesting lecture on nature conservancy and the development of the Forestry Commission since 1919.

Attendance rose to 66 for the 24 November meeting, a lecture entitled *Fuel-Injection Systems*, given by Mr. D. S. Holford. This was an excellent lecture, with coloured slides used to illustrate the more difficult aspects of fuel injection. To start the evening, Mr. D. F. Bidgood, Controller of Planning, South Western Telecommunications Region, presented Mr. M. T. Rowe with an IPOEE Certificate of Merit for his entry in the 1974–75 Essay Competition. Mr. Rowe gained second place with his essay, entitled *The Post Office Telecommunications New Internal Works Planning and Control Procedures*.

The South Western Regional Technical Quiz has been attended with enthusiasm, by the team and supporters alike. After a closely-fought contest with Truro, Exeter Centre went forward to the quarter-final of the National Technical Quiz, the team being Messrs. W. West, I. Elston, I. Lightfoot (Captain), M. T. Rowe, R. Allen and J. Petherick. Our sincere thanks go to our questionmaster, Mr. Bidgood, who was assisted by Mr. Boothroyd (timekeeper), Mr. G. Andrew, Head of Planning and Works Division, Exeter Telephone Area, (adjudicator), and Mr. G. Harris, Executive Engineer, Truro Telephone Area, (adjudicator).

On behalf of the Exeter Associate Section Centre, I would like to express our gratitude to Mr. J. Gregory, General Manager, Exeter Telephone Area, for his enthusiasm and participation in the Centre's activities.

J. W. Clark

Inverness Centre

Our 1975–76 session started on Thursday 11 September 1975 with a talk and films on fishing, transport and tourism, given by Messrs. Grassie and Munro of the Highlands and Islands Development Board. The attendance for this meeting was rather disappointing, but it was enjoyed by those who were present.

On 8 October, a party of 12 visited W. A. Baxter & Sons (Food Manufacturers), at Fochabers, and then continued on to Aberdeen to the Marine Research Laboratory at Torry—a long, but much enjoyed, trip.

Mr. J. C. Glennie, Executive Engineer (Maintenance), Aberdeen and North of Scotland Telephone Area, spoke on the subject of maintenance on Thursday 13 November. This talk, which was attended by 19 members, was well illustrated and very informative. My thanks to Mr. Glennie for undertaking this lecture within a year of taking up his present post.

Our last meeting of 1975 was a lecture entitled *Radio Communication in Scotland*, given by Messrs. F. Howe and

J. Nimmo, Scottish Telecommunications Board. This meeting was well attended, and a very lively discussion followed it.

On 21 November, a team from Inverness travelled to Blair Atholl to meet a combined team from Dundee and Edinburgh Centres in the Scottish regional final of the National Technical Quiz Competition. The Inverness team consisted of Messrs. C. Horn, D. C. Bell, W. Vass, J. Murray, W. MacLeod and V. Chiffers. Unfortunately, Inverness lost by one point. Regardless of the result, however, the evening was a great success.

K. D. MacCallum

London Centre

Our annual conference was held at the Institution of Electrical Engineers, Savoy Place, London WC2, and the following officers were elected.

Chairman: Mr. R. Gray (City Area).
Vice-Chairman: Mr. J. Dow (London Test Section).
Secretary: Mr. P. Harding (North West Area).
Assistant Secretary: Mr. C. Webb (South East Area).
Treasurer: Mr. N. Clark (North West Area).

Mr. L. Woods has been elected as Radio Secretary; he organizes ham radio contacts. Also, Mr. C. Lee, the North West Area Liaison Officer, runs classes for radio hams of the future.

On his promotion, Mr. C. Fry has had to relinquish his post as editor of the London Centre's *New Quarterly Journal* (*NQJ*), but still gives his help and guidance. The new editor is Mr. B. Gardner, and his first edition is excellent. If anyone has items of interest for inclusion in the *NQJ*, would they please contact Mr. Gardner (telephone 01-462 1691).

The London Region Technical Quiz, organized by Mr. D. Thomas, started in January. This is a 5-round competition, the final of which is to be held at Fleet Building on 21 April. The Trainee Technician (Apprentice) Quiz, organized by Mr. P. Shaw, started at the same time. The date of the final is yet to be announced.

