The Telecommunication Journal of Australia

VOL. 11, No. 3

Registered at the General Post Office, Melbourne, for transmission by post as a periodical.

FEBRUARY, 1958

CONTENTS

■

■

POLICY

THE object of the Postal Electrical Society of Victoria is to promote diffusion of knowledge in the communication services of the Post Office.

In advancing this object by the publication of this Journal the Board of Editors is not responsible for the statements made or the opinions expressed in any of the articles in this Journal, unless such statement is made specifically by the Board.

Editors are welcome to use not more than one-third of any article provided credit is given at the beginning or end, thus:—From "The Telecommunication Journal of Australia."

BACK COPIES:

The Society has available, in quantity, the following back copies of the Journal:—

Volume	6	Numbers	1 - 6	published	1946-48
„	7	„	1 - 6	„	1948-50
„	8	„	1, 2 & 4	„	1950-52
„	9	„	1 - 6	„	1952-54
„	10	„	1 - 6	„	1954-57
„	11	„	1 - 2	„	1957-59

These Journals may be supplied, on demand, at 10/- per set of three or at 4/- per single copy. Back copies of some earlier numbers are available but it is recommended that inquiry first be made to the Secretary, as to the availability of any particular number. In the event of the Society being unable to supply any number, it wall act as an agent to assist subscribers in obtaining a copy. The Society does not repurchase Journals but readers having copies which are no longer required should give details to the Secretary, who may thus be able to advise other readers where the back copies may be obtained.

DISTRIBUTION:

This Journal is available to members of the Postal Electrical Society of Victoria without charge. Non-members may obtain copies of all publications of the Society on the payment of 10/- p.a. Single copies of this Journal are available at 4/- each.

COMMUNICATIONS:

All communications should be addressed to:—

Hon. Secretary,
Postal Electrical Society of Victoria,
G.P.O., Box 4050, Melbourne.

All remittances should be made payable to "The Postal Electrical Society of Victoria," and endorsed "Not negotiable."

The
Telecommunication Journal
of Australia

VOL. 11, No. 3 FEBRUARY, 1958

COCOS-COTTESLOE UNDERSEA TELEGRAPH REPEATER

*R. E. KNIGHTLEY, A.M.I.E.Aust.**

INTRODUCTION

On August 5, 1957, the first submarine amplifier directly connected with the Australian International Telegraph System was lowered to the sea floor about 60 nautical miles from Cottesloe, near Perth. The installation of the repeater has enabled a significant increase in signalling speed on the cable concerned.

TRAFFIC CONSIDERATIONS

Cottesloe is Australia's western gateway to the British Commonwealth world-wide cable network and is connected to that network via Cocos Islands. Two cables span the 1,750 nautical miles between Cocos and Cottesloe. The older of these ("Cosclo 1") was laid in 1901 and could reliably handle signalling speeds of only about 15 bauds, while the other ("Cosclo 2") is of 1926 vintage and enables existing instruments to cope with 40 bauds quite comfortably.

In thinking of these signalling speeds, it must be remembered that 3-condition codes are used over long submarine cables. If we were to accept 40 baud signals from such a cable and convert them into 7.5 unit start/stop two-condition teleprinter signals, we should in fact require the teleprinter to work at a speed of 90 bauds in lieu of the Australian Post Office standard of 50 bauds.

Before the installation of the repeater, Cosclo 1 was worked duplex between Cottesloe and Durban via Cocos at a signalling speed of 750 elements per minute (that is 12.5 bauds), while Cosclo 2, being loaded and therefore unsuitable for duplex, was time switched between Cottesloe and Singapore via Cocos (12 hours to Singapore and then 12 hours from Singapore) at a speed of 1800 elements per minute, that is 30 bauds.

While this arrangement made the best possible use of the existing combination of cable characteristics and terminal machinery, it had three drawbacks:—

(1) Slowness of traffic clearances over one cable.
(2) Difficulties of maintaining a duplex balance between stations 2,000 miles apart.
(3) Unbalanced nature of a time-switched, high speed circuit on one cable coupled with a low speed, duplex circuit on the other.

