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CONTENTS

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THE STORY OF THE OVERLAND TELEGRAPH LINE

A. R. Cameron

Introduction

The early achievements of Postal engineers and others in developing communications between the isolated communities of the continent which ultimately became the Commonwealth of Australia are fascinating and instructive to all interested in the art of telecommunication, but none perhaps is more interesting and indicative of the tenacity and pertinacity of the pioneers than that of the establishment of the overland telegraph line between Port Augusta and Port Darwin shortly after the continent had been crossed for the first time by Mr. McDouall-Stuart.

This line formed part of the communication link between England and the Australian States, and the following article, which is based on original documents, describes its inception and ultimate completion.

Agreement to Construct Line: The original agreement concerning the establishment of communications between Australia and England was entered into on the 29th day of August, 1871, between the Governor of the province of South Australia on the one part, and the British-Australian Telegraph Company Ltd. on the other. In brief, the articles of the agreement provided that the Company lay down at any part of the Australian coast in or near Port Darwin, the land end of a submarine cable to be used for the purpose of telegraphic communication with Europe. An area of land not exceeding six acres was to be allotted to the Company for the purposes of providing a residence for its officers and for landing, maintaining and protecting the cable. On the other hand, the Government was bound to construct, complete and open for traffic a line of telegraph wire between Port Darwin and Adelaide on or before the 31st December, 1871. Further, this line had to be maintained in working communication with the existing line from Adelaide to Melbourne.

Under Article 9 of the agreement, the Company in the event of serious failure of the land line reserved the right to terminate the agreement or at its option take possession of the whole of the land line, any section thereof and all the stations and works, etc., and retain in its possession these acquirements until such time as all expenses incurred in repairing, maintaining and working same, with interest thereon at the rate of 6% per annum, be paid to them by the Government.

Article 10 gave somewhat reciprocal authority to the Government to take over the submarine cable and any buildings, instruments, etc., associated therewith.

Under Article 12 it was provided that if the land line be not completed and open for traffic by the 31st day of December, 1871, the Company could at any time thereafter lay down and complete a line of telegraphic communication between their cable at Port Darwin and Burketown, Queensland, or any point on the northern coast of the province of South Australia.

Long prior to the agreement, however, preliminary arrangements had been made for the construction of the line and as early as 20th August, 1870, a not unimportant date in the history of the line, we find that after many months of preparation the first construction party set out from Adelaide for the interior of the continent. There are many excellently recorded reminiscences of the various phases of the work undertaken by the Government itself. In this curtailed description, however, it is not possible to give any but a brief glimpse of the particulars of the undertaking as a whole. This sketch may serve to revive interest in the wonderful achievements of the staunch band connected with the evolving of the scheme, the negotiations and the final completion of the communication engineering feat of a magnitude unparalleled in the history of Australia.

In order that this engineering work might be presented in its proper perspective brief details are included of the various attempts made by the eminent explorer, McDouall-Stuart, to cross Australia from south to north and also of his final victorious effort, which feat no doubt was a major incentive in assisting the Government and Charles Todd (subsequently Sir Charles Todd) to arrive at a decision to construct the overland telegraph line.

Early Proposals for Establishment of Telegraphic Communication Between England and Australia

Reference to the early developments in connection with the Overland Telegraph Line is contained in the notes of a lecture in the handwriting of Sir Chas. Todd, written in 1873. In this lecture he states:—

> "The first proposition came from Messrs. Brett and Carmichael in a letter addressed to the Colonial Government in 1854 enclosing a chart of lines originated by them in the Mediterranean, and projected extensions to India, China, and Australia. This offer was renewed in 1858. When it first came before me the cable was to be laid from Ceylon to the West Coast of Australia in two sections connecting at the Cocos or Keeling Islands."

Another scheme was submitted in 1857 by Messrs. Carr and others.

Further reference to the Overland Telegraph Line is contained in Parliamentary Papers 127/1859, wherein Todd reports under date July 18th, 1859, on a letter from F. Gisborne, representing the promoters who proposed to lay a cable from Java to Moreton Bay, to the Governor, Sir R. G. MacDonnell, respecting a project for telegraph communication by way of India between Great Britain and Australia. His report states, inter alia:—

> "With regard to its further extension (that is, the extension of the cable from India), we have a choice of four routes:—
>
> **1st:** Via Ceylon to Western Australia.
> **2nd:** Java to Western Australia.
> **3rd:** From Timor to the northern coast of Australia, near to Cambridge Gulf and thence overland to Adelaide.
> **4th:** Mr. Gisborne's proposed route. From Java via Timor to Port Essington, and round the eastern coast to Moreton Bay."

After commenting on the various proposed routes, he states in connection with the third proposal:—

> "The third route has naturally enough obtained advocates in South Australia, where our hopes have been raised by the discovery of valuable country by Messrs. Stuart, Babbage and Warburton, and the confident tone assumed by those explorers as to its extension northwards, but nowhere else am I aware of its being regarded with similar favour—perhaps owing to the generally prevailing belief of the desert character of the whole interior.
>
> "Having had occasional conversations with the three gentlemen I have just named, I do think it probable that an overland route will ultimately be found prac-

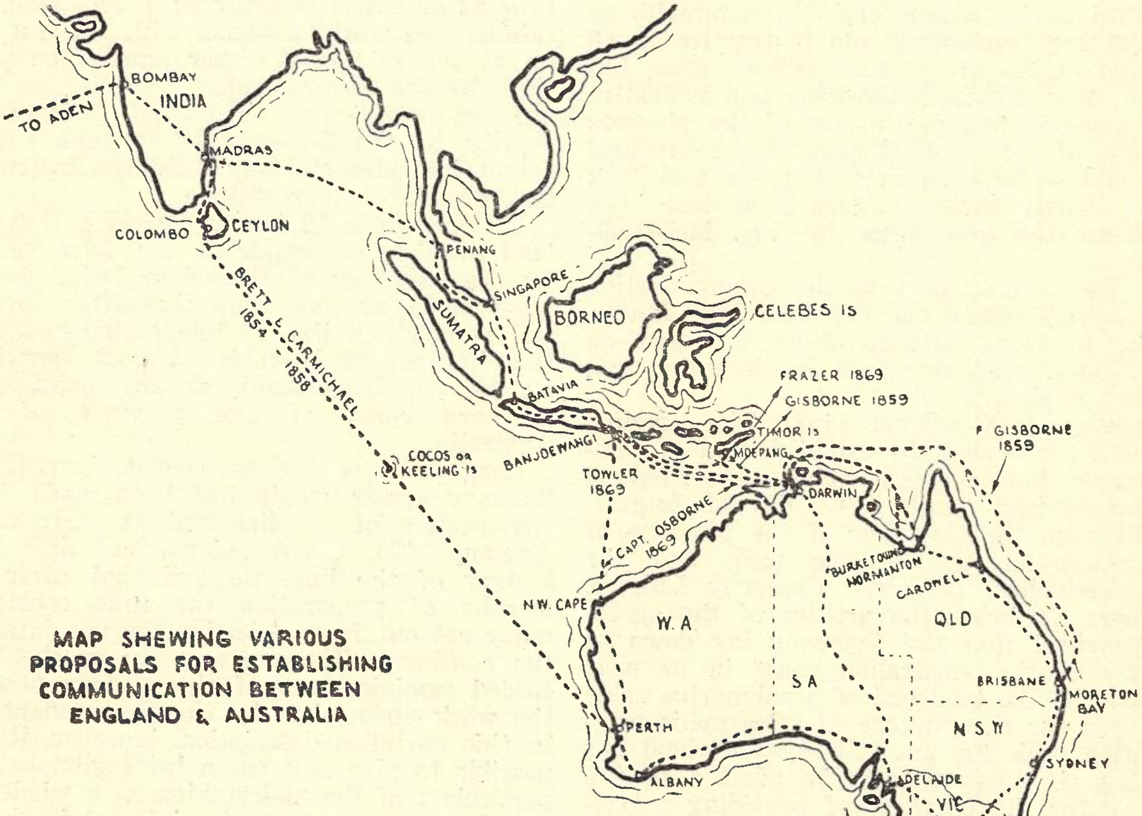


Fig. 1.

ticable; and, while I am writing, Mr. Stuart's return to Adelaide, after having crossed (as I hear) our northern boundary and found valuable country still stretching to the north, confirms my opinion in this respect; and I would recommend that Mr. Gisborne should be immediately placed in possession of the results of Mr. Stuart's explorations.

"The overland line would not be more than half the distance, while the cost would be only one-fourth. This too would, in that case, become the route by which the horse market in India would be supplied.

"I do not wish it to be understood that I am advocating a line across a desert; it is only on its being shown to traverse country available for settlement that I recommend its adoption."

During the latter part of 1859, Mr. Francis Gisborne visited Australia with a view to obtaining subsidies for the laying of a cable from Java to Moreton Bay at an estimated cost of £800,000, increased in 1862 to £1,100,000, involving a subsidy of £50,000 per annum.

About this time (1862) Stuart was successful in crossing Australia, and on his reporting that the line was practicable and would pass through a vast extent of country available for settlement, Sir Charles Todd seems to have then been firmly convinced that the construction of the line could be satisfactorily accomplished.

Preliminary Estimate

In a report dated, Adelaide, October 8th, 1862, he comments on the prospectus issued by the promoters of the Anglo-Australian and China Telegraph, and states:—

"In a letter addressed to myself—a copy of which accompanies this report—Mr. Gisborne says the promoters would be prepared to meet Australian lines at whatever point they might be brought to, provided they could be completed by the end of 1864. He expresses his doubts as to the practicability, or expediency, if practicable, of having long land lines traversing an unsettled country with a hostile or mischievous native population, and he urged the difficulty of maintaining such a line in good working order, when completed.

"There is, of course, considerable force in the objections raised by Mr. Gisborne; but I must confess that, in my opinion, the way for a land line seems clearer now than it did, even two years ago.

"The comparative ease with which Burke, Landsborough, and McKinlay have separately crossed to and from Carpentaria, and the encouraging descriptions given by those explorers of the country, all indicate the speedy occupation of the territory between Coopers Creek and Carpentaria, and in South Australia we have already stations within a short distance of the former.

"A land line offers so many collateral advantages, besides its diminished cost, that I cannot forbear urging the desirableness, before pledging ourselves to Mr. Gisborne's scheme in its entirety, of immediate steps being taken to determine the feasibility of carrying the wire to the North Coast.

"The construction of a land line would appear to rest with South Australia or Queensland, according to the route selected. We have now a choice of four, viz.:—

1st: Port Augusta, by Stuart's route, to the Victoria River, Cambridge Gulf.

2nd: Port Augusta, via Coopers Creek to Carpentaria, by Burke's or McKinlay's route, and then to Port Essington or Cambridge Gulf.

(**Note:** Port Essington is in the vicinity of Darwin.)

3rd: Port Augusta to King George's Sound in Western Australia to the neighbourhood of Exmouth Bay.

4th: Moreton Bay to Port Essington or Cambridge Gulf.

"With the first, second and fourth the submarine line would be the same; with the third it would have to be in one length to Java. The cost of the land section would vary from £150,000 to £185,000; and the submarine, taking the distance from the North Coast to Cape Cedano, East Java, £240,000. . . . On the overland line it would be necessary to have stations every 100 miles or so, say, twelve stations in all. At each station beyond the settled districts there should be a staff of four persons—one electrician and three line men.

"I have before expressed the opinion that, by attaching a run to each station, persons properly qualified might be induced to undertake the very light duties of the office at a reasonable rate of remuneration; and such a course would afford profitable employment to the assistants or line men. Failing that, however, I would estimate the cost of maintenance of the land section as follows:—

Twelve stations, salaries and maintenance ..	£12,000
Contingent expenditure	5,000
Renewal funds	3,000
Total annual maintenance	£20,000

"It should be borne in mind that both of the foregoing estimates are on preliminary and rough approximations. They are both, in my opinion, considerably in excess of what the actual expenditure would be. I have very largely increased my estimate of the annual cost of land line; but at first extra precautions would have to be taken to secure the integrity of the line, and I do not wish to prejudice the public mind by under-estimating the cost of that route, and over-estimating that advocated by Mr. Gisborne. I wish to see the work commenced, successfully completed, and that plan adopted, which, after due consideration, shall be thought best calculated to secure the object we mutually seek to accomplish.

(Note: Mr. Gisborne's first estimate of the annual cost of maintenance of cable and line, Java to Brisbane, was £18,000, but eventually increased to £50,000. The cable and line maintenance charges estimated by Sir Charles Todd were £28,000.)

"In a work of such magnitude, nothing can be done without the united action of the Colonies concerned; and as the best means of securing this, I would recommend that a conference should be held between the heads of the Telegraph Departments in Victoria, New South Wales, Queensland and South Australia, who, being practically acquainted with all the details, would be best able to consider the whole question, and give the results of their meeting in a joint return to their respective Governments."

In Mr. Gisborne's letter to Sir Charles Todd he states:—

"I have lately conferred with Sir Richard MacDonnell upon this subject (termination of cable), and have no desire to adopt any other terminus than Cambridge Gulf if South Australia will extend its telegraph system to that point by the end of 1864, when we shall be prepared to lay our cable if the assistance we asked for is granted.

"I must, at the same time, state that I do not believe, for many obvious reasons, that any of the Colonies will assist South Australia in carrying out such a work, nor do I believe it to be practicable to carry it out within that time; I might add, if necessary, that I do not believe that such a line of telegraph will be maintained in permanent working order until the white population becomes considerable and continuous throughout the intervening country."

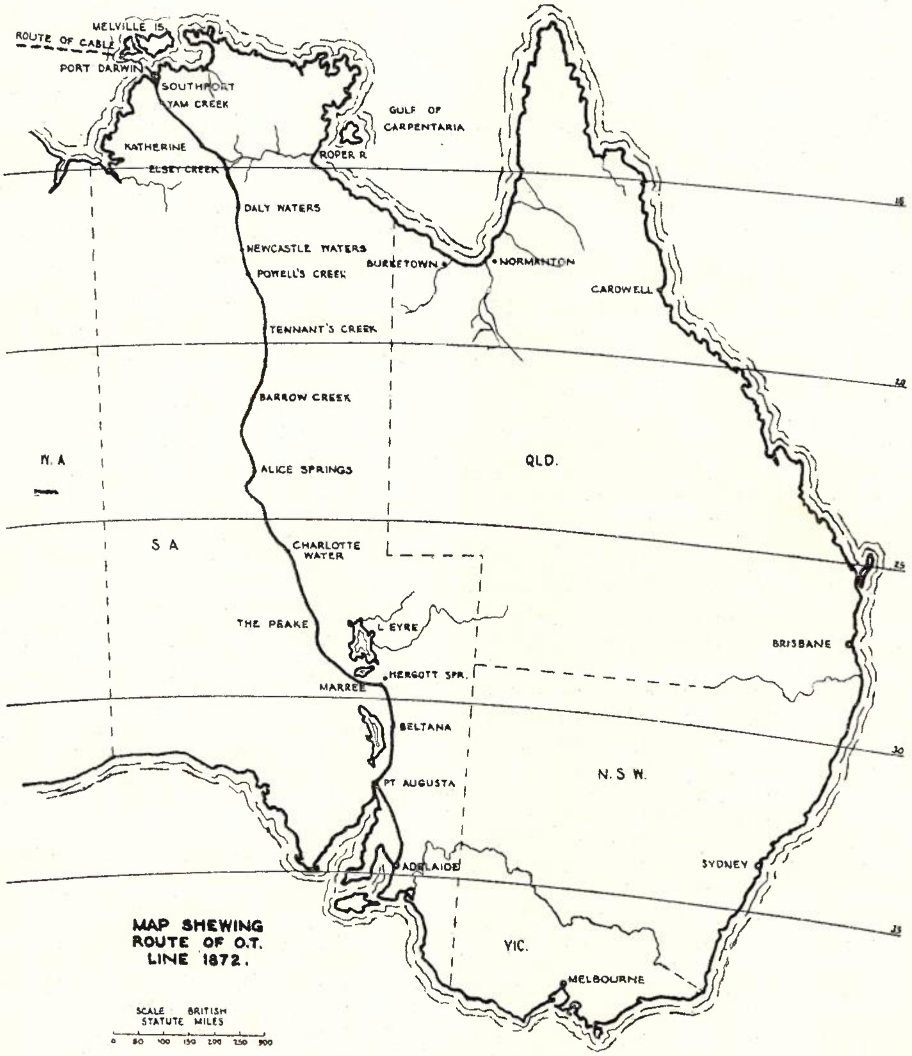


Fig. 2.

Limitation of Routes

Matters then seemed to remain in more or less abeyance until 1869, when Todd, in a further report to Parliament dated August, 1869, in connection with the proposed Anglo-Australian Telegraphs, states:—

"In connection with this work, our choice is now practically limited to two routes:—

1st: Western—a land line from Port Augusta to King George's Sound and Perth, thence via submarine cable to Ceylon.

2nd: Northern—an extension of the Queensland line from Cardwell to the Gulf of Carpentaria, Burketown or Normanton, and thence—

- (a) by the continuation of land line through the Northern Territory of South Australia to Port Darwin, then cable to East Java;
- (b) by cable from Normanton or Burketown to East Java, connecting Port Darwin, as an intermediate station.

"The connection with Java by route (a) is, therefore, the cheapest we could adopt, being little more than half the cost of the Western, and, on this account, although while our messages have to traverse

> the Indian lines, etc., it will recommend itself to many. The principal objections to the Northern route, in my opinion, are the great extent of monsoon country to be traversed by the land lines, etc. . . ."

Proposal 2 (b) was submitted by Mr. Fraser to the Queensland Government. This proposal was to lay a cable from Banjoewangie to Burketown or Normanton, and, if required by South Australia, another station in the Northern Territory. In connection with this scheme, Todd reports:—

> "All circumstances considered, if the Northern route is taken, I would recommend the land line terminating at Port Darwin, provided the Queensland Government will meet us at the boundary."

Sir Charles made no recommendation for a particular route, but pointed out, whichever route is adopted, he strongly urged the importance of the Government retaining the construction and control of the land section in their own hands.

In a subsequent report to the Government, dated 1st October, 1869, he commented on the following schemes for providing communication between England and Australia:—

(1) Mr. Towler's scheme of a coast line from Adelaide, through Western Australia to North-West Cape and from thence by cable to East Java.

(2) Mr. Fraser's scheme of extending the British-Indian lines from Rangoon to Singapore and then to Burketown, via East Java and Timor.

(3) Captain Osborn's scheme—Java to Gulf of Carpentaria or North-West Cape, Western Australia.

Captain Osborn points out that of the two systems, submarine and aerial, although the first cost of the former is by far the greater, still, in the long run, it is the most economical, requiring, if well laid, little if any charge for maintenance, and apart from the cost there is an increase in conviction in Europe of the utter impossibility of maintaining land aerial lines in wild, unsettled country or during times of war, rebellion or civil commotion except at a ruinous cost.

Captain Osborn, writing from England under date 24th August, 1869, suggests a route from Java to the Gulf of Carpentaria because the States of Victoria, New South Wales and Queensland are already connected, and because preparatory surveys have been made for the extension of land lines through Queensland to the Gulf of Carpentaria.

He pointed out, however, that if Victoria desired a Western route, the cable could be laid from Java to the North-West Cape at the North of Western Australia at a considerable saving. This, of course, left difficulty of construction of line between South Australia around the coast to the North-West Cape of Western Australia.

Proposal by Telegraph Construction and Maintenance Company

In addition to the above schemes, all of which involved either guarantees or subsidies or both on the part of the Government, the Telegraph Construction and Maintenance Company, in association with the British-Australian Telegraph Company, entered into the field and undertook to lay a cable connecting Singapore and Darwin, together with the building of a land line extending from the latter place to Normanton, Queensland. Although the prospectus of the Company provided for a land line from Darwin to Normanton, Sir Chas. was apprehensive as to whether the Company would actually terminate the cable at Port Darwin, and construct the land line to Normanton, thinking that possibly the Company, having no inducement to make Darwin the cable terminus, would eventually carry the cable direct from Banjoewangie to Normanton. Concerning this scheme, Commander Noel Osborne, R.N., representing the British-Australian Telegraph Company, reached Adelaide in April, 1870, and in connection with his visit Sir Charles states:—

> "I took the first opportunity of discussing with him my old project of a land line directly across the Continent, and pointed out the great advantages such a line would possess over one which kept for so great a distance in the tropics and flooded country of the Northern Territory and the lowlands around the Gulf of Carpentaria. I also showed that our line would be much shorter, and that Queensland could easily tap it by an extension from Normanton.
>
> "Mr. Strangways, who was then Attorney-General, and in whom the Overland line had found one of its earliest promoters in connection with Stuart's explorations, now took the matter up very warmly, and on receiving an official report from me, a Bill authorising the necessary loan was drafted and laid before Parliament; and notwithstanding a ministerial crisis, the Bill was passed by a large majority, and then, perhaps for the first time, I fully realised the vastness of the undertaking I had pledged myself to carry out. Understand me, I was as sanguine as ever with regard to the practicability of the thing, but the short space of time allotted to me, only 18 months, greatly increased my difficulties. The Bill was passed in June, 1870, and under the contract I had to open communication with Port Darwin by the 1st January, 1872."

Exploration Work of J. McDouall Stuart

At this stage, in order to emphasise the stupendous task undertaken by Todd, it might be interesting to recall the exploration work of John McDouall Stuart, as his was the only party to cross from coast to coast through Central Australia before the work of erecting the line was undertaken.

Before McDouall Stuart endeavoured to cross Australia he examined the country around Lake Eyre in 1859. One of the places of interest to the Department named on this expedition was Hergott Springs (now Maree), Hergott being one of the party accompanying Stuart.

Stuart's First Attempt to Cross Australia: In March, 1860, McDouall Stuart set out on his first attempt to cross Australia. He succeeded in reaching the MacDonnell Ranges and, in addition to naming these, he named the Finke, Chambers Pillar, and several creeks on the way.

Stuart proceeded further north, and on the 22nd April, 1860, wrote:—

> "To-day I find from my observations of the sun that I am now camped in the centre of Australia."

Next day Stuart ascended Central Mt. Sturt, about 2½ miles away, and after erecting a cairn and placing a flag thereon he observed:—

> "May it be a sign to the natives that the dawn of Liberty, Civilization and Christianity is about to break upon them."

From the vicinity of Mt. Sturt, Stuart made three unsuccessful attempts to reach the Victoria River, and then pushed northwards, reaching Attack Creek on June 26th, where his party encountered hostile natives. Although only 250 miles from the Northern Coast, Stuart abandoned the idea of going on and returned to Adelaide in October, 1860.

Stuart's Second Attempt to Cross Australia: On the 29th November, 1860, McDouall Stuart again left Adelaide in a further endeavour to reach the North Coast. The party reached Attack Creek on 25th April, 1861, and from there crossed Sturt Plain and discovered Newcastle Waters. From the latter place several attempts to reach Victoria River were made, but each failed and then efforts were made to penetrate the scrub lying directly north. A point approximately 150 miles from the coast was reached. The expedition, however, was forced to return and Adelaide was reached on 23rd September, 1861.

Stuart's Third Attempt to Cross Australia: On 21st October, 1861, Stuart made his third attempt and again camped at Newcastle Waters. From here the party travelled to Daly Waters, but were then forced north-eastward to the Strangways River, a tributary of the Roper, discovered by Leichhardt. From the Roper, Stuart struck north-west, striking the Adelaide River, and, following it to the sea, arriving at the Northern Coast on 24th July, 1862, just nine months after starting out.

The above brief outline of J. McDouall Stuart's various expeditions northwards has been included in order to show some of the many great difficulties which must have beset Todd, and because the most important result of Stuart's trip was the opening up of a route for the Overland Telegraph Line which the South Australian Government was so anxious to possess.

Offer to Survey Route

So soon as it was known that the line was to be constructed, explorer John McKinlay offered his services

> "to explore, fix and determine the best route, precisely fixing this between the two places named (Port Darwin and Port Augusta), or to any intermediate point that may be determined."

Briefly his terms were:—

Exclusive use of Melville and Bathurst Islands for 25 years; 15 years at peppercorn rental; 5 years at 5/- per square mile; 5 years at 10/- per mile, etc.; plus £1,000.

The party was to consist of eight men, and McKinlay selected Wm. McMinn as Surveyor. The party was to be equipped, fed and paid by the Government.

Preliminary Action Relative to the Construction

A preliminary loan of £120,000 was authorised in connection with the construction of the land line. Tenders were primarily invited for the construction of the whole line, and although one tender was accepted, negotiations fell through and it was finally decided to divide the line into three sections. The first and third sections, i.e., the end sections were to be carried out by contract, and the central and most difficult portion was to be constructed by the Government.

The lower section from Port Augusta to 500 miles north was let by contract to Mr. E. D. Bagot at £41 per mile, and the northern end section was let by contract to Messrs. Darwent and Dalwood at varying prices from £62 to £89 per mile, the Government to provide in each case wire and insulators.

Mr. McMinn was appointed Departmental Overseer for the latter contract, and he was accompanied by Messrs. Howley and Stapleton, operators, with two sets of instruments for the purpose of keeping up communication during the progress of the construction.

The route of the line was to follow that traversed by John McDouall Stuart, with the northern terminus at Darwin. As little information of the country to be passed through was known, Todd arranged to fit out and despatch an exploring party in advance of the construction party. The exploring party, under the command of Mr. John Ross, left Adelaide in July, 1870.

Battle of Land Routes

By his timely action in inducing the South Australian Government to enter into the agreement with Commander Noel Osborne, of the B.A.T. Company, for the construction of the Overland Telegraph Line there is little doubt that Todd forestalled the efforts of Queensland and thus incurred the envy of that State. In order to show the feeling which existed at the time, it might be of interest to quote the following report which was submitted by him to the Chief Secretary, South Australian Government, approximately twelve months after the construction had begun:—

"General Post Office, Adelaide.
"19th May, 1871.

"Sir,—I have the honor to bring under your notice the following extract from the last annual report of the Superintendent of Telegraphs in Queensland, referring to the Overland Line of Telegraph to Port Darwin, now in course of construction:—

'I mentioned in my last annual report that a Company had been formed in England for the purpose of supplying this missing link (Java to Normanton), and that an agent was shortly expected in Australia to make the necessary preliminary arrangements with the several Colonial Governments interested in this important undertaking.

'The Company's agent arrived in Adelaide on the 11th of April last year, and at once, without reference to the Eastern Colonies, entered into a provisional arrangement with the South Australian Government to land the cable at Port Darwin, on the northern coast, that Government agreeing at the same time to construct a line 1,600 miles in length, to the above point, and open it for the transmission of business by the end of 1871. The Queensland Government having been duly advised of these proceedings, instructed the Agent-General in London, by the April mail (1870), to lose no time in communicating with the Company's Directors, and clearly point out the absurdity and the impracticability of the proposed scheme; every exertion has since been made, and a reasonable guarantee offered in order to induce the British-Australian Company to carry out their original proposal, namely, connect with the Queensland lines at Carpentaria, but at present without success.

'I will now endeavour to point out, as briefly as may be, the respective merits of the two lines. The overland line from Port Augusta will follow Stuart's tracks to the Roper, thence by as direct a course as possible to Port Darwin. The country this line will traverse between Lake Torrens and Newcastle Waters, extending over fourteen degrees of latitude, is described as scarcely better than a desert, where little or no timber can be obtained for construction purposes, and, during dry seasons, is, for the most part, devoid of permanent surface water, and feed for cattle cannot be obtained. In wet seasons, many localities on the route are evidently subjected to inundations, and the country generally may be considered difficult for transport of material and stores required for construction and maintenance purposes. On the other hand, the Queensland lines traverse settled country throughout, they have been severely tested in all seasons, and prove to work both regularly and well; they are better cleared and more substantially built than those in course of construction by the Government of South Australia, and therefore less liable to interruption. Although the most strenuous efforts are apparently being made in order to open up communication with Port Darwin by the end of the current year, at present there seems to be little prospect of the work being completed for many months after the expiration of that period. All hopes of working a line of this description with anything like regularity must, I fear, be abandoned, at any rate, until the country is thoroughly opened up and permanently occupied.

'Under these circumstances, it will be readily perceived that the interests of the Australian Colonists and their correspondents throughout the world, will be best served for some time to come by extending the cable to the terminus of the Queensland system at Carpentaria—thereby securing regular communication, as by this route the land lines in Australia traverse settled country throughout, and are at all times accessible for working and repairs.

'In the event of the British-Australian Company confirming the arrangements entered into between their agent and the South Australian Government—which by last advices was not decided—I would still respectfully recommend that the Eastern Colonies unite in carrying a cable to Koepang, or, if necessary, to Java, as I feel convinced that the Port Darwin line will not be completed by the time specified; and, when completed, cannot be depended upon for regular communication.'

"Without wishing for one moment to attribute any intention on the part of Mr. Cracknell to exaggerate the difficulties with which we may have to contend, or any desire to depreciate the manner in which the work is being carried out, the remarks I have quoted are so evidently calculated to mislead, that I have deemed it my duty to bring the matter at once before the Government, the more especially as I find from two articles lately published in the Melbourne 'Argus' and Sydney 'Morning Herald,' that the action taken by South Australia in connexion with this important undertaking is altogether misunderstood; and that, owing to the adverse views officially promulgated by Mr. W. J. Cracknell as to the impracticable character of the South Australian scheme, and its alleged unreliableness when completed, it is advised that a second cable should be laid from Java to Normanton.

"Mr. Cracknell makes two statements which, if correct, would very properly be regarded as grave objections to the line we are constructing being relied upon by the other Colonies or by the British-Australian Telegraph Company, who have embarked so much capital in bringing a cable to meet us. He says that the country traversed is little better than a desert, where little or no timber can be obtained, and in dry seasons is, for the most part, devoid of permanent surface water, and that feed for cattle cannot be obtained. And further, that the line is not being erected in so substantial a manner as the Queensland line, under his control.

"It is much to be regretted that an officer in Mr. Cracknell's position should, through zeal for his own department, have spoken so positively and disparagingly of works carried on here, without first making himself certain as to facts on which he speaks.

"I might, were it necessary or desirable, retort by referring in detail to the lengthened interruptions that have been occasioned by floods on the Queensland lines, but it will be sufficient for me to compare the slow progress making on the Cardwell and Normanton section, of only some 370 miles in length, with the rapid progress being made with the Port Darwin line, to show that their difficulties must at least be as great, if not greater, than any we have hitherto met with. The Normanton line was, I believe, commenced in the early part of last year, and is not expected to be completed till August; whilst, in the short space of seven months, we have erected equal to 700 miles of line, and transported large quantities of material, besides sheep and cattle, into the very heart of Australia. I may point out, too, that our line will be worked under much more favorable climatic conditions, and that, till we near the Northern Territory, it will be exceptionally free from bush fires. Mr.

Cracknell refers to the distance the South Australian line traverses unoccupied country; but the same may be said of the greater part of the Queensland lines for a considerable distance south of Cardwell.

"I will now proceed to meet the objections raised by Mr. Cracknell to the Port Darwin line, and as I shall have to refer to different sections of the line it will be clearer if I here recapitulate the manner in which the work has been divided amongst the several parties employed in the construction.

"Starting from Port Augusta, the line keeps the Western Plains, a little to the east of the Flinders Range, running north for about 180 miles, where it turns westerly, passing between the head of Lake Torrens and Lake Eyre towards Mount Hamilton, and thence northwards past the Strangways Springs, crossing the Neales north of Mount Kingston, and from there direct, by way of the Treuer, to Stuart's track, which is then generally followed to the Roper, and so on to Port Darwin. The total length of the line is estimated at 1,700 or 1,800 miles.

"In laying it out great care is being taken to avoid flats or lowlands subject to inundation, and to keep near to permanent waters.

"The first 500 miles from Port Augusta, extending to or beyond latitude 27 deg., has been let to Mr. Bagot. From latitude 27 deg. to latitude 19½ deg. or beyond, five Government parties are employed, strongly equipped, and having an abundant supply of materials and rations. Each party has a degree and a half, or from 110 to 120 miles of line to put up; they are, for the sake of convenience, respectively designated sections, A, B, C, D and E; section A extending from latitude 27 deg. to 25½ deg., B from 25½ deg. to 24 deg. (i.e., to the MacDonnell Ranges), and so on. From Port Darwin to the Roper and thence to the north end of section E (19½ deg.), the line is being built under contract by Messrs. Darwent and Dalwood.

"Separate contracts have been let for the cartage of materials and rations from Port Augusta, up into the interior, as far as latitude 19½ deg.

"I need only further add, by way of explanation, that the five Government parties started from Port Augusta at the end of September, and reached the MacDonnell Ranges at the end of February. Darwent and Dalwood, having shipped their party with materials, stock and rations in the steamer 'Omeo,' 1,000 tons, and the 'St. Magnus,' commenced their work at Port Darwin in the middle of September. A third vessel took the balance of materials required in February. Mr. Bagot commenced his section at Port Augusta in October.

"The route selected for the overland line is not a new one; nor is the nature of the country under a variety of seasons unknown to us. The late Mr. Stuart, in his several journeys, saw it under all aspects, and traversed it in the driest seasons. His last, and successful, journey was accomplished under most adverse circumstances; in several places no rain had fallen for many months; and yet, he reports, at its termination, that with the exception of two nights, he was never without a sufficient supply of water; and that he saw no difficulty in taking over a herd of horses at any time.

"During the last severe drought many thousands of sheep were sent north of the Neales or north of Lake Eyre, where the country was well watered and feed abundant; and the experience of our own parties now at work in the centre shows that the country is much better watered than is generally supposed—that, in fact, with ordinary care, and with proper means of storage, there is no reason to anticipate more difficulty in maintaining stations anywhere along the route we follow than would at first have been experienced in many districts now thickly settled and under cultivation. One of the officers, writing in March last, the worst season of the year, says, 'The more I see of this country the less I dread it,' and frequent reference is made to the splendid feed.

"With regard to timber, the only extensive stretch of country in which there is little or no serviceable timber near the line is between Leigh's Creek, north of Beltana, and a little north of latitude 27 deg., a distance of over 300 miles, with the exception of some fine timber discovered by Mr. Babbage near Mt. Margaret. I mention this to show how easily we have overcome what may have seemed elsewhere to be a great difficulty. The whole of the distance mentioned, extending over the northern half of Mr. Bagot's contract (the first 500 miles) and the southern half of Section A (latitude 27 deg. to 25½ deg.), has now been provided for, poles being already planted over the greater portion, and the remainder are being rapidly deposited by a large number of teams. Indeed, so rapidly is the work being pushed forward that the iron poles ordered for this section of the line have, for the most part, arrived too late, and only 1,500 will be used, the remainder being stored or used elsewhere.

"From a little north of latitude 27 deg., our working parties have found an abundance of fine gum trees, making splendid poles, extending up to the MacDonnell Ranges, and the line is progressing rapidly; and beyond the MacDonnell Ranges, the explorations of Mr. Stuart, and the more recent journey of Mr. Ross, show that there is no great distance without timber; indeed, the farther we get north the less appear to be our difficulties in respect to both water and timber.

"Next, with regard to the future maintenance, I feel it to be unnecessary for me to assure the Government that the line is being erected in a most substantial manner. The wire is of the very best quality, specially manufactured for us by Messrs. Johnson & Nephew, and the insulators are of the most approved form.

"The bulk of the poles on this side are heavy gum saplings, many twelve inches in diameter at the butt, none less than nine or ten inches, and pine poles of similar dimensions. Not fewer than twenty to the mile are being planted.

"Three thousand wrought-iron poles (galvanised) have been imported, of which a large number are now being carted up for the section between 400 and 500 miles from Port Augusta. The remainder, if not required for the interior, will probably be sent to Port Darwin and distributed over those portions of the line which are most exposed to bush fires in the dry season. From Port Augusta, and all through the interior, the line will be perfectly safe, and every precaution will be taken in the northern sections, where the vegetation is more luxuriant.

"The clearing is mostly very light, except in the Northern Territory, but the line will be well cleared throughout.

"There will be substantially built stations about every 150 or 180 miles, at each of which, beyond the settled districts, it is proposed to place four persons, with every appliance for effecting repairs, and well provisioned. Where there is not a permanent supply of water at hand, it is intended to build large tanks, capable of holding eighteen months' supply, and along the line wells will be sunk or water stored at convenient intervals.