The London Centre was honoured to receive the Cotswold Trophy. This trophy was donated to the Associate Section National Committee by the Gloucester Centre, to be awarded annually to the centre carrying out the aims of the IPOEE in the most exemplary manner.

I am also pleased to report that there are now 4 workshops active in the London Telecommunications Region, which are being well attended by our members.

P. Harding

Nottingham Centre

Nottingham Centre's 1975–76 session is almost complete, and I am happy to report that all of our functions have been well attended and, to the best of my knowledge, greatly enjoyed.

Visits in August and September, to the Automobile Association's National Training School at Widmerpool and the Whiteley Electrical Radio Co. Ltd. at Mansfield, were very well received, getting the Centre off to a good start at a time when interest seemed to be ebbing.

These visits were followed by another quite successful one to T. Bailey Forman (Printers) Ltd. in Nottingham, where we saw the *Nottingham Evening Post* being printed, and each received a copy "hot off the press".

November saw representatives of our Centre at the Regional Lecture at Leicester, but, because of the pressures of the Christmas period, it was decided that an event in December would be inappropriate.

A film evening in January was highly successful, and was attended by our Centre's President, Mr. K. Chandler. I must thank Mr. M. Rush for his assistance in the organization of this event.

Future items on the programme include a lecture by the Nottingham Telephone Area's Heads of Division, the Regional Quiz, and visits to the Morgan Motor Co. Ltd. and the Home Brewery.

The 1976–77 programme is now being arranged, and members are being invited to suggest items they would like to see on the programme. If, in fact, these items are not practicable for this year, they will, of course, be carried forward to a future programme.

Finally I would like to express the committee's desire to see as many of our members as possible at meetings during the coming year.

R. H. Marsh

The Associate Section National Committee Report

1975–76 Year-Book

The 1975–76 London Centre Associate Section year-book is entitled *Introducing Telex*. It consists of over 100 pages of information and diagrams, tracing the history of the Telex service from the earliest equipment to modern practice, including details of international switching and transmission, and computer networks. A small number of year-books have been made available for any IPOEE member who wishes to have a copy, and may be obtained from the secretary of the National Committee (telephone 01-462 1843).

Electronic Timer-and-Scoreboard Competition

Ten entries have been received for this competition and, bearing in mind the amount of design and practical work required to produce an entry, this is very encouraging. The entries will be examined at the British Post Office Technical Training College, Stone, in early May by an advisory panel of 3 senior-section members, drawn from the technical staff at the college, and 3 National Committee members, on the day prior to the annual conference. The advisory panel, headed by the President of the Associate Section, Mr. K. Stotesbury, will scrutinize the specifications and drawings for the theoretical aspects and practicability of the entries, and make their recommendations to the National Committee. A prize of £25 will be awarded for the winning entry.

National News

A news-sheet has been issued to keep members up to date on developments within the National Committee during the negotiations on restyling the *National News*. It is hoped to return to a full printed magazine as soon as an economical method of production has been devised.

Motor Spares

The national motor-spares discount scheme, introduced last year, has been very successful, and has now been extended to cover new and second-hand cars, car and van hire services, and UK and Continental holidays. Further details are available from the secretary of the National Committee (telephone 01-462 1843).

C. J. Webb

Notes and Comments

Correspondence

Long-Term Planning Group,
North West Telecommunications Board,
Manchester.

Dear Sir,

I am grateful to Mr. J. R. McCubbin for his reply to my letter (*POEEJ*, Vol. 68, pp. 127 and 264, July 1975 and Jan. 1976), in which he gives interesting background information to the long-term study of the UK trunk network, prepared in 1967.

My letter was prompted by an interest in the new concept of long-term planning and forecasting put forward, with differing emphasis, by the authors of the books *The Limits to Growth* and *Small is Beautiful*.

If the conclusions reached in the report *Britain 2001 AD* are regarded as no longer tenable in the light of world events during the last few years, perhaps the production of a more up-to-date report, with similar objectives, could be considered. *Britain 2001 AD* forecast 3 possible lines of future development, all broadly similar. Any new study would probably need to consider at least 2 main possibilities, widely different in character, based on

(*a*) the traditional concept of growth, and

(*b*) the conservationist, humanist idea of a stabilized economy.