Installation of the repeater has enabled the simplex signalling speed of the slow cable to be increased to the speed capability of Cable 2, thus eliminating all three of the disadvantages mentioned above. Indeed, the cable signalling speed has been sufficiently increased to enable the operation of two time shared incoming channels with complementary outgoing channels on the fast, loaded cable.

The arrangement is shown in schematic form in Fig. 1, in which the broken lines show the previously existing arrangements and the solid lines show the present circuits. It will be seen that the time multiplex channels work at different speeds, the speed to and from Durban being only half that of the Singapore link. This is due to the differing capabilities of the circuits available beyond Cocos. It will further be noted that received traffic terminates on code converter reperforators. These units accept 3-condition cable code morse signals at their input but feed out 2-condition morse (Wheatstone) tape for transmission over landlines and radio links to Sydney and Melbourne. The reverse applies in the outwards direction.

The Cottesloe installation was, of course, complemented by suitable time multiplex equipment and branching arrangements at Cocos Islands.

GENERAL THEORY

The familiar equation, $C = BT \log (1 + P/N)$, has a somewhat sinister import for the engineer who is faced with the need to increase the information carrying capacity of an old gutta percha insulated submarine cable.

A variation of the effective bandwidth component could be achieved only by a high order of capital outlay (renewal of the cable), while an increase in signal to noise ratio could not be achieved by

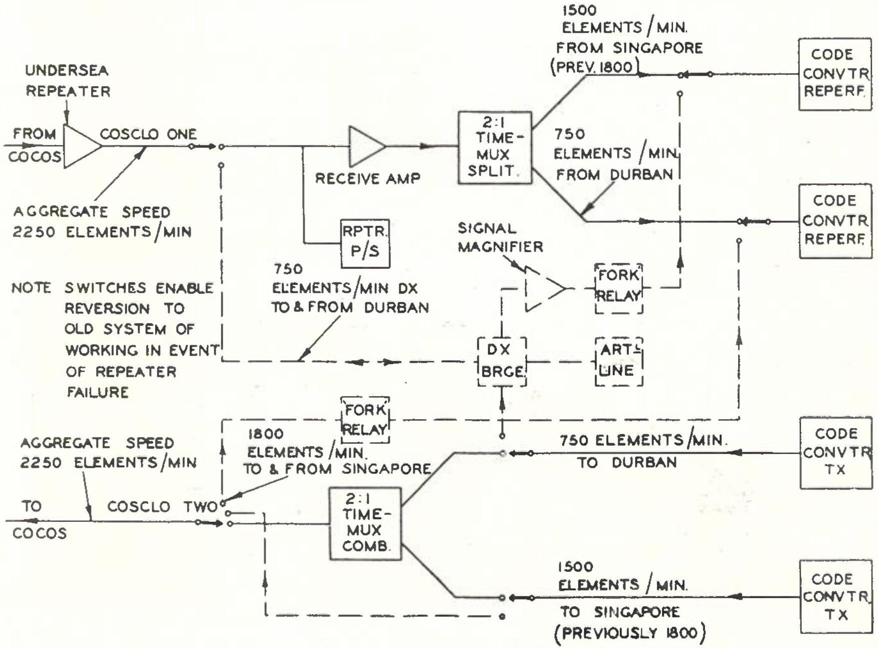


Fig. 1.—Block Schematic of Cocos-Cottesloe Cable Equipment.

---

* Mr. Knightley is a Senior Engineer, The Overseas Telecommunications Commission (Australia), Sydney.

simply increasing DC sending voltages as there would be a risk of damaging the cable insulation. There is, however, an alternative means of improving P/N. Although by no means technically simple, the capital outlay is not unreasonably high.

The majority of noise entering a submarine cable is induced into the circuit on the continental shelf where the cable is within the field of atmospheric electrical disturbances and man-made noise. In the deep sea the noise entering a cable is negligible. Thus, by installing a high gain amplifier at a point where signal power can be multiplied without increase in noise power, signalling speeds may be appreciably improved.

In the case described here an amplifier with an 85 db gain has been installed some 60 nautical miles (75 statute) off-shore at a depth of about 580 fathoms (3,500 ft.).