"One station has already been erected at the Peake, close to permanent springs, and plans of those for the interior have been sent to each of the five Government parties working between latitudes 27 deg. and 19½ deg.

"What I have said will, I think, conclusively show that every provision has been made for the work being carried out in an efficient manner, and that when completed it will be as reliable as any of the existing lines in the Australian Colonies. It will be really freer from interruptions, and when they do occur no delays need be apprehended arising from the supposed impracticable nature of the country, as that is more imaginary than real; in proof of which I need only state that in the space of a few months we have carted from Port Augusta about 250 tons of materials into the centre of Australia, and have there, at the present time, several thousands of sheep and a large number of horses and bullocks. All of these have travelled up without any serious difficulty, and although many of the teams have had a load of two and a half tons, the stock are reported to be in better condition than when they left Port Augusta.

"With regard to the time of the work being completed, I can only say that, at present, there seems to be every probability of communication being established by the end of the present year. On Bagot's contract of 500 miles, at the present date, poles are erected for about 350 miles from Port Augusta; and sufficient for 150 miles more are cut and being rapidly distributed. The wire has been mostly carted, and will be put up at the rate of over 100 miles a month—commencing in a day or two. A field operator will accompany the wiring party to keep up the communication with Port Augusta and Adelaide.

"All the materials required for the five interior sections, extending over 600 miles north of latitude 27 deg., are now up with the working parties, as well as rations for twelve months. On two of the sections, A and B, the work was commenced in February, and by the end of March about 100 miles of poles were planted. Our last advices, dated the middle of March, reported the crossing of the MacDonnell Ranges—a good passage having been discovered; and it was then thought that two sections, C and D, would be at work in April, and section E in May.

"I quite expect to have communication for 800 miles north of Port Augusta by the end of September, and the line well advanced by the three parties beyond, who will have been at work several months.

"On the Northern side, from Port Darwin, we have no late advices, but we know that in the first seven weeks ending November 8th ninety miles of line were completed, and communication established with Port Darwin—a field operator accompanying the construction party. Supposing the work to have progressed at an average rate of eight miles a week since then, they will have completed over 300 miles, at the

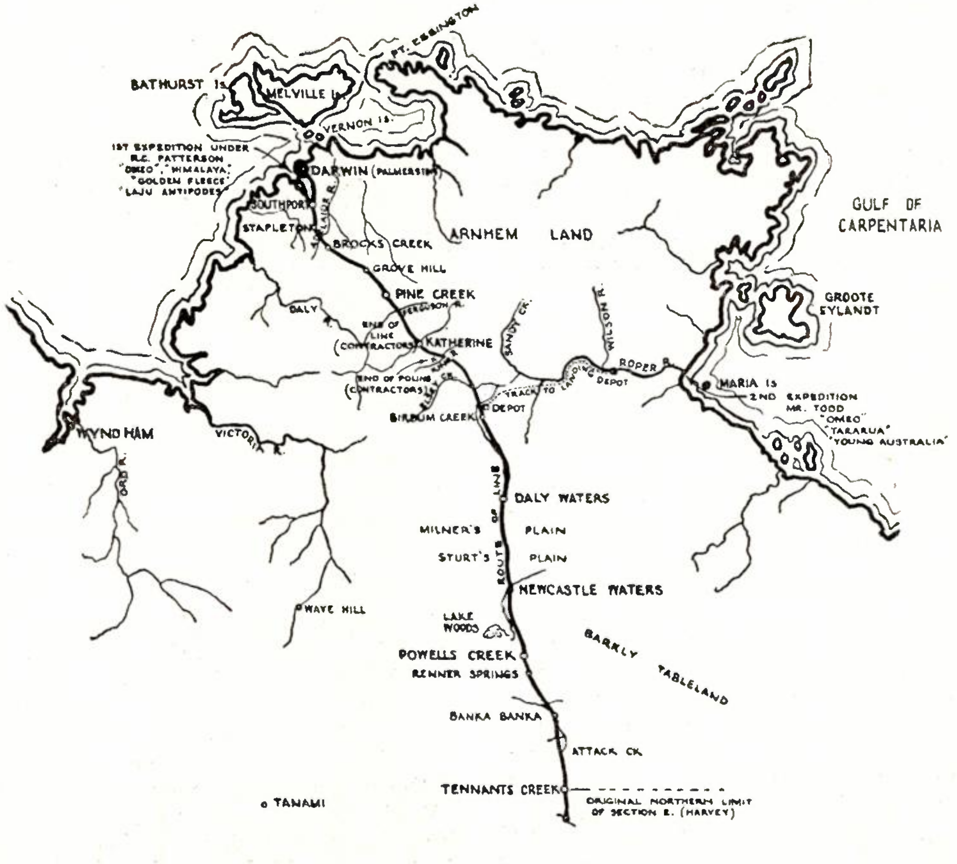


Fig. 3.—Map of North Australia Showing Route of Northern End of Line.

present date; and, at the same rate, having all the materials at hand, they will complete 550 miles by the end of the year.

"The mouth of the Roper has been surveyed, and found to be navigable for a considerable distance, which has been availed of by sending all the materials for the line, south of that river, round by sea, instead of being carted overland.

"I have the honor, etc.,
"CHAS. TODD."

Breakdown of Northern Contract

At about this time good progress had been made on the lower and central sections, but the position in connection with Darwent and Dalwood, contractors for the northern section, is a different story. After approximately 225 miles of poles and 156 miles of wire had been erected the contract broke down, and this news reached Adelaide with the arrival of Mr. McMinn (Overseer) in July, 1871. This news was a great blow to Sir Charles, who was supervising operations from Strangways Springs at the time. However, a large expedition was rapidly fitted out and placed under the charge of Mr. Patterson.

Owing to the failure of the northern section, arrangements were made for Mr. Harvey's party (Section E) to push the line on as far north of his section as possible by erecting, in the first instance, only 10 (half the specified number) poles to the mile. These instructions, of necessity, involved the despatch of a further large supply of rations, as it was certain that some of the Central parties would have to remain on the work much longer than was at first anticipated. The net effect of this action resulted in 82 miles of line north of the boundary of Harvey's original section being constructed.

Both Todd and Patterson agreed that the main base of operations for the relief construction party for the northern section should be located at the Roper River, but it was decided that less risk would be incurred by landing at Darwin. As will be subsequently seen, this decision proved disastrous and was the main cause of the delay in the completion of the line beyond the specified time.

(To be continued)

X-RAYS AND THEIR USE IN THE P.M.G. RESEARCH LABORATORIES

P. R. Brett, B.Sc.

Introduction: When X-rays were first discovered in 1895 by Roentgen, their character, as their name suggests, was unknown. They immediately became the subject of intense scientific research, and within a few years were identified as electromagnetic radiations occupying the gap in the electromagnetic spectrum between the extreme ultra-violet and the gamma rays given off from the nuclei of some radio-active substances. See Fig. 1.

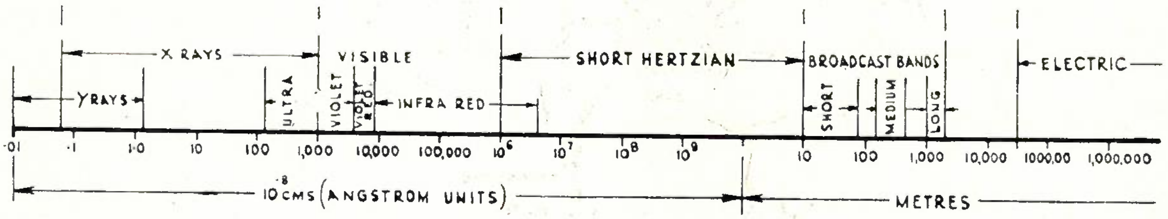


FIG. 1- ELECTRO MAGNETIC SPECTRUM

If electricity is passed through a gas at low pressure, cathode rays pass from the cathode to the anode. These cathode rays were identified as electrons by J. J. Thomson, and it was found that X-rays are produced when these electrons collide with the atoms of any target which may be placed in their path. These X-rays will penetrate considerable thicknesses of materials that are opaque to visible radiations, and this penetrating power increases as the frequency of the X radiation is increased.

When the potential is first applied to an X-ray tube, the few positive ions that exist in any gas are accelerated towards the cathode, and as a result of this bombardment electrons are emitted. These electrons are accelerated towards the anode and develop sufficient energy to create more positive ions as they pass through the gas, and so the discharge is maintained.

In the operation of this type of tube, known as the "gas-filled tube," the gas plays an essential part, and a residual gas pressure of about one-millionth of an atmosphere must be maintained. This residual gas limits the potential that can be applied to the tube, and, as the frequency of the X radiation depends on the applied potential, the penetrating power or "hardness" of the X-rays from a gas-filled tube is limited.

With the development of the knowledge of thermionic emission, it became apparent that electrons could be produced at the cathode by using a heated filament, and in 1913 the Coolidge tube appeared. In this tube the production of electrons at the cathode is not dependent on the presence of gas, and, in fact, the operation of the tube is hindered by any residual gases. Thus there was no fundamental factor limiting the potential that can be applied to the tube, and the hardness of the X-rays is limited only by considerations of construction.

Brief Theoretical Discussion of X Radiation: (a) If the intensity-frequency curve is drawn for the X radiation from a given target it is found that the curve obtained is somewhat as shown in Fig. 2.

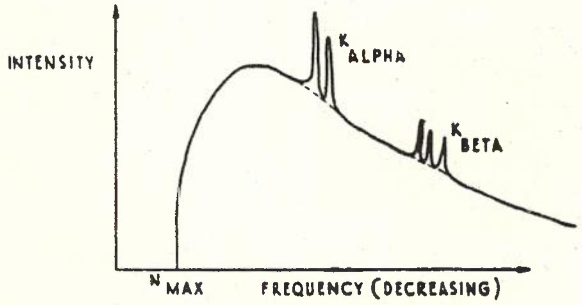


FIG. 2 - INTENSITY - FREQUENCY DISTRIBUTION OF RADIATION FROM A METAL TARGET.

There is a continuous spectrum, starting abruptly at a high frequency limit n_{max}, and extending continuously to lower frequencies, and, superimposed on this, we have a line spectrum. This means that at certain definite frequencies the energy is considerably higher than at adjacent frequencies. The explanation of this follows readily from a consideration of elementary quantum ideas.

(b) **Continuous Spectrum:** When an electron emitted from the cathode reaches the target it has an energy given by Ve where V electrostatic unit is the potential applied to the tube and e is the electronic charge. When the electron reaches the target it suffers a retardation due to the influence of the atoms of the target, and the energy lost is radiated as a pulse of X radiation.

This pulse of X radiation has energy hn where h is Planck's constant $= 6.610 \times 10^{-27}$ erg second, and n is the frequency of the X radiation. Using the principle of conservation of energy, we get:

$$hn = \text{energy lost by the electron} \quad \ldots\ldots \quad (1)$$

The greatest amount of energy that the cathode electron can lose is Ve, and this happens if the electron is brought to rest by a single process, i.e., there is a maximum frequency of the X radiation given by:

$$hn_{max} = Ve \quad \ldots\ldots \quad (2)$$

All electrons are not brought to rest by a single process, but, in general, they are gradually slowed down by a series of processes, each one involving different energy losses. For each energy loss by the electron there is a pulse of X radiation emitted with a frequency given by equation (1), and as all energy losses up to Ve may occur with different electrons, all frequencies less than n_{max} are represented and a continuous spectrum is obtained. This continuous radiation is known as the "white" radiation.

(c) **The Line Spectrum:** The explanation of this is slightly more involved, and entails a consideration of the electron distribution in the atoms of the target.

For elementary considerations, an atom may be represented diagrammatically by Fig. 3. There is a central nucleus surrounded by electrons, which rotate about the nucleus in definite groups of orbits known as shells. The number of electrons in a shell and the distances of the shells from the nucleus vary according to the type of atom. The innermost shell is known as the K shell, and contains a maximum of two electrons. The second shell is known as the L shell, and contains a maximum of eight electrons, and so on.

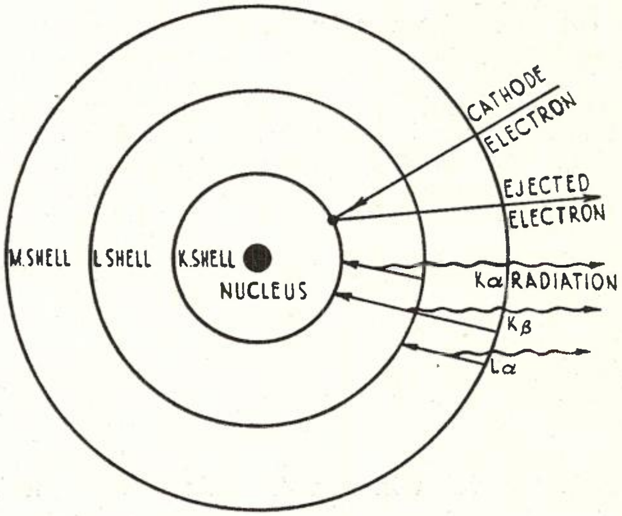


Fig. 3.—Diagrammatic Representation of an Atom.

The electrons rotate about the nucleus without loss of energy, but if an electron changes from one shell to another there is an energy change. Electrons in larger orbits have greater energies than electrons in smaller orbits. Thus, if E_K is the energy of an electron in a K orbit, etc., then

$$E_K < E_L < E_M \quad \ldots\ldots \quad (3)$$

If an electron is dislodged from a K orbit there is a vacancy in the K shell, and an electron falls in from an outer shell to take its place. If the vacancy is filled by an electron from the L shell, then there is a loss of energy given by $E_L - E_K$ and this energy is radiated as X radiation with the frequency given by

$$hn = E_L - E_K \quad \ldots\ldots \quad (4)$$

Consider the atom in Fig. 3 as being part of the target of an X-ray tube. This atom is being bombarded with electrons from the cathode, and if these are of sufficient energy an electron may be knocked from the K shell. This vacancy may be filled by an electron from the L shell, in which case we have a radiation of frequency given by $hn = E_L - E_K$. This is known as the K alpha radiation. If the vacancy is filled by an electron from the M shell we have another radiation known as the K Beta radiation of frequency, given by

$$hn = E_M - E_K \quad \ldots\ldots \quad (5)$$

In a similar way, if the electron is dislodged from the L shell, we get the L alpha and the L beta radiation, etc. The energies of the electron orbits are constant for the atoms of each element, but vary from element to element. In this way we get a radiation produced that is characteristic of the atoms of the target.

Use of X-rays in the P.M.G. Research Laboratories

The industrial use of X-rays falls into two distinct divisions:

(a) The radiographic examination of opaque articles, and

(b) The determination of crystal structure.

Radiographic Examination: When X-rays pass through material it is found that the intensity of the emergent beam is less than the intensity of the incident beam, and that this diminution in intensity is dependent on the thickness of material traversed and also on the nature of the material. Heavy elements are more absorbent than light elements, the absorption depending approximately on the atomic weight of the element.

If an article, made of a good absorber, is placed between an X-ray tube and a photographic plate or a fluorescent screen, a shadow of the article will be produced on the screen or plate. This fact is used in equipment designed for radiographic examinations. A small portable apparatus is illustrated in Fig. 4. This was designed for examining cable joints, but may be used for the examination of any small articles.

The article to be examined is placed on an "X-ray transparent" platform, and a photographic plate is placed over it, or else the image is viewed visually by means of a fluorescent screen. Exposures for photographic work vary with the thickness and density of the article being examined. For very thick castings the exposures may be many hours, and special arrangements are necessary to enable the tubes to operate continuously for long periods. For the normal run of work in the laboratory the exposures do not exceed 15 seconds. An automatic pre-set switch for making exposures is incorporated in the equipment.

The penetrating power of the X-rays depends on the frequency, and this is controlled by controlling the potential applied to the tube. In the apparatus illustrated, the potential is continuously variable between 35 kV and 85 kV.

The intensity of the X-rays depends on the number of electrons striking the target, and this is controlled by controlling the filament temperature.

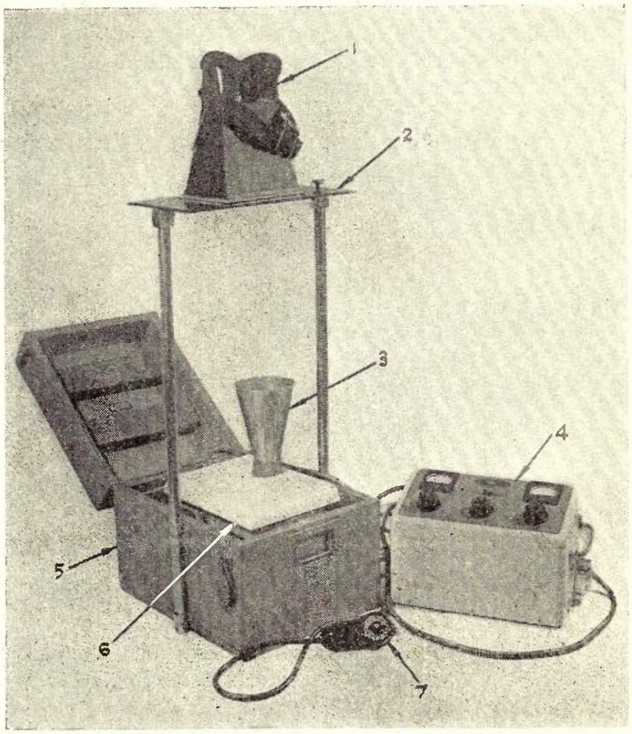


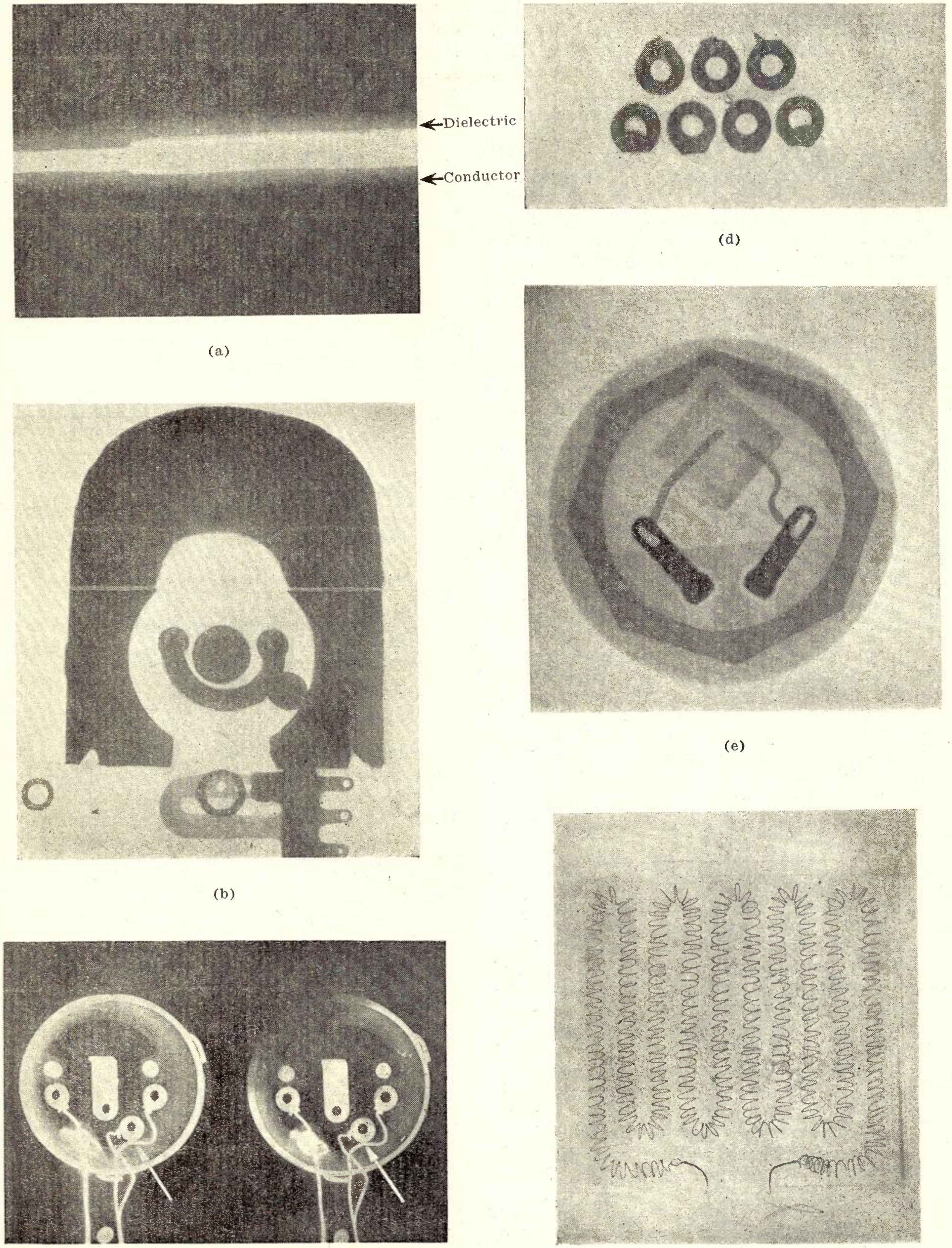
Fig. 4.—Portable X-Ray Radiographic Equipment.

(1) Device for viewing X-Ray shadows on fluorescent screen.
(2) X-Ray transparent platform.
(3) Shield to confine X-Rays to a cone and protect the operator.
(4) Unit for control of beam intensity and penetrating power.
(5) Carrying case for transformer and X-Ray tube unit.
(6) Transformer and tube unit.
(7) Preset timing switch.

With the high voltages that are applied to X-ray tubes, it is only possible to pass very low currents unless special arrangements are made for cooling the target. This is usually done by water cooling, but with a portable unit this is not always possible, and the tube must be operated within certain strict limits to avoid overheating with consequent loss of efficiency, due to pitting of the target, and also to avoid the risk of damage to the glass envelope of the tube.

This type of equipment can be used for the examination of castings, moulded products, etc., for voids, cracks, or inhomogenities, for the examination of welds for flaws, and for the examination of the interior structure of assemblies that it is inconvenient or impossible to dismantle without destroying the whole assembly. One of the great virtues of this method of examination is that it is non-destructive.

The accompanying photographs, Fig. 5, are representative samples of radiographic photographs taken in the laboratory.



(a)

(b)

(c)

(d)

(e)

(f)

Fig. 5.

Fig. 5 (a) is a section of an X-ray photograph of a joint in a submarine cable. The photograph shows the junction in the cable conductor and the surrounding cable dielectric. The point of interest in this photograph is the variation in intensity of the X-ray shadow cast by the cable dielectric. This indicates that the dielectric used in this case has air bubbles in it, and so would have an appreciable porosity. In addition, the air bubbles would cause an alteration to the cable characteristics, and also would increase the liability of the cable to failure. This use of X-rays found application during repair to the Tasmanian submarine telephone cable. All the joints were examined by X-ray before the cable was replaced, and in this way joints that could cause trouble in the operation of the cable were detected and subsequent trouble avoided.

Fig. 5 (b) is an X-ray of a small generator. The generator in question did not have the output that was expected. The fault could have been detected by dismantling the generator, but this was rather inconvenient, and instead an X-ray photograph was taken. The reason for the poor output was readily seen to be the air gap between the permanent magnet and the pole pieces, which increased the reluctance of the magnetic circuit and so reduced the flux between the pole pieces.

Fig. 5 (c) is two stereoscopic X-ray photos taken of a section of a handset. The handset was faulty, and the location of the fault could normally only be determined by destroying the moulded material of the handset. Stereoscopic X-ray pictures were taken of the handset; i.e., two pictures were taken from slightly different angles, and the results illustrated were obtained. When these stereoscopic pictures are viewed in a stereoscope a three-dimensional picture is seen, and in this way the fault was shown to be due to a short circuit at the point marked with the arrow.

Fig. 5 (d) illustrates another case where X-rays served to locate a fault in a moulded article. The article in question is a moulded relay base plate. Trouble was experienced with the base plate, and it was realised that if the bakelite was destroyed in an endeavour to locate the fault, there was a strong possibility of the fault being destroyed also. However, an X-ray photograph was taken, and the fault was shown to be due to some fine metal turnings making a short circuit between two of the relay terminal sockets.

Figs. 5 (e) and (f) are X-ray photographs of a piezo-electric crystal receiver and a ceramic hot plate, and serve to illustrate how the internal structure of assemblies that cannot be dismantled without destroying the assembly can easily be checked by means of X-rays.

Other uses of this method of examination will suggest themselves to the reader. An application that has been tried overseas involves the use of X-rays for the examination of wooden telephone poles to ascertain if they are sound or whether they need to be replaced.

Characteristic X-ray Spectra and their Use for the Determination of Crystal Structure: Most substances occur in nature in crystalline formation, and it is possible to use the characteristic radiation from an X-ray tube to obtain information regarding the internal structure of these crystals.

In a crystal the atoms of the molecules of the material are arranged in a space lattice. See Fig. 6. In effect, the different types of space lattice are determined by the axial lengths, X, Y and Z, and by the angles between these axes, a, b and c. It is found that, with few exceptions, the space lattice is characteristic of the chemical substance, and if this space lattice can be determined, then it can be used to identify the substance in the same way as optical spectra can be used to identify radiating atoms or molecules.

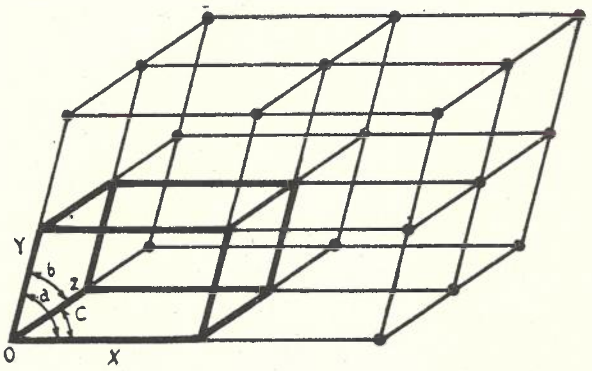


FIG. 6- CRYSTAL LATTICE

Consider a crystal lattice having atomic planes —A, B and C distance d apart—see Fig. 7, and imagine a parallel beam of X-rays incident at angle θ to the planes. These are reflected at an equal angle θ. The reflected ray in direction OP is made up of two rays (1) that fraction of QR that is reflected at O and (2) that fraction of LM that is reflected at N.

As X-rays are electromagnetic radiations, there will be a phase difference between the two rays arriving at O, depending on the path difference (MN + NO — OR). Because of this phase difference interference will occur in the reflected beam, and it can be readily shown that the condition for constructive interference is:

$$n \lambda = 2d \sin \theta \qquad (6)$$

where $n = 1, 2, 3$, etc., and λ is the wavelength of the incident radiation.

In order to obtain intelligible results, this formula, known as the Bragg equation, calls for the use of a monochromatic radiation, and use is made of the characteristic radiation from an X-ray tube. Any unwanted components of the characteristic radiation are absorbed by appropriate filters.

Then for a given wavelength and a constant lattice parameter d there will be constructive

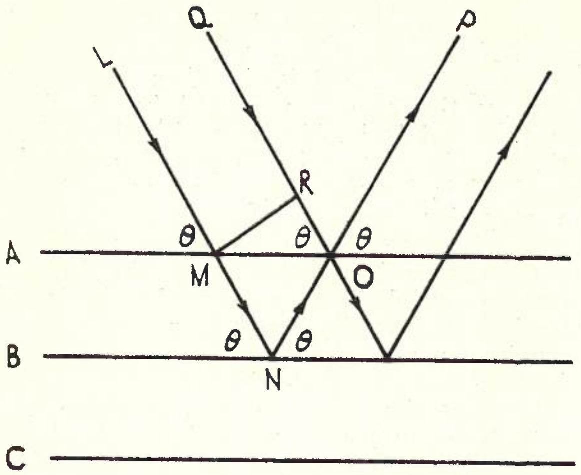


FIG. 7

interference for a certain angle of incidence θ. Conversely, if d is unknown, the direction for constructive interference can be determined experimentally by using a photographic plate placed in a known position relative to the specimen and d can be calculated from the known value of λ and the measured value of θ.

Actually, it is not quite as simple as this, because, in a space lattice, there is an unlimited number of atomic planes, each having a different value of d and in theory each of these will produce a spot on the photograph. In practice, only those planes having large numbers of atoms cause sufficient reflection to cause a visible spot on the film. Pictures taken by this method are called Laue pictures, and may be taken either by transmission through the sample or by back reflection from it. See Fig. 8. Pictures of this type are not used very extensively, as a single large crystal is required, and even with a simple crystal structure, an extremely complicated diffraction pattern is obtained. The pattern is further complicated by the fact that reflections take place in three dimensions instead of two, as was assumed in the simple discussion above.

An important development of the crystal diffraction method came when Debye and Scherrer in Europe, and Hull in America, developed the powder method of X-ray diffraction. In this method the crystalline sample is powdered into tiny crystallites, which are mounted in some convenient way in the X-ray beam, and the sample is surrounded by a cylindrical film as shown in Fig. 8. The crystallites are randomly oriented in the sample, and each one produces its own pattern of Laue spots. These merge together to form a line. In this way we obtain a line diffraction pattern. The sample is usually rotated in the beam to increase the probability of a crystallite coming into such a position that constructive interference occurs.

The pictures obtained are symmetrical about the centre of the film, and from the separation of the lines, the geometry of the camera, and the known X-ray wavelength, it is possible to calculate the separation of the atomic planes that caused any particular pair of lines. In this way the characteristic atomic spacings can be obtained.

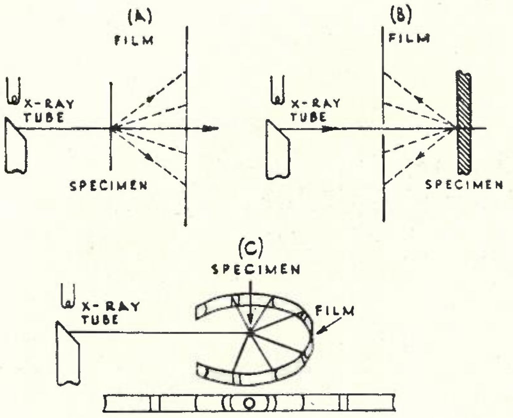


FIG. 8. ARRANGEMENT FOR PHOTOGRAPHING X RAY DIFFRACTION PATTERNS. (A) TRANSMISSION (B) BACK REFLECTION. AND (C) POWDER PHOTOGRAPHS.

The characteristic spacings of some thousand chemical substances have been listed by the American Society for Testing Materials in conjunction with the American National Research Council, and by comparison with these cards an unknown salt can often be identified.

The apparatus used in the laboratory is illustrated in Fig. 9. It is a Siemens and Halske X-ray Diffraction Unit, using a cobalt anode X-ray tube, operating up to 45 kV, and about 7-10 mA tube current. The anode is water cooled, and the circuits are so arranged that if the water flow is insufficient to cool the tube a buzzer sounds and the tube is automatically switched off. The tube is completely shielded, and the X-rays emerge through three windows placed at 120 deg. to each other. Three cameras can be operated at the one time. In order to ensure that a parallel beam is incident on the sample, the X-rays are passed through a collimating system of slits. These slits are changeable, and the ones in general use are the 1 mm. and the 0.5 mm. slits. The $K\alpha$ radiation only is used, the $K\beta$ being removed by an iron filter.

The unit is provided with Debye-Scherrer, Laue and back reflection cameras; the Debye-Scherrer cameras being the ones most commonly in use. The samples are mounted in the centre of the camera and rotated slowly during the exposure, which takes about 60 minutes with a 1 mm. slit.

The photographs, when developed, are measured in a device made in the laboratories workshop, which has a scale calibrated to give the atomic spacings directly, and so the tedious mathematical calculations are eliminated.

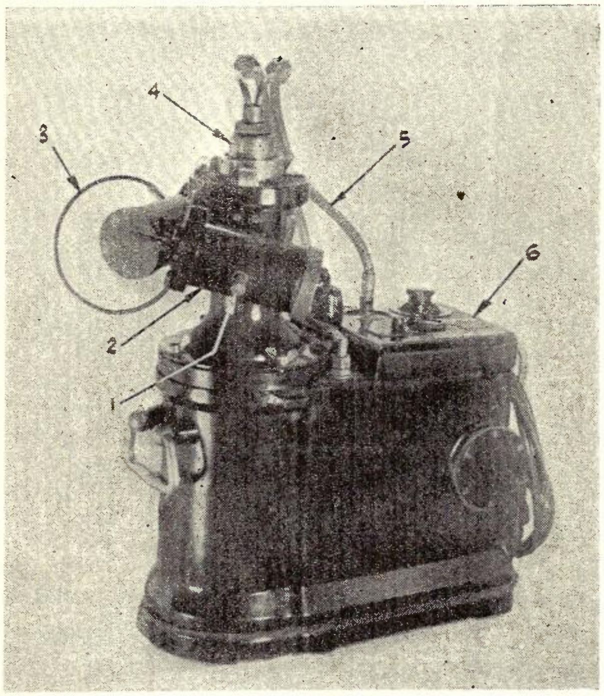


Fig. 9.—Siemens and Halske X-Ray Diffraction Unit.

(1) Trap to absorb direct beam of X-Rays to prevent fogging of the film due to scattering.
(2) Cylindrical camera.
(3) Flexible shaft for rotating specimens during exposure. The shaft is driven by a motor which is not shown in the photograph.
(4) Metal shield of X-Ray tube.
(5) Water piping for carrying water to the anode.
(6) Control panel.

As the X-ray diffraction method is a comparatively young method of analysis, by no means all chemical substances have been listed, and often a substance is obtained that does not correspond to any in the ASTM lists. The procedure in cases like this is to endeavour to produce a material having the same diffraction pattern by controlled experiment in the laboratory, and in this way unknown substances can often be identified. A particular case of this procedure is detailed below. See also Research Laboratory Report No. 2517.

An extremely small quantity (about .001 cc.) of corrosion product scraped from a Cadmium plated component of some electrical equipment received from overseas was submitted to the laboratory for identification. An X-ray diffraction pattern was obtained, but this did not correspond to any of those listed in the available published data. The vapours that are most likely to be present in a packing case during transport of the equipment are water vapour, acetic acid vapour arising from the wood of the packing case, and vapours arising from linseed oil in the paints on the wood. A series of experiments was then set up in which pieces of Cadmium were subjected separately to water vapour, acetic acid vapour, and the vapours arising from linseed oil for a period of about six weeks. The corrosion products formed were then examined by the X-ray diffraction technique, and the diffraction patterns obtained. The pattern produced by the corrosion caused by the linseed oil was found to be identical with the unknown pattern. As the chief vapour arising from linseed oil is formic acid, it was suspected that the corrosion product was cadmium formate. Some cadmium formate was then produced in the Chemistry Laboratory, and its diffraction pattern obtained. This was found to be identical with that of the unknown salt, or in other words, the unknown corrosion product was identified as cadmium formate, probably caused by vapours arising from the paints in the packing cases.

The X-ray diffraction method can also be used to determine the composition of alloys. For example, at ordinary temperatures, a Ni-Fe alloy with greater than about 34 per cent. Ni has a face centred cubic lattice, and the lattice parameter varies as the percentage of nickel is increased. Information correlating lattice parameter and alloy composition is available, and if the lattice parameter for an unknown Ni-Fe alloy is known, it is possible to obtain the composition of the alloy from the published data. Another use of the X-ray diffraction method is for studying phase changes that take place in metals and alloys under the action of heat. Changes of phase are accompanied by changes of crystal structure, and so the phase changes can be followed. This application proved useful recently in the laboratory when a simplified heat treatment of telephone magnets was being developed.

The method also lends itself readily to the determination of preferred orientation in crystals, and to the detection of strains in the crystal structure. If there is a preferred orientation, then more reflections take place in one direction than another, and the intensity of the lines is uneven. If strains exist in the crystals, then the diffraction lines are distorted due to distortion of the crystal lattice.

The Laue or back reflection methods can be used to determine the orientation of quartz crystals that are used for oscillator control, but the method is rather tedious for plates of completely unknown orientation.

Quantitative work with X-ray diffraction patterns is rather difficult, owing to the difficulty of standardising the conditions of the experiment. A few quantitative measurements have been made using a spectraphotometer recording on a Speedomax Recorder, but the results obtained have not been very satisfactory.