Taken as a basis for long-term planning, this would entail keeping the options open as long as possible, to allow ultimate development in either one direction or the other. The inclusion of the second option would introduce factors and relationships that do not, at present, figure in the long-term plans of the various sectors of the economy.

Such an updated economic and sociological study would be of general interest, as well as providing basic information for use in the preparation of more specialized studies.

Yours faithfully,
H. G. Gange

12 Coldharbour,
Chickerell,
Weymouth,
Dorset.

Dear Sir,

Surely there is an error in the historical introduction to the article *A New Concept in Submarine Cable Depots* by T. M. Emery (*POEEJ*, Vol. 68, p. 149, Oct. 1975). When the Electric and International Telegraph Company was nationalized in 1870, the British Post Office took over its vessel *Monarch* I, which, unfortunately, made one voyage for her new owners before being relegated to a coal hulk. It was not until 1883 that *Monarch* II was built.

In 1890, the Submarine Telegraph Company was nationalized, the British Post Office acquiring the *Lady Carmichael*, which was renamed *Alert* (I). This vessel was built in 1871, purchased by the Submarine Telegraph Company in 1880, and named after the wife of the Chairman of the Company.

Mr. Emery's article implies that the Submarine Telegraph Company was nationalized in 1870, and that *Monarch* I and *Alert* I were in service together; that is not so.

Yours sincerely,
K. R. Haigh

Publication of Correspondence

The Board of Editors would like to publish correspondence on engineering, technical or other aspects of articles published in the *Journal*, or on related topics.

Letters of sufficient interest will be published under "Notes and Comments". Correspondents should note that, as it is necessary to send copy to the printer well before publication date, it will be possible to consider letters for publication in the July issue only if they are received before 14 May 1976.

Letters intended for publication should be sent to the Managing Editor, *The POEE Journal*, NP 9.3.4, Room S 08, River Plate House, Finsbury Circus, London EC2M 7LY.

Corrections

In Fig. 4 of the article *Programmable Automatic Testers in the British Post Office Factories Division*, published in the January 1976 issue, a comma should be shown adjacent to the input lead to bistable circuit 2, indicating that that lead is connected to the symbolic character lead representing that punctuation mark.

The Editorial to the October 1975 issue is inaccurate, in that the responsibility for all adult technical education will pass to 2 bodies: the Technician Education Council, covering England, Northern Ireland and Wales, and the Scottish Council for Technical Education, covering Scotland.

Regional Notes and Short Articles

The Board of Editors would like to encourage contributions suitable for publication under "Regional Notes", and short articles dealing with current topics related to engineering, or of general interest to engineers in the British Post Office (BPO).

As a guide, there are about 750 words to a page, allowing for diagrams; Regional Notes are generally up to about 500 words in length. Articles and Regional Notes should preferably be illustrated, where possible, by photographs or sketches. Contributions should be sent to the Managing Editor, *The POEE Journal*, NP 9.3.4, Room S08, River Plate House, Finsbury Circus, London EC2M 7LY.

Guidance for Authors

Some guiding notes are available to authors to help them prepare manuscripts of *Journal* articles in a way that will assist in securing uniformity of presentation, simplify the work of the *Journal's* printer and illustrators, and help ensure that author's wishes are easily interpreted. Any author preparing an article for the *Journal*, who is not already in possession of the notes, is asked to write to the Managing Editor to obtain a copy.

It is emphasized that all contributions to the *Journal*, including those for Regional Notes and Associate Section Notes, must be typed, with double spacing between lines, on one side only of each sheet of paper. Articles, and contributions for Regional Notes, must be approved for publication at General Manager/Head of Division (Regional Controller) level.

Each circuit diagram or sketch should be drawn on a separate sheet of paper; neat sketches are all that are required. Photographs should be clear and sharply focused. Prints should preferably be glossy and should be unmounted, any notes or captions being written on a separate sheet of paper. Good colour prints can be accepted for black-and-white reproduction. Negatives are not required.

Special Issues and Back Numbers

Copies of the April 1974 issue covering sector switching centres, and the October 1973 special issue on the 60 MHz transmission system, are still available.

Back numbers can be purchased, price 60p each (including postage and packaging), for all issues from January 1972 to date.