THE REPEATER

A 6-valve amplifier, the repeater is housed in a heavy steel torpedo-like casing filled with an atmosphere of dry nitrogen. Fig. 2 shows the repeater prior to laying. The casing is designed to withstand an external pressure of 3 tons per square inch, although in this instance the pressure is only about ½ ton per square inch.

A push-pull input stage drives a 4-valve push-pull/parallel output stage. Power for filament heating and HT supply is fed to the amplifier along the cable conductor from Cottesloe, and the valve filaments and HT circuits are so arranged that a variety of faulty valve conditions will not render the repeater inoperative but will merely reduce its gain. Even in the event of complete failure of the unit, it can be switched out of circuit and the system reverted to straight through unamplified working until repairs can be effected.

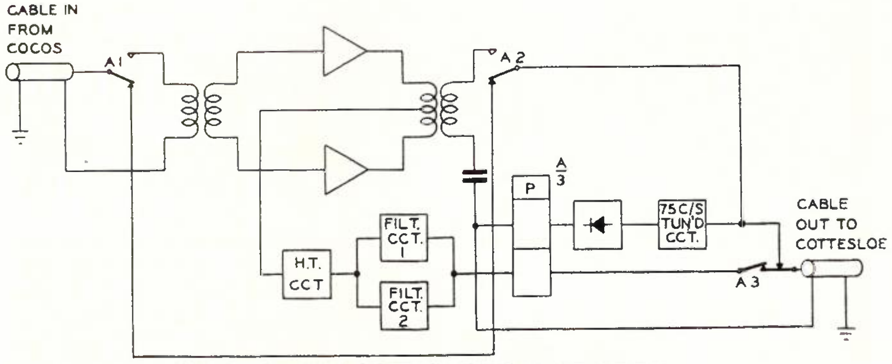


Fig. 3.—Simplified Schematic Circuit of the Repeater.

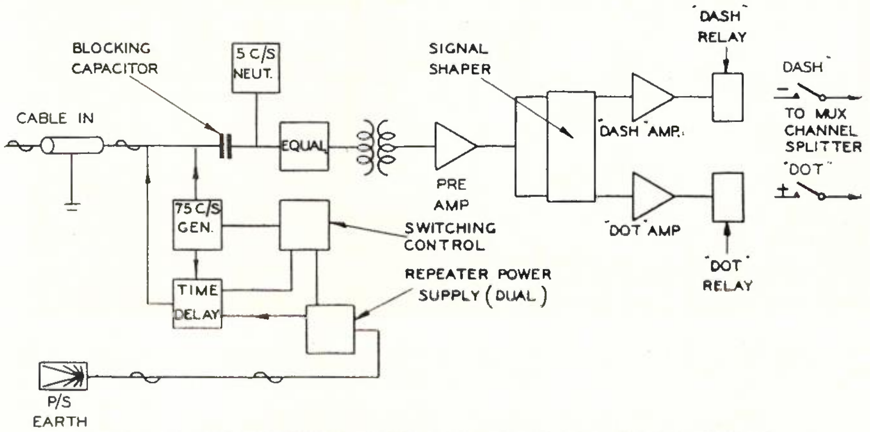


Fig. 4.—Simplified Schematic Circuit of the Terminal Equipment, Cottesloe.