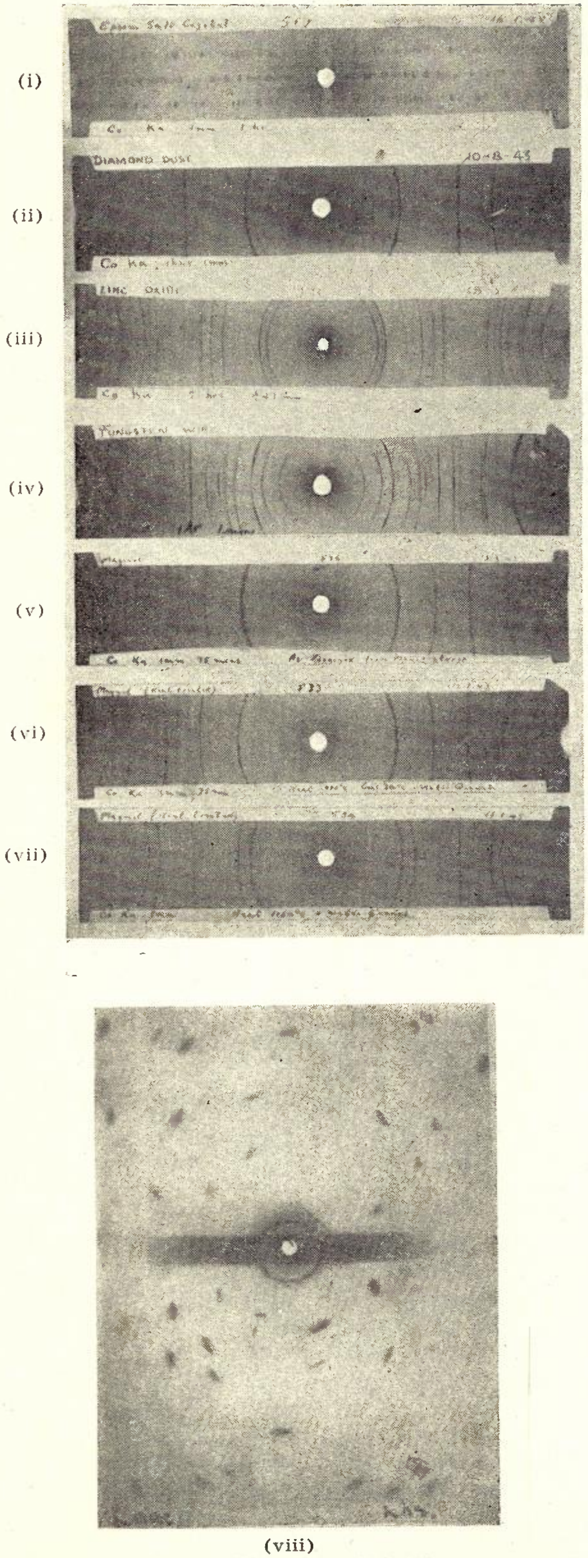
Fig. 10 shows examples of the type of diffraction patterns obtained with the apparatus.

Fig. 10 (i) is the diffraction pattern produced by a single epsom salt ($MgSO_4 . 7H_2O$) when it is rotated in the beam of X-rays in the cylindrical camera.

The apparatus is arranged as in Fig. 8 (c).

Each set of crystal planes produces a spot on the film.

Fig. 10 (ii) is the diffraction pattern produced by some diamond dust. A close examination of the lines on the film shows that they are not continuous, but are made up of a large number of individual spots. This shows that the crystallites in the diamond dust are randomly oriented, but that they are relatively few in number, and of relatively large size.



(viii)

Fig. 10.—Diffraction Patterns.

Fig. 10 (iii) is a normal powder diffraction pattern. It is impossible to see any graininess in the lines and they are of even intensity. This indicates that there is a large number of small crystallites, and that they are randomly oriented.

Fig. 10 (iv) is the pattern produced by a tungsten wire. There is no graininess in the lines, but they are of uneven intensity. This indicates that there are a large number of small crystallites, but that they have a preferred orientation, and so produce more reflections in some directions than in others.

Figs. 10 (v), (vi) and (vii) are a series of X-ray diffraction patterns obtained during experiments to determine the best heat treatment for bell magnets. The magnets when received had poor magnetic properties, and the pattern obtained, Fig. 10 (v), indicates that the crystal lattice is a body centred cubic lattice. Fig. 10 (vi) is the pattern obtained after a magnet had been heated to 800 deg. C., then cooled in air to 300 deg. C. and water quenched. There is no apparent change in the structure. Fig. 10 (vii) shows the pattern obtained when the magnet was heated to 1150 deg. C. and water quenched. With the rapid cooling obtained in water the magnet retains the structure that it had under the conditions of high temperature. This structure is seen to be changed and the pattern is now that produced by a face centred cubic lattice. In actual fact, heating to 1150 deg. C. has caused a phase change to take place, the alpha-iron being changed to gamma-iron.

It was found that the best magnets were obtained when the heat treatment was so arranged that the magnet was made up of a mixture of these two types of crystal.

Fig. 10 (viii) is a Laue diffraction pattern obtained from a quartz crystal, the apparatus being arranged as in Fig. 8 (a).

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(2) Applied X-Rays, Clark.

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(4) X-Rays in Industry: Part 1: An historical survey of the discovery and application of X-rays.—Siemens Engineering Supplement, June/July, 1943.

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TELEPHONE RECEIVERS

J. C. Wilson

Introduction: The first practical telephone instrument was demonstrated in 1876 by Alexander Graham Bell. It consisted of a single bi-polar electromagnetic diaphragm armature unit, which was used both to transmit and reproduce speech. This principle is still the one most commonly employed in present-day telephone receivers because of its simplicity, but the carbon type microphone soon displaced it as a transmitter because of its higher output, this being due to the fact that it is inherently an amplifier as it controls power but does not generate it. Many other devices have since been developed to convert electrical energy to acoustical energy, and their principles have been understood for many years now.

Much progress has been made in the refinements of receiver design during the last decade, in which the products of research in materials, especially magnetic materials, have enabled telephone engineers to develop very sensitive receivers. The present war has stimulated development considerably because of the urgent demands from the fighting services for receivers with high sensitivity, a prescribed frequency response, and freedom from distortion for use in planes and tanks, where high ambient noise levels exist. Another common demand is light weight and small size, which has led to the development of earplug receivers; these employ well known principles but depend mainly for their existence on the improved materials referred to.

It is the purpose of this article to describe briefly the common types of receivers in use, together with characteristics of some new materials used in them and their advantages, also the principles of the refinements employed and methods of testing.

General: A telephone receiver is essentially a device for converting electrical energy to acoustical energy. This is generally achieved by first converting the electrical energy to mechanical energy in the form of movement of a diaphragm; these movements or vibrations in turn excite the volume of air enclosed within the ear and the boundary of the receiver. The receivers described in the following paragraphs are classified according to the method used to drive the diaphragm. The important characteristics associated with each method are its efficiency in converting electrical energy to mechanical energy, inherent distortion, frequency response, and finally simplicity of construction which generally decides which method will be adopted. The frequency response can be controlled to some extent by judicious choice of the diaphragm structure. This method, however, is generally difficult and unreliable. The general practice at present is to design the electromechanical system to give maximum sensitivity and attenuate or reinforce frequencies where peaks or troughs occur respectively by acoustical means. This action, known as acoustical equalization, is generally accompanied by a loss of acoustical power and can only be justified to the extent of the excess power available. The latter is obtained by employing improved materials in the electromechanical system. The Type 2P Receiver at present being introduced by the Department and described in Vol. 2, No. 6, p. 366, is designed on these principles.

Electromagnetic Diaphragm Armature Type: Reference is made to this receiver in the introduction, and no doubt readers will be familiar with its appearance. The Departmental Type 1L is a well-known example. Fig. 1 is a diagrammatic sketch of the unit in its simplest form in which a circular diaphragm of magnetic material is held at a small distance from the poles of a bi-polar magnet providing a steady flux. An alternating flux proportional to the electric current to be reproduced is introduced by means of coils wound on the pole pieces which generally consist of a high permeability, magnetically soft material.

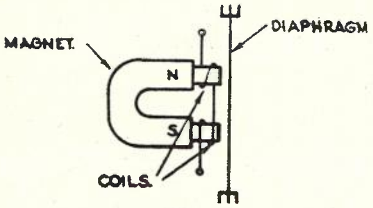


Fig. 1.

It can be shown mathematically (see Appendix I) that the driving force exerted on the diaphragm when a sinusoidal current is applied to the receiver consists of four main components as follows:—

(i) A steady force dependent only on the strength of the permanent magnet.

(ii) A steady force assisting (i) and of magnitude depending on the number of turns on the receiver and the value of the alternating current.

(iii) A sinusoidal force of the same frequency as the impressed current, its magnitude being directly proportional to the strength of the permanent magnet, number of turns and value of alternating current. This is the useful component.

(iv) A sinusoidal force of twice the frequency of the impressed force of magnitude which is proportional to the square of the product of the number of turns and value of the alternating current. This is a distortion component.

It will be seen from (iii) and (iv) that it is desirable to increase the strength of the permanent magnet because it increases the output of the desired component whilst leaving the distortion component unaffected. Actually, the ratio of distortion to wanted component is reduced.

It is further shown in the Appendix that if a complex current (i.e., a combination of more than one frequency) is applied to the receiver that additional sum and difference frequencies or modulation products appear. These are also independent of the strength of the permanent magnet.

It might be suggested that reducing the air gap between the pole pieces and diaphragm to a minimum consistent with freedom of movement of the diaphragm would increase the sensitivity of the receiver by reducing the reluctance of the magnetic circuit. This action would eventually result in magnetic saturation of the diaphragm and, in practice, the optimum air gap is determined experimentally.

The forces described above are only the mechanical forces acting on the diaphragm, and the amount of acoustical energy generated depends on the velocity at which these forces can drive it. It is shown in Appendix IV. that, within limits, the behaviour of a diaphragm is analagous to that of a series resonant electrical circuit, and its velocity for any applied force can be calculated as the current in an electrical circuit would be calculated. Furthermore, the acoustical construction of the receiver can influence the motion of the diaphragm to a considerable extent, although in the Type 1L and other simple receivers of this type this influence is negligible.

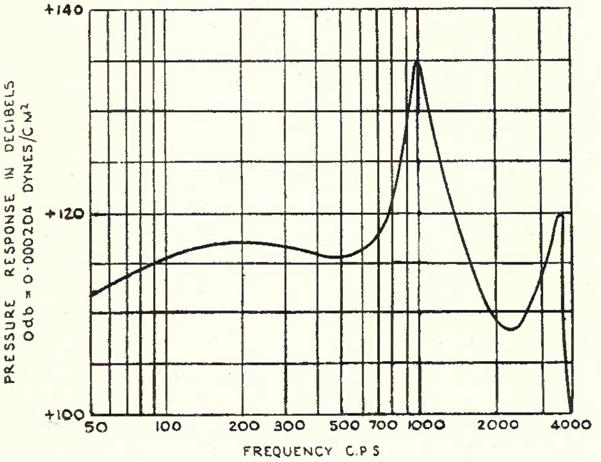


Fig. 2.—Typical Response Curve of Type 1L Receiver (Input 1.0V Const.).

Fig. 2 shows a typical 1L Receiver frequency response curve, the large peak being due to the main resonance of the diaphragm. The second peak is due to another form of resonance which is described in Appendix IV. In the early days of wireless telegraphy, a receiver with this type of frequency response characteristic was favoured because it was extremely sensitive to the wanted frequency, generally 1000 c.p.s., and not to other frequencies which exist in the form of noise, etc.; clearly the required action was that of a narrow band-pass filter of which this receiver is a type. The resonant peaks of other modes of vibration of the diaphragm, occurring as they do at much higher frequencies, are not of much use in commercial telephone receivers. However, some receivers are designed so the diaphragm is not clamped but just supported around the edge; this action results in a lowering of the main resonant frequency and an even greater reduction in the second resonant frequency. This, in conjunction with acoustic equalization, helps to extend the useful range of the receiver. A big advantage obtained from this construction is greater stability of important characteristics which change with temperature. It will be appreciated that considerable changes will take place in a firmly clamped diaphragm if the temperature coefficients of expansion of the diaphragm and clamp materials are different.

Electromagnetic Balanced Armature Type: This type is also commonly known as the Baldwin Type, two slightly different forms being shown in Figs. 3a and b. In both cases, each end of the armature which is high permeability magnetic material is held between pole pieces of a permanent magnet. The two sets of pole pieces carry flux in the same direction. The coil carrying the speech current is wound on a former with internal cross-section made just large enough to permit the necessary movement of the armature. In Fig. 3a longitudinal magnetization of the armature by the energizing coil will cause it to rotate through a small angle about the pivot, while the result in Fig. 3b is transverse vibration of the armature. The movements so obtained are transmitted to the diaphragm by the armature extension, the latter components being of light non-magnetic materials.

The principle was first disclosed by Frank L. Capps, in U.S. Patent No. 441,396, issued in 1890; in this case a pivoted armature was used. Clamping the armature at the end was introduced by Nahant, U.S. Patent No. 1,547,772, for the sake of mechanical convenience. Although other improvements were made in the design, Nathaniel Baldwin in 1910 first made this type of unit a commercial proposition, both as an ordinary receiver and a loudspeaker, and on this account his name is associated with it. Baldwin Receivers and Loudspeakers were popular in the early days of radio, but were quickly displaced when the moving coil loudspeaker was introduced.

The mechanical construction is obviously delicate, but present-day production techniques are solving this problem, and fairly stable receivers with higher sensitivity than any other type are being produced. Identical units are at present commonly used as transmitters and receivers in "sound powered" telephone systems, so named because they make telephone communication possible, without the use of external power. The efficiency of the modern unit as a transmitter is generally about 30 db lower than the carbon transmitter, while receivers are commonly 10 to 12 db better than the ordinary telephone receiver. As the circuit requirements are simple, quite efficient communication can be obtained over short lines. The advantage of dispensing with batteries and auxiliary equipment favours sound powered systems for use in battle areas and on ships.

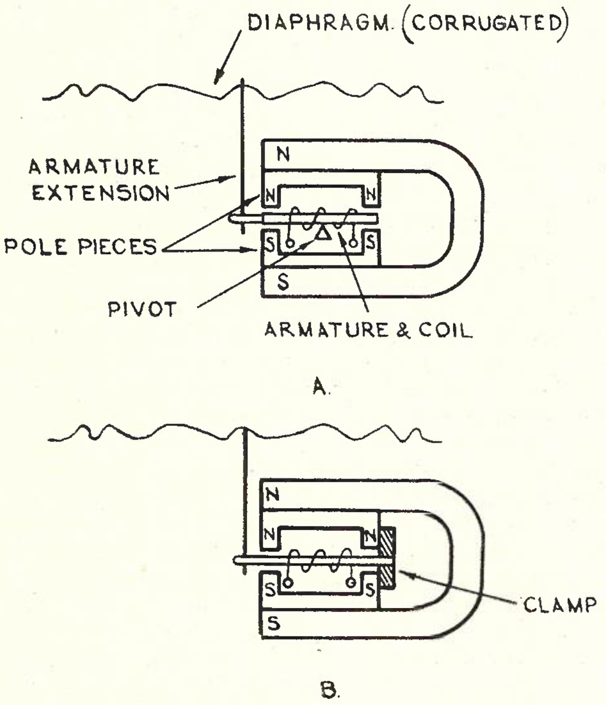


Fig. 3.—Moving Armature Receivers.
(A) Armature pivoted at centre.
(B) Armature clamped at one end.

Action of Balanced Armature Unit: The type shown in Fig. 3a will be considered first. When the armature is in its central position the magnetic forces due to the four poles are balanced; if, however, it is given a small displacement in either direction the force exerted by the poles approached will be increased whilst that due to the poles from which it recedes will be diminished, thus a restoring force will be required to arrest further movement in the direction of displacement. The armature is therefore balanced in unstable equilibrium, a condition which contributes much to the sensitivity of the unit. The restoring force is provided by the stiffness of the diaphragm.

An analysis of the driving force developed by the input current is given in Appendix II. It is shown that no distortion components exist in the driving force, but further analysis of the action of the armature would show that odd order harmonics are developed, also that intermodulation components are developed if the driving force is complex. However, if the armature is not situated in the precise centre of the magnetic circuit, the distortion components reach a high percentage, especially the second harmonic, which is theoretically absent for a perfectly balanced armature.

The armature in this unit is generally made very light and the constants of the diaphragm contribute most to the mechanical impedance. The corrugations in the diagphragm increase its stiffness and determine its modes of virbation. Fig. 4 shows a typical response curve; the advantage of controlling the modes of vibration by corrugating the diaphragm is evident by the closely spaced resonance peaks of the modes above the fundamental, giving improved high frequency response.

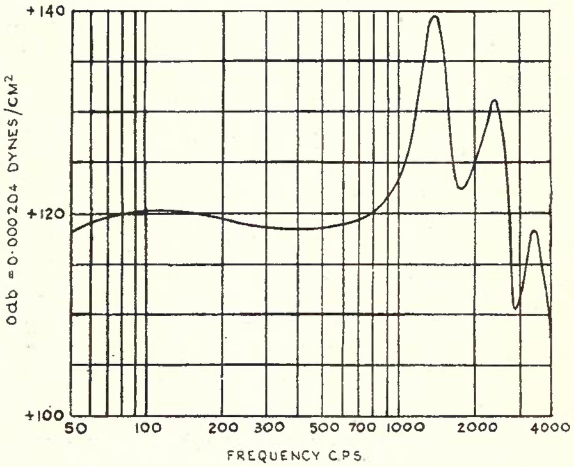


Fig. 4.—Typical Response Curve of Moving Armature Receiver (Input 1.0V Const.).

The action of the type shown in Fig. 3b is similar, except that the effect of the driving force is halved, because the armature is clamped at one end. Some manufacturers claim that the simpler construction permits use of smaller air gaps and this loss can be compensated for. The mechanical constants of the clamped armature contribute much more to the mechanical impedance of the system than in the other type.

Both types have the advantage that when the armature is properly adjusted, the magnetic flux density in it is small. This permits use of the material in a condition of high permeability and not near saturation as is sometimes the case in the attracted armature type.

Electrodynamic (Moving-coil) Type: The first application of the moving coil system for receivers is described in "The Electrician," Vol. 2, p. 253, April 14, 1879.[4] Details of the construction of this receiver, however, are not readily available at the present time.

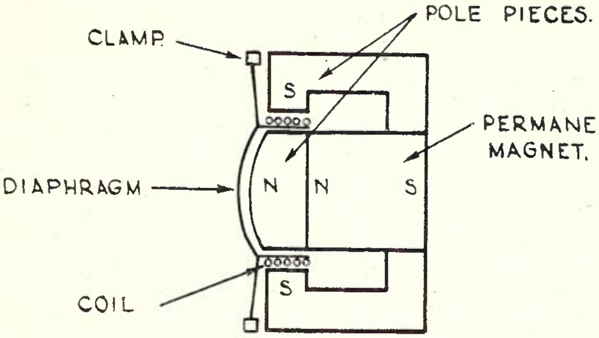


Fig. 5.—Construction of Simple Moving Coil Receiver.

A simple modern form of construction is shown in Fig. 5. The diaphragm, generally of aluminium alloy or paper similar to that used in loudspeaker cones, is shaped like a spherical dome to increase its rigidity. The coil is wound on a former attached to the base of the dome and inserted in the radial gap of the pot-shaped magnet system, in which a permanent magnet provides the steady flux. Most moving-coil receivers are acoustically equalized to give very linear frequency response. In fact, the first systematic application of acoustical methods of receiver equalization was made in this type of receiver by Wente & Thuras[5] of the Bell Telephone Laboratories. High quality moving-coil receivers are used in applications requiring stable performance, such as standards in Reference Systems for Telephone Transmission[6] and Broadcast Monitoring, otherwise their use has been limited because of their expensiveness and frequently heavy weight due to the large magnet system necessary to produce the intense flux density required in the air gap.

Operation of Moving Coil Receiver: The force exerted on the coil by the interaction of the steady flux and that due to the coil current is parallel to the axis of the coil. Its magnitude is directly proportional to that of the current and direction dependent on the polarity of the current. The value of this force, which contains no distortion components, is given in Appendix III. A small amount of distortion generally occurs in practice due to the non-linearity of the mechanical constants of the diaphragm. This is reduced by the current due to the back e.m.f. in a manner similar to the reduction of distortion obtained in a feedback amplifier. As the value of back e.m.f. is directly proportional to the linear velocity of the coil, there is less reduction of harmonic content in the output at low frequencies than at high frequencies. The main compliance of the mechanical system is provided by the flat annular section of the diaphragm and the mass by the dome and coil structure. Other modes of vibration only occur at very high frequencies in a well-designed diaphragm.

A typical response curve for a high quality moving-coil receiver such as is used for broadcast monitoring purposes is shown in Fig. 6.

Crystal Receivers: In this type of receiver use is made of the piezo-electric effect of Rochelle Salt ($KNaC_4H_4O_6 + 4H_2O$) or other crystals. The effect was discovered by the brothers J. and P. Curie, who in 1880 observed that a charge appeared on the surface of an X- or Curie-cut quartz crystal when a force was applied to it. The inverse effect was predicted by Lippman and verified by the Curies in the following year. A. M. Nicholson, of the Bell Telephone Laboratories, was the first to make use of Rochelle Salt in electro-acoustic apparatus and demonstrated piezo-electric loudspeakers, microphones and phonograph pick-ups in 1917. So far as is known Rochelle Salt exhibits a much larger piezo-electric effect than any other crystal, but loses this property permanently if heated to a temperature higher than 130° F.

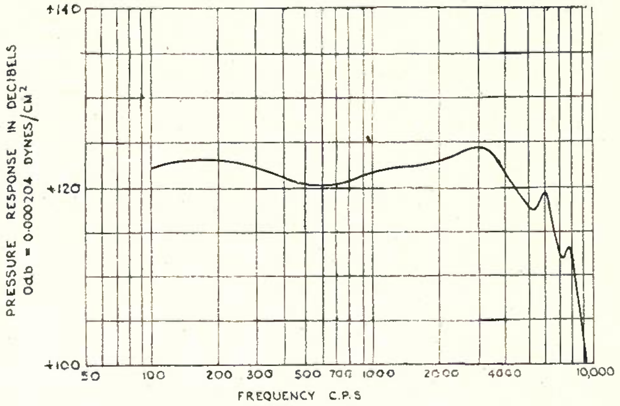
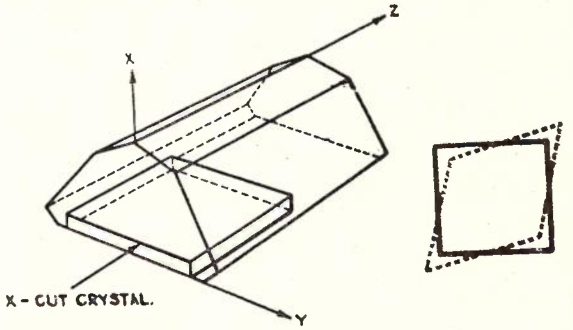
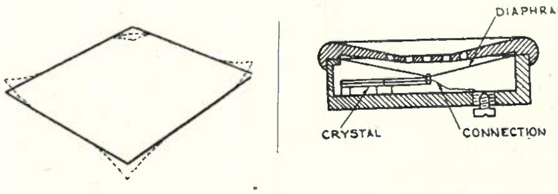


Fig. 6.—Response Curve of Wide Band Moving Coil Receiver (Input 30 MA Const.).



A.—Half Crystal of Rochelle Salt.

B.—Mode of Deformation of X-Cut Crystal.



C.—Mode of Deformation of Twister Bimorph.

D.—Cross Section of Crystal Receiver.

Fig. 7.

Various crystal cuts, each with some particular advantages, are employed in electro-acoustic apparatus; that most commonly employed in telephone receivers is the twister plate bi-morph in which X-cut plates are oriented so that the strains in the two plates are opposite in sign. Fig. 7 shows details of the crystal, also construction of a receiver in which three corners of the bi-morph element are secured to thin rubber pads securely fastened to the case. A light paper conical diaphragm is attached to the free corner of the crystal. This construction is the most sensitive but is also the most affected by changes in temperature.

The resonant frequencies of the crystal element are generally well above the voice-frequency range, and the shape of the response curve is controlled by the acoustical construction and constants of the diaphragm. The impedance of these receivers is generally very high, in the order of 100,000 ohms. Many factors are involved in determining the mechanical force produced for a given electrical input, the main one being the piezo-electric constants of the crystal. The sensitivity of most receivers of this type, however, is comparable with electro-magnetic and electro-dynamic types.

ACOUSTIC EQUALIZATION

General: Consider a diaphragm forming the lid of a shallow thick-walled cylinder which has a small hole in it, as shown in Fig. 8. If the hole is plugged and the diaphragm pressed inwards the air is compressed; on removal of the pressure displacing the diaphragm the excess air pressure assists to restore it. The air cavity therefore acts as a spring which adds stiffness to the diaphragm. If the hole is open and the diaphragm driven at a very low frequency, a current of air will flow through the hole in accordance with the direction of movement of the diaphragm. The reaction on the diaphragm is that of moving a mass approximating that of the volume of air in the hole. At much higher frequencies, however, the movement of the plug of air in the hole will be negligible due to its inertia, the reaction on the diaphragm being the stiffness of the air in the cavity. We can represent this cavity and hole by an electrical circuit containing inductance and capacitance in parallel, because at low frequencies a circuit of this type offers inductive reactance, and at high frequencies capacitive or stiffness reactance. This analogy only holds when the dimensions of the acoustical system are very small compared with the wavelength of sound for any frequency we are considering.

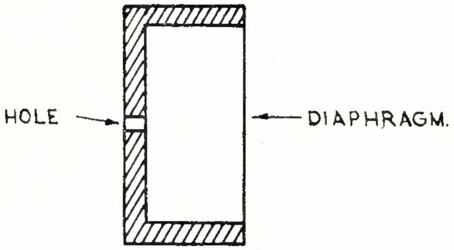


Fig. 8.

At any frequency the velocity of the plug of air will be governed by the viscosity of the air and the surface area of the hole, that is, by the resistance that the hole offers to flow of air. Sometimes this resistance is purposely increased by inserting a bolt of fibrous material in the hole or covering it with layers of finely woven silk fabric.

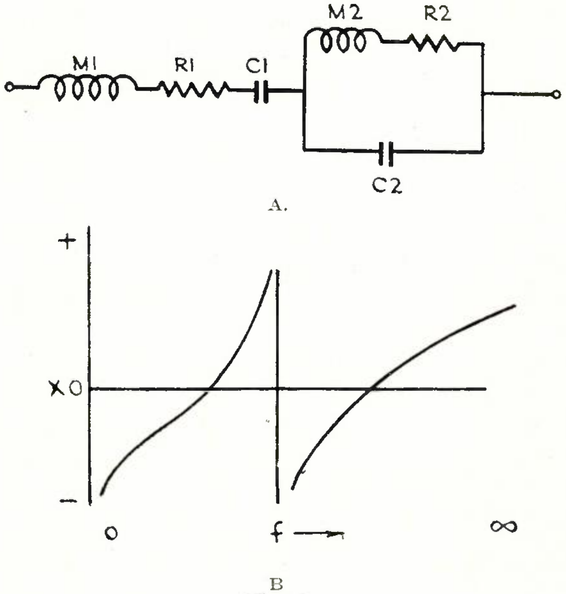


Fig. 9.

The behaviour of the complete system, considering the fundamental resonance of the diaphragm only, is analogous to the electrical circuit shown in Fig. 9a, where—

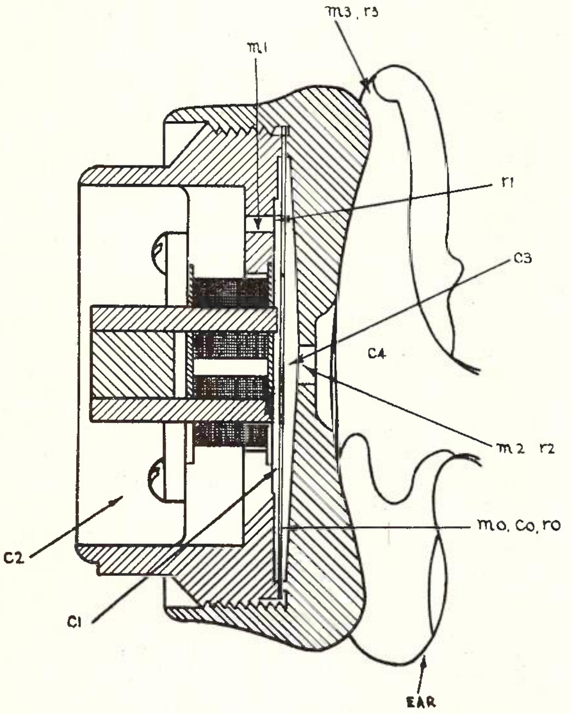
M_1 = equivalent mass of diaphragm.
C_1 = equivalent compliance of diaphragm.
R_1 = equivalent resistance of diaphragm.
M_2 = equivalent mass of air in the hole.
R_2 = equivalent resistance to flow of air in the hole.
C_2 = equivalent compliance of air in the cavity (inverse of stiffness).

The reactance characteristic of this circuit is shown in Fig. 9b. Resonances occur at the two frequencies where the reactance is zero while anti-resonance occurs at the pole (frequency where curve is asymptotic).

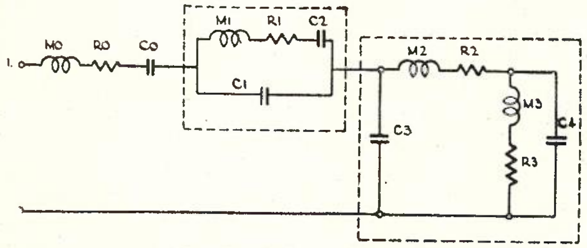
Instead of one current peak only, representing the resonance of the diaphragm, we have two peaks and one trough, the magnitudes of which can be controlled by the resistance in the hole.

By suitable manipulation of cavities and leaks, profound modifications can be made to the response characteristics of a receiver. The 2P receiver, described in the following section, is equalized by this method. It must be remembered that equalization can be accomplished regardless of what driving method is employed, but the desirability of using it to extend the frequency range is governed by the amount of higher order distortion components introduced by the driving mechanism.

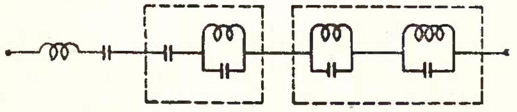
Equalization of 2P Receiver: A diagram of the Departmental Type 2P receiver placed on an ear and the analogous electrical circuit are shown on Figs. 10a and b. The circuit constants are as follows:—



A.—Equalised Receiver Against Ear.



B.—Equivalent Circuit.



C.—Simplified Equivalent Circuit.

Fig. 10.

M_0 = mass of diaphragm.
M_1 = mass of air in hole behind diaphragm.
M_2 = mass of air in earcap holes.
M_3 = mass of air in leak between earcap and ear cartilage.
R_0 = resistance of diaphragm.
R_1 = resistance in hole behind diaphragm.
R_2 = resistance in earcap holes.
R_3 = resistance in leak between earcap and ear cartilage.
C_0 = compliance of diaphragm.
C_1 = compliance of cavity behind diaphragm.
C_2 = compliance of cavity in body of receiver.
C_3 = compliance of cavity in front of diaphragm.
C_4 = compliance of ear cavity.

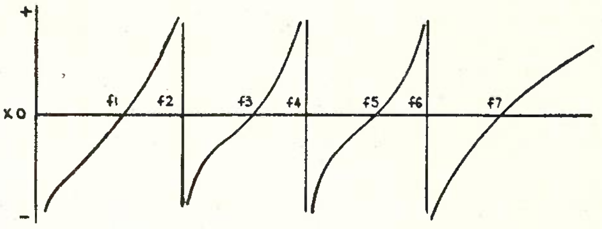


Fig. 11.—Reactance Curve for Fig. 10B.

The simplified equivalent circuit shown in Fig. 10b has a reactance characteristic shown in Fig. 11, resonances occurring at f_1, f_3, f_5 and f_7, and anti-resonances at f_2, f_4 and f_6. These points are indicated approximately in a typical response curve for a 2P Receiver shown in Fig. 12, where the effective damping of the resonances will be observed.

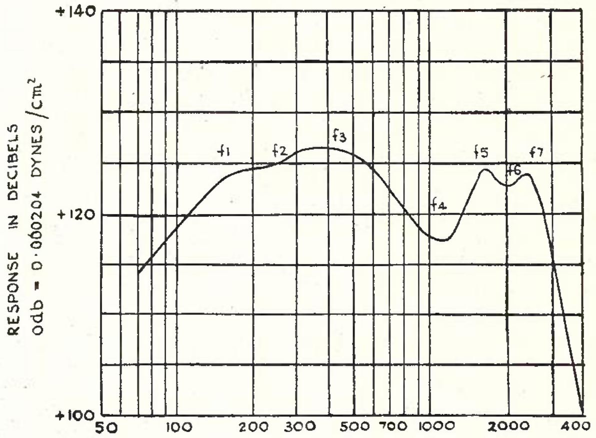


Fig. 12.—Typical Response Curve of Type 2P Receiver (with Leak Between Earcap and Ear) (Tested with 1.0V Constant).

NEW MATERIALS

Many new materials used in communication apparatus have been described in Vol. 4, No. 4, p. 193. Advantages gained by using some of these materials in receiver manufacture are discussed in this section.

Permanent Magnets: The criteria for suitability of a permanent magnet material are its residual induction, coercive force and maximum energy (BH) product. The following table shows approximate values for these quantities in some recently developed nickel-iron alloys and in the best materials previously used.

	Type	Residual Induction (Gauss)	Coercive Force (Oersteds)	Max. Energy Products (Gauss-Oersteds $\times 10^{-6}$)
Old Alloys[7]	Tungsten Steel	10,000	65	2.6
	15% Cobalt Chromium Steel	8,400	200	6.4
	35% Cobalt Steel	9,000	240	8.1
New Alloys[8]	Nipermag B	5,500	670	13.0
	Alnico II	7,200	610	16.5
	Alnico III	6,800	500	14.0
	Alnico V	12,300	580	45.0

In applications such as telephone receivers where the only large demagnetizing influence is from the air gaps, the volume of a permanent magnet required to give a certain value of flux is inversely proportional to the maximum BH product. The advantages of using the new materials will be obvious from the table.

Magnetic Materials for Diaphragms and Pole Pieces: Materials for these applications should have high permeability over the range of magnetizing force encountered. High electrical resistivity is also required to reduce eddy current losses. Many recently developed nickel-iron alloys have the required properties if properly heat-treated, but are adversely affected by cold-working. An alloy containing approximately 36% nickel will withstand limited cold-working and is frequently used for these components. Its permeability is approximately two or three times that for high quality ingot iron and electrical resistivity about six times as great.[8]

Vanadium-permendur, composition 49% iron, 49% cobalt and 2% vanadium is used in 2P Receiver diaphragms. Its permeability is approximately constant for a wide range of magnetizing forces and electrical resistivity high.

Other Materials: The development of plastics has produced many materials suitable for use in receivers. The important advantages gained by their use are resistance to wear, heat and light, dimensional stability, pleasing appearance, simple production methods, light weight, and superior electrical properties.

RECEIVER TESTING

The properties of receivers that we are interested in are the amount of acoustical power they will deliver to the ear for a certain electrical input, also the variation of this power with frequency. Neglecting loss of power in the insensitive parts of the ear, the power W delivered to the eardrum is—

$$W = \frac{P^2}{Z} \text{ ergs.}$$

where P = Sound pressure in dynes/sq. cm.
Z = Acoustical impedance of ear drum in c.g.s. units.

It is not easy to determine the impedance of an ear drum, and this factor will not be the same with all people. This difficulty is generally overcome by taking an average value of ear drum impedance and measuring the sound pressure developed in a cavity of the same volume as an average ear by means of a small microphone; the volume generally assumed is 6 ccs.[9] The output at various frequencies is related in decibels to the minimum sound pressure that can be detected by the average ear, i.e., 0.000204 r.m.s. dynes/sq. cm. at 1000 c.p.s.

The frequency characteristics of receivers vary so much that a comparison of their performance with output v. frequency measurements is difficult and voice-ear methods of testing are generally used for this purpose.[10] For production testing of receivers which are expected to have similar characteristics, a Telephone Efficiency Tester is used, such as that described in Vol. 2, No. 6, p. 353.