Copies of the July and October 1970, and the January 1971, issues are also still available. These issues contain all 3 parts of *Progress in Postal Engineering* by N. C. C. de Jong. The July 1970 issue also contains articles on the Post Office Technical Training College at Stone, the multi-frequency signalling equipment of the trunk transit network, local transmission planning, and the Echo Suppressor No. 7A.

The October 1970 issue contains articles on Purdon radio tower and gas turbines. The January 1971 issue contains articles on London's new generation of auto-manual centres and cast-iron split ducts for the shore-ends of submarine cables.

Orders, by post only, should be addressed to *The Post Office Electrical Engineers' Journal* (Sales), 2–12 Gresham Street, London EC2V 7AG. Cheques and postal orders, payable to "*The POEE Journal*", should be crossed "& Co.", and enclosed with the order. Cash should not be sent through the post.

Institution of Post Office Electrical Engineers

IPOEE Central Library

Members are reminded that prize-winning essays, Associate Section prize-winning papers and various unpublished papers are held in the Library for loan, and that a list will be sent on request. Field Medal award-winning papers are also held for loan, and are listed in the Library Catalogue.

Printed Papers of the Institution are available on loan, or can be purchased from the Library. A list of papers will be sent on request.

The following books have been added to the IPOEE Library since the publication of the 1974 Library Catalogue. Any member who does not have a copy of the catalogue can obtain one from the Librarian, IPOEE, 2–12 Gresham Street, London EC2V 7AG. Library requisition forms are also available from the Librarian, from honorary local secretaries, and from Associate Section local-centre secretaries and representatives.

5079 *Computer Appreciation.* T. F. Fry (new edition, 1975).

Primarily aimed at students, but will appeal to all who feel the need to familiarize themselves with the topic.

5191 *Digital Electronic Circuits and Systems.* N. M. Morris (1974).

For anyone requiring a thorough grounding in digital electronics.

5192 *Understanding High Fidelity.* M. Clifford (1972).

For any high-fidelity-equipment owner who wishes to understand his equipment—from beginners to experienced enthusiasts.

5193 *Practical Transistor Circuits for Modern Testing Equipment.* B. B. Babani (1974).

Much of the material in this book originally appeared as articles in *Electronics Australia.*

5194 *Engineering Measurements.* C. V. Collett and A. D. Hope (1974).

Primarily intended to fulfil the need for a textbook on engineering measurements for those studying for the Higher National Certificate in engineering, but consideration has been given to the more general needs of technician engineers.

5195 *Electronic Troubleshooting: A Manual for Engineers and Technicians.* C. N. Herrick (America, 1974).

A well-illustrated book that keeps theory to a minimum and emphasizes fault-location techniques for electronic circuitry.

5196 *The International Telex Service.* R. N. Renton (1974).

Reviewed in the *POEEJ*, Vol. 68, p. 76, July 1975.

5197 *Beyond Babel: New Directions in Communications.* Brenda Maddox (1972).

This is not a technical book; it is about change and resistance to change in communications as a political subject, and concentrates on satellite communications, television and telephones.

5198 *Electrical Principles and Testing Methods.* B. Woollard (1974).

Reviewed in the *POEEJ*, Vol. 68, p. 148, Oct. 1975.

5199 *Elements of Transistor Pulse Circuits.* T. D. Towers (second edition, 1974).

Designed to provide electronic engineers, and others who may be interested, with a review of the building blocks commonly used in pulse circuits. The treatment is mainly descriptive and entirely from a practical aspect.

5200 *Field-Effect Transistors in Integrated Circuits.* J. T. Wallmark and L. G. Carlstedt (Sweden, 1974).

A concise fully-illustrated text on the use of field-effect transistors in the construction of integrated circuits.

5201 *Electronic Equipment Reliability.* J. C. Cluley (1974).

Describes the principles of assessing the reliability of electronic equipment, including the mathematical background and methods that may be used to improve reliability, at a level suitable for degree-level and diploma-level students of electronic engineering.

E. DOHERTY
Librarian

Subscriptions and Back Numbers

The *Journal* is published quarterly in April, July, October and January, at 35p per copy, 60p per copy including postage and packaging (annual subscription: £2·40; Canada and the USA: $6·00).