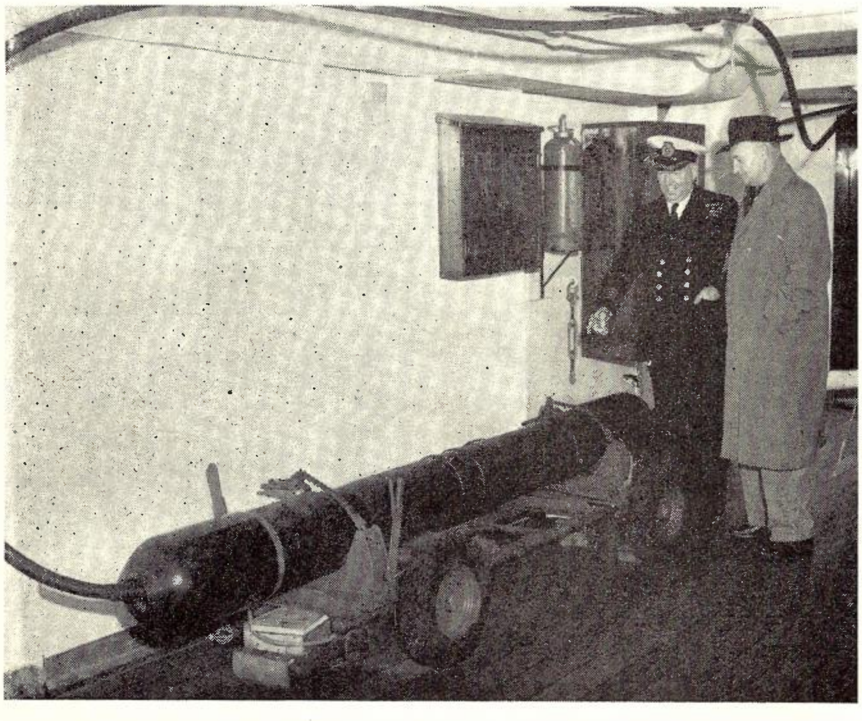


Fig. 2.—The Repeater in its Case on board C.S. "Recorder".

Fig. 3 shows a much simplified schematic circuit of the repeater, including control circuitry, the operation being as follows. Under unamplified conditions, signals incoming from Cocos pass direct to Cottesloe via relay contacts A1 and A2. To switch in the repeater, a 75 cycle tone is applied to the Cottesloe end of the circuit and via a tuned acceptor circuit and rectifier, this tone operates the control relay A through its operate winding. Contacts A1 and A2 switch the repeater into circuit while contact A3 applies power to the repeater and holds relay A operated. The two separate filament circuits enable the repeater to continue functioning even though one valve filament (or even more in particular combinations) should become open circuit.

In practice, of course, the circuitry includes a number of refinements, for example, the control unit incorporates guard relays to cover the warm up period of the valves.

TERMINAL EQUIPMENT

While the installation of the repeater was accompanied by the provision of time division multiplex equipment throughout the Indian Ocean network, Cottesloe Cable Station was equipped in addition with the power supply equipment and receiving terminal amplifier equipment, the arrangement being indicated in Fig. 4. Fig. 5 is a photograph of the terminal equipment.

When switching in the repeater, a 75 cycle tone is fed out along the cable and, after a delay to ensure operation

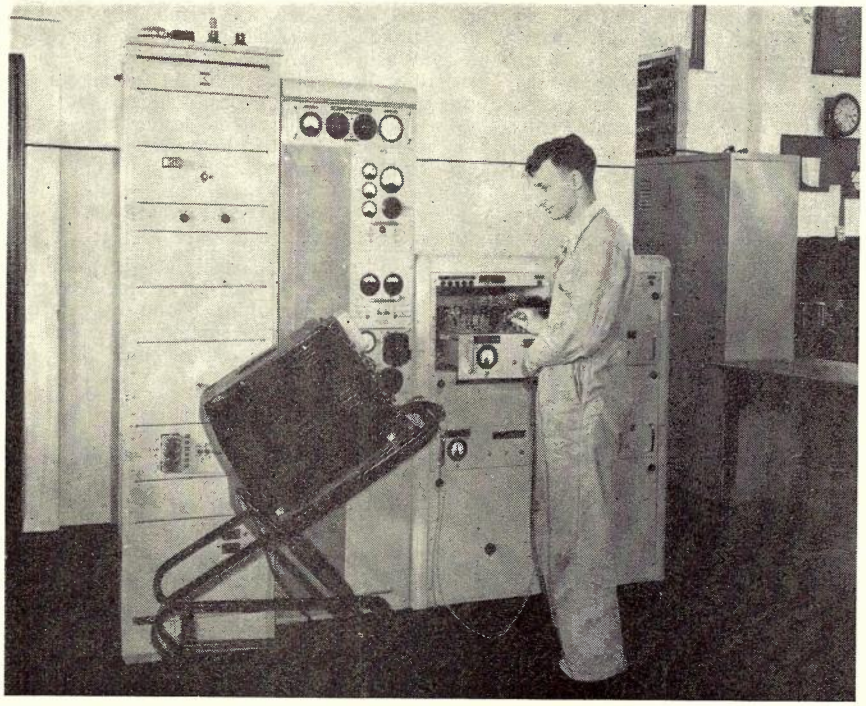


Fig. 5.—Terminal Equipment, Cottesloe, showing left to right: Receiving Terminal Amplifier, Repeater Power Supply, Multiplex Channelling Combiners and Multiplex Channelling Splitters.