Conclusion: The benefits derived from improvement in circuit design and line transmission technique ultimately depend for their full appreciation on the quality of the electro-acoustical instruments, which the subscriber uses; improvements in these instruments therefore serve a twofold purpose. Telephone receivers with improved response characteristics and no loss in sensitivity are now available. It is reasonable to predict that designers will produce receivers in future with much higher sensitivity, combined with improved response and distortion characteristics.

APPENDIX I.

Driving Force in Moving Armature Receiver

The steady flux in the magnetic circuit is given by the following equation:

$$\phi_1 = M/R \quad \ldots\ldots\ldots \quad (1)$$

where ϕ_1 = flux
M = magneto-motive force of the magnet
R = reluctance of the magnetic circuit.

In practice, both M and R are somewhat difficult to calculate and are determined by empirical means. The flux due to a sinusoidal alternating current. $I_m \sin \omega t$ is given by:

$$\phi_2 = \frac{4\ NI_m \text{ Sin } \omega t}{10\ R} \quad \ldots \quad (2)$$

where ϕ_2 = alternating flux
I_m = maximum value of current in amperes
$\omega = 2\pi f$
f = frequency in c.p.s.
t = time in seconds
N = total number of turns.

The force acting on the diaphragm is given by:

$$F_M = \frac{2\ (\phi_1 + \phi_2)^2}{8\pi A} \quad \ldots \quad (3)$$

$$= \frac{1}{R^2A}\left(\frac{M^2}{4\pi} + \frac{MN\ I_m \text{ Sin } \omega t}{5} + \frac{\pi N^2\ I_m^2}{50} - \frac{\pi N^2\ I_m^2 \cos 2\omega t}{50}\right) \quad \ldots \quad (4)$$

when the applied current is sinusoidal.

where F_M = force in dynes
A = effective area of one pole.

If the applied alternating current be complex, e.g., $I_m \sin \omega_m t + I_n \sin \omega_n t$, the force acting on the diaphragm will be:

$$F_M = \frac{1}{R^2A}\left(\frac{M^2}{4\pi} + \frac{MN\ (I_m \text{ Sin } \omega_m t + I_n \sin \omega_n t)}{5} + \frac{\pi N^2\ (I_m + I_n)^2}{50} - \frac{\pi N^2\ (I_m^2 \cos 2\omega_m t + I_n^2 \cos 2\omega_n t)}{50} + \frac{2\ \pi N^2 I_m I_n\ [\cos(\omega_m - \omega_n)t - \cos(\omega_m + \omega_n)t]}{50}\right) \ldots (5)$$

The last term of this equation is different from any obtained in equation (4) and shows the presence of distortion in the form of modulation components.

APPENDIX II.

Driving Force in Balanced Armature Receiver

The steady force due to the permanent magnet at each pole is given by:

$$F_M = \phi_1^2/8\ \pi\ A \quad \ldots \quad (1)$$

where ϕ_1 = total flux at each pole due to permanent magnet
A = effective area of the pole piece.

The flux ϕ_2 at each pole due to a current in the coil is:

$$\phi_2 = 4\ \pi\ NI/20R \quad \ldots \quad (2)$$

where N = number of turns in the coil
I = current in amperes
R = reluctance of the magnetic circuit the coil energises.

As the forces exerted on the armature by opposite poles are opposite in direction, the sum of the forces F_A acting on the armature is:

$$F_A = \frac{2\ (\phi_1 + \phi_2)^2}{8\ \pi\ A} - \frac{2\ (\phi_1 - \phi_2)^2}{8\ \pi\ A}$$

$$= \phi_1\ \phi_2/\ \pi\ A \quad \ldots \quad (3)$$

$$\text{or } F_A = \frac{\phi_1\ NI \sin \omega\ t}{5RA} \quad \ldots \quad (4)$$

for an alternating current I $\sin\omega t$.

It is interesting to note that the second harmonic component is absent in eq. (4) due to the push-pull arrangement of the magnetic circuit.

APPENDIX III.

Driving Force in Moving Coil Receiver

The driving force in a moving coil receiver is given by:

$$F = B\ l\ I/10 \quad \ldots \quad (1)$$

where F = force in dynes
B = flux density in air gap
l = total length of coil winding in cm.
I = coil current in amperes.

APPENDIX IV.

Action of Diaphragms

It will be well to emphasize once again that the expressions derived in the Appendices are for the magnetic force acting on the diaphragm; the acoustical force that is produced will be a function of the velocity with which this force can move the diaphragm. In this regard it can be shown that the behaviour of a diaphragm, as well as some other mechanical systems, is analogous to that of a series electrical circuit containing inductance, capacitance and resistance.

Consider a diaphragm clamped around its circumference and apply a force to its centre in a direction at right angles to its plane; it will be easily understood that the displacement produced will depend on the force applied, also, when the force is removed (providing it has not exceeded the elastic limit of the material and permanently deformed the diaphragm) that the diaphragm tends to move back to its original position, i.e., it has acquired potential energy. We know from Hooke's Law for a spring with linear constants (and within limits a diaphragm behaves in this way) that:

$$d = F/S \quad \ldots \quad (1)$$

where d = distance the spring is displaced
F = applied force
S = stiffness of spring.

We also know that the potential energy P contained by a deformed spring is:

$$P = \tfrac{1}{2}\ S\ d^2 \quad \ldots \quad (2)$$

These equations are analogous to those which define the behaviour of a condenser.

$$Q = CV \quad \ldots \quad (1a)$$

$$\text{and } W = CV^2/2 = Q^2/2C \quad \ldots \quad (2a)$$

where Q = charge on the condenser
C = capacity of condenser
V = voltage across condenser
W = energy stored in condenser.

If C were replaced by 1/s, where s is the inverse of capacitance, it is seen that the two sets of equations have the same form, thus:

Q is analogous to d;
C = 1/s is analogous to 1/S;
V is analogous to F;
W is analogous to P;

then the behaviour of a spring and a condenser can be said to be analogous.

We will now proceed with the observations on the diaphragm from where we found it possessed a tendency to restore to its normal position. If we remove the force suddenly, the diaphragm will quickly restore (much too quickly to be seen) to its normal position, and overshoot the mark—it must possess energy to do this—and we know from elementary mechanics that a mass m moving with velocity v has Kinetic energy K defined as follows:

$$K = \tfrac{1}{2}mv^2 \quad \ldots\ldots \quad (3)$$

We also know that the energy stored in an inductance and released when the source of current is removed is:

$$W = \tfrac{1}{2}Li^2 \quad \ldots\ldots \quad (3a)$$

where W = energy stored in inductance
L = units of inductance
i = current;

an equation similar in form to equation (3), thus:

K is analogous to W;
m is analogous to L;
v is analogous to i;

which shows that the dynamic behaviour of mass is analogous to that of inductance.

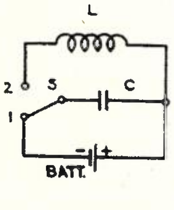


Fig. 13.

If the Kinetic energy of the diaphragm when it reached its normal position were equal to the potential energy given to it, i.e., no energy had been dissipated, it would continue to vibrate for ever, as would the tuned circuit, shown in Fig. 13, continue to oscillate for ever if the switch were thrown from position 1 to position 2, and there were no resistance in the circuit. Actually, when the diaphragm has completed one full cycle of movement it does not return quite as far as it was originally displaced, which indicates that it has lost energy. The loss in energy:

$$P_1 - P_2 = v^2 R_M \quad \ldots\ldots \quad (4)$$

where R_M = the mechanical resistance.

This is analogous to the performance of the tuned circuit of Fig. 13, if a series resistance R were inserted in it, where the loss of energy is defined as the difference between the values of two successive maxima of charge in the condenser, i.e.:

$$Q_1 - Q_2 = i^2R \quad \ldots\ldots \quad (4a)$$

We have already satisfied ourselves that v is analogous to i, so we now assume that R_M is analogous to R and as R determines the current in the electrical circuit, so does R_M determine the linear velocity of the diaphragm.

Having established these analogies we can now derive an equation for the velocity with which the diaphragm will move when a sinusoidal force F_M sin t is applied to it:

$$v = \frac{F_M \sin \omega t}{Z_{Me}} \quad \ldots\ldots \quad (5)$$

$$\text{where } Z_{Me} = \sqrt{R_{Me}^2 + \left(\omega M_e - \frac{1}{\omega C_e}\right)^2} \quad \ldots \quad (6)$$

where Z_{Me} = effective mechanical impedance
R_{Me} = effective mechanical resistance
M_e = effective mass
C_e = effective compliance (inverse of Stiffness S).

This is similar in form to the equation for current in a series R, L, C circuit.

This explanation may seem convincing, but is not always easy to apply in the case of a clamped diaphragm. Chladni[1] in 1787 showed experimentally that a diaphragm has many resonances each accompanied by a particular mode of vibration, since then others[2] have determined theoretically that there is an infinite number of modes and have calculated their resonant frequencies. Our simple resonant circuit is not then truly analogous for all frequencies, but it is sufficiently accurate for determining the performance of a telephone receiver diaphragm in the first mode, which is the most predominant and for which the resonance generally occurs at about 1000 c.p.s. The frequency of this resonance is given by the expression:

$$f = \frac{1}{2\pi\sqrt{M_e\ C_e}} \div 0.4745\ \frac{t}{r^2}\sqrt{\frac{Y}{\rho\,(1 - \sigma^2)}} \quad \ldots\ldots \quad (7)$$

where M_e = effective mass of diaphragm

$$= \frac{9\pi r^2 t\rho}{5} \quad \ldots\ldots \quad (8)^3$$

and C_e = effective compliance of diaphragm

$$= \frac{r\,(1 - \sigma^2)}{16\pi t^3 Y} \quad \ldots\ldots \quad (9)^2$$

t = thickness of diaphragm in cm.
r = radius of diaphragm in cm.
Y = Young's modulus of diaphragm material dynes/cm².
ρ = density of diaphragm material.
σ = Poisson's ratio of diaphragm material.

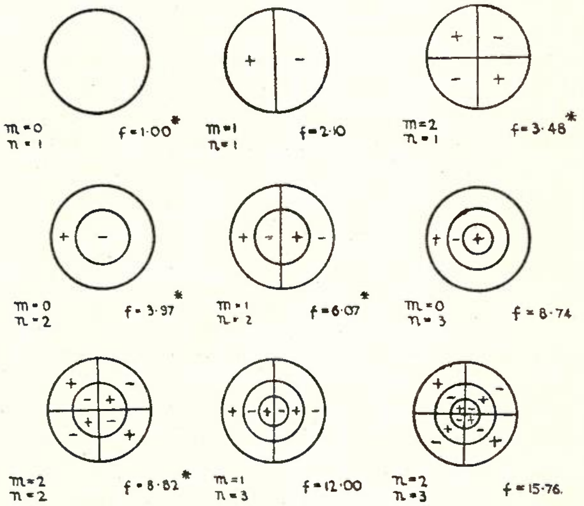


Fig. 14.—First Nine Modes of Vibration of a Circular Clamped Diaphragm.

m = number of nodal diameters.
n = number of nodal circles (circumference included).
Signs (+ or —) represent phase of movement.
(No movement occurs at the nodes.)

Fig. 14 shows the first nine modes of vibration of a circular clamped diaphragm, together with the relation between the resonant frequencies which should be noted is not harmonic. Those marked with an asterisk can be excited in a Type 1L Receiver and may be observed by spreading fine powder on the diaphragm and driving it at the particular frequency. The powder becomes agitated at the antinodes (areas where greatest movement occurs) and settles in heaps along the nodes (lines where there is no movement). The effects of acoustical load and back e.m.f. have been purposely neglected in this analysis.

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THE VICTORIAN TIME SIGNAL SERVICE

A. H. Cannon, B.E.E.

Summary: This article describes in some detail the time service given by, and the timing and signalling equipment used at, the Melbourne Observatory until its Time Department closed down on 19th June, 1945. This equipment is being taken over as a going concern by the Postmaster-General's Department to ensure continuity of the service. As soon as possible new equipment will be provided, using modern apparatus with which the operating staff of the Department is more familiar.

Introduction: The equipment used at the Melbourne Observatory to provide the Victorian Time Signal Service was built up over many years under the direction of four Government Astronomers, considerable development occurring during the period (from 1915 onwards) when the late Dr. J. M. Baldwin was in charge. With the retirement of Dr. Baldwin in September, 1943, from the State Government service, the responsibility for the Victorian Time Service was taken over by the Commonwealth Government and placed under the control of the Commonwealth Astronomer. In order to provide continuity of service, arrangements were made for the Observatory to carry on with Dr. Baldwin as Officer-in-Charge until a Victorian Time Signal Service could be provided which was based upon the determination of Fundamental Time at the Commonwealth Observatory at Mt. Stromlo, Canberra. Because of the clear atmospheric conditions usually existing at Canberra, and the staff and equipment already at the Observatory, Mt. Stromlo Observatory is well fitted to make Fundamental Time determinations, but it is not practicable for it to originate the actual time signals needed by the State of Victoria. Line rental charges indicated that this should be done by equipment located near the copper centre of Melbourne.

A number of factors led to the Postmaster-General's Department being requested to undertake, on behalf of the Commonwealth Observatory, the generation and distribution of Victorian Time Signals; these factors were the department's technical and distribution facilities, its existing interest in supplying time to the public, and the fact that as portion of its Frequency Standard technique, it had in operation synchronous clocks which were more precise than any of the pendulum master clocks used by Australian Observatories.

The permanent equipment used to provide Time Signals will employ electronic and mechanical components with which operating staff of the Post-office can readily become familiar. However, as the provision of such equipment would take a considerable time, and as it was necessary to close down the Melbourne Observatory Time Service by the middle of 1945, it was decided to transfer the pendulum clocks time signal equipment from the Melbourne Observatory to the P.M.G. Research Laboratories and to operate the service from there as an interim measure, pending the provision of new equipment which would be operated by the department's State Administration.

This was done, and the first time signals from the Research Laboratories were transmitted at 2.48 p.m. on 19/6/45.

Consequently, this article deals with the equipment used at the Melbourne Observatory, together with mention of changes and additions made after installation of the first group of clocks at the Research Laboratories. The proposed new equipment will be the subject of a later article.

Historical: The Melbourne Observatory was first established at Williamstown, opening in July, 1853, with Mr. R. L. Ellery as Astronomer. Because of rapid deterioration in observing conditions (due to smoke and dust), the establishment was moved to its present site on a basalt hillock at South Yarra in 1864, and continued operations from there until June, 1945.

One of the first clocks obtained for the Williamstown Observatory came from England, and is still in service, being used now as the Mean Time "A" clock. Although showing wear in some parts, it still keeps time reasonably accurately, frequently showing changes of rate of less than one second per day.

Until recently the Observatory possessed, as its Master Clocks, two Shortt Free Pendulum Clocks: Shortt No. 5 obtained in 1925 (approx.), and Shortt No. 59, obtained in 1933 (approx.). Clocks of this type have given outstanding performances all over the world, and No. 5 and No. 59 were no exceptions, although No. 5 was noticeably the more stable of the two.

The other two important clocks used in the time service were the Signalling Clocks, known as the Normal Clock and the Seth Thomas Clock. The former was made at the Observatory soon after it was established at South Yarra, and the latter was purchased from U.S.A. Both are giving good service still, but, of course, their second to second uniformity cannot be compared with that of modern high-grade synchronous electric clocks, such as are controlled by quartz crystal frequency standards.

For some years after 1853, time balls at Williamstown and in the city were the only way in which Observatory time was made public; then the Railways became the first "individual" subscriber to receive time signals, and rapidly the number of subscribers grew to include clock-making and business firms and Parliament House. At that time power for the electric signalling currents was obtained from large banks of wet Leclanché cells, each subscriber having his own battery at the Observatory.

Gradual progress added such improvements as a special transmitter for marine time signals and a special transmitter for radio time signals, although due to lack of funds the equipment was not modernised as much as desired.

Fundamental Time Determination: By definition, Time is measured in terms of the daily rotation of the earth about its North-South axis, and a "day" is the popular name for the time interval between two successive passages of the sun overhead. Because of various natural causes, of which the most prominent are the elliptical shape of the earth's orbit around the sun and the inclination of the earth's North-South axis to the plane of this orbit, the actual length of a solar day varies throughout the year. Consequently, our normal timekeeping is based upon the Mean Solar Day, which is an average taken over a whole year. To increase the accuracy of time determinations, the passage of stars overhead is substituted for the passage of the sun, and, as the movements of these bodies have been observed for many years, their apparent positions are known to a high degree of accuracy. Actually, as the accuracy of time-measuring devices—clocks—is improved, it becomes possible to calculate the apparent positions of these bodies more precisely and so prepare the way for still more accurate determinations of fundamental time.

Fig. 1.—The Observatory (Williamstown), 1862.

The Troughton and Simms telescope used at the Melbourne Observatory is typical of high-grade astronomical practice, and is specially constructed to facilitate the observation of celestial bodies for precise time determinations and other measurements. It is known as a reversible transit telescope, and is constructed so that, as it swings to sight different stars, its line of sight moves in a plane which runs North and South, and is perpendicular to the earth's surface; this permits simple checks to determine any small deviation of the actual direction of the telescope from its correct position, and so makes possible the co-ordination of observations on successive nights.

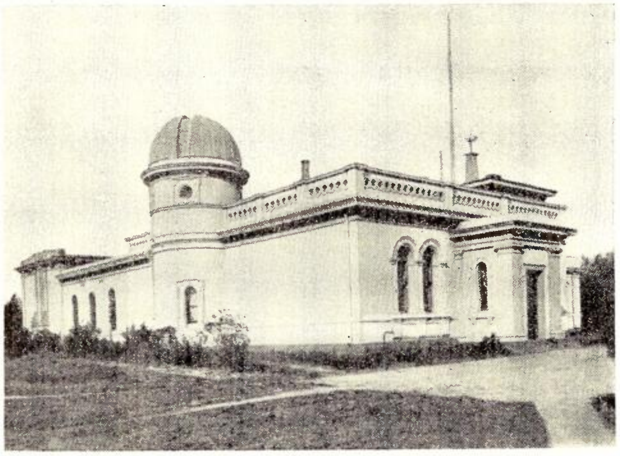


Fig. 2.—The Melbourne Observatory, South Yarra.

Solar and Sidereal Time: Suppose for the moment that we have an accurate clock, capable of ticking at the same rate for a long time. Then if we recorded, from day to day, the times indicated by the clock, when the Sun and also some selected star crossed the North-South plane, perpendicular to the earth's surface, in our locality, we would find that the length of time between successive crossings of the Sun was slightly longer than that between successive crossings of the star. The actual amount is approximately 4 minutes, and after counting 365 solar days, we would find that we had counted 366 star, or sidereal, days, and had returned to our original position.

A clock constructed so that its full cycle (of 24 hours) is equal to the time between two successive passages of the selected star, is called a sidereal (star) clock; the master clocks used by Observatories are usually arranged to keep sidereal time because this is the time used in precision time determinations.

The signalling clocks (e.g., those used to provide time signals for use outside the Observatory) are adjusted to keep Mean Solar Time as accurately as possible, and are usually automatically controlled by the Master Clocks, at infrequent intervals (say, every five or ten minutes). This reduction in the work which the Master Clock has to do considerably improves the timekeeping accuracy.

DETAILS OF THE VICTORIAN TIME SERVICE

General: As stated above, this service was provided for many years from the Observatory in South Yarra. Star observations there were made with the eight-inch reversible transit telescope, and were used to check the two Shortt Master Clocks. Associated with each Master Clock was a complete chain of working clocks in order to provide an operating and a stand-by system. These latter clocks were all of the weight-driven, pendulum type, with dead beat escapements. In the following discussion mention will only be made of the working group of clocks.

Types of Time Signals: Four different types of signals were provided:

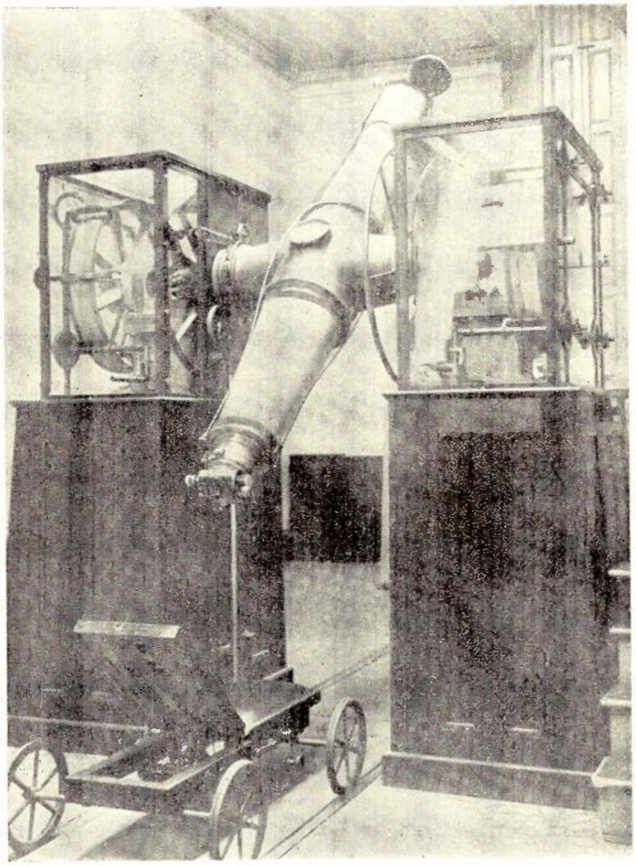


Fig. 3.—The Transit Telescope (the Observatory, Melbourne).

(1) The "XNG," or International Marine navigation time signal. This signal lasted for three minutes, ending precisely at the hour; during the 57th minute a series of "X" morse code signals, for identification, were generated, followed by six timing pips, the last pip of which occurred at the end of the minute; during the 58th and 59th minutes similar signals occurred, except that "N" signals and then "G" signals replaced the "X" signals of the 57th minute.

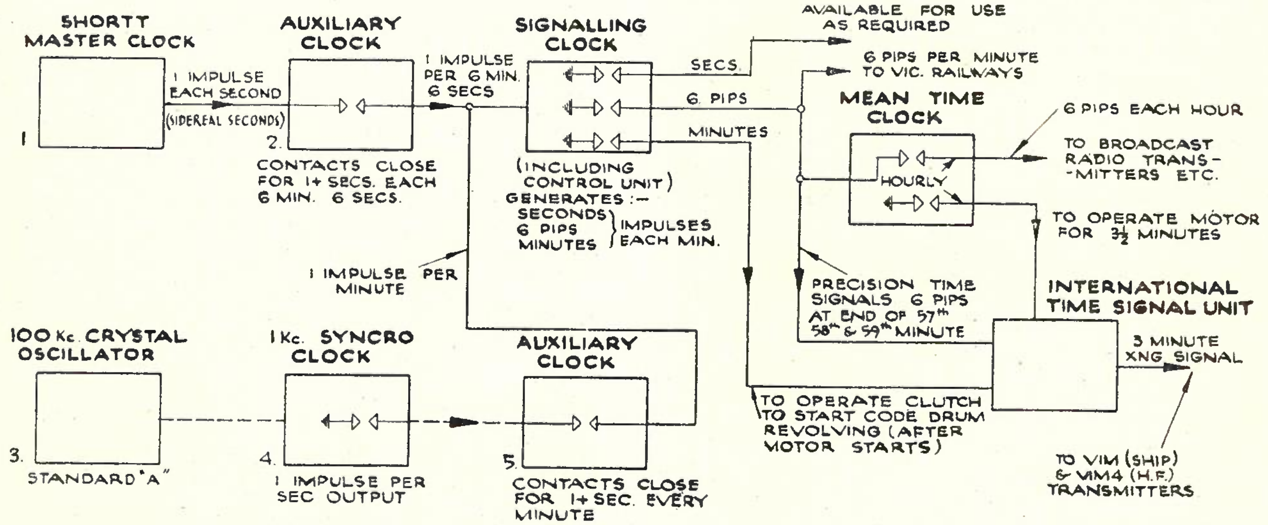
(2) The "6 pips" broadcast time signal, at the end of each hour, which consisted of a warning pip at 40 seconds, another at 50 seconds, and six timing pips at the end of the 55th, 56th,

57th, 58th, 59th and 60th seconds (the last pip again marking the exact hour).

(3) The "6 pips" signal of (2), repeated once per minute; these signals were used for precision civil timekeeping by the Railways Department, and by some watchmakers.

(4) Pips each second, excepting an omission for identification on the 3rd second; these were used by the Postmaster-General's Department to assist checking the Primary Frequency Standard.

Time Signal Generation Equipment: Four clocks were used to provide these signals:



Units 1 and 2 were at the Observatory. They are now replaced by Units 3, 4 and 5 at P.M.G. Research Laboratories.
Fig. 4.—Temporary Time Signal Service Block Schematic of Time-Generation Equipment.

(1) The "Shortt" Master Clock; this consisted of two separate units—the "Free Pendulum" and the "Slave Pendulum."

(2) The Signalling Clock, which generated all the actual time signals, repeating each cycle of signals once per minute.

(3) The Mean Time Clock, which selected certain of the time signals (e.g., those near the end of the hour) as required for the "XNG" signal and the 6 pips broadcast signal, and also performed certain auxiliary operations.

(4) The Auxiliary Clock, which selected the time interval between two consecutive corrections of the Signalling Clock by the Master Clock.

The Master Clock kept Sidereal Time, the Signalling Clock and the Mean Time Clock kept Mean Solar Time, and the Auxiliary Clock ran at a rate approximating Mean Solar Time, but adjusted to perform its correction function correctly.

In addition, a motor driven drum carrying raised projections on its surface, corresponding to the code XNG, and fitted with numerous auxiliary switches and relays, was used to generate the identification portion of the navigation signals.

Miscellaneous Equipment: Power was supplied by two sets of six volt 60 amp hour trickle charged batteries, and a plug type single line switchboard was used for testing and for routine comparisons of the various clocks. The main auxiliary equipment consisted of a single pen, weight driven drum chronograph, a high-speed tape chronograph and electronic switch, an accurate chronometer, and a radio receiver. The drum chronograph was fitted with a special governor, giving a pen speed of approximately ¾-inch per minute, and was used for most of the inter-comparisons of observatory clocks and radio time signals.

Clock and other relays were generally of low resistance, drawing currents of the order of half an ampere, resulting in operating times estimated as a few milliseconds.

DETAILED DESCRIPTION OF EQUIPMENT

Shortt Master Clock: The aim of the designer, in a clock of this nature, is to make the pull of gravity the sole factor affecting its swing. Disturbing factors are of two kinds—those which are, to some extent, necessary, e.g., the driving force necessary to keep the pendulum swinging, and those which are unnecessary, e.g., changes of temperature.

The outstanding feature of the Shortt "Free Pendulum" Master Clock is the ingenious way in which the Free Pendulum driving impulse is initiated; this is done by the use of another Pendulum, the slave, so that the master, or free, pendulum is only interfered with very slightly. As well as this all possible refinements are incorporated in the master pendulum.

In detail, the master clock is composed of two separate clocks, known as the Free Pendulum Clock and the Slave Clock. Both keep very closely in step, and are adjusted to keep (usually) sidereal time. The Free Pendulum is usually mounted on rock in a location free from vibration and from earth movements which might affect the value of the constant of gravitation. Although the pendulum is temperature compensated, some care is taken to keep the room, or vault, temperature as steady as possible. The pendulum itself swings in a constant pressure cylinder, the air pressure in which is adjusted to be only a few cm. of mercury, as this gives the best balance between certain residual effects. Because of the low pressure only a small driving force is required, and the mechanism is arranged so that this is given relatively seldom and in a gradual manner, at the centre of the swing of the pendulum, so as to cause a minimum of interference with the evenness of its oscillation. This is the only unavoidable disturbance which the Free Pendulum suffers because the work of counting the time duration between successive applications of the driving force, and of tripping the mechanism to apply the driving force, is done by the Slave Pendulum.

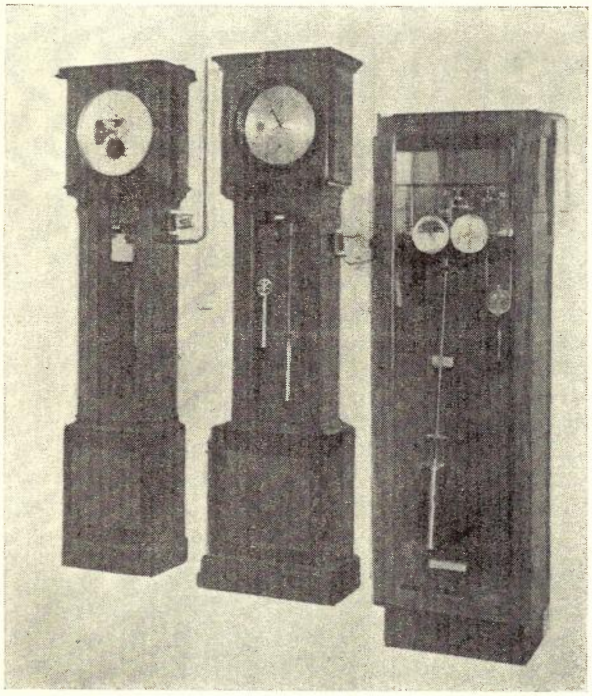


Fig. 5.—Time Signal Clocks, P.M.G. Research Laboratories. Left to right: Mean Time Clock, Auxiliary Clock, Signalling Clock.

The Free Pendulum is driven by a small weight applied by the jewel R on to the wheel J attached to the pendulum rod; as R drops it first pushes the free pendulum sideways in the direction of its motion at that instant, and then drops clear of the inclined surface to trip a catch which closes a contact in the electrical circuit used to transmit a synchronising impulse to the Slave pendulum. Normally, each second synchronising impulse speeds up the Slave, which would otherwise run slow, so that on the average the Slave keeps correct time. The Slave counts seconds to determine when the jewel driving the Free Pendulum shall be released again, and also supplies the outside time signals (via other clocks, of course). The Slave is a robust, high-quality clock self-driven by the small roller which runs down the inclined plane on the arm attached to the pendulum rod. It is usually mounted in an easily accessible location, and its routine maintenance requires the control of its own rate (i.e., between successive synchronising impulses from the free pendulum), by the adjustment of small weights on its bob, so that consecutive synchronising impulses alternatively miss and act on it.

As the Free Pendulum is impulsed every 30 seconds, the Slave clock is only required to run so that its error is small over a time of 60 seconds, since after that time the synchronising impulse from the free pendulum will adjust the time error in the Slave by any amount necessary. So the ideal driving conditions for the free pendulum, of a uniform force applied for uniform times at uniform time intervals, are met almost perfectly.

Before the Shortt "Free" pendulum was invented the non-uniformity of driving conditions was the major obstacle to more precise timekeeping. For many years after its introduction in 1921 the Shortt clock was unrivalled, and competitors and technique were so backward that it was hard to analyse its imperfections. With the advent of more precise "Crystal Clocks," which form portion of Frequency Standards, a more accurate clock and means for measuring short period (second to second or day to day) irregularities of the Shortt have become available, and work is going on in England, at least, to improve the Shortt clock still further. As it is possible that this will result in a considerable increase in accuracy, and because of

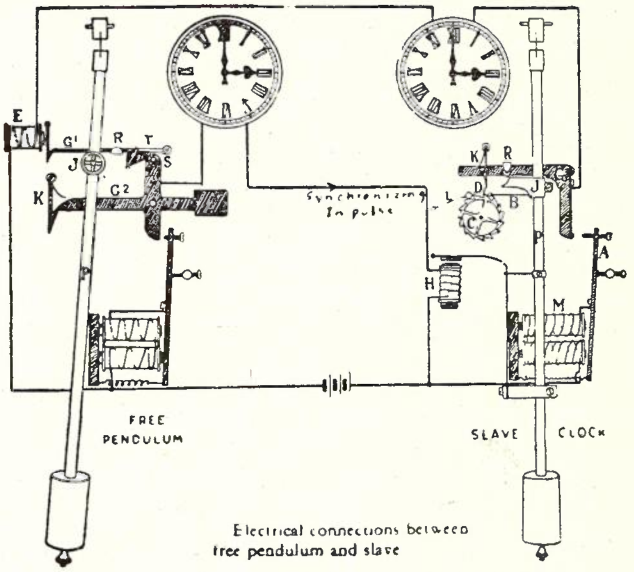


Fig. 6.—Shortt Free Pendulum Clock Electrical Connections.

the simplicity (and hence reliability) of the pendulum clock, this work is of some importance. However, further discussion of this point is outside the scope of this paper.

Because the Free Pendulum is constructed to be independent, as far as possible, of outside forces, difficulty is usually experienced in changing its rate occasionally to compensate for the slight amount of ageing which occurs. This was done, in the case of the Victorian Observatory, by a small permanent magnet, under the bottom of the evacuated case, which interacted with the steel pendulum rod; the range of control was approximately one second per day.

The Signalling Clock: This was a high-grade pendulum clock, weight-driven through a dead beat escapement; it was adjusted to keep Mean Solar Time, and generated the actual time signals. It was controlled by the Shortt Master Clock, the correction impulses occurring each six minutes six seconds (Solar).

All the time signalling was done by arms carrying electrical contacts, which were operated by teeth on wheels mounted on the shaft rotating once per minute. There were three of these wheels, and they were cut to give, respectively, signals at each second (except the third after the minute, which was omitted for identification), at 40, 50, 55, 56, 57, 58, 59 and 60 seconds, and at the third second only (i.e., one signal a minute).

Control of the Signalling by the Master Clock: It will be remembered that the duration (T) of one complete oscillation of a pendulum swinging free of all controlling forces except that of gravity is

$$T = 2\pi \sqrt{\frac{L}{g}}$$

where, if T is in seconds and L is feet, then g is in ft./sec./sec. and is = 32 (approx.). L is the distance between the point of suspension and the centre of mass of the pendulum. This indicates that variation of L will be a ready means of varying T, and, in practice, coarse adjustments of T are made by screwing the bob up or down the pendulum rod, and fine adjustments by adding weights on the top of the bob; as this latter step effectively raises the centre of mass of the pendulum and so decreases L, any added weight will decrease the length of the period of oscillation and so make the clock run fast.

At the Melbourne Observatory, control of the signalling clock, by the master clock, was obtained by the use of mechanism which caused a small weight to be put on or lifted off a tray attached securely to the pendulum rod. The clock was adjusted by varying the small weights on the top of the pendulum bob so that, with the control weight off, it ran slow by approximately ¾ second a day, and the size of the weight was chosen to make it gain approximately ¾ second a day when the weight was on. With these adjustments made correctly, the control weight was, over a period of, say, 61 minutes, down in the tray for as long as it was lifted up out of the tray, and with corrections made each six minutes, approximately, the clock would usually gain, or lose, approximately three milliseconds, before the position of the control weight was altered.

Mean Time Clock: As well as providing signals for the XNG unit as described later, this clock was used to eliminate, for broadcast transmitters, 59 of the 60 "six pip" signals generated each hour by the signalling clock. As the signals to be transmitted occurred on the 40th, 50th, and then 55th to 60th seconds, the Mean Time clock contacts concerned were closed from 45 seconds before the hour to 15 seconds (approximately) after. These requirements specify the timekeeping precision required of the Mean Time Clock; to provide a factor of safety, time errors of more than five seconds are not permissible, and, as the rate of the clock is usually better than one second per day, a reasonable margin is available for long week-ends, holidays, etc.

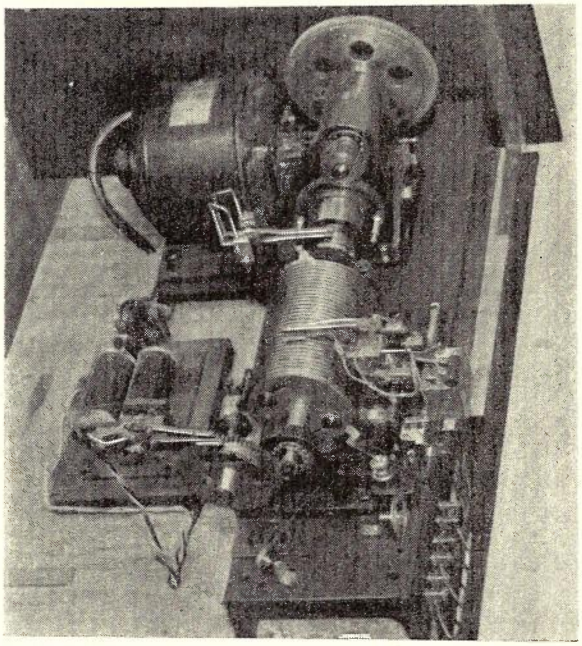


Fig. 7.—International Time Signal or XNG Unit (looking down), P.M.G. Research Laboratories.