The price to British Post Office staff is 27p per copy.

Back numbers will be supplied if available, price 35p (60p including postage and packaging). At present, copies are available of all issues from July 1970 to date, with the exceptions of April, July and October 1971 which are now sold out.

Orders, by post only, should be addressed to *The Post Office Electrical Engineers' Journal*, 2–12 Gresham Street, London EC2V 7AG.

Employees of the British Post Office can obtain the *Journal* through local agents.

Binding

Readers can have their copies bound at a cost of £3·00 including return postage by sending the complete set of parts, with a remittance, to Press Binders Ltd., 4 Iliffe Yard, London SE17.

Remittances

Remittances for all items (except binding) should be made payable to "*The POEE Journal*" and should be crossed "& Co."

Advertisements

All correspondence relating to advertisement space reservations, copy, proofs etc., should be addressed to the Advertisement Manager, *The Post Office Electrical Engineers' Journal*, 2–12 Gresham Street, London EC2V 7AG.

Distribution and Sales

Correspondence relating to the distribution and sale of the *Journal* should be addressed to *The Post Office Electrical Engineers' Journal* (Sales), 2–12 Gresham Street, London EC2V 7AG.

Communications

With the exceptions indicated above, all communications should be addressed to the Managing Editor, *The Post Office Electrical Engineers' Journal*, NP 9.3.4, Room S 08, River Plate House, Finsbury Circus, London EC2M 7LY.

Model Answers Books

Books of model answers to certain of the City and Guilds of London Institute examinations in telecommunications are published by the Board of Editors. Details of the books available are given at the end of the Supplement to the *Journal*. Copies of the syllabi and question papers are not sold by *The Post Office Electrical Engineers' Journal*, but may be purchased from the Department of Technology, City and Guilds of London Institute, 76 Portland Place, London W1N 4AA.

The Data Printer
that's more than a data printer

How the ENM 4850 meets the data logging requirements of a number of different users.

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4850 is used for multipoint monitoring of processes or establishments to provide continuous visual and electrical confirmation of a safe condition. In an alarm condition, the electrical readout can trigger an audible or visual warning and the printout records the fault and location in red. On alarm clearance, a similar printout is provided in black.

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Video editing requires accurate synchronization of sound to vision from a host of different inputs. The 4850 is extensively used to monitor these inputs, typically frame numbers, tape input references etc., to provide a complete record of the make-up of the finished tape.

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With the increasing popularity of self-service petrol filling stations, 4850's can be used to provide a record of fuel dispensed by grade, pump number, time and date and most important – cash value. A printed record prevents arguments after the pump readings have been reset to zero, and provides an automatic check on fuel stocks and cash intake.

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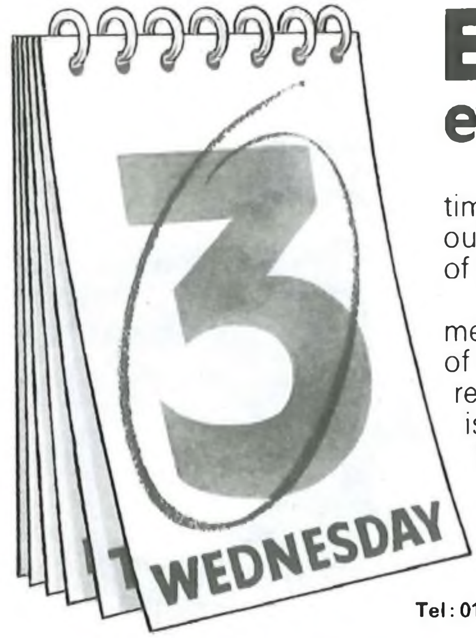