of the repeater control circuit, HT is applied to the cable conductor. The voltage applied in this case is 265V., the voltage at the repeater being 215V. In order to achieve the maximum advantage from the amplified signals, the constant current power supply is heavily regulated, even to the extent of providing its own earth plate in the sea about a mile off shore.

Incoming telegraph signals pass to the receiving terminal amplifier via a blocking capacitor to isolate it from the power circuit. The 50 cycle neutraliser is a reactive network with variable voltage and phase which are adjusted to cancel out any stray induction from local primary power sources. Beyond the preamplifier, the signals are split to two independent amplifiers and these operate dash and dot relays according to the incoming polarity of the 3-condition code elements. To compensate for differentiation of the signals by the repeater, the signal shaper is a resistance capacity network with a rising characteristic adjusted so that the output of the dash/dot relays simulates the DC wave form applied to the cable at the distant end.

JOINT OPERATION

The new circuit arrangement is the result of co-operation between the British Post Office Research Station, Cable & Wireless Limited of London, and the Overseas Telecommunications Commission (Australia). C. & W. Limited are the owners of the cables while O.T.C. (A.) owns and manages the stations at Cottesloe and Cocos.

Both repeater and power supply were designed and built in the U.K. following successful trials of two similar amplifiers between the U.K. and Gibraltar. The receiving terminal equipment was installed by O.T.C. (A.) while the repeater installation was carried out by the C. & W. Limited cable ship, "Recorder", with a consulting engineer from C. & W. Limited conducting the commissioning operations at Cottesloe in conjunction with staff of O.T.C. (A.). The unequal speed time multiplex channelling equipment was designed and built by C. & W. Limited.

After exhaustive laboratory tests, a total of about 20 miles of polythene insulated deep sea cable was jointed to the tails of the repeater and the assembly was shipped in a water tank to Singapore where it was transferred to the "Recorder". There were two reasons for joining such long tails to the repeater. Firstly, the cable to be picked up and cut was nearly 60 years of age, and hence it was advisable to have spare cable on the repeater to carry past possible damage to the old gutta percha cable. Secondly, it was desired to have the initial splice on the ocean floor before passing the repeater over the ship's side and then to have the repeater on the bottom before doing the final splice.

When the "Recorder" arrived at Cottesloe on July 26, the shore-based installation was complete. On July 29 the power supply earth plate and connecting cable to the shore were laid and the ship headed seawards next day. Fig. 6 shows the shore end operations at Cottesloe associated with the repeater power supply earth cable. After nearly a week of adverse weather the "Recorder" was able to pick up the cable on Sunday, August 4 and on August 5 to announce completion of the final splice.

The last phase of the line-up at Cottesloe then commenced. The equaliser in the input to the terminal amplifier (see Fig. 4) had been designed in England from a knowledge of the cable's characteristics and the approximate loca-