Auxiliary Clock: This clock carried one pair of make contacts which were closed each six minutes six seconds for approximately one and a quarter seconds, during which time a control impulse from the master clock was permitted to pass to the correction unit of the signalling clock.

XNG Transmitter: This unit, under the control of the signalling clock, generated the identification portion of the XNG signal; the time signal portion of the XNG signal (viz., the six pips at the end of each minute) was transmitted direct from the signalling clock to obtain the highest possible accuracy.

Driven by a synchronous motor through a magnetic clutch, was the programme drum (approximately 6in. long and 3½in. diameter) which carried the XNG signals in the form of raised projections on its cylindrical surface; as required at the start of a run, a pair of electrical contact carrying arms were released by an electro-magnet to cause one end of the lower arm to trail on the drum surface so that it was raised by each projection sufficiently to close the two contacts. A deep spiral thread (6 turns per inch) was cut into the surface of the drum, running in between the signalling projections, and into this was fitted a hardened steel tongue which was fastened on to the base of a carriage which carried the two contact arms mentioned above; consequently, when the drum rotated, the contact making arms were moved parallel to the main axis of the drum, so that the arms passed over each signalling projection in turn. On this contact arm carriage was also mounted, at the forward end, a trip mechanism to open the circuit of the magnetic clutch when the contact arms reached the end of the XNG programme; while at the rear end of the contact arm carriage was a spring-loaded projection which, when the carriage had almost completed its return stroke, caused a spring steel finger to swing out and, by engaging a projection on the rear end of the programme drum, stop its revolution without excessive shock.

The full programme lasted practically three minutes, and near the end of each minute the time signal output of the unit was switched from the drum contact arms to take the six pips from the output of the signalling clock by a cam operated from main drum drive shaft.

The induction motor was started at 3 minutes 14 seconds before the hour, and stopped 15 seconds after the hour by relays controlled from an hourly contact (lasting for three and a half minutes) on the Mean Time Clock; while the magnetic clutch was started at 2 minutes 57 seconds before the hour by the minute signal on the signalling clock. Use of the correct minute signal was ensured by keeping its circuit open until the Mean Time Clock hourly signal occurred. The first minute impulse after this circuit became closed locked up the trip mechanism carried at the forward end of the programme arm carriage and so closed the magnetic clutch circuit and held it closed until the trip mechanism was unlocked mechanically by the drum after the programme had been concluded.

As stated above, drive on the forward transmitting portion of the cycle was by electric motor; at the end of the forward portion of the cycle the clutch was de-energised, allowing the drum to be rotated in the opposite direction back to its start position by a torque provided by a weight-loaded cord which had been wound up while time signals were being transmitted. This reverse rotation of the programme drum also returned the contact arm carriage, which was gravity-loaded to assist this movement.

Switching Facilities: In order to permit the maximum use of clocks in the reserve group comprehensive arrangements were made to switch in practically any clock of the reserve group, in place of its corresponding member of the working group. At the same time arrangements were provided to enable the various clocks to be readily inter-compared, using a tape or drum chronograph.

Overall Accuracy of the Equipment: The main factors controlling this, under normal operating conditions, were the deviation of the master clock from its predicted value (obtained by extrapolation based on star observations) and the irregularities in the spacing of the teeth of the transmitting wheels on the seconds shaft.

Star observations were normally attempted each night, but owing to Melbourne weather conditions periods of up to a week between satisfactory observations were common. On many occasions the master clocks would keep time to within, say, 10 milliseconds, over this period, but on other occasions errors of as much as 50 milliseconds were noted. The position was further complicated by the inaccuracy of the star observations (the probable error was usually about 25 milliseconds); this made several consecutive star observations necessary before the master clock error could be determined reliably. In addition, the spacing of the teeth in the seconds wheels could cause errors of 10 or 20 milliseconds.

Consequently the estimated probable error lay between 20 milliseconds (when conditions were stable) to possibly 60 or 70 milliseconds when conditions were bad. Over the last few years this latter figure was considerably reduced to, say, 20 or 30 milliseconds) by the use of the Post-office Crystal Clock (Frequency Standard) as a third master clock.

Modifications Made When Installing the Time Signalling Equipment at the Research Laboratories: Continuity of operations during the change from Observatory to Post-office operation was obtained by installing the clock group, which had been in reserve at the Observatory, in the Research Laboratories. The master clock of this group was not available, having on August, 1944, been sent to Mt. Stromlo Observatory. At the Research Laboratories, the function of this clock was performed by a synchronous clock driven from one of the crystal oscillators of the Primary Frequency Standard. This gives a greater accuracy and flexibility, at the cost of greater fault liability. This greater fault liability will shortly be practically eliminated by the insertion of a stable pendulum clock between the synchronous clock and the signalling clock to carry on as a master clock if the synchronous clock stops. Because the crystal master clock keeps Mean Solar time certain auxiliary equipment was modified to enable the original control system of the Signalling clocks to be maintained.

Some increase in the reliability of the control of the Signalling clock (which had been giving erratic trouble at the Observatory) was obtained by increasing the control weight and also shortening the time between comparisons of the Master and Signalling clocks.

Better use of cable pairs was made by installing splitting relays (for the hourly six pips signal) at City West Exchange.

Use of Frequency Standard Equipment with the Pendulum Clock Units: Although all details of this aspect have not been finalized, the following notes are included as a matter of interest:

At present the main units of the Frequency Standard are two 100 kC quartz oscillators ("A" and "B"); held as a stand-by is the previous Frequency Standard, a 1000 c.p.s. Valve Maintained Tuning Fork.

Timing of all three units is effected (using divide by ten multi-vibrators as necessary) by driving 1000 c.p.s. synchronous clocks from portion of the output of the unit concerned.

As well as indicating in a conventional way, hours, minutes and seconds, the one r.p.s. shafts of these clocks produce seconds impulses of high precision (erratic variations are of the order of one millisecond). The phase of these in seconds impulses can be precisely adjusted by moving the back (normally fixed) contact of the pair of seconds contacts, so that the contacts make earlier or later. Seconds Signals generated from a "Crystal" clock operated in this way (from Standard "A" at present) are transmitted twice daily over a normal telephone carrier circuit to Mt. Stromlo Observatory, Canberra. Comparison of these signals at the Observatory, with star observations and radio time signals provides the link between Time Signals generated in Melbourne and Fundamental Time, and also provides one means for calibrating the Frequency Standard.

The precision of this method of time keeping can be gauged from the fact that it is possible to predict ahead, on the basis of past behaviour against Observatory Time Signals, that "Frequency Standard" time after an interval of, say, one month. will be within 20 milliseconds of the corrected Observatory Time Signals at that date. (Corrections are usually not known till some weeks afterwards.)

Seconds impulses generated in this way are converted into electrical power by the use of gas discharge tubes as impulse generators, and the pulses of power, after being lengthened, are fed into the Signalling Clock control circuit in place of signals previously generated by the Slave portion of the Shortt Master Clock.

The phase differences between series of second signals from various sources (e.g., time signals, synchronous or pendulum clocks) are determined in several ways, e.g., by the use of pen or spark tape chronographs, or by adjusting the phase of one series to cause it to coincide with the series of seconds impulses from another source. In the former case, measurements can be made with negligible delay and errors of less than two milliseconds; while in the latter case the delay is also small and the measurement inaccuracy can be made less than one millisecond. In this latter case, coincidence can be observed visually on a Cathode Ray Oscillograph, or audibly by feeding the signals into a special Valve Oscillator/amplifier unit which drives a loud speaker; here coincidence is indicated aurally by a cancellation of one signal by the other, or by their super-position.

A purely electrical method of controlling a weight-driven pendulum is being developed to supersede the lifted-dropped weight method at present used on the signalling clock; such a development is necessary, because in the event of failure of the control signals the control weight remains dropped, thus giving the clock a large gaining rate. The unit being developed determines the phase of the pendulum clock seconds, relative to the control seconds, and converts this phase difference into a unidirectional magnetic force, which operates on a permanent magnet fastened to the bottom of the pendulum bob, and so causes what is, in effect, a change in the value of the constant of gravitation, as far as the period of the pendulum is concerned. This system of control is expected to be especially useful when applied to the Shortt Clock, where the master pendulum swings in an evacuated space, thus rendering impracticable control of its rate by the usual method of adding small weights to, or removing them from, the pendulum bob.

Future Action: It is proposed to instal new equipment, using electronic and telephone apparatus, at City West Exchange as soon as possible, so that the service can be handled by the department's normal operating staff.

Acknowledgment: The author's personal thanks are due to the late Dr. J. M. Baldwin and members of the Observatory staff; and to the officers concerned in the Research Laboratories, for their interest and enthusiasm.

VERY HIGH FREQUENCY CHANNELS IN RADIO BROADCAST SYSTEMS

J. F. Ward, B.A., B.Sc.

INTRODUCTION

The use of a radio link as a method of transmitting an audio frequency programme from a given pick-up point to the conventional, amplitude modulated, broadcast frequency radio transmitter has been employed in specialised cases for a number of years, both in Australia and overseas. Recently, however, the development of broadcast services operating at very high frequencies has given a new application of increasing importance to this type of programme channel.

This application lies in the provision of audio frequency programme channels from studios to remote broadcast transmitters by means of very high or ultra high frequency radio links. The two main reasons for the new importance assumed by these V.H.F. channels arise mainly from the adoption of high fidelity systems of radio broadcasting.

Firstly, the transmission of V.H.F. power (as is necessary in high fidelity broadcasting systems) suffers the limitations imposed by the need for an optical or quasi-optical propagation path, which in turn means that the broadcast transmitter must be located at a high altitude to command a large service area. Suitable eminences upon which high-powered V.H.F. transmitting stations can be built are few, and, for sociological reasons, are not usually associated with large centres of population; hence the practice has arisen of locating the studios of such stations at the centres of commerce, whilst the associated transmitters are built at locations of suitable altitude, perhaps 10 to 200 miles distant. This means that long programme lines are unavoidable. Furthermore, to exploit the inherent characteristic of V.H.F. broadcast systems, which is their capability of high fidelity transmission or wide-band audio frequency modulation, it is necessary to attain a better response characteristic for the programme line. The provision of long metallic open wire or cable programme circuits with an appreciably flat response from 30 cycles per second to 15,000 cycles per second, as sought in high fidelity transmission, for example, is electrically difficult, and when over bad terrain is also physically difficult, and, in addition, very costly. Despite this, however, there are many miles of open wire lines of this type in use at the present time.

Secondly, to produce the new electrical characteristics mentioned, it is necessary, in the case of the aerial line, to observe stricter physical tolerances, and this in turn emphasises the disadvantage of the metallic circuit. The relatively inaccessible terrain so frequently encountered in providing channels to the remote, elevated locations at which the broadcast transmitters are situated, and the long distances through regions which would not normally be served by main traffic routes, and which are, therefore, unsuitable for the economic provision of repeater station facilities, are also important factors to be considered.

W. R. David (16) points out that the difficulties of obtaining open wire programme lines capable of meeting the Federal Communications Commission of America requirements for F.M. stations, may render such lines uneconomical even over short distances. Further, on any programme line serving an important broadcast station, freedom from interruption is a prime requirement. To provide maintenance sufficient to ensure this under the conditions already outlined, where difficult terrain, high wind velocities, heavy snowfalls, and extreme atmospheric electrical hazards prevail over long distances, becomes a major engineering task. It is because of the above factors, together with others of less importance such as the short time taken for installation, the low capital cost, and the redundance of right-of-way demands, that V.H.F. studio-to-transmitter links have been adopted in a number of cases.

At present the frequencies employed for the links vary from 40 megacycles per second up to well over 300 megacycles per second, covering the very high and the ultra-high frequency spectrum, although in America an attempt has been made to allocate a portion of the spectrum above 300 megacycles per second for this particular service. The term V.H.F. link, when used henceforth in this article, will refer to all channels of the above type, whether operating in the V.H.F. (30 to 300 mc/s) or U.H.F. (300 to 3,000 mc/s) portion of the radio frequency spectrum. The application of services of this type has increased to such an extent in the United States of America that the Federal Communications Commission (1) has designated them Studio to Transmitter Links, referred to as S-T Links.

Since the regulations governing the operation of V.H.F. broadcast stations are necessarily stringent, the requirements for the associated radio links must be of a similar standard. For such work the general practice has been to use frequency modulation of the V.H.F. carrier, although there is no technical reason why wide-band, amplitude modulation methods should not be employed. As an indication of the standards required and the trends in design in this field, the following summary of the F.C.C. (1) regulations relating to S-T Links in America is given:

Definition: The term "S-T Broadcast Station" means a station used to transmit programmes from the main studio to the transmitter of a H.F. broadcast station.

Frequency: 330.4 to 343.6 megacycles per second.

Deviation Frequency: Not greater than ± 200 kilocycles per second.

Power: To be a minimum. Of the order of 25 watt.

Noise: 60 db. below 100% modulation.

Distortion: Not greater than 2% r.m.s.

Response: Within 2 db. of the standard R.M.A. 100 micro-second pre-emphasis characteristics.

Antenna: The power gain of a studio to transmitter transmitting antenna, toward the receiver shall be 10 (field gain 3.16) times the free space field from a doublet, and in all other directions, 30 degrees or more off the line of the receiver, the power gain shall not exceed $\frac{1}{4}$ the free space field from a doublet. The free space field of a doublet is taken as 137.6 mv/m for 1 kW. at 1 mile.

It is to be expected that the number of links complying with this specification will grow as more and more V.H.F. broadcast transmitters are installed. This increase in V.H.F. broadcasting appears to have been brought about by the suitability of that portion of the spectrum for the allocation of more station frequencies than hitherto available; the use of wide band and frequency modulation methods; the design of antennæ of high gain with small physical dimensions and the inherent stability of V.H.F. radio propagation conditions.

PROPAGATION

A vital factor underlying the adoption of channels of the type outlined above has been the increasing empirical and mathematical knowledge of the behaviour of electro-magnetic radiation at the frequencies concerned over various distances, types of terrain and for variable tropospheric conditions. Selected bibliographical references to the main phenomena in this study are given under (2)-(5), (8), (9), (11) at the end of this article.

At present, it is usual to operate V.H.F. links only over optical or quasi-optical distances, and with arrays appreciably above ground level. This means the field strength at the receiving point consists mainly of the space wave, which is, in turn, the vector sum of the direct and the ground reflected waves. However, a great deal of information is now available regarding the propagation characteristics of V.H.F. transmissions which utilise the indirect ray, i.e., the ray refracted in the atmosphere, and which is the main source of received energy for ranges well beyond the optical. It appears that for soundly designed and suitably located equipment and antennæ systems, reliability at these extreme ranges exists for considerably greater than 90% of the time. For broadcasting work, however, a reliability of the order of 100% is required, and further experimental information must be obtained and further technical development achieved before the same confidence can be placed in non-optical V.H.F. channels as can be placed in transmission over purely optical paths. Some typical received field strength recordings are shown in Fig. 1.

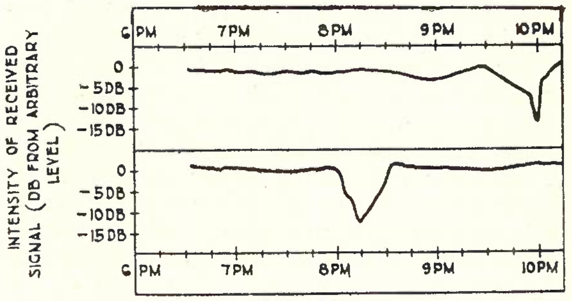


Fig. 1a.

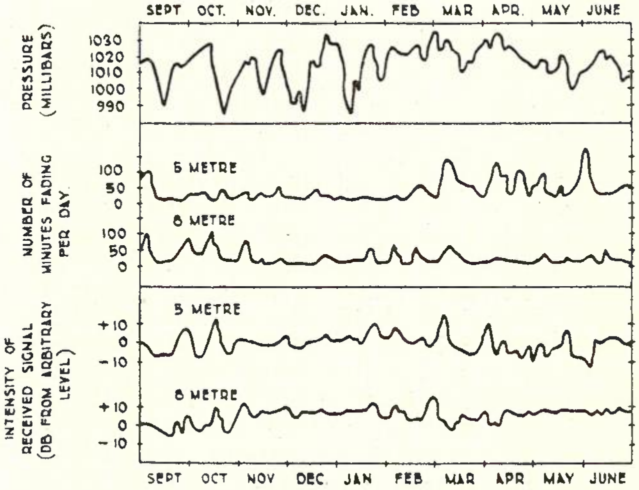


Fig. 1b.

For the first of these, six interruptions, totalling about three hours over a period of seven months continuous operation, were recorded, and the character of two of these fades is shown (the path was slightly greater than optical). The second case gives results obtained by Smith-Rose and Stickland (14) over a long path, including 36 non-optical miles of transmission, and shows a degree of correlation of atmospheric pressure with field strength. A commercial carrier telephone service has been provided over the latter link for several years.

At present, however, the unreliability of received signal strength due to rapid random changes of atmospheric conditions cannot be satisfactorily reduced, and it is doubtful whether attempts should be made to use V.H.F. programme channels over unfavourable transmission paths. It might be pointed out here that, under adverse conditions, it is usually the actual intermittent fading which determines the workable limit rather than any low average level of signal strength.

Now the space wave field strength for optical transmission depends on the interference pattern set up between the direct and the ground reflected rays. This pattern, therefore, depends on the relative phase and amplitude relationships of these two waves, and these, in turn, depend on the magnitude and angle of the ground reflection co-efficients between the transmitting and receiving points. It has been found that this complex co-efficient is different for vertically and horizontally polarised radiation. Moreover, there is a peculiarity here in that, in the former case, the reflection co-efficient varies greatly with variation in the angle of incidence, whereas in the latter this variation is much smaller. Usually, propagation is carried out under grazing incidence conditions, in which case there appears to be little difference in behaviour between vertically and horizontally polarised radiation, but in practice the latter is commonly utilized as higher signal to noise ratios are then possible, since the major part of artificial radio frequency noise is vertically polarised.

The ground reflection co-efficient for horizontally polarised radiation has a phase angle of 180 degrees in relation to the incident radiation; hence for a single reflection at grazing incidence, it is probable that the directly received and reflected rays will be nearly 180 degrees out of phase, and, since under these conditions, the path length, and so the attenuation is approximately the same, the resultant field strength will be much lower than that due to either the direct or reflected radiation alone. If, now, it can be so arranged that the latter ray undergoes a dual reflection in order to reach the receiving point, it will probably be approximately in phase with the direct ray, and even though the amplitudes of the radiations are now different due to different amounts of attenuation, a considerable improvement in resultant field strength can be expected.

In view of this, and also since standing wave systems can be set up at the receiving point due to reflections from adjacent objects yielding multiple propagation paths, it is usual to determine the best location for the receiving array by field experiment to determine the position of a suitable radio frequency voltage antinode.

In Fig. 2, two contours over actual paths are given. To achieve clarity, the vertical scale is distorted in relation to the horizontal, and a factor included to allow for refraction around the earth's surface.

Since both atmospheric and artificially generated electrical interference covers a very large portion of the V.H.F. spectrum, reception of these unwanted signals is unavoidable. Notwithstanding this, adverse effects are encountered infrequently in practice for the following reasons:

(i) High level artificial interference can be prohibited by suitable regulations.

(ii) The receiving array is situated, where possible, in an electrically quiet locality so far as artificially generated radio frequency noise is concerned.

(iii) The high directivity of the receiving array reduces the magnitude of the interference voltages in relation to the signal voltage.

(iv) The "capture effect" characteristic of F.M. receivers introduces discrimination in favour of the stronger (i.e., in most cases the desired) signal. The degree of discrimination depends upon the frequency separation of the two signals as well as their relative magnitudes.

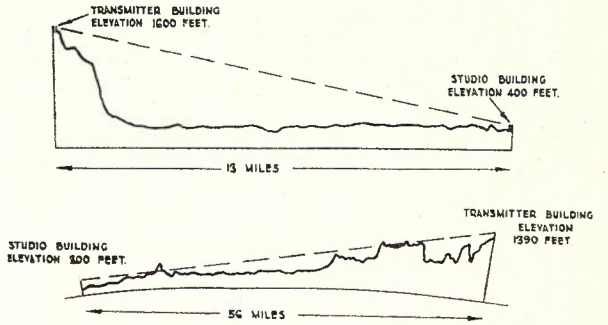


Fig. 2.

EQUIPMENT

Transmitter: The frequency allocation for these links is precisely defined and pre-supposes that the frequency of each transmitter is crystal controlled. The power output depends on the overall design of the link. The three relevant factors in this design are the power output, the array gain determining the overall equivalent of the link, and the signal to noise ratio desired at the input stage of the receiver. It is sound engineering to reduce the transmitter power output to a minimum and to use high gain arrays and receivers of high sensitivity. Generally speaking, the power used is of the order of 20 watts. Wide-band modulation is necessary, and often frequency modulation is employed. At present, standard reactance tube or phase shift modulation methods with suitable pre-emphasis and de-emphasis (13) are in operation.

Receiver: Normally, this will be of the superheterodyne type, of high sensitivity with wideband intermediate frequency circuits to fulfil the high fidelity requirements, and in most cases will have a crystal controlled local oscillator, operating at a low harmonic of the detection frequency. As for transmitters, amplitude and frequency modulation methods are in use.

Overall signal to noise ratio is usually the best criterion of a satisfactory V.H.F. link, and investigations have been carried out by Herold (12) and others to determine the optimum coupling conditions from the antenna to the first signal frequency stage grid of a very high frequency receiver. The factors of importance are firstly the antenna noise, which is reduced by employing a highly directional receiving array, erected if possible in electrically quiet surroundings; and secondly, depending upon band width limitations, the ratio of the input shunt resistance of the first tube to the equivalent noise resistance. Fig. 3 shows that the conditions under which this latter ratio is a maximum, hence yielding a maximum signal to noise ratio, are not those which hold for maximum gain.

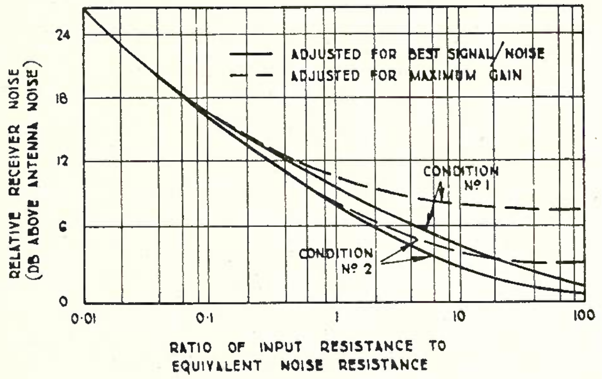


Fig. 3.

In fact, if the coupling from the antenna to the grid of the first tube is designed for optimum gain, these curves indicate that the advantage to be derived by increasing the ratio above unity is small; but if, on the other hand, optimum signal to noise ratio coupling is adopted, it is desirable to design carefully the circuit elements in the input to obtain a value of the ratio approaching 100. This fact is of considerable importance, since received field strengths encountered in non-optical V.H.F. transmissions will often be of low absolute value.

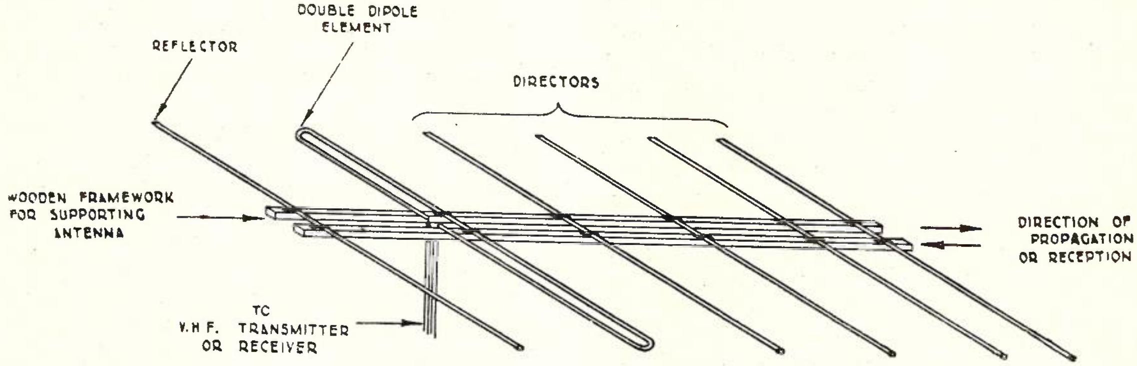


Fig. 4a.

Aerial Equipment: The use of very high frequencies enables highly directional array systems of small physical dimensions to be designed. This is important for three reasons. Firstly, higher array gain means lower transmitter powers, e.g., using an array with a gain of 10 db. at the transmitting and receiving points with a 10 watt transmitter, produces a signal at the receiver input equal to that which would be obtained from a 1 kW. transmitter using simple dipoles at the two terminals of the circuit. Secondly, high transmitting directivity means less interference to adjacent V.H.F. radio receiving equipment; and, thirdly, high receiving directivity means minimum extraneous noise pick-up. An excellent treatment of the design considerations applying here is given in (18).

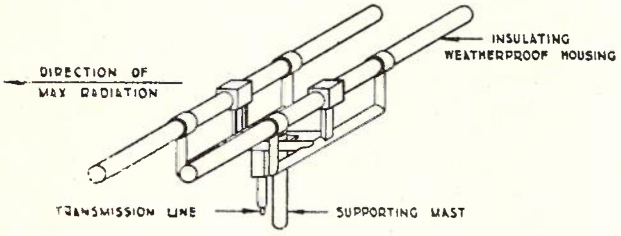
The number of types of arrays which can be used is diverse and depends largely on the actual frequency of operation—the ability to design for higher directivity increasing, of course, with rise in frequency. Conventional systems of panel arrays, using half-wave elements in broadside and stacked arrangements with parasitically driven reflecting curtains, have been used to give a gain, in the transmitting direction, over a single dipole of up to 16 db. This figure is the approximate practical limit in gain for this type of array. More compact, and also quite efficient electrically, is the Yagi arrangement, shown in Fig. 4a, which uses a number of directors with one or more reflector elements arranged in an end-fire system and driven by a dipole or a double dipole if impedance matching conditions are suited to it.

Within the U.H.F. spectrum parabolic reflectors become of reasonable physical dimensions towards the upper frequency limit, and gains of more than 30 db. over the elementary dipole are obtained. Typical plane polar diagrams of a rotational parabola are given in Fig. 5.

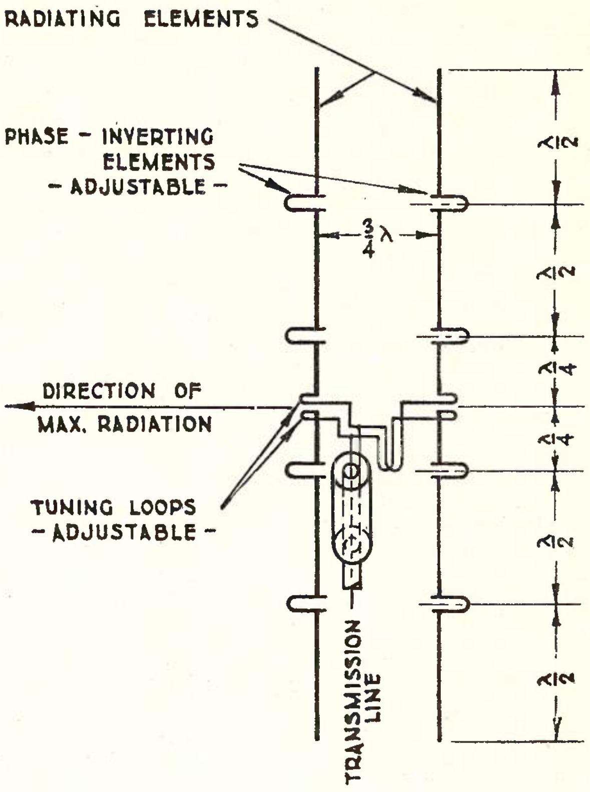
At the receiving end of the link, it is often necessary, because of the elevation of the site, to provide some means of retaining the efficiency of the array system under conditions of heavy snow and ice. In some cases, the array is completely housed in a suitably shaped gas-filled envelope, whilst in others, the array elements themselves are heated electrically to prevent ice formation.

Feeding and Matching Methods: The use of V.H.F. and U.H.F. equipment allows transmitting and receiving aerials to be coupled to the transmitters and receivers respectively by means of coaxial cables or by hollow cylindrical or rectangular wave guides if frequencies of the order of 1,000 mc/s or higher are adopted. Two important properties of coaxial cables or wave guides are the complete shielding from extraneous radio frequency pickup afforded and the comparatively high attenuation they introduce. The loss, which in the case of typical coaxial cable, is about 3 db. per 100 feet at 100 mc/s, and for wave guides of the order of 0.1 db. per 100 feet at 3,000 mc/s, necessitates short feeder lengths, which means the arrays must be situated as close as practicable to the equipment at both transmitting and receiving points.

Just as it is possible at very high frequencies to design and precisely tune array systems, so it is possible to design and accurately adjust matching devices for use between the feeder output and the array input. The method of matching usually depends on applying in shunt across the feeder line a reactive element derived by a short or open circuit coaxial line of the order of a quarter wave long at the operating frequency.



PHYSICAL CONSTRUCTION



SCHEMATIC

Fig. 4b.

The theory of impedance transformation along known lengths of coaxial line has been thoroughly developed, and allows matching to be carried out at positions which are physically convenient in relation to the array location.

The general tendency in the design of S-T links is to utilise as far as possible arrays and feeding systems which are physically and electrically equivalent at the two terminals of the channel, and standard arrays which conform electrically to the requirements of the F.C.C. (1) are now produced commercially in America (see Fig. 4b).

Power Supplies: At the V.H.F. transmitting point commercial A.C. power is usually available, but at the distant elevated receiving site, power has to be generated. Usually, of course, this will be provided by the power supply to the V.H.F. broadcast transmitting station situated nearby, but in some installations it has been a better proposition to generate power for the V.H.F. receiving equipment by a separate motor alternator set; whilst in other cases wind-driven generator equipment has proved effective. It will be appreciated that the topographical and meteorological conditions existing at these locations are almost completely favourable towards the production of power from wind-driven equipment.

Monitoring Equipment: In the case of remotely controlled V.H.F. channels, it is desirable to have some signal, indicating the satisfactory working of the link, relayed to an attended station. The most positive system is to use a monitoring dipole (at a suitable location near the transmitting array), with a diode detector whose output is relayed over a metallic circuit.

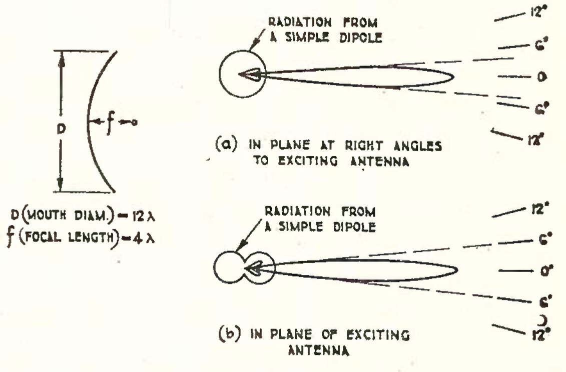


Fig. 5.

In the case of channels which are frequency modulated, suitable equipment for the measurement of the deviation frequency is desirable, and since most of the readily available equipment of this type is designed at present for checking the deviations of ± 75 Kc/s or ± 200 Kc/s, this factor is an important one in the choice of the deviation to be used over the V.H.F. channel. As well as deviation frequency, it is desirable also to have an indication of the emission of spurious signals, the mean carrier frequency without modulation, the fidelity of the modulated signal, and an alarm to indicate over-modulation.

OVERSEAS PRACTICE

The general principles in the design of transmitters, receivers, aerials, and miscellaneous equipment given above are based on practice in England and America, but a few specific installations might be mentioned as indicative of the general trend.

Transmitting, receiving and array equipment designed by the General Electric Co. to meet the requirements of S-T links in America has been described by Goetter (15). This F.M. system utilises a 25 watt reactance tube modulated transmitter with the mean frequency crystal controlled, and has a deviation frequency of ± 75 Kc/s. A system of frequency stabilization is employed, and a monitoring channel provided. The arrays have a gain of 10 db., and are similar to that shown in Fig. 4b.

The F.M. broadcast transmitters W.S.M. (10) and W.M.I.T. of U.S.A. are both driven over radio links operating at or above 300 mc/s; the latter over a path of 116 miles, which is just greater than optical. Of particular interest in this instance is the use of single and double wire tilted rhombic arrays, of side length 4 and 6 wave lengths respectively, for transmitting and receiving purposes. Panel arrays of stacked elements using reflecting curtains yielding theoretical gains of up to 16 db. are in use in other installations, and in one case such a configuration is mounted at the top of an 880 foot steel broadcast radiator and fed via a coaxial line by means of a radio frequency filter network.

The corner array (6), (7), which is a special case of a dipole with a sheet reflector, has also been used successfully to give gains of greater than 15 db. with small physical dimensions. A sheet reflector behind a dipole has the unique property of needing no tuning so long as its area is extensive with reference to the wave length of the radiation in use. The corner array, which is an approximation to this condition, is likewise found to be non-critical as regards the tuning of the parasitic elements so long as a large number of such elements is used.

The British Post-office has used V.H.F. links mainly to provide multi-channel carrier telephone facilities to its adjacent island networks, but circuits of the types employed could be used readily in place of open wire programme circuits. Wide-band F.M. transmitters rated at only 1 watt aerial power, driving panel type arrays of approximately 15 db. gain, are in use to give reliable channels over optical and quasi-optical paths. Output level variations of up to 3 db. over periods of from 5 to 30 minutes have been recorded. Experience over these systems has confirmed that frequency modulation tends to give working signal to noise ratios for greater periods than does amplitude modulation. Experiments by the B.P.O. on propagation conditions at 60 mc/s for ranges of up to 300 miles have given results that have encouraged further extensive observation over these extreme ranges.

AUSTRALIAN EXPERIMENTS

A V.H.F. channel operating at 37.2 mc/s has been set up between a main studio and a 10 kW. National Transmitting Station of the conventional amplitude modulated type. The path is optical, due to the suitable choice of transmitting and receiving locations. The transmitting and receiving arrays, which are similar, and of the six element Yagi type using a double (or folded) dipole as the driven element, give an approximate gain over the link of 12 db. The physical construction of the array is shown in Fig. 4a. Amplitude modulation is used; the transmitted power is about 10 watts and both the transmitter and receiver are crystal controlled. Provision has been made by means of a cable circuit from the broadcast control room to remotely control the transmitter, which is situated at the top of a high city building. The metallic portion of the programme circuit is likewise routed to the modulator of the transmitter in this cable. Some work has been carried out on the installation of a single channel carrier telephone system over the link to give an additional audio channel for the emergency control of a second National Transmitter situated at the same receiving site.

As in the case of the B.P.O., a number of V.H.F. links have been installed to provide radio telephone services between the mainland and certain islands.

CONCLUSIONS

After reviewing the technical aspects, the economic features, and the overseas practice relating to very high frequency programme channels, it would appear that the future design tendencies will be as follows:

(i) As far as possible optical paths will be chosen, since effective propagation does not then depend primarily on refraction from air mass layers exhibiting marked discontinuities of refractive index.

(ii) In view of the better noise characteristics, horizontally polarised radiation will be adopted.

(iii) Because of improved signal to noise ratio and freedom from interference, frequency modulation systems will be used.

(iv) Until fixed by international agreement the frequencies employed will increase towards the upper limit of the ultra high frequency spectrum, since array systems are more efficient, capable of greater directivity, and easier to construct physically for these frequencies.

A logical development from the progress made up to the present is the use of remotely controlled repeating centres to provide channels of high reliability between studios and transmitters separated by propagation paths well beyond the optical range. For preference, these stations will be purely radio frequency amplification points, and will not require any demodulation equipment.