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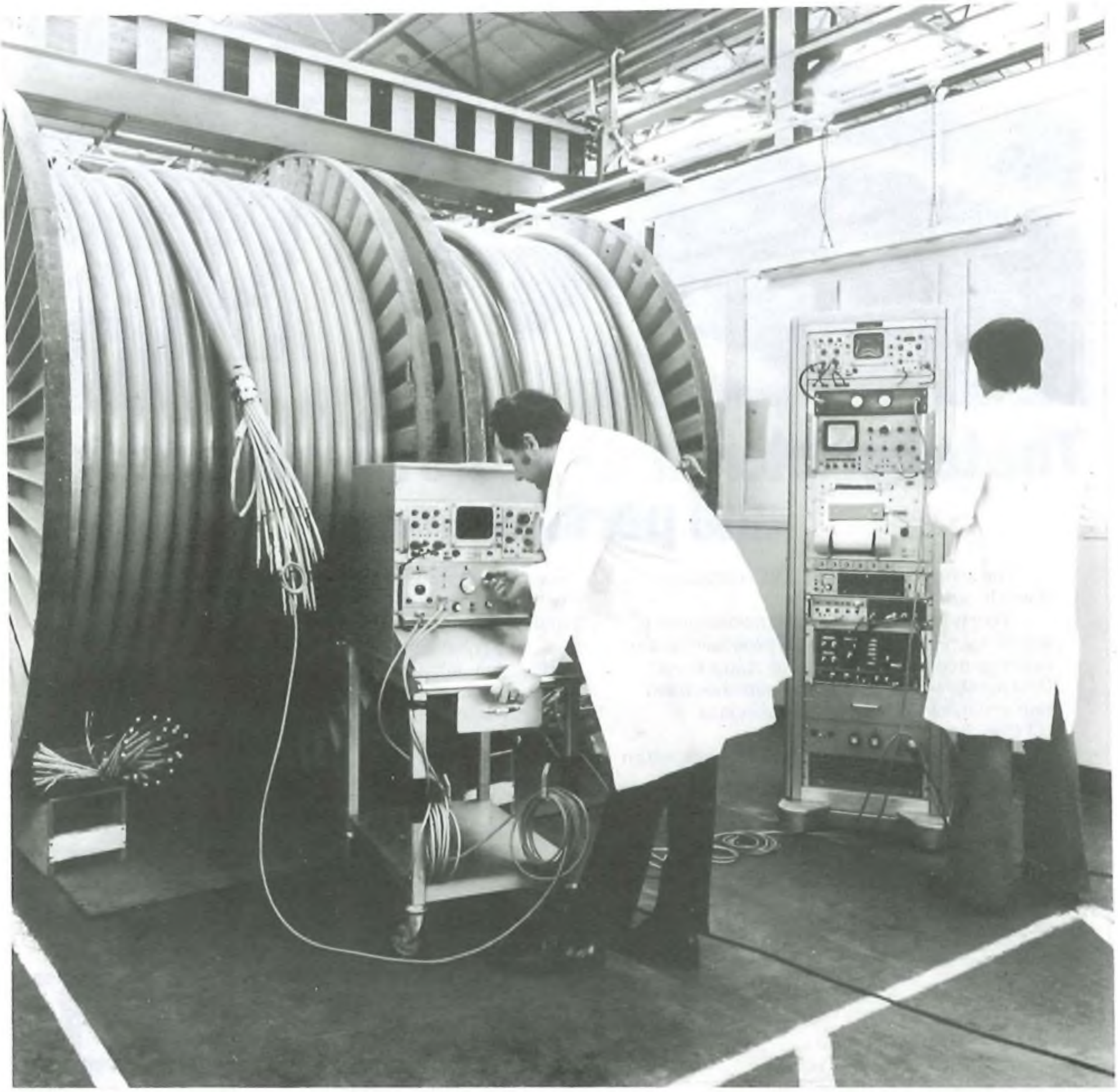

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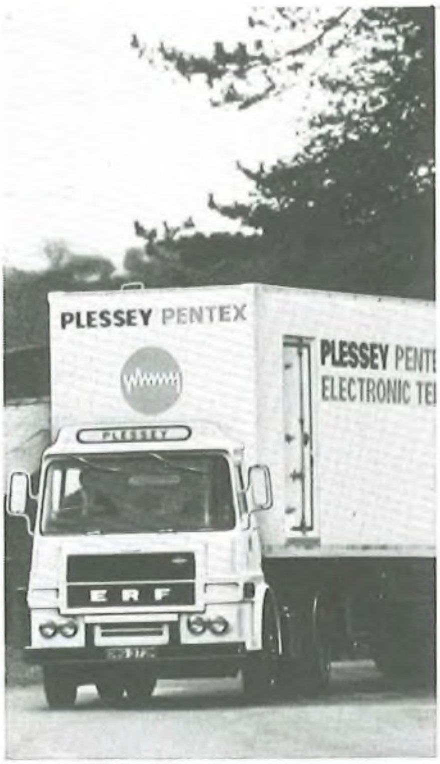