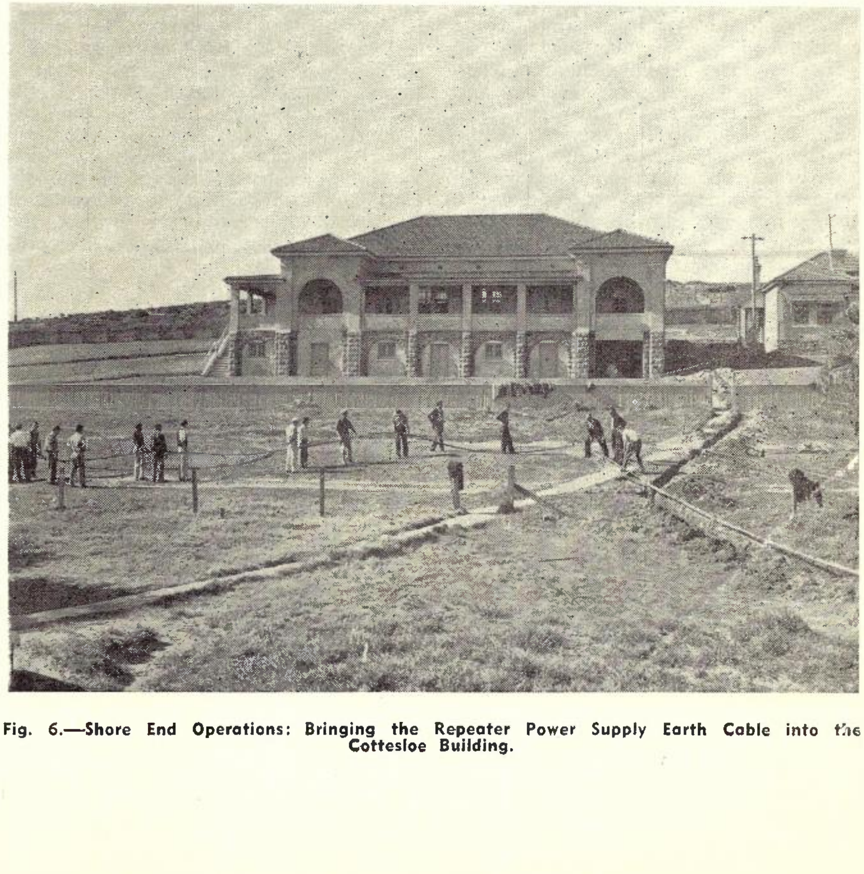


Fig. 6.—Shore End Operations: Bringing the Repeater Power Supply Earth Cable into the Cottesloe Building.

tion of the repeater. After insertion of the repeater, it was necessary to modify this input circuitry according to the difference between forecast and actual performance. It was further necessary to insert compensating networks in the artificial line (see Fig. 1) to regain an accurate duplex balance. These activities were completed in time for the whole installation to pass full-scale tests over the week-end of August 17-18.

FUTURE DEVELOPMENTS

Referring again to Fig. 1, it will be noted that the Singapore circuit now works at a speed of 1,500 elements per minute, corresponding to a speed of 56.5 bauds when converted to 5-unit start-stop teleprinter signals. A conversion to teleprinter working will indeed be the end result of this installation when automatic 5-unit to 3-condition (and vice versa) code converters are provided on the Indian Ocean network within the next two years.

Installation of the repeater has enabled equal simplex speeds to be achieved over two cables, one of which is a quarter of a century older than the other and the existence of these facilities will enable us to integrate this cable network with those international circuits which already employ 5-unit machines.

Work is already in hand in the United Kingdom on repeaters for other parts of the cable network terminating in Australia, New Zealand and the Far East. When the projected repeaters have been installed there will be a substantial uniformity in speeds throughout the international system despite the widely differing electrical properties of the cables concerned.

ACKNOWLEDGMENT

The Editors of the Telecommunication Journal of Australia wish to thank the General Manager, The Overseas Telecommunications Commission (Australia) for kindly supplying for publication the photographs used in this article.

AN AUTOMATIC FAULT RECORDER FOR AUTOMATIC ROUTINERS

G. V. O'MULLANE[*]

INTRODUCTION

Testing automatic exchange equipment absorbs a large number of manhours and with the ever increasing amount of apparatus to be tested it has become a problem with comparatively small staffs available to perform tests at periods the frequency of which will ensure that defective or unstandard apparatus will be quickly detected and be made serviceable again. Generally automatic routiners are used to test various types of apparatus in use. Routiners vary in their circuits, component parts, etc., according to the type of apparatus to be tested but all follow a standard plan of operation. The routiner subjects each switch in turn to a series of tests and when those tests are successfully completed it automatically connects to the next switch where the tests are repeated.