Finally, it might be suggested that, since the technical difficulties can be overcome, the comparatively slow introduction of V.H.F. radio for providing telephone channels has been due mainly to economic factors. For this particular type of service highly efficient line plant usually exists, and it is fairly uncommon to find the necessary combination of sufficient community of interest between two large centres and the suitability of conditions for very high frequency radio propagation between them. On the other hand, in the studio to transmitter circuit, there is a technical need which cannot be supplied economically by any alternative means, and the experience of the present installations seems to indicate that it will be the accepted practice rather than the exception to use radio link programme channels in the post-war development of V.H.F. radio broadcasting.

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ADELAIDE TRUNK EXCHANGE: INTERSTATE OPERATING SUITE

D. Jeffs and A. K. Forrest

Prior to the installation of the new interstate suite, the trunk network centring on Adelaide consisted of 219 circuits, 100 being voice frequency dialling circuits similar to those described in Vol. 2, No. 6, page 337, the remainder being operated on a ring down basis.

The operating positions available for handling trunk traffic were:

(a) Suite of 24 Siemens trunk positions,
(b) 6 locally made interstate positions, and
(c) 2 trunk "A" positions.

The last-mentioned are situated on the main Central switchboard and carry the incoming traffic originating in official offices, which work on a "single ticket" system.

With the increase in trunk traffic, and the proposal to provide additional interstate channels, it was decided to instal a suite of 10 "interstate" positions, on which all traffic over interstate circuits would be handled, the vacated positions then being arranged for intrastate working.

Fig. 1.—Operating Suite.

The operators' positions shown in Fig. 1 were made in the Adelaide workshops, and are of similar design to those used in the Melbourne Trunk Exchange, but the keyshelf layout (Fig. 2) is arranged to suit the equipment provided. Each position is equipped with 3 Trunk Termination circuits, later referred to as the answering (ANS) side, to which are connected the "interstate" circuits under the control of that particular operator. These are shown on the left of Fig. 2, while on the right are shown 5 connecting circuits, later referred to as the CALL side, over which the operator sets up the call to the circuit or subscriber required. The connecting circuits terminate on 200 outlet 2000 type selectors on the banks of which are connected:

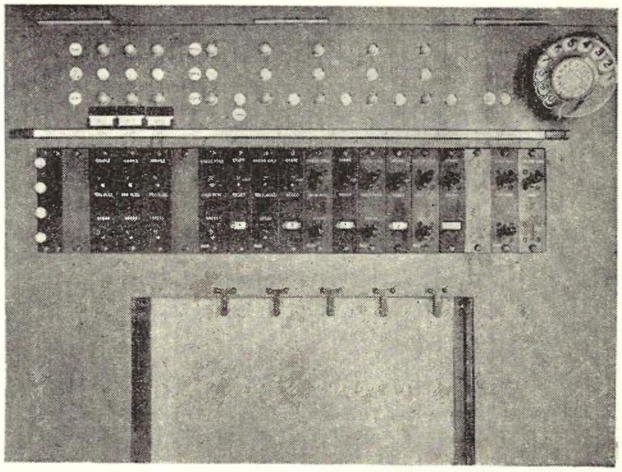


Fig. 2.—Keyshelf Layout.

(1) Circuits to trunk stations which have an appreciable amount of interstate traffic.
(2) Junctions to the "intrastate" board for connecting to other trunk circuits.
(3) Junctions to "Central" manual exchange, and
(4) Junctions to "Tandem" exchange for access to the metropolitan automatic network.

Access to any line or group of lines connected to the trunk selector multiple is obtained by dialling a three-figure number. The first digit is absorbed in the selector control circuit (see Trunking diagram, Fig. 3) and acts as a wiper switching digit only. The second digit selects the required level, whilst the third digit selects the bank contact in the level corresponding to the first line of the required group. If the first line is engaged, the switch will automatically search over the remaining lines in the group until a free line is found. If all the lines in the group are engaged, busy tone is fed to the operator. An individual line in any group can be dialled if necessary, in which case that line only is tested.

Interstate lines are worked on a "back to back" basis in association with a teletype order wire channel. The teletype channel is used for passing all the necessary information relating

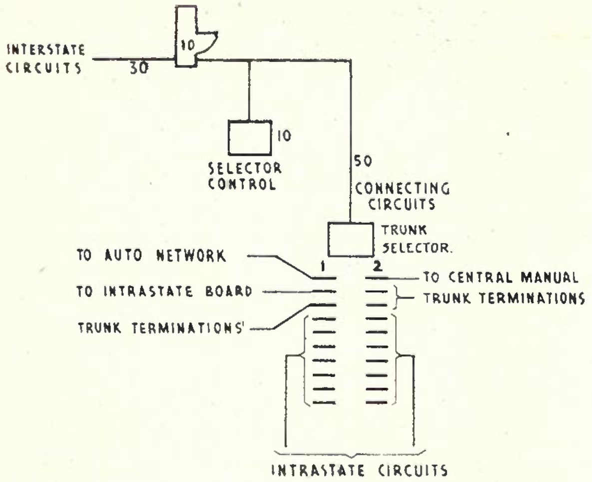


Fig. 3.—Trunking Diagram.

to the calls which are to be completed over the telephone channel. Three interstate lines are the maximum that an operator can effectively handle, but five connecting circuits are provided so that two additional subscribers may be called in readiness for connection to the interstate circuit upon completion of a previous call. Coupling arrangements provide for coupling any termination on a position to any of its connecting circuits. This arrangement results in a high effective occupancy of the trunk lines.

KEYSHELF EQUIPMENT (FIG. 2)

TRUNK TERMINATION: Engaged Lamp (Eng.) is alight whenever the trunk channel is in use.

Call and Clear Lamp acts as a calling signal when the channel is free, and a clearing or recall signal when the channel is engaged.

Couple Lamp is alight when the channel is engaged on the position but is not coupled to a connecting circuit.

Couple Key (non-locking) is used when coupling a trunk termination to a connecting circuit.

Trunk Rlse. Key (non-locking) to release the trunk termination from the position.

Speak (Ans.) Key engages the trunk termination on the position, connects operator's speaking circuit to the trunk channel, and when first operated lights the engaged and couple lamps. This key is used whenever the operator desires to speak on the "interstate" circuit only, and if used when the termination is coupled to a connecting circuit, it acts as a decouple key.

CONNECTING CIRCUIT: Engaged Lamp (Eng.) is alight while the selector associated with the connecting circuit is "off normal."

Supervisory Lamp (Supv.) on calls to metropolitan subscribers is extinguished when called subscriber answers and relights when he clears. On calls over intrastate trunk line, it acts as a ring-off or recall signal.

Couple Lamp is alight when the engaged connecting circuit is not coupled to a trunk termination.

Check Couple Key (non-locking) is used in conjunction with the monitoring key (Mon.) to indicate which circuits are coupled together by causing the relevant couple lamps to flash.

Selector Release Key (Selr. Rlse.), non-locking, releases the connecting circuit and its associated selector.

Speak Key (Call) (locking), connects operator's speaking circuit to connecting circuit, and when coupled to a trunk termination allows the operator to speak to both parties.

Monitor Key (Mon.) (locking), permits the operator to monitor a call by connecting the speaking pair of a connecting circuit through a valve amplifier to the operator's receiver. The valve amplifier has a high impedance input to avoid interference on an established connection.

Timer Start Key (Start.) is operated when call is being timed.

Timer Reset Key (Reset.) is used to reset timer to its normal position, 0.0 minutes.

Timer Lamp lights at 2.8 to 3 minutes and again from 5.8 to 6 minutes as an indication to the operator that a 3-minute period is almost completed. At 8.8 to 9 minutes the lamp flashes to inform the operator that the timer must be reset if timing is to continue beyond 9 minutes.

Timer is a modified 100 A type register, operated by a pulse every 6 seconds when a call is being timed, and records time in minutes and 1-10th minutes. Timer can only operate when the connecting circuit supervisory lamp is not alight, and consequently stops when the called subscriber clears. It also controls signals on timer lamp.

COMMON POSITION EQUIPMENT: The **Dial** is used in selecting the trunk or junction group, and on metropolitan automatic calls to complete the call to the wanted subscriber.

Dial Key with a **Speak (Call.) Key** operated connects the dialling circuit to the relevant connecting circuit. The dial key permits the selector, if the line dialled is engaged, to search over the remainder of the group until a free line is found.

Dial Individual Line Key (Dial Ind. Line) permits the connecting circuit selector to test the line dialled only. If the line dialled is engaged, busy tone is returned to the operator.

Ring Key with a **Speak (Ans.)** or **Speak (Call.)** key operated causes ringing current to be applied to call the wanted station.

Buzz Monitor (Buzz Mon.) operates a buzzer to attract the attention of a monitor, and lights a lamp to indicate the position calling.

Connect Monitor with a **Speak (Call)** key operated permits a circuit on the monitor's post to be connected to any connecting circuit.

Monitor Connected Lamp (Mon. Cnctd.) lights to indicate that the monitor's circuit has switched to the connecting circuit desired and that the operator can leave the circuit and proceed with her duties.

KEYSHELF OPERATION

Incoming Call on Interstate Trunk: Call and clear lamp lights.

Call answered by operating trunk speak key—call and clear lamp extinguished and engaged and couple lamps light.

To obtain wanted subscriber: Restore trunk speak key and operate speak key of a free connecting circuit, then position dial key and dial the wanted number. Engaged and couple lamps light, and if the call is to a metropolitan subscriber the supervisory lamp (Supv.) also lights. When the called subscriber answers the supervisory lamp goes out.

Coupling: To couple a trunk circuit to a connecting circuit, operate the connecting circuit speak key and the trunk couple key of the circuits to be coupled. When coupling is effected the couple lamps go out.

To Decouple: Operate trunk speak key.

On a call to intrastate trunk station set up on connecting circuit, and with speak key thrown, operate position ring key. This applies ringing to the trunk line to call the distant station. A ring off or recall signal will light the supervisory lamp, which will be extinguished when the operator answers. The circuit arrangement is such that only one speak key can be effective at a time, and it is therefore necessary for the operator to leave a circuit by restoring its speak key before operating any other speak key. This feature prevents coupling of circuits via the speak commons.

As all interstate channels are normally worked on a "back to back" basis, it is necessary, when connection is required between two such circuits, to arrange to have one of them released. The operator handling the call then obtains access to the channel required on a connecting circuit, and the call is then handled in the usual way. Each trunk termination is provided with an appearance on the trunk selector bank multiple for this purpose.

FUNCTIONS OF SWITCHING CIRCUITS

Trunk Termination is a relay set which acts as a line circuit for the trunk channel. It receives calling signals, connects the operator to the channel when desired and controls lamp signals on the switchboard.

Operator's Position Circuit includes the operator's speaking and monitoring circuits, and provides for the resetting of any call or recall signal from any trunk station. It also provides for dialling on connecting circuits and for either group search, or connection to a particular circuit.

Selector Control Circuit is common to the five connecting circuits on a position, accepts dialling from the operator's position circuit, and controls the selector of the connecting circuit.

Selector Circuit: The selectors are modified 2000 type 200 outlet group selectors, which, under the control of the selector control and operator's position circuits, select the required line and control the lighting of the engaged, supervisory and coupling lamps in the associated position circuit as required by the circuit conditions.

Coupling Circuit is a relay set associated with each position to provide for coupling any of the 3 trunk terminations with any of the 5 connecting circuits. It consists of an "A," "B" and "C" set of 5 relays each, the "A" set providing for coupling between trunk termination 1 and any connecting circuit, the "B" set for trunk termination 2, and the "C" set for trunk termination 3. The speak key of a connecting circuit, being thrown, provides a circuit for its coupling relays to be offered to the trunk terminations, and the operation of the trunk termination couple key selects the particular relay required. The action of coupling removes a 600 ohm termination from the trunk termination and connecting circuit, which are coupled together, and extinguishes the relevant couple lamps.

The intrastate trunk equipment with which this system had to work is of the sleeve control type, each intrastate trunk circuit terminating on a relay set which provided the sleeve circuit shown on Fig. 4 (a), which represents "free" line conditions. The rectifier MR is an addition to the original circuit made necessary by the new equipment.

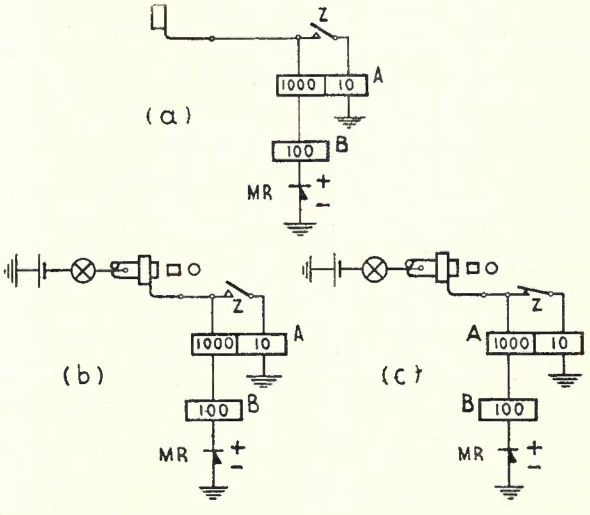


Fig. 4.—(a) Free and (b), (c) Busy Conditions.

When a cord is inserted in a trunk jack, battery (24 v. neg.), through the cord circuit supervisory lamp, is applied to the sleeve of the jack, Fig. 4 (b), and the line is marked "engaged" to other operators. In Fig. 4 (c) is shown the circuit after the country station has given a ring off signal, relay Z being operated applies a 10 ohm earth to the sleeve of the jack.

The tip, ring, and sleeve of the intrastate trunk circuits are wired to the positive, negative, and private of the interstate selector banks, and the testing circuit of the selector control circuit is arranged (Fig. 5) to recognise the conditions shown in Fig. 4 (b) and (c) as "busy."

The problem was for a testing relay to distinguish between conditions (a), and (b) or (c) with minimum alteration to existing relay sets and cord circuits. It was decided to insert rectifier MR as shown and connect positive battery to relay T. This solution proved to be simple and effective.

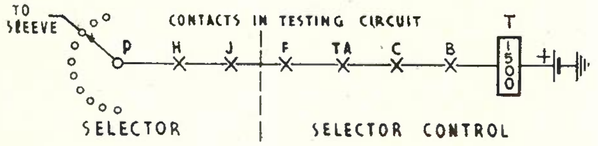


Fig. 5.—Selector Testing Circuit.

Relay T is fitted with a nickel iron core, and is fast to operate and release. If the line dialled is busy, relay T operates and completes a circuit for a self-interrupted drive of the rotary magnet. Each bank contact is tested in turn, and on reaching a free line relay T releases and stops further rotary stepping. When the dial individual line key is used by the operator, the self-interrupted drive circuit is opened, and if relay T operates because the line is busy, another relay, TB, is operated and releases relay F, which removes T from the testing circuit to prevent it interfering with another selector testing over the same group.

DIGIT ABSORPTION AND WIPER SWITCHING

The first digit dialled into the selector control circuit is either 1 or 2, and does not affect the selector, its purpose being to determine which set of wipers is to be used. These elements of the circuit are shown in Fig. 6. Relay DB (not shown) is operated by the position dial key and remains operated during the dialling of all digits, and relay A (not shown) is operated from the position dialling loop and responds to dialling. A1 operates relay B, which holds during impulsing.

First digit 1. On the first release of A, relay C operates from earth via release keys, A1, DB6, TB6, B2, C500 to battery, and at C5 prepares a circuit for relay W. When A again operates, relay W operates and locks through W3 and DB7. As the digit dialled was 1, relay C releases in the inter-train pause and relay MA operates from earth through A1, C5, W2, MA

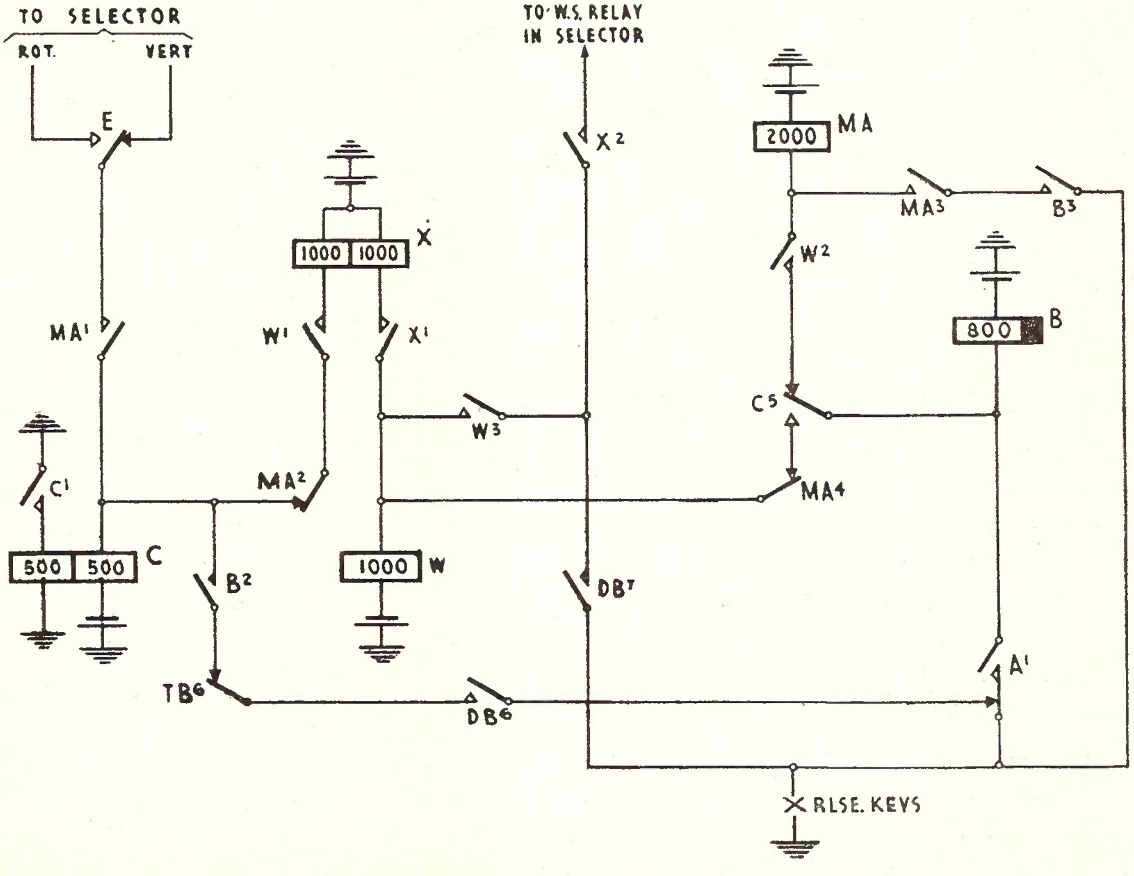


Fig. 6.—Digit Absorbing and Wiper Switching Circuit.

2000 to battery. MA locks through MA3 and B3, and further impulse trains are transmitted to the selector vertical and rotary magnets through MA1. No wiper switching takes place when the first digit is 1, as the wipers are connected to give access to the 100 group normally.

First digit 2. The operation is the same to the point where relay W operates on the second operation of A. W1 prepares a circuit for relay X, and when relay A releases on the second impulse, X operates from earth through the release keys, A1, DB6, TB6, B2, MA2, W1, X 1000 to battery. Relay X locks through X1, W3 and DB7 to earth via release keys and at X2 feeds earth to the selector to operate the wiper switching relay WS, which switches the circuit to the upper set of wipers for access to the 200 group. On the release of C, at the end of the train relay, MA operates and subsequent impulse trains are fed to the selector via MA1.

TIMING PULSES AND ALARMS

The call fee indicators are A.P.O. Clock No. 44A. They differ from those used in the Melbourne Trunk Exchange and described in Vol. 4, No. 1, page 10, in the following respects:

(a) The indicating drums normally stand at 0.0.
(b) It is reset electrically at the rate of ten impulses per second.
(c) The control key is of the vertical lever type with three positions, namely, stop, start and reset.

Six-second Pulse: A Master Clock B.P.O. No. 46 is used to originate the 6-second pulse. In case of master clock failure, emergency pulse generation is derived from a system of 3 relays controlled by a 3-second cam (0.5 on 2.5 off) on the Tandem Exchange ringer, as shown in Fig. 7, in which the control keys are omitted. Relay A operates on receipt of the 500 milli-second pulse, followed by B at the end of the pulse. Contact B1 prepares a circuit for C which operates on the next pulse. C2 releases A and B, but C3 maintains C for the duration of the pulse, C1 delivering a 500 milli-second pulse into the distribution relays. The cycle is recommenced on the next pulse.

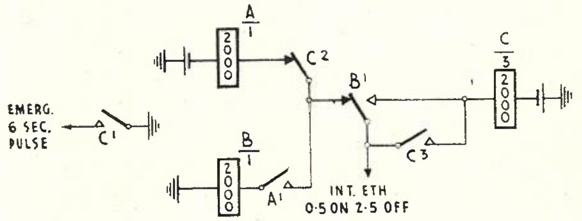


Fig. 7.—Emergency 6-Second Pulse.

Pulse Distribution: The 6-second pulse is split up into three separate non-coincident pulses by means of distribution relays (see Fig. 8), and become known as the W, X and Y pulses. The

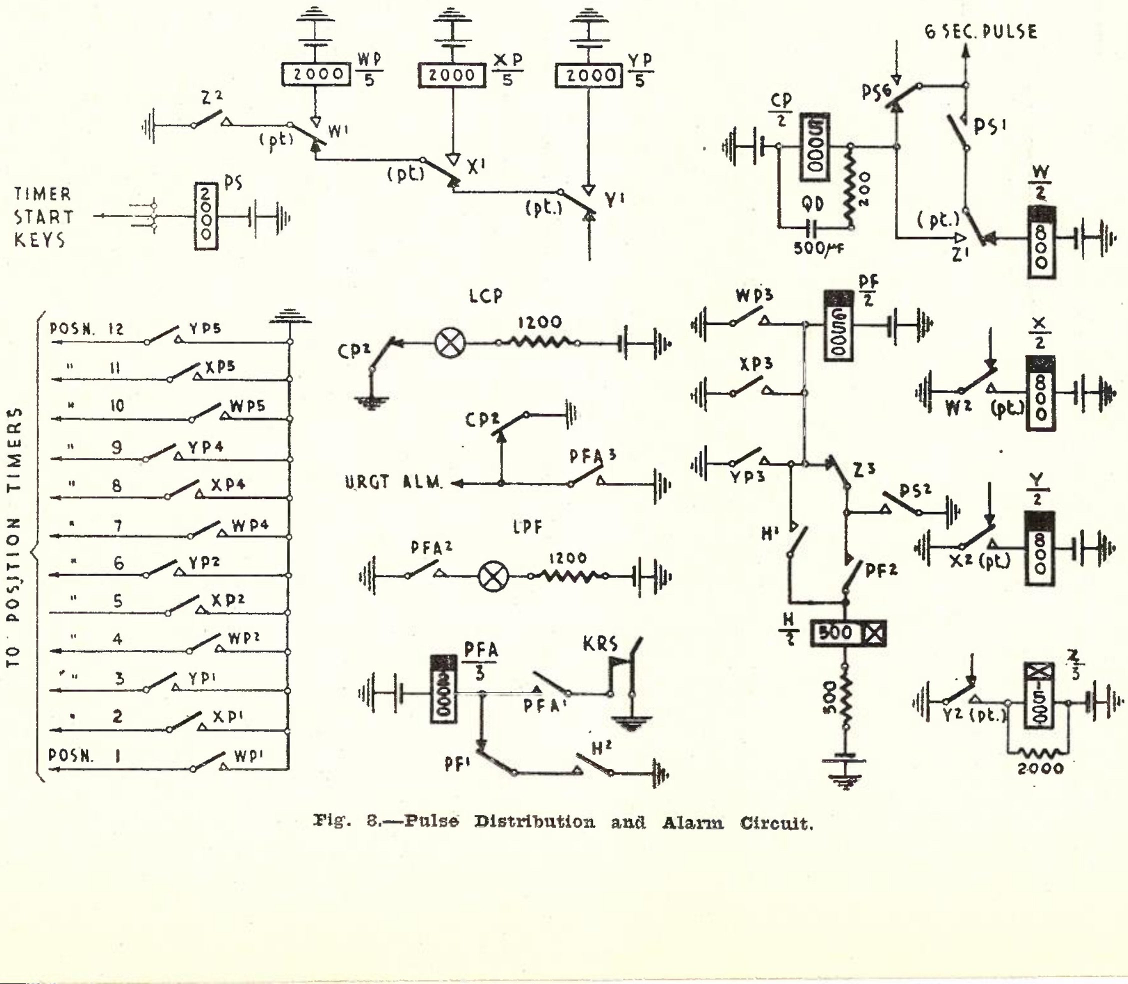


Fig. 8.—Pulse Distribution and Alarm Circuit.

distribution relays are under the control of relay PS (which is energised as long as any timer start key is operated) and only function when timing is in progress. The distribution relays are in duplicate and provision is made (by means of keys not shown) to check the release lags of the idle set by utilising Routine Test Set No. 22.

Pulse Alarms: Relays are used to give alarms should either the Master Clock or distributing relays fail, the alarms also being controlled by relay PS. With no timing taking place, the 500 micro-farad condenser QD is charged from the primary 6-second pulse over contacts PS6. The discharge of QD will maintain relay CP for approximately ten seconds. When timing is in progress the break of PS6 makes QD dependent on charge spurts over Z1.

Contacts of relays WP, XP, and YP deliver the actual pulses to the timers and relay failure gives the following alarm. PS2 operates PF. PF2 operates H, which locks under the control of PS2. When Z3 opens, PF is made dependent on the W, X and Y pulses. Slow release PF will hold over the transit time of the pulses, but releases if either pulse is missing, and PFA operates over PF1 and H2. The operation of PFA3, or release of CP2, gives an urgent alarm.

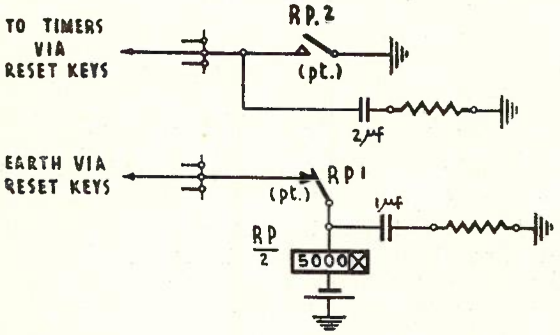


Fig. 9.—Reset Pulse.

Reset Pulse (see Fig. 9): The 10 per second reset impulses are generated by a self-interrupted relay RP, which functions when any timer reset key is open.

MONITOR'S LINE FINDER

Any interstate call may be connected to the monitor or officer in charge by a call set up through the trunk selector multiple, but this method is precluded for a call which is already set up to a local subscriber. To enable this to be done, an 8 x 25 uniselector used as a 4-level 50-outlet switch acts as a line finder—the five connecting circuits of each of the 10 positions being connected to its banks.

A finder bank contact is marked by a telephonist operating her connect monitor key and the relevant Speak (call) key giving a calling signal on the monitor's pillar.

To accept the call the monitor operates the Line Finder key. When the line is found a visual signal is returned to the telephonist, who then restores all keys, leaving the call under the control of the monitor.

ROUTINE TEST SET

The connecting circuits use a 2,000 type selector, the relays of which have been re-arranged, one departure being that it does not contain an A or impulsing relay, that relay being situated in the position Selector Control circuit and common to five selectors.

A means for routining these switches has been provided in the form of a routine test set built in on the Trunk Selector Board. It incorporates its own operator's and selector control circuits, enabling the function of a switch to be checked without taking a manual position out of service, the relevant connecting circuit being marked engaged on the position. The test set may also be used as a "buttinski," allowing a technician to monitor across a switch without disturbing any of its circuit elements.

THE DESIGN AND CONSTRUCTION OF UNDERGROUND CONDUITS FOR TELEPHONE CABLES

A. N. Hoggart, B.Sc.

PART V.:

EXCAVATION—USE OF MECHANICAL AIDS

In this section a general description and method of application of various mechanical aids used on excavating trenches for conduit works will be given. General comments regarding the use of mechanical aids were made in the last section.

Trenching Machines: This group of machines operates generally on the same principle as the bucket dredge. The digging mechanism consists essentially of a boom carrying an endless chain of buckets, each bucket being fitted with cutting teeth. The machine is powered by a powerful internal combustion engine, and is mounted on caterpillar treads. The machine is driven slowly forward along the line of the trench, and the upward movement of the bucket teeth cuts the soil in the working face. The buckets raise the soil and discharge it on to a conveyor belt, which allows the soil to drop clear on one side or other of the trench. The machine will cut a trench to the maximum depth designed for in one operation. The teeth cut the excavated material into a comparatively finely divided state, which facilitates back filling and consolidation of the trench.

The boom, which is mounted at the rear of the machine, may be vertical, as in the "Barber-Greene" Ditcher, or at an angle, as in the case of the "Parsons" Excavator. In other machines the buckets are arranged on a circular frame or wheel. The depth of the trench can be varied by movement of the boom up or down, under the control of the operator. The width of the trench is fixed by the width across the cutting teeth, but this can be increased by the attachment of extra fittings, carrying additional teeth, e.g., a machine which normally cuts an 18 in. trench can be made to cut 21 in. or 24 in. trench by special fittings and extra teeth. The boom can be raised clear of the ground for travelling.

The caterpillar track provides a firm grip on the ground to provide the required pressure against the working face to enable the teeth to cut into the soil; this feature is very important if, as in wet conditions, it is difficult to obtain a grip on the ground. Wide treads are used to distribute the weight over a wide area and reduce the risk of bogging in bad ground, and also reduce the risk of damaging pavement surfaces.

When digging the machine is required to move forward at a much lower speed than when travelling, and at the same time a greater tractive effort is required. In the Barber-Greene Ditcher, this is provided for by providing two transmission systems; firstly, a 3-speed transmission as normally provided on cars and tractors, and a subsidiary 5-speed transmission which is brought into use when digging. This enables the speed of the machine to be varied over a wide range to suit the conditions under which it is operating; at the same time the bucket line speed is held relatively constant. For example, in the Barber-Greene Ditcher, the travelling speed varies from $\frac{3}{4}$ m.p.h. in low gear to 2 m.p.h. in high. When digging the speed can be varied between 18 and 96 inches per minute with 3-speed transmission in first gear, and between 15 and 77 inches per minute with 3-speed transmission in second gear, according to 5-speed transmission gear used. By changing a sprocket on the idler shaft a lower range of speeds (down to 10 inches per minute) or a higher range (up to 131 inches per minute) can be obtained.

If the machine strikes an obstruction, e.g., a rock or pipe, an overload release device is brought into operation to stop the machine, so as to prevent it being damaged, and to give warning to the operator of the presence of the obstruction.

Normally the machine will leave in the trench a quantity of loose soil, which has escaped lifting out by the bucket, and which must then be removed by hand. If a steel screen is attached to the boom behind the buckets, to act as a scraper to keep the loose soil up to the buckets, the necessity for hand removal of spoil will be practically dispensed with. The screen will, of course, be of the same width as the trench and adjusted to reach the bottom of the trench.

The trench can be readily graded when using the Barber-Greene Ditcher if levels have been previously taken and the depth of trench at various points determined. To the boom of the machine a pointer is fixed, say, 6 feet (or more if a deeper trench is required at any point), from the bottom of the bucket chain; the pointer should extend clear of the machine to a point where it is clearly visible to the operator. At each end of each manhole to manhole length a stake is set up in the ground and adjusted to the same height above the bottom of the trench as the pointer is from the lowest point of the bucket chain. The stakes should be slightly further from the centre line of the trench than the distance from the centre line of the boom to the end of the pointer. Intermediate stakes are set up and levelled by means of sighting rods as described in Part III.

A line is then run along the top of the stakes and drawn tight. If the driver of the machine adjusts the position of the boom to keep the pointer level with the line, the trench will be automatically dug to the required depth and grade throughout. This procedure considerably simplifies the levelling of the completed trench; the line is also helpful in keeping the machine on the correct line.

Trenching machines can be used under most soil conditions, viz., loam, clay, gravel, etc., but are not usable in solid stone or rock, or in very soft soils in which the trench walls are not self-supporting. The machine will remove small stones or boulders, but where large stones are firmly embedded in the soil, these should be by-passed and removed by other means. Light road surfaces, e.g., gravel, can be cut without difficulty, but the machine is unsuitable for cutting heavy roads or concrete. Trenching machines can be used along the nature strip in suburban streets, but it is desirable to protect any pavement surface, over which the machine may pass, by laying down wide planks under the caterpillar treads. In such areas, the location of all underground services should be ascertained exactly (preferably by pot holing) so that the boom can be raised at each service, and damage to other authorities' plant avoided. The vertical boom type of machine has the advantage that the trench can be dug to the full depth close up to either side of the obstruction, leaving a minimum of soil to be removed by other means.

The Barber-Greene Model 44C Ditcher has been extensively used on conduit works in Australia, and particulars regarding various types of this machine are furnished in Table I.:

The last two types in the table are known as Pipeline Specials, being designed in particular for trenching for pipes. The conveyor belt will discharge a maximum distance of 5ft. 11in. from the centre line of the trench in the case of machines designed for 4 ft. or 5 ft. 6 in. deep trenches, and 7 ft. in the case of machines designed for 7 ft. deep trenches. The power unit is a four-cylinder petrol engine. The bearing area of each tread is 7 ft. 6 in. by 14 in., giving a maximum bearing pressure of approximately 7½ lb. per square inch. Fig. 29 shows a Barber-Greene Ditcher.

TABLE 1—Details of Barber-Greene Ditchers

Nominal Width of Boom	Possible Widths of Trench	Maximum Depth of Trench	H.P. of Engine	Weight	Width Across Tracks	Maximum Overall Length	Clearance Height	
							Boom Raised	Boom Lowered
				lbs.				
12″	12″, 14″, 18″	5′6″	41	16,100	7′2″	16′8″	12′	11′-3″
18″	18″, 21″, 24″	5′6″	41	17,750	7′2″	16′8″	12′	11′-3″
18″	18″, 21″, 24″	7′	41	18,460	7′2″	16′8″	13′-6″	11′-3″
18″	18″, 21″, 24″	7′	51	19,220	7′2″	16′8″	13′-6″	11′-3″
12″	12″, 14″, 18″	4′	51	16,600	7′2″	16′8″	11′-3″	11′-3″
18″	18″, 21″	4′	51	10,600	7′2″	16′8″	11′-3″	11′-3″

Pneumatic Excavating Equipment: Pneumatic excavating equipment comprises various pneumatic tools, together with an air compressor to supply compressed air for operation of the tools.

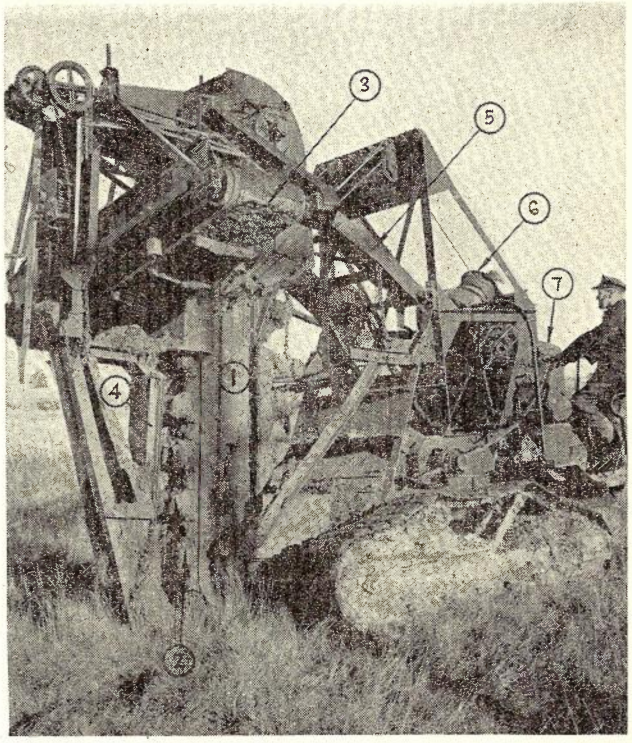


Fig. 29.—Barber-Greene Ditcher.
Reference:
1. Digging Boom.
2. Buckets.
3. Conveyor Belt for Soil Disposal, adjustable either side.
4. Scraper Screen.
5. Beam supporting the Boom.
6. Boom Hoisting Mechanism.
7. Power Unit.