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APRIL 1976

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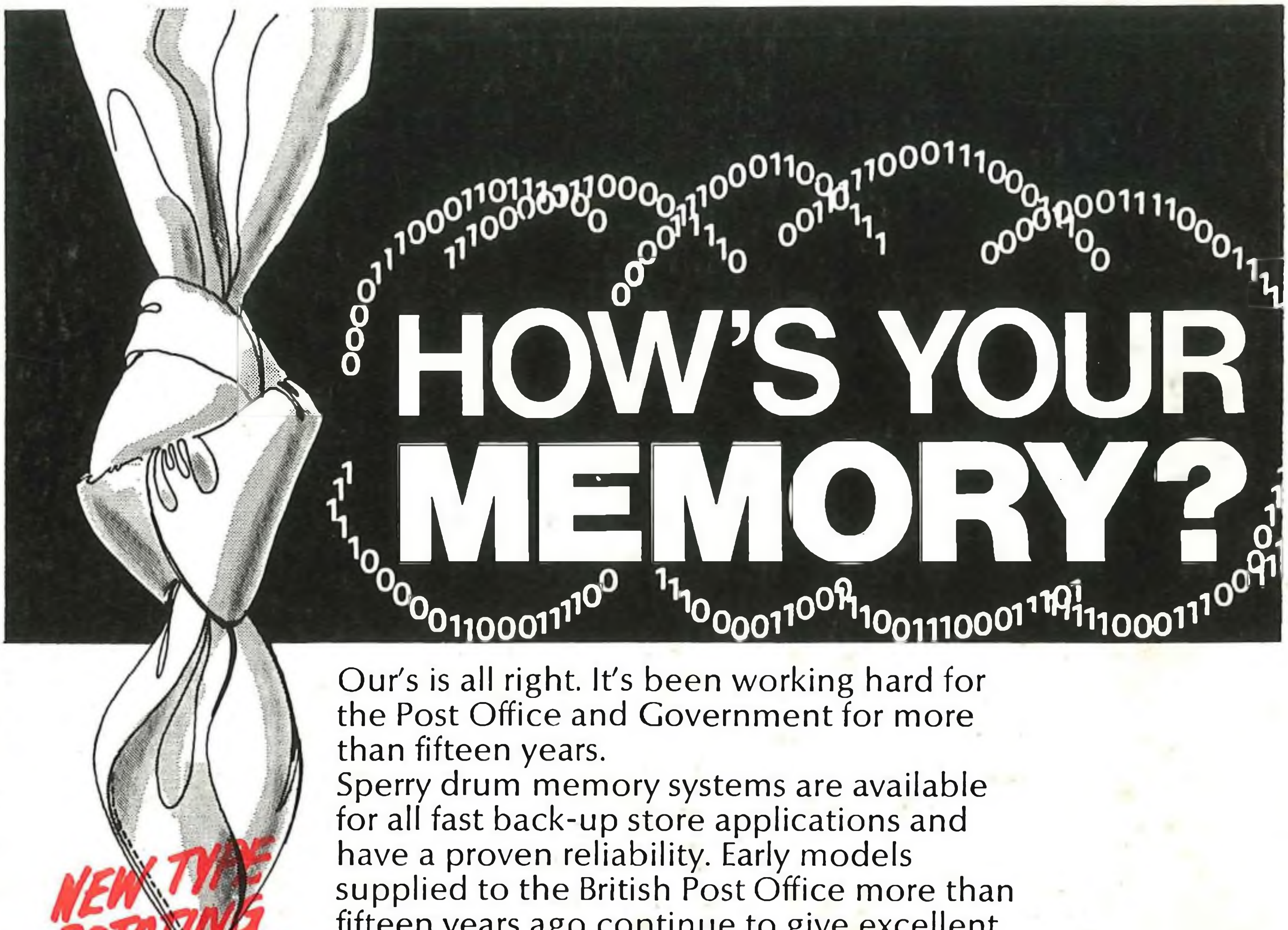

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