When a switch fails to comply with any test condition applied or when a busy switch is met, the routiner stops and an audible alarm operates. A number of operated lamps on the routiner lamp display panel will identify the faulty switch and the particular fault condition by giving rack, shelf, switch and fault numbers. Manual attention is then required to record these lamp numbers and to resume the testing on the next switch. A typical routiner access arrangement is shown in Fig. 1 and a photograph of a selector routiner lamp panel is shown in Fig. 2.

The greater proportion of the apparatus is tested during light traffic periods and in the Collingwood exchange, which is the main for the J group, the testing is done during the late evening and night shifts. Staffing at these times is at a minimum and the nature of the attending technicians' duties can make it impossible to attend the routiner promptly when the stop alarm operates. Accordingly there is a tendency for the audible alarm for the routiner to be switched off, the testing technician visiting the routiner at irregular intervals. According to the size of the exchange, a number of routiners will be testing simultaneously and considerable overall testing time can be lost by routiners standing idle after a test failure or on meeting a busy switch. At this point it is necessary for the technician to note particulars of the failure and to restart the routiner testing on the next switch.

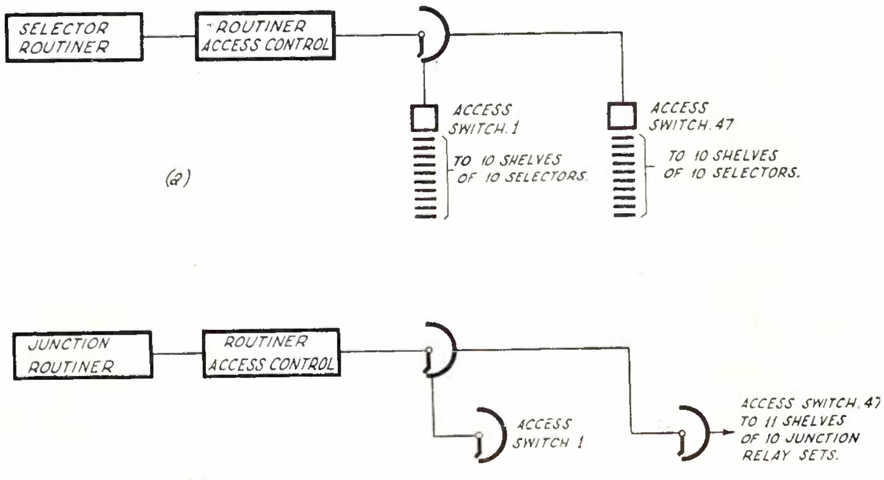


Fig. 1.—Typical Routiner Access Arrangement.

THE AUTOMATIC RECORDER SCHEME

To eliminate this loss of testing time a circuit which makes the routiner fully automatic has been designed. Using a Morkrum teletype machine and some control apparatus, a selector routiner at Collingwood exchange, without any attention after the initial starting, will test over a group of 2,000 selectors and record the necessary particulars of every switch failure during that test. Fig. 3 is a block schematic of the scheme. The recorder control shown in Fig. 4 associated with each routiner consists of three uniselectors and a number of relays. Fig. 5 is a photograph of the Morkrum printer including a recording indicating faults after a typical testing run on a group of selectors

The circuit was designed on the basis of using one teletype for each routiner but after 12 months operation it was thought advantages would be gained by using one teletype machine to record for a number of routiners testing simultaneously. This development has been tried out. A second teletype was installed as a common unit and control apparatus connected to one relay set routiner linking it to a common teletype. This arrangement has given satisfactory operation for over 12 months.

---

[*] Mr. O'Mullane who retired recently, was a Senior Technician at the Collingwood exchange, Victoria. The equipment described in this article was developed by him and was the subject of an award by the Improvements Board.

At present the routiner has sole use of the teletype and a complete test of the idea waits on installation of the individual control apparatus and linking up to the teletype of four other routiners. The apparatus used is as follows:—

Common Apparatus—
- One Morkrum Printer (P)
- One 2-Level Uniselector (Finder Switch)
- 8 Relays

Individual to each Routiner—
- One 16-Level Siemens Motor Uniselector (MU)
- One 8-Level Uniselector (Control Switch)
- One 4-Level Uniselector (First fault Marker