The pneumatic tools in general use for conduit excavating work are:

Paving Breaker (or Road Ripper).
Rock Drill (Jack Hammer Type).
Spader (or Clay Digger).
Pick.
Back Fill Tamper.

Typical examples of these are illustrated in Fig. 30.

Each of the above types of tools is intended primarily for a specific class of work as detailed below; they all, however, operate on the same general principle, i.e., a rapid series of blows are communicated to the operating point, which is thus driven into the material being excavated.

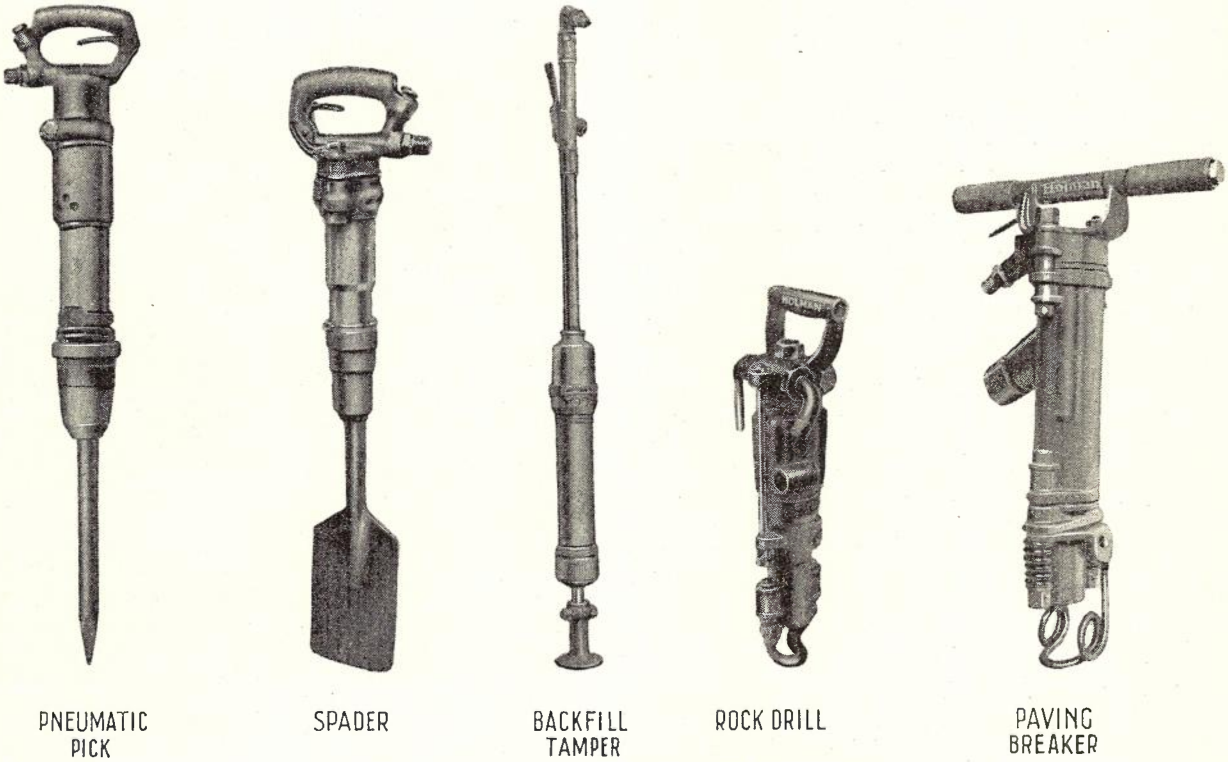


Fig. 30.—Pneumatic Tools Used for Excavating.

Fig. 31 shows a cross-section of a typical type of pneumatic tool (pneumatic pick). The method of operation is as follows:

When trigger C is depressed the opening of valve D permits the entry of compressed air from the airline into the machine to apply continual pressure at ports N, P and Q. Air passes via P across lower face of main valve F, then past auxiliary valve M, via ports R, and through ports in valve M, thence via ports S to front end of piston H. The space behind the piston is open to the atmosphere via ports U; the piston is accordingly forced toward the upper end of the cylinder. On completion of the stroke, air from S is free to exhaust into the atmosphere via U, thus causing a drop of pressure on one side of valve F, which operates to allow live air to enter the cylinder via ports V, at the same time cutting off compressed air from ports R and S. The piston therefore moves forward on its

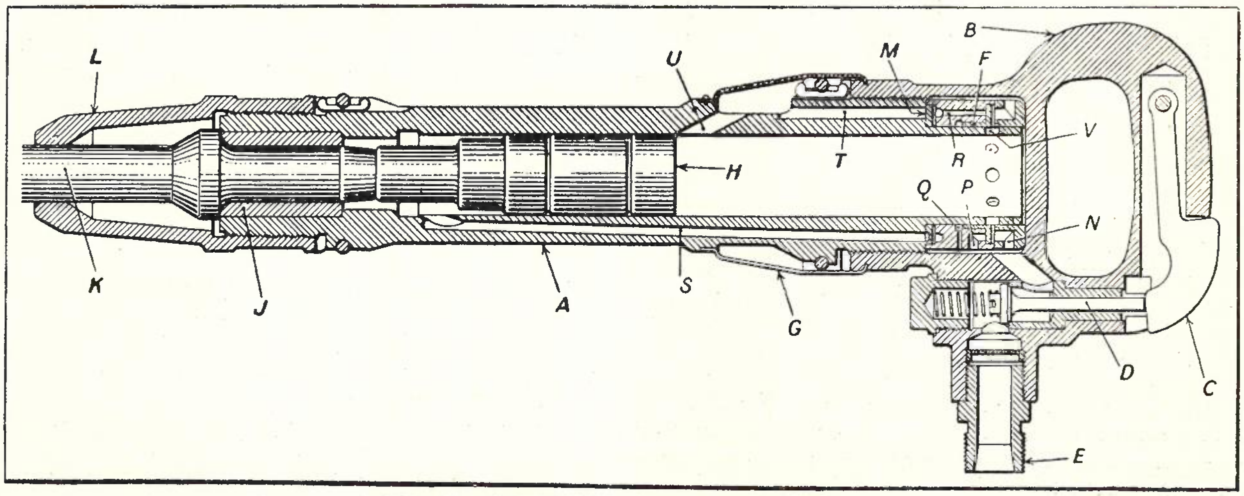


Fig. 31.—Cross-section of Pneumatic Pick.

power stroke, on completion of which the drop of pressure due to exhaust of air through U results in valve F moving to its rear seat. After port U has been covered in the down stroke any air trapped in the forward end of the cylinder is exhausted via ports S, valve M and ports T. At the end of each stroke a small quantity of air is allowed to remain in front of the piston; this air acts as a cushion and so as to reduce jarring of the machine against the operator's hand, and also prevents damage to the piston and other parts.

Air Compressors: For conduit excavating work, portable petrol or Diesel engine driven compressors are most suitable, arranged in one or other of the following mountings:

(a) Truck mounted type.
(b) Trailer type—2 or 4 wheel, pneumatic tyres.
(c) Trailer type—4 wheel, solid rubber or steel tyres.

Truck mounted compressors are used where a highly portable compressor is required, necessitating frequent changes of location. For general purposes, the pneumatic tyred trailer type is most useful, as the construction permits the machine to be towed behind a motor-vehicle at normal traffic speeds. Compressors fitted with solid rubber or steel tyred wheels can be towed only at low speeds, and therefore are preferably used on works where changes of location are infrequent.

Pneumatic tools used for excavating work normally work at a pressure of 70-80 lb. per square inch, and accordingly air compressors are usually designed to permit of normal continuous operation at an air pressure of 100 lb. per square in., and at a maximum air pressure of approximately 125 lb. sq. in. The capacity of air compressors is measured by the volume of free air displaced by the pistons of the compressor cylinders when the compressor is operating at the normal working pressure, viz., 100 lb. sq. in.

Table 2 gives typical data regarding various capacities of compressors and number of different types of tools operated by the various machines:

chines will naturally be governed by the extent of the work, the smaller machines being best used on small works, and the larger on major projects, where it is desired to operate a larger number of tools simultaneously. Machines of the 120-130 cu. ft. min. size are useful general-purpose machines, and have been used considerably on conduit works in the past.

Paving Breakers: Paving breakers, also known as concrete breakers or road rippers, are used for breaking down road pavements of all types, concrete, rock, etc. These machines are marketed in a range of sizes varying in weight from about 45 lb. to 90 lb. The heavier machines will handle the hardest concrete-breaking jobs or the thickest pavements. The lighter machines are more suited to medium hard conditions, while the lightest are particularly adapted to work in confined positions, or where it is desired to use the machine in a horizontal position.

Paving breakers are designed to give a series of heavy reciprocating blows to the point, which quickly breaks down the material being excavated. Paving breakers usually give of order of 1500 blows per minute, and consume about 55 cubic feet of free air at the normal working pressure.

For general work, concrete breaking, etc., a diamond pointed steel (moil) is used; these are available in different lengths, from 18 to 43 inches, to suit conditions. A variety of other tools can be used with the machine, extending its use over a wide range of conditions, thereby making the pavement breaker a most important tool on excavating work. Typical tools are illustrated in Fig. 32, and the following notes relate to particular uses of these:

Asphalt Cutters are used for cutting asphalt pavement along the edge of the trench.

Spade converts the breaker into a powerful clay digger.

Tamper enables the breaker to be used as an efficient rammer for refilled soil; it should not be used on the layers of soil adjacent to the conduits, owing to danger of the machine damaging the conduits.

TABLE 2—Pneumatic Compressors

Capacity Cu.ft./min.	B.H.P. of Engine	Approximate Number of Tools which can be Operated			
		Rock Drill	Paving Breaker	Spader	Tamper
75-80	24	1	1	2	2
120-130	31	2	2	4	4
180-200	43	3-4	3-4	6	6
240-250	58	4-5	5	8	8

One compressor may be used to operate different types of tools at the one time; e.g., a compressor of 120-130 cu. ft. min. capacity would operate one paving breaker and two spaders simultaneously.

The application of the various sizes of ma-

Chisel points are useful for trimming off the sides of the trench, etc.

The plug and feathers attachment permits the use of the breaker for driving the plug when breaking down rock by the plug and feather method.

A further adjunct provided by some makers is a fitting to permit the breaker to be used for driving boards for timbering of trenches.

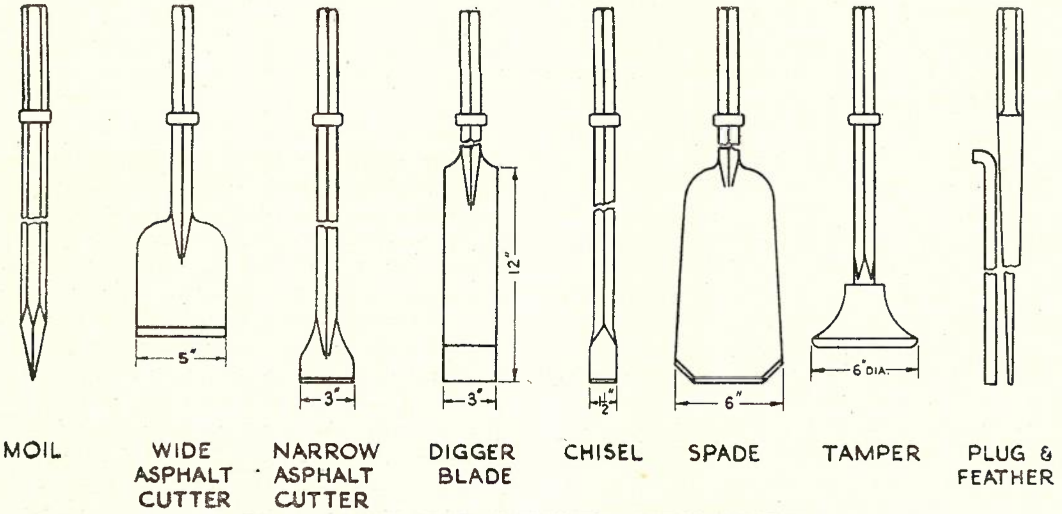


Fig. 32.—Accessory Tools Used with Paving Breakers.

Rock Drills: Rock drills of the jack hammer type are used for drilling rock, etc., particularly shot holes for explosives, or for plug and feathers. In this machine, in addition to the reciprocating motion, the steel is given a turn of a few degrees after each blow, the object being to prevent the drill becoming jammed in the hole, and to ensure a round hole. As the drill gives approximately 1800 or more blows per minute, the rotation of steel appears to be continuous, although actually intermittent.

Rock drills are made in a variety of types and sizes, and are largely used in mining and quarrying. The lighter, hand-held type (30 to 40 lb. weight) usually meets requirements for conduit work, these being suitable for drilling holes up to 8 or 10 ft. in depth. The air consumption of such a machine is in the vicinity of 50 cu. ft. of free air per minute at normal operating pressure (approximately 75 to 80 lb. per sq. in.).

Drill steels used may be either chisel-pointed, for use in softer rocks, and star or cross-pointed (4 or 6 point) for hard rocks. The tip of the drill is always wider than the shank. For drilling deep holes, successively longer drills are used, the successive drills being of smaller diameter as the hole deepens, so as to avoid the drill binding in the hole. Drill steels are normally hollow, as most pneumatic drills are so designed that portion of the compressed air is directed through the hollow drill steel to the point to blow dust and chips out of the drill holes. This assists in preventing drills binding in the hole.

Clay Digger: Clay diggers or spaders are lightweight pneumatic tools fitted with a spade point, and are ideal for excavation in clay, shale and similar soils, which can be cut out with reciprocating blows with a spade. They are ideal for cleaning up the sides of trenches. These machines vary in weight from 20 to 40 lb., and consume 25 to 35 cu. ft. of free air per minute at normal working pressure (70-80 lb. per sq. in.).

For normal work a flat spade is used, but for work in headings, tunnels, etc., a curved spade is frequently more convenient. With some makes of machines accessory tools, such as diamond points, asphalt cutters, chisels, etc., can be fitted, enabling the machine to be used as a light pneumatic pick or for other special applications.

Pneumatic Picks: Where conditions are such that a lighter machine than a paving breaker is desired, but more economical and speedier working than hand picking is required, use can be made of pneumatic picks, such as illustrated in Fig. 31. These tools weigh only 20-35 lb., and consume considerably less air (approximately 35 cubic ft. per minute), and are more convenient to use in awkward positions than the paving breaker.

Pneumatic picks are therefore ideal for breaking down hard soil, gravel, soft or friable stone, or in other conditions in which sufficiently rapid progress can be made with the light machines. Pneumatic picks also entail less fatigue on the operator than the heavy pavement breaker. A diamond pointed steel is normally used.

Back Fill Tamper: For consolidating the refilled soil in trenches, pneumatic back fill tampers are effective. These machines usually weigh in the vicinity of 40 lb. and consume about 35 cu. ft. of air per minute. The rammer is usually of the order of 5 in. to 7 in. diameter, thereby covering a fair area at a time.

These machines differ from most other pneumatic tools, in that the blows are not so rapidly given, being as low as 350 per minute; the stroke is also comparatively long, viz., 5 to 7 in. Special care is necessary in using mechanical tampers close to pipes and conduits owing to danger of causing damage; it is advisable to ram the first layer of refill by hand and use the machine for the remainder.

Petrol-driven Hammers and Drills: One disadvantage of pneumatic tools is the need for a compressor, and the consequent moving of this heavy equipment from place to place. On works such as isolated road crossings or for small jobs dispersed over an area, the cost of transporting a compressor from place to place is frequently so high as to render the use of pneumatic tools uneconomical. For such cases there are available self-contained portable petrol-driven hammers and drills, such as the Warsop and the Barco. The former machine is described in the article "Portable Petrol-driven Rock Drills and Concrete Breaking Machines," by J. J. Edwards, B.Sc.(Eng), A.C.G.I., A.M.I.E.E., in P.O.E.E. Journal, vol. 29, part III., page 196.

These machines incorporate a single-cylinder petrol engine, which provides the motive power, the force of the explosion of the petrol-air mixture in the cylinder being communicated to the working point by the piston, giving in effect a similar action to that provided by pneumatic tools.

These portable units are usually of two types, viz., pavement breaker and rock drill, which have similar functions to the corresponding pneumatic tools. The pavement breaker can be fitted with a series of accessory tools similar to those described for the pneumatic pavement breaker, permitting its use under a range of conditions. The rock drill includes the facility for turning the drill steel in continuous drilling operations, and is usually convertible into a pavement breaker, thereby permitting the one machine to be used for both purposes.

The petrol-driven machines weigh in the vicinity of 80-100 lb., and are therefore heavier than the corresponding pneumatic tools. Their weight and independence render them highly portable, and therefore ideal for shifting from one small job to another. On the other hand, being heavier than pneumatic tools, they are more tiring on the operator. The air compressor and pneumatic tools are still to be preferred for the larger works.

The Barco Hammer uses battery ignition, the battery being accommodated in a separate battery box, connected to the machine by means of flexible leads. The battery normally consists of 6 heavy duty dry cells, but for continuous operation it is desirable to substitute a 6-volt accumulator. Cooling is by means of radial fins. Fig. 33 shows a Barco hammer in operation. In the rock drill, the bit is turned by a hand-operated swivel ratchet, automatic rotation not being provided. For blowing the drill hole, a separate source of compressed air, e.g., a small compressor, is required; however, holes can be drilled without this facility, although slower. The normal machine can be used for rock drilling by rotating the whole machine backwards and forwards through an arc of a circle. W. Engeman, in his article on "The Sydney-Newcastle-Maitland Cable" (Telecommunication Journal, vol. 2, No. 6), gives some details of the use of Barco hammers on this work.

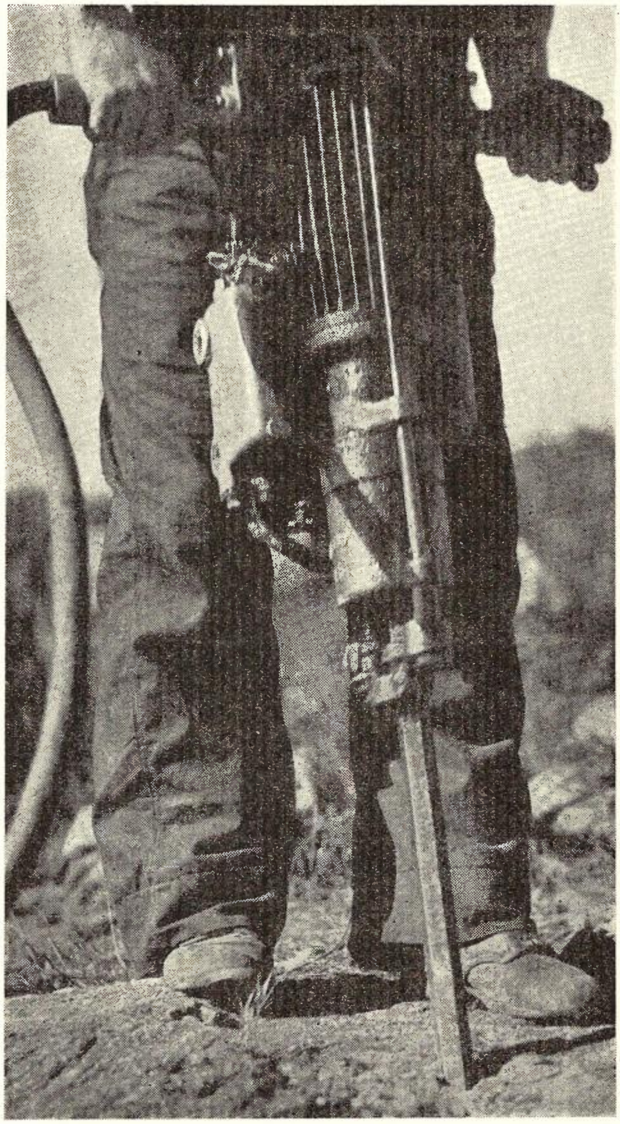


Fig. 33.—Barco Hammer in Use.

The Warsop machine is different in that it incorporates an inverted single-cylinder two-stroke engine, which drives cooling fans and a flywheel magneto for ignition. Two pistons working in the one cylinder are used, the upper to drive the two-stroke engine, the lower to drive the drill steel. The Warsop rock drill incorporates an automatic rotational mechanism for the drill steel, and also forces air through the hollow steel for clearing the drill hole.

The Rototiller: The Rototiller, although designed as an agricultural machine, has nevertheless proved a useful machine for trench excavating. The device consists of a 2-stroke petrol engine of 7½ h.p., geared to sharp-pointed rotating tynes in the form of hooks under spring tension. As the tynes rotate they cut into the soil, breaking it up, so that it can be readily shovelled out of the trench; at the same time, the machine propels itself along the trench. Fig. 34 shows the Rototiller in operation, the rapidly rotating tynes being visible under the rear guard. It will be seen that the machine is controlled by one man.

The Rototiller has proved suitable for use in all classes of soil, including shale, but is not suitable for use in rock. At each traverse of the trench it cuts the soil up to a depth of 6 to 8 inches, and will keep eight or more shovellers occupied behind the machine. The Rototiller will cut a trench 16 inches or 24 inches wide, according to the machine in use.

Whilst the Rototiller will not excavate a trench as quickly or as economically as a trenching machine, it is an inexpensive, light portable machine which will enable trenches to be dug more economically than with wholly manual labour. On account of its portability, it is particularly suitable for small works, or in sections where it is not practicable to use heavy plant.

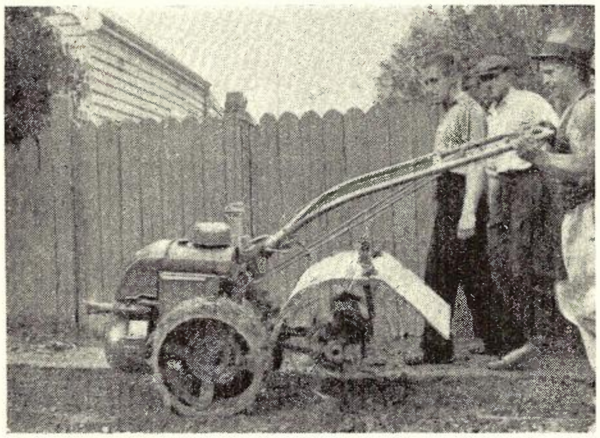


Fig. 34.—Rototiller in Operation.

Plows: Where other types of mechanical equipment are not available, use can be made of plows for breaking up the ground for excavating by hand. For this purpose a deep rooter plow would be most suitable, a crawler type tractor being used for pulling the plow. It is known that in the U.S.A. tractor-drawn rooter plows have been used to loosen the soil in preparation for excavating with a trenching machine; presumably this enabled the progress of the work to be speeded up to the extent of effecting overall economies. One advantage is that hidden obstructions, such as rocks, boulders, large roots, etc., could be located and cleared before the ditcher reached them.

Bulldozer: The bulldozer consists essentially of a curved blade mounted on side arms extending to the front of a crawler tractor, the blade being raised or lowered by means of a power hoist. Bulldozers are used for refilling trenches as shown in Fig. 35, and by this means the excavated soil can be rapidly returned to the trench. When using a bulldozer for back filling, it is necessary to avoid possible damage to the conduits themselves or alteration to their alignment by the soil being dropped into the trench; it is therefore advisable to fill in by hand to a few inches above the conduits and tamp well before using the Bulldozer.

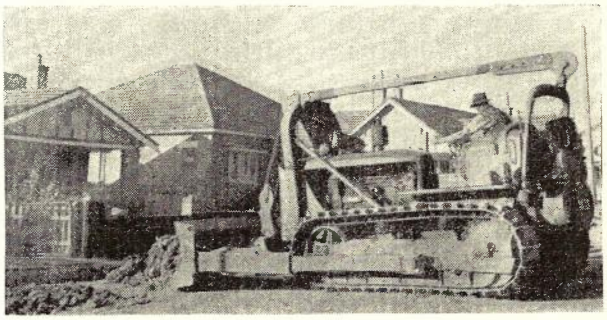


Fig. 35.—Bulldozer in Action—Refilling Trench.

Ramming of the trench may be done by hand, by means of a pneumatic or other mechanical rammer, or by driving the bulldozer along the trench with one tractor tread in the trench, using the weight of the machine to consolidate the refill.

Bulldozers can also be used for clearing trees, scrub and other obstructions as may occur along country roads, in preparation for conduit work, for levelling ground, filling in depressions, or forming surplus spoil into heaps preparatory to loading and carting away.

End Loader: The End Loader is also a tractor-mounted device; in this it takes the form of a scoop mounted on sidearms. The scoop is filled by driving the machine into the heap of soil to be loaded, the scoop is then raised, and the load carried to the discharging point, where, by the operation of a release catch, the scoop discharges by pivoting on the side arms. Fig. 36 shows an end loader in operation.

End Loaders are used for loading surplus spoil into trucks for carting away from the job. Apart from the saving of hand labour in filling the trucks, the more rapid filling of the trucks reduces idle time of trucks, enabling each truck to handle more material each day. If tipping trucks are also used, the use of hand labour is practically dispensed with in the cartage of surplus spoil. The end loader can also be used for refilling trenches and other similar applications.

The foregoing notes indicate that there is available a variety of mechanical aids to conduit excavating work covering a wide range of types and applications, which is brought about by the various conditions under which conduit works are carried out. For the large works the use of the heavier, more expensive, and more powerful machine, such as trenching machines, air compressors, and pneumatic tools, bulldozer and end loader would probably be justified. For smaller works, such items as the Rototiller, petrol-driven hammers and drills, etc., may be more appropriate.

Fig. 36.—End Loader.

To obtain the best results in using mechanical equipment on conduit work, it is necessary that close attention be given to the following:

1. No machine should be used for work for which it was not designed, or beyond its capacity.
2. Each machine should be maintained in good mechanical condition, and the maker's instructions regarding maintenance and lubrication carefully followed. A breakdown of mechanical equipment in the middle of a job can cause heavy economic loss and delay.
3. Certain parts are subject to considerable wear or breakages, and adequate spares of these should always be to hand.
4. All cutting points, teeth, drill steels, tynes, etc., should be kept properly sharp.
5. Proper organisation of the work is essential, as any avoidable ineffective time on the part of the machines or the workman represents economic wastage.

The types of machines referred to in this section are in the main those which have been used on conduit work in Australia; other types are no doubt in use in overseas countries. The scope for use of mechanical aids on conduit excavating work is great, and no doubt improved types of machines for this work will become available in the future.

The illustrations of pneumatic tools in this section are by courtesy of Messrs. Holman Bros. Ltd., whose assistance is acknowledged.

A NEW TYPE OF BIMOTIONAL SWITCH WIPER SPRING

E. J. Bulte, B.Sc.

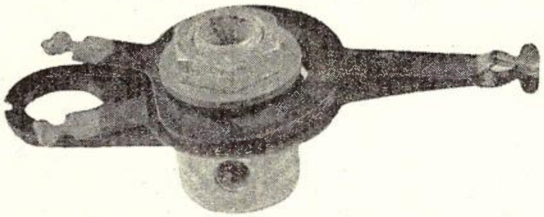
The wipers of bimotional switches are important links in the control and speech connections in automatic exchanges, and exacting electrical and mechanical standards are required of them if trouble-free service is to be given. It is not surprising that, in spite of the continuous development taking place, the wiper is still considered as a weak link in the complete operating chain. New ideas for improving the performance of wipers are, therefore, of special interest, and the purpose of this article is to give information of a variation of design of wiper spring suggested by Mr. J. F. Reilly, of Melbourne, and which is now under test by the Department. The experience to date suggests that, in many respects, the new wiper gives improved performance in comparison with existing standards, and it is, therefore, likely to play an important part in the future history of wiper design.

Extensive investigations have been carried out in this and other countries with wipers of various shapes, manufactured in brass, phosphor bronze, nickel silver, stainless steel, etc. Some of the more commonly known shapes of bimotional switch wipers used by the Department are given in Fig. 1, which shows photographs of the standard wiper assemblies for:

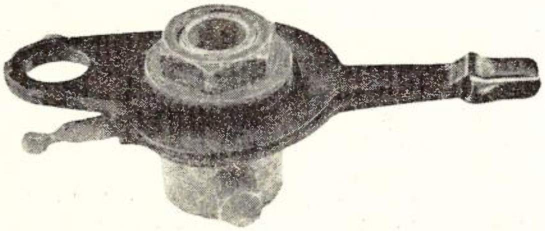
(a) Pre-2000 type equipment.
(b) Siemens No. 16 type equipment.
(c) Siemens No. 51 type equipment and R.A.X.'s.
(d) 2000 type equipment.

While there are many different types of faults associated with wiper operation, the majority are due in some way to the wear which takes places due to the continuous rubbing of the wipers over the bank contacts, the amount depending on such factors as the number of times the wipers move over the contacts, the grit on the surfaces, and the material of which the wipers and contacts are made. Microphonic noise is one of the particular troubles experienced which may be due to the wear, grit on the surfaces, or other factors causing variable resistance. The new design primarily aims at an improved electrical contact and a minimum effect on performance as wear takes place.

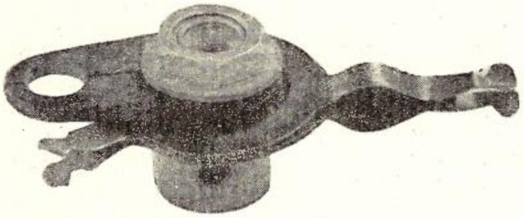
The feature of the new design, applied to an assembly for use with pre-2000 type switches, is shown in Fig. 2. The end of the wiper spring is turned at right angles to the surface to form a tip, the edge of which makes contact with the bank. The bend is made at an oblique angle to the longitudinal axis of the spring, so that the tip sweeps across the contacts with a raking action, which will distribute the wear on the bank contacts. The action is somewhat similar to that of the contact in some variable resistance boxes. To prevent the springs from interlocking when assembled for use on pre-2000 type, single contact, private banks, it is necessary that the top and bottom springs should be of the same "hand," the contact tips then meeting in the general form of a cross, instead of a line, as shown in Fig. 2, which depicts the assembly for line wipers.



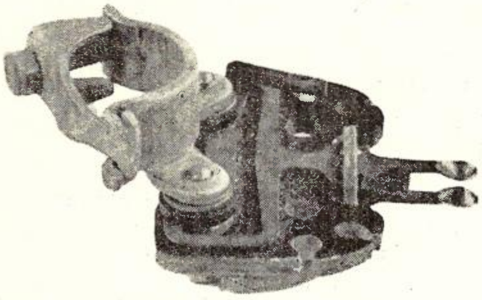
(a) Wiper Assembly for Pre-2000 Type Equipment.



(b) Wiper Assembly for Siemens No. 16 Equipment.



(c) Wiper Assembly for Siemens No. 51 Equipment and R.A.X.'s.



(d) Wiper Assembly for 2000 Type Equipment.

Fig. 1.

The shape of the tip is such that it should have a comparatively long life before trouble will be caused due to wear. Moreover, the raking action would have the effect of cleaning the contact. These factors would be expected to minimise microphonic action. Early trials indicate that, in comparison with the standard type, microphonic noise troubles are reduced, and a longer useful life is obtained. Other advantages are that there is a greater margin of safety against cutting in between bank levels, and it is easier to inspect the wipers for wear when they are in position on the switch.

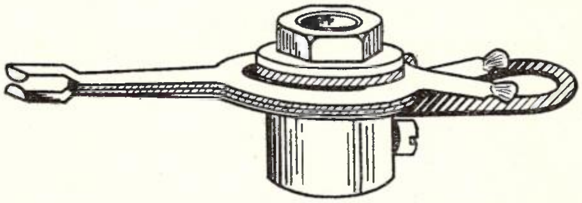


Fig. 2.—Assembly with New Type Wiper Springs.

The first springs of this type were tried out 10 years ago, and samples have remained in service for the intervening period, with encouraging results. The design as originally submitted has been modified slightly to eliminate bridging between contacts (this can occur on the standard type of pre-2000 type assembly, after the springs wear, causing objectionable "clicks" in conversations in progress on the bank contacts over which the wipers pass). This has been done by decreasing the width of the spring at the tip. In order to compensate for the smaller wearing surface thus provided, the amount of turnover at the tip of the spring was increased slightly. This also provides an additional factor of safety against "cutting in" between levels. The extended trials now proceeding give hopes of confirming the earlier promise of improvement in the service by the use of springs of the new design.

Several thousand are now in use, and many more will be put into service in the near future. The trial has been extended to the 2000 type equipment and Fig. 3 shows the assembly with the new design applied to the 2000 type wiper assembly.

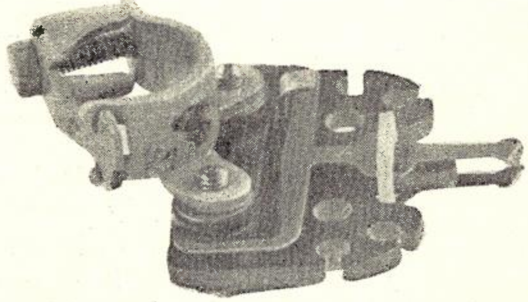


Fig. 3.—New Design of Wiper Applied to 2000 Type Wiper Assembly.

The adjustments are generally similar to those necessary for the standard wiper assembly. In the pre-2000 type, the adjustment of the line and the private wiper assemblies should provide for a gap of 16 ± 6 mils between the tips when the springs are off the bank. The adjustment is made at the angular set, using suitable pliers. For single private wiper assemblies, however, the tips of the wipers should touch when off the bank. The normal contact pressures are 35 grammes for line and for double private assemblies, and 30 grammes for single private assemblies. In the 2000 type assemblies the gap is 16 ± 4 mils between the tips of line wipers, when the springs are off the bank. The adjustment is made at the straight portion of the spring in front of the collar.

Until the present trials are completed and all data carefully examined, the full value of the design in overcoming all obstacles will not be known, but the results to date indicate that the new design is a definate contribution to the solution of wiper problems.

ANSWERS TO EXAMINATION PAPERS

The answers to examination papers are not claimed to be thoroughly exhaustive and complete. They are, however, accurate so far as they go and as such might be given by any student capable of securing high marks.

EXAMINATION No. 2561.—MECHANIC GRADE 2—TELEPHONE INSTALLATION AND MAINTENANCE

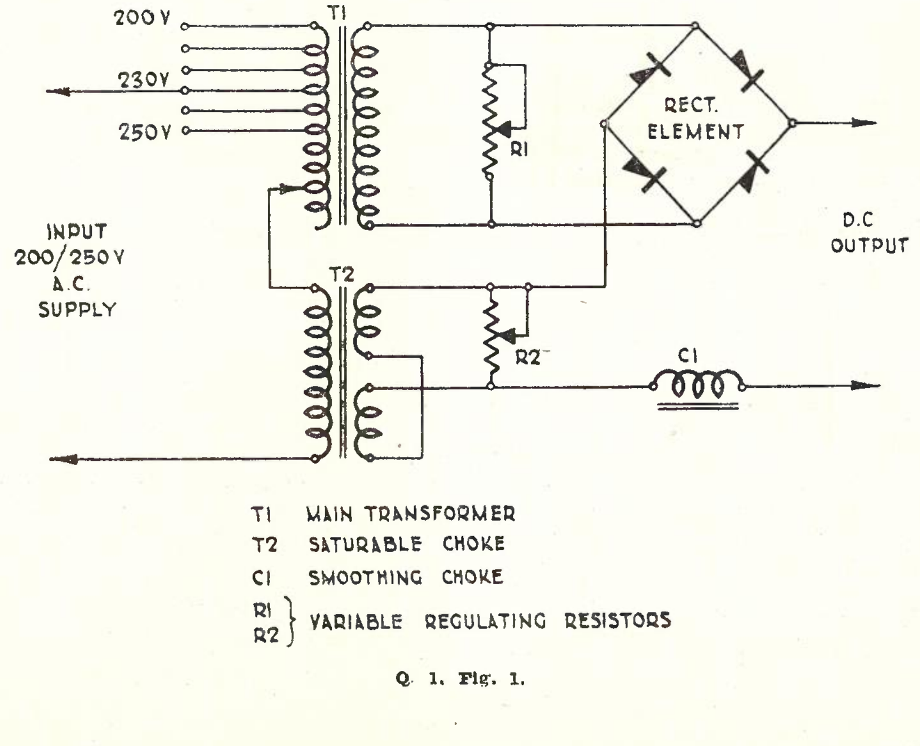
M. A. Bowden

Q. 1.—Explain the operation of any automatic voltage control dry plate rectifier used by the Department. Illustrate your answer with simple sketches.

A.—The following description applies more particularly to the saturated choke type dry plate constant voltage rectifier used extensively for battery charging in connection with P.A.B.X. and R.A.X. installations. The equipment consists of a main transformer to reduce the public electric supply voltage to that required for the equipment, usually 50 volts; a single phase bridge connected dry plate rectifier to convert the transformed AC to DC; a saturable choke to regulate the voltage of the input between the upper and lower permissible limits, smoothing choke, resistors, etc., to permit adjustment of the output to meet varying local conditions. The connections are as shown in Figure 1.

Referring to the diagram, the operation of the circuit is as follows: The input voltage divides between the primary windings of T1 and T2. Assuming the voltage induced in T1 secondary is just sufficient to cause a low value DC current to flow in the output circuit, a slight degree of saturation in the core of T2 will result, reducing the impedance of T2 to AC and correspondingly increasing the AC drop across T1 primary. This in turn increases the charging rate causing further saturation of T2, the inter-action continuing until T2 core becomes fully saturated, which occurs when the full rated output of the rectifier is being obtained.

As the DC output from the rectifier decreases due to the increasing voltage of the battery as it becomes fully charged, the process described above is reversed until, at the maximum battery voltage, the output of the rectifier reduces to a very low value, being just sufficient to give a trickle charge to restore standing losses in the battery.



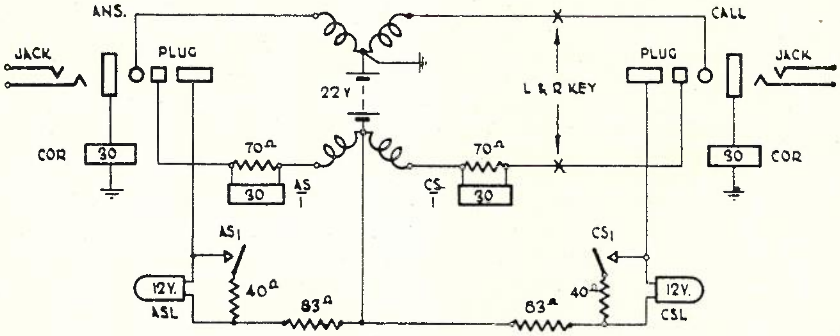
Q. 1. Fig. 1.

The resistors R1 and R2 have no bearing on the general operation of the circuit but provide a ready means of adjusting the values of current in T1 and T2 to give the voltage range desired for any particular case. The function of R1 is to permit adjustment of the cut-in voltage of the rectifier. The principal function of R2 is to adjust the value of DC magnetising current of T2 to vary the charging rate and cut off voltage value.

Q. 2.—Explain the operation of the cord circuit supervisory signals in a C.B. exchange and illustrate your answer by means of a sketch.

A.—A schematic diagram of the relevant portions of the cord circuit is shown in Figure 1.

AS/1 and ASL are the supervisory relay and supervisory lamp respectively associated with the answering cord. CS/1 and CSL are the supervisory relay and supervisory lamp associated with the calling cord. Each supervisory relay is shunted by a non-inductive resistance. This resistance provides a low resistance path for voice frequency currents, which would be impeded by the highly inductive relay winding. When the answering cord is inserted in the local jack to answer a call, current flows from pos. battery, transformer winding, tip of plug, ans. jack, through the loop of the calling subscriber's telephone, ring of jack and plug, AS/1, transformer winding to neg. battery. Relay AS/1 operates and places a 40 ohm N.I.R. shunt across ASL. The sleeve circuit is completed from pos. battery, cut-off relay C.O.R., sleeve of jack and plug, 12V. supy. lamp and 40 ohm resistance in parallel, 83 ohm resistance to neg. battery. Supy. lamp ASL does not light as in the shunted condition insufficient current flows through the lamp to cause the filament to glow. The Telephonist ascertains the wanted number, tests the line if for a local call, inserts the calling plug in the jack of the wanted line and operates the ringing key. Connections of the L & R key are not shown in the diagram. The sleeve circuit of the calling plug is completed and supervisory lamp CSL glows until the called party answers. This is because relay CS/1 has not operated and the supervisory lamp is unshunted. When the called party answers CS/1 operates and shunts lamp CSL, which ceases to glow. When either party replaces the receiver, the line loop is broken, the associated supervisory relay restores, and the shunt is removed from the associated supervisory lamp which glows. The glowing of both lamps indicates to the Telephonist that both subscribers have replaced the receivers. The Telephonist then registers the call and takes down the connection.



Q. 2, Fig. 1.

Q. 3.—What facilities are provided by the M.D.F. in an Automatic or Manual Exchange, and under what conditions do the various protective devices operate?

A.—Facilities are provided to:—

(a) Terminate the street cables which enter the Exchange.

(b) Terminate cables which connect with exchange apparatus.

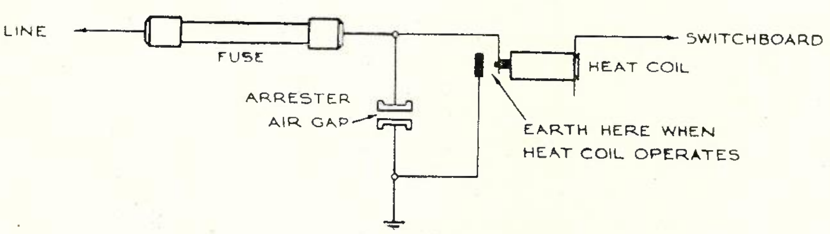
(c) Cross-connect a particular cable and pair with the allotted exchange circuit, whether subscriber's line or junction.

(d) Protect the exchange apparatus from electrical hazards. Protection is given by:—

- (i) Fuses mounted on the U.G. cable side of the M.D.F.
- (ii) Heat Coils and Arresters mounted on the switchboard side.

(e) Facilities for connecting lines to the Test Desk for fault location and identification.

The electrical relationship between the fuse, heat coil and arrester, when connected in a circuit are shown in Fig. 1.



Q. 3, Fig. 1.

Should a high voltage due to a lightning discharge be impressed upon the external circuit, it will cause a spark at the air gap of the arrester and the charge will be dissipated to earth. In the event of a particularly heavy lightning discharge or a contact with a high voltage power line, continued discharge at the arrester carbons will occur and the resistance of the air gap may be reduced due to the bridging of the gap by carbon dust at the area of sparking. Under this condition the discharge current will rise due to the lowering of the resistance at the carbons and the fuse will operate to open the circuit. In the event of contact wtih another circuit of voltage not sufficiently high to discharge across the arrester air gap, current will pass through the heat coil to earth at some portion of the exchange apparatus. If the current flowing reaches harmful proportions, the heat coil will operate and earth the line. A direct path to earth having been provided, the line current will be increased and, if of sufficiently high value, will operate the fuse and disconnect the line.

Q. 4.—Why are D.S.R.'s or S.S.R.'s used in branch exchanges? Briefly describe the switching operation during a call to a subscriber in the local area and a call via the main exchange.

A.—S.S.R.'s or D.S.R.'s are used in Branch exchanges to permit the completion of calls between subscribers connected to the same branch without the need for occupying junctions to and from the main exchange for this type of connection. The use of these switches also permits calls to be made directly between neighbouring branch exchanges in the same main exchange group without routing the call through the main exchange. For calls to and through the main exchange the S.S.R. (or a D.S.R.) acts as a first selector and repeater combined.

On being seized the switch guards itself against intrusion and causes the associated junction pre-selector to search for a free junction to the main exchange. It also prepares itself for the first train of dialling impulses on receipt of which it steps vertically to the level corresponding to the number of impulses dialled. The repeating elements in the switch repeat the dialled impulses over the junction to the main exchange operating the first selector at that exchange. At the end of the impulse train the switch cuts in to the first contact on the level reached and tests.

If the digit dialled corresponds to the main exchange group but not to the local branch, the switch releases and restores to normal, the junction being held, together with the associated first selector. The second impulse train causes the switch to step vertically again, the impulses being repeated to the main exchange as before and operating a second selector in that exchange. If this digit is that of the local branch the switch releases the junction portion of the connection and acts as a second selector, the wipers rotating to find a free trunk to a local third selector. Subsequent trains of impulses complete the connection on local 3rd, 4th and final selector switches in the branch exchange.

A call to or beyond the main exchange proceeds similarly to a local call up to the point where the second train of impulses has been dialled. If the second digit does not represent the local branch exchange the S.S.R. remains in the position taken up at the end of the second impulse train, and acts as a repeater, subsequent digits being transmitted over the junction to the main to set appropriate selectors in that exchange.

Q. 5.—Describe the floating battery system of supplying power to a large Telephone Exchange. What are the advantages of the system as compared with the charge-discharge system?

A.—With the floating system, the output of the charging generator is connected to the battery while the battery is connected to the exchange load. A true floating condition exists when the charging current is equal to the discharge current. The generator then is supplying power to operate the exchange, no current is drawn from the battery, and therefore the chemical condition of the battery remains unchanged. If a battery is fully charged when it is connected to the exchange load, it is possible to keep it in that condition by floating continuously. Usually the generator is not running continuously, and the battery becomes partly discharged during these periods. It is customary, therefore, to adjust the generator output to a value slightly higher than the discharge current to compensate for the battery discharge when the charging plant is not operating.

Advantages of the Floating System

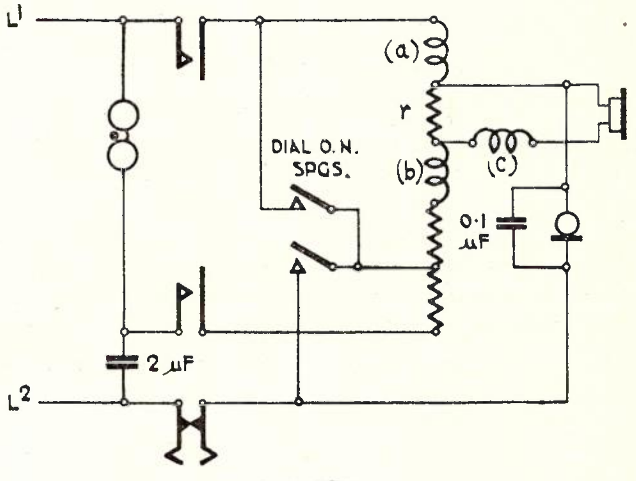
(a) The battery is kept fully charged, therefore batteries of smaller capacity may be used as the full capacity of the battery is almost always available in the event of failure of the power supply.

(b) Chemical changes in the battery are limited and, because of this, there is less likelihood of the buckling and disintegration of the plates. As a result, a longer battery life can be expected.

(c) In the charge-discharge method some power efficiency is lost in the charging set and in the battery, whereas during floating the energy loss is confined to the charging plant.

Q. 6.—Draw the circuit of a 332 type automatic or magneto telephone and briefly explain its operation.

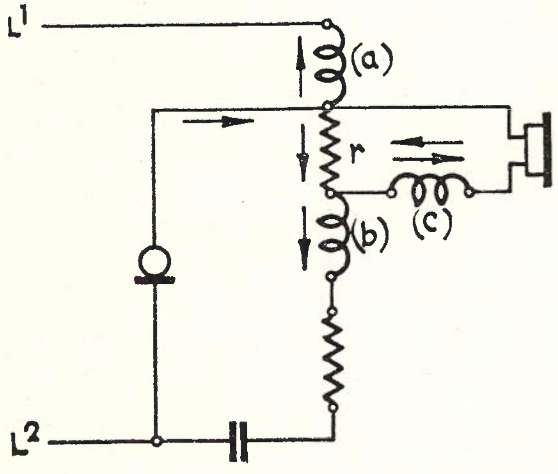
A.—The schematic circuit of the automatic telephone is shown in Fig. 1.



Q. 6, Fig. 1.

The elements of the transmitting and receiving circuits are shown in Fig. 2.

The telephone is provided with an anti-sidetone induction coil to reduce sidetone to a moderately low level. The operation of the circuit during the transmission of speech is as follows: Assume that the transmitter current at any instant is in the direction of the arrows (Fig. 2). The currents through induction coil windings (a) and (b) are in opposite directions but because of winding differences, the flux produced by winding (b) is greater than that produced by winding (a). The resultant flux induces an E.M.F. in winding (c) to produce sidetone current in the receiver. At the same time there is a P.D. across non-inductive resistance r which causes current to flow through the receiver in a direction opposite to that of the induced current. The sidetone is thereby reduced.



Q. 6, Fig. 2.

Winding (b) also acts as the primary of a step-up transformer with respect to winding (a), the interaction resulting in an increased current through (a) and therefore in the line circuit.

When speech is being received the greater part of the current will pass through winding (a) and the transmitter which forms a path of low impedance. The varying flux produced in winding (a) will induce an alternating E.M.F. across winding (c) to produce speech currents in the receiver.

The bell and dial connections are shown in Figure 1.

The transmitter has connected in parallel with it an 0.1 μF. condenser. This is to prevent radio programmes from being detected by the coherer action of the carbon granules and heard as music and speech in the receiver. The condenser by-passes any radio signals which may be received.

Q. 7.—What equipment is provided for the supply and control of ringing current and tones in a modern automatic exchange? Your answer should include the safeguards provided against failure of the public electric supply of the equipment.

A.—The equipment provided for the supply of ringing current and tones comprises the following:—

Two ringing generators, one driven by an A.C. motor from the Public Electric Supply, being normally used to supply the exchange, and a second machine of the dynamotor type, driven from 50-volt exchange battery being used as a stand-by machine in case of power failure or breakdown. Each generator, in addition to supplying 16-2/3 C/s ringing current, is equipped with an inductor type generator for the supply of 400 C/s. 133 C/s. and 33 C/s. for busy, number unobtainable, ringing and dialling tone respectively. The characteristic interruptions of the basic tones necessary to distinguish the various signals are effected by means of cam-operated spring sets mounted on a secondary shaft forming part of each ringing machine.

A ringing control panel is provided on which is mounted the following equipment:—

(a) A two button start stop switch for the mains operated machine.

(b) A start switch for the battery operated machine.

(c) A multi-pole rotary switch.

(d) A telephone receiver for monitoring the various tones.

(e) A group of keys for applying ring fail conditions in order to test the operation of the change-over equipment.

(f) Other minor items such as distribution fuses and lamps to indicate ring fail, fuse operated conditions, etc.

The multi-pole switch mentioned in (c) automatically disconnects the mains driven machine when commercial power fails, starts the battery driven machine, and connects it to the exchange load. To reconnect the mains driven machine it is necessary to operate the start button on the control panel and to re-set the multi-pole switch by hand.

Q. 8.—Explain the principle of the method used on a test desk to measure the make and break impulse ratio of a dial. What is the standard ratio and why is it important to keep the ratio as near to the standard as possible?

A.—The impulse ratio make period is read as a deflection on the test-desk voltmeter. The meter is of the moving coil type and registers the average value of a rapidly changing current passing through it. When the voltmeter is connected to a D.C. source of E.M.F. of appropriate value a full scale deflection of, say, 100 divisions is obtained. On open circuit, of course, the reading is 0. If the circuit to the meter be opened and closed rapidly the periods being of equal duration the needle of the voltmeter will take up a position midway between the open and closed positions, i.e., the meter will indicate a 50% make period. Similarly if the closed circuit time is one-third of the total time the meter reading will be one-third of the full scale reading, i.e., a 33-1/3% make. The test desk circuit is arranged to make use of this feature. When it is desired to check the ratio of a dial, a circuit which includes the dial and a rheostat is connected to the desk voltmeter. With the loop closed and the dial held off normal the rheostat is adjusted until a meter reading of 100 is obtained. A key of the desk is operated momentarily and the reading thereby reduced to 33. This is to set the needle to the approximate position to be taken up by the needle when the circuit is interrupted by the dial. (On some meters the rheostat is adjusted to give an initial deflection of 75, in which case a reading of 25 indicates a 33-1/3% make.) The dial is pulled to "0" and released and the deflection of the meter needle during impulsing is noted. The deflection is read as the percentage make of the dial. The meter needle does not take up a steady position during impulsing but oscillates slightly about the mean position. By using a heavily damped meter the oscillations are kept small.

The standard ratio is 33-1/3% make 66-2/3% break and relates to the dial itself. A dial in a telephone is shunted by a condenser. The effect of the capacity is to lengthen the make period of the impulse to such an extent that the test-desk meter will register approximately 37% when a 33% dial in a telephone is being checked.

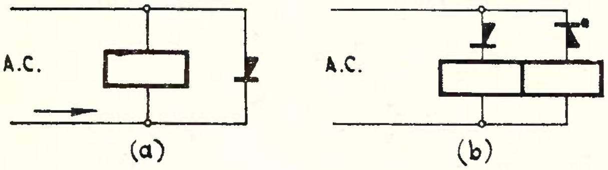
It is important to keep the ratio as near standard as possible to ensure the correct operation of the exchange switches.

If the make period be too short, the time during which the A relay is operated will be reduced, the B relay will release and cause the release of the switch.

If the make period be too long, the operated time of the A relay will be increased and the switch magnet will not be fully energised. In either case ineffective calls will be experienced.

Q. 9.—Show by means of simple sketches how a dry plate rectifier is used
(a) to permit the operation of an ordinary telephone type relay by an alternating current;
(b) to permit the use of an ordinary telephone type relay as a polarised relay.
Explain the circuit operation in each case.

A.—(a)

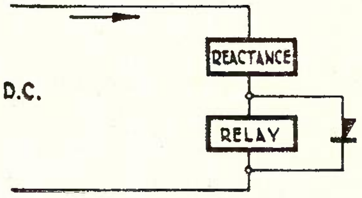


(a) (b)

Q. 9, Fig. 1.

Figure 1(a) shows the connections for a single coil relay. This arrangement is used only on circuits where the current through the rectifier is not excessive. On one half cycle of, say, a ringing pulse current flows in the direction of the arrow. The rectifier is non-conductive to this direction of current; the current passes through the relay which operates. On the reversal of current the rectifier is conductive and of low resistance compared with the relay. Most of the current therefore passes through the rectifier. The rectifier also provides a discharge path for the inductive current from the relay, i.e., the relay is made slow releasing and the armature is held until the next half cycle when current again flows through the relay. A preferable arrangement is that shown in Figure 1 (b), i.e., a double winding relay with a rectifier in series with each winding. The relay operates on either winding, one of which is energised by current from each half cycle. By this method also the line resistance is kept constant and there is no risk of excessive current through the rectifier.

(b) Figure 2 shows an arrangement whereby an ordinary relay may be polarised.



Q. 9, Fig. 2.

The relay will not operate when current flows in the direction of the arrow for the reason outlined in (a) but will operate when the line polarity is reversed. Because of the low resistance of the rectifier in the conducting direction a high resistance coil is connected in series with the relay, which has a comparatively low resistance. This ensures that the line current is relatively constant before and after reversal and within the current carrying capacity of the rectifier.

Q. 10.—What are the functions of a final selector repeater and with what type of equipment are they associated?

A.—Final selector repeaters are used with E. & F. Type P.A.B.X.'s, usually in association with 50 Point Uniselector Type Line Finders, to permit local connections being dialled on a 2-digit basis, and at the same time, permit out-going calls to be obtained by dialling 0. The switch functions as a regular final selector for local calls on levels one to nine and as an auto auto repeater with rotary testing facilities on level 0 for out-going calls.

The functions performed are as follow:

Local calls—levels one to nine.

1. On seizure:
   (a) Guards itself against intrusion.
   (b) Starts ringing machine.
   (c) Returns dialling tone to caller.
2. 1st Impulse Train:
   (a) Steps vertically to the level corresponding to the digit dialled.
   (b) Prepares itself to receive rotary impulses.
3. Second Impulse Train:
   (a) Steps horizontally to the required contact.
   (b) Tests the contact, and if busy returns busy tone to the caller.
   (c) If the contact is free, guards the called line, applies ringing current to the called line and ringing tone to the caller.
4. Called sub-answers:
   (a) Disconnects ringing current and ringing tone.
   (b) Switches caller to called line and provides a speaking bridge with talking battery for both caller and called lines.
5. Calling party restores receiver.
   (a) Releases and returns to normal releasing all associated apparatus.

Out-going Call Level 0

1. On seizure functions as for local call.
2. First impulse train:
   (a) Steps to level 0.
   (b) Cuts-in and searches the level for a free outlet.
   (c) Returns busy signal to the caller, if all outlets are busy.
   (d) Switches through on reaching a free outlet and busies the trunk seized against intrusion.
3. Subsequent impulse trains:
   (a) Repeats the impulses to the distant exchange.
4. Caller restores to normal:
   (a) Releases and returns to normal, releasing all associated apparatus.

EXAMINATION No. 2490.—MECHANIC GRADE 2—TELEGRAPH MAINTENANCE SECTION

A. R. Glendinning

Q. 5.—Compare the functions of the polarised relay with those of the non-polarised relay. Explain the differences in and the reasons for the respective designs.

A.—(a) The main functions of the polarised telegraph relay are:

(1) To operate under the control of current reversals.

(2) To remain unaffected by equal currents flowing in the windings when used as a differential relay.

(3) To be capable of working high speed signals.

(b) The main functions of a non-polarised relay are:

(1) To operate on increase and decrease of current irrespective of polarity.

(2) To restore armature under the tension of a controlling spring.

(3) If used differentially behave as (a) (2) above.

The chief difference in design is in the inclusion of a permanent magnet in the polarised relay, hence the name "polarised." There are thus two forces acting on the relay tongue; that due to the magnetic field of the magnet and that due to the varying magnetic field set up by the current passing through the coils. The tongue is, in effect, an extension of the permanent magnet, and its movement is controlled entirely by the polarity of the battery applied to the relay coils.

In modern polarised telegraph relays the coils are mounted vertically, and, as in all differentially wound relays, part of each winding is wound on each core, the winding being thus divided to preserve magnetic balance as far as possible. Contact adjustment is provided by two threaded screws mounted at the top of the assembly. Marking or spacing bias may be given the relay by another screw provided for this purpose. The relay is totally enclosed to prevent damage and to keep out dust.

The non-polarised relay is controlled by a change in current irrespective of direction, hence the armature must have some mechanical means provided to restore it when the current falls in value. This adjustment is provided by a tension spring. The morse relay is the simplest of this type.

The differential non-polarised relay is generally similar in design and appearance to the polarised relay described, but without a permanent magnet. Some type of spring tension control is provided to restore the armature. The B.P.O. type is the more common example.

The Western Union Quad neutral relay is another differentially wound non-polarised relay, but with an extra coil, known as a holding coil, wound on both cores. The external design of this relay is generally similar to the morse relay, but the coil design facilitates more rapid current changes therein.

Q. 6.—Describe and explain the use of at least six measuring tools used on the repair and test bench in Telegraph Maintenance Workshops.

A.—Six types of measuring tools in general use on the test and repair bench at a Maintenance Workshop are:—

(1) Micrometers.
(2) Vernier Calipers.
(3) Depth Gauge Micrometers.
(4) Spring Balances.
(5) Thickness Gauges.
(6) Drill and Steel Wire Gauges.

The Micrometer consists essentially of five parts: the frame, anvil, spindle, sleeve, and thimble. The spindle is threaded 40 T.P.I., and moves in a threaded sleeve. The thimble encloses the outer end. The adjustable sleeve and the edge of the rotating thimble are so graduated that the outer dimension of an object placed between the anvil and the end of the spindle may be read directly in 1,000ths of an inch. By means of a Vernier on the sleeve dimensions down to 10,000ths of an inch may be measured.

The Vernier Caliper is also used for fine outside measurements. The head of the main T-shaped piece is used as the fixed jaw and the piece to be measured is placed between this jaw and the movable arm which carries a vernier and slides on the main piece. A fine adjustment screw is provided. Dimensions to 1,000th of an inch are read directly from the graduations on the main piece and the vernier scale.

The Depth Gauge Micrometer, except for the difference in the shape of the frame and the absence of the anvil, is similar in principle and operation to the micrometer. It is used for measuring depths such as those of slots and blind holes to an accuracy difficult to achieve with the usual measuring methods. In making measurements, the shoulders rest on the edges of the slot to be measured and the spindle is screwed forward until it touches bottom. The depth may be then read from the sleeve and thimble graduations.

The Spring Balances are used for measuring pressures or tensions, and both types may be obtained calibrated to read either grams or ounces.

Spring balances consist generally of three main parts; the body, on which is engraved the scale; the spring carrying the pointer; and a device to attach the spring to the object to be measured.

In the Tension Balance, this device is usually in the form of a hook, while in the pressure balance, a finger extending well clear of the body is provided. In measuring, the pressures or tensions are read directly from the engraved scale.

Thickness Gauges consist of a number of metal leaves of varying thicknesses pivoted together and fitted for convenience in a metal holder. The thickness of each leaf in 1,000ths of an inch is stamped clearly on one side. The leaves may be used singly or together, and a variety of measurements may thus be made. The tool is used for measurements of relay contact gaps and clearances between moving parts. These gauges are also used frequently to check wear in machines.

The Drill and Wire Gauge is a plate of hardened steel in which accurate holes covering drill sizes from Nos. 1 to 60 have been made. The size of each hole (and drill diameter) in thousandths of an inch is engraved on the plate alongside each hole. The plate is a ready reference for drill and wire sizes between 0.0400 and 0.228 inches.

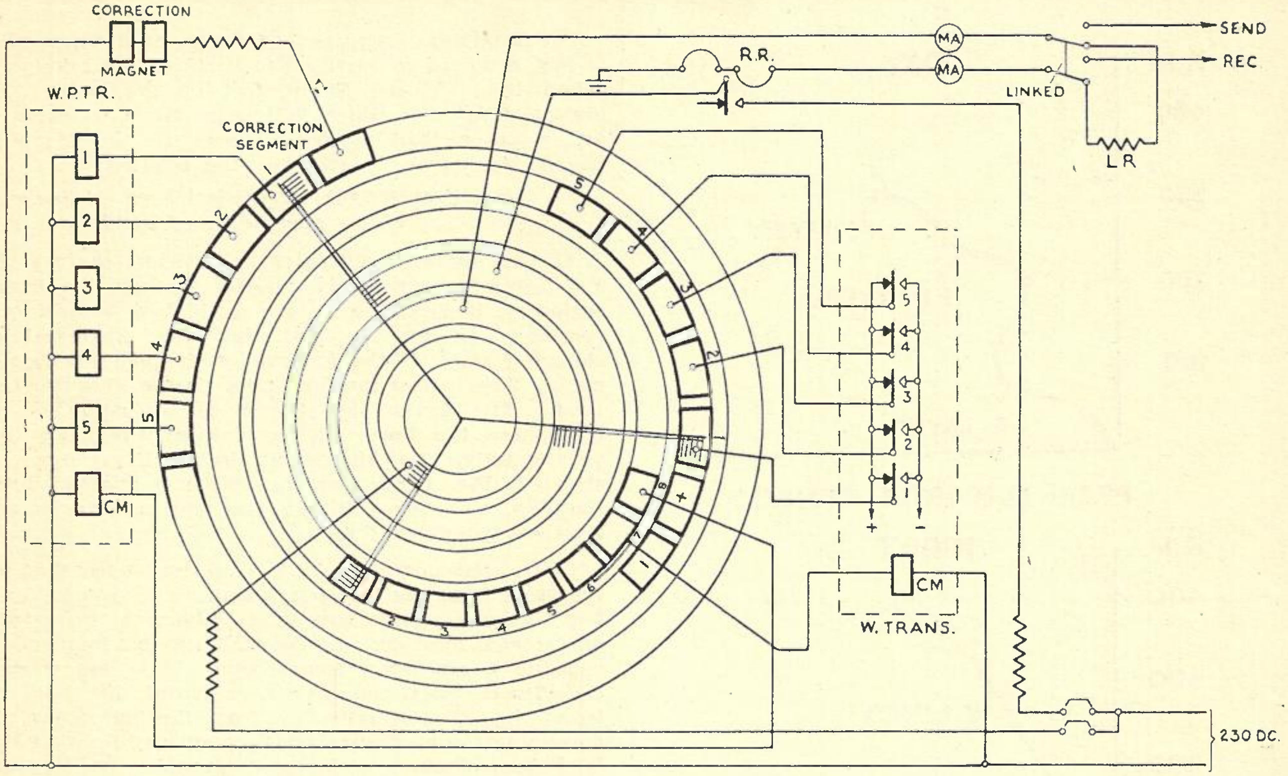
Q. 7.—Describe the kinds of milling cutters that are commonly used in a milling machine.

A.—See answer to Q. No. 7, Examination No. 2559, Telecommunication Journal, Vol. 5, No. 3, February, 1945.

Q. 8.—The Distributor Arms at both ends of a multiplex circuit have to run in unison. Explain why this is necessary. Draw a diagram showing the essential connexions to the distributor.

A.—The Murray Multiplex Distributor divides the line time evenly between the channels wired thereto.

Figure 1 shows the essential connections of a four channel Murray Multiplex Distributor. The Distributor has the switch and rings set for a local trial run. With the switch in the working position, the relay RR will be controlled by incoming signals from the distant transmitting ring instead of by the home signals as in the condition shown in the figure. The Distributor is constructed with three segmented and three plain rings, one of each comprising a pair. The brushes, driven by the phonic motor, passing over these rings, complete the battery connection between the plain rings and the segmented ones. These pairs of rings are known as receiving, transmitting, and local rings, and their functions are indicated by these names.



Q. 8, Fig. 1.

In transmitting, the send segments of the distributor are connected in turn to the line as the brushes pass over them. The positive or negative battery applied to the segment in accordance with the 5 element code set up by the transmitter is thus passed to line. In receiving, it is necessary, therefore, for the receiving brushes to be passing over the appropriate receiving segment as each code element is passed on by the receiving relay.

Taking one channel which may be called W, for example, this means that as the signal element from number one segment of the distant transmitting ring arrives at the receiving end, the home receiving brush must be commencing its travel across the number one receiving segment of W channel. This relation must hold for the five segments of this channel, and all others wired to the distributor, otherwise the code elements transmitted to our W channel would be arriving when the receiving brushes were moving over the receiving segments of some other channel, thus making the reception unintelligible.

EXAMINATION No. 2473.—ENGINEER TRANSMISSION—SECTION 2—RADIO TRANSMISSION

W. H. Hatfield

Q. 4.—In short wave transmission and reception over long distances explain the following:—

(i) Why different frequencies are employed for "daylight" and "darkness" transmission paths.

(ii) Why different frequencies are used for the "short" and "long" transmission paths.

(iii) Why the optimum frequency for transmission between two given points changes seasonally and from year to year.

A.—In considering the radiation of electromagnetic waves from a transmitting aerial, the radiated waves may be separated into two sections:—

(a) The ground wave, which is propagated horizontally, and which is attenuated due to earth losses, the rate of attenuation being independent of time or season, and is greater the higher the frequency of the wave.

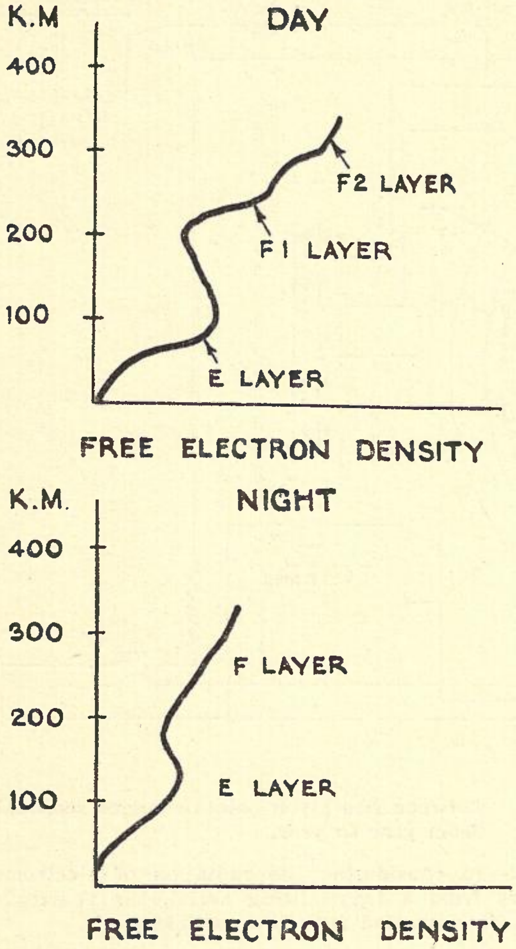
(b) The sky wave, which is propagated at an angle to the horizontal.

Due to the rapid attenuation of the ground wave at high frequencies, the effective area for reception is small, and long distance short wave communication is accomplished by means of the sky wave, which is returned to earth by an ionised region existing in the upper atmosphere (the Ionosphere).

The low pressure gases of the ionosphere are ionised (split up into free electrons and positive ions) by ultra violet radiation from the sun. The degree of ionisation, or density of free electrons, normally varies with height and from day to night as shown in Fig. 1.

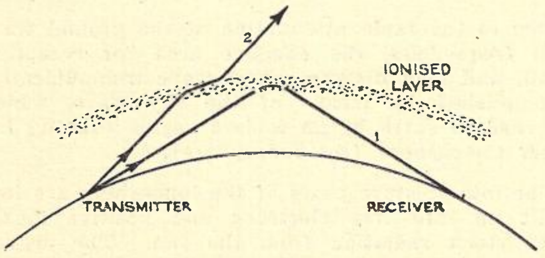
Variations in electron density in the lower E layer, where the gas is comparatively dense, follow closely the conditions of daylight and darkness. In the upper (F_1 and F_2) layers, where the gas is less dense and recombination of positive ions and electrons is slower, the ionised condition persists longer after sunset.

When an electromagnetic wave enters an ionised region, the wave is bent and, depending upon the fre-



Q. 4, Fig. 1.

quency and the degree of ionisation of the region, may be returned to earth, as shown at 1 in Fig. 2. If the frequency is too high, the wave passes through the ionised region, and is not returned, as shown at 2 in Fig. 2.



Q. 4, Fig. 2.

The maximum frequency of transmitted wave which is just returned to earth, with vertical transmission, is called the "Critical Frequency" of the layer. The highest frequency which is just returned to earth, at angles other than vertical, known as the Maximum Usable Frequency, is given by the relation

Max. Usable Freq. = Critical Freq. × Sec θ
where θ = Angle of Incidence.

As the higher frequencies are attenuated less than the lower frequencies in passing through the ionised region, it is desirable to use as high a frequency as possible. In practice, to allow for the constantly changing state of the ionosphere, frequencies approximately 20% below the Maximum Usable Frequency are used. The lower the degree of ionisation of the ionosphere the lower is the Critical Frequency and, consequently, the Maximum Usable Frequency. As shown in Fig. 1, the electron density is greatest during the day, and hence higher frequencies may be used than are possible at night.

In transmission over long distances, more than one reflection from the ionosphere may be necessary (Multi-hop transmission) to cover the distance between transmitter and receiver. In determining the frequency to use for a multi-hop transmission, it is necessary to consider the local time at the centre of each hop, that is, at the point of reflection from the ionosphere, and determine the maximum usable frequency for that time. We, thus, obtain a series of frequencies, one for each hop, and if we use a frequency higher than that required for the lowest frequency, the signal will be lost at that section. Thus the frequency used for multi-hop transmission is governed by the portion of the path requiring the lowest frequency for satisfactory reflection.

Along the great circle path between two points, different darkness conditions will prevail along the "short" and "long" paths, and the optimum frequency will, therefore, be different for the two directions of transmission.

Just as the ionisation of the upper atmosphere varies daily, increasing as the sun becomes more nearly overhead, so there is a seasonal variation in intensity of ionisation, and a consequent variation in critical frequency, corresponding generally with the position of the sun, the higher critical frequencies occurring in summer and the lower critical frequencies in winter. These variations are particularly regular in the lower or "E" layer.

In addition to the daily and seasonal variations, the ionisation of the upper atmosphere is influenced by sun-spot activity, the intensity of ionisation, and hence the critical frequency, following the 11-year sun-spot cycle, and varying from a minimum at a sun-spot minimum to a maximum at a sun-spot maximum.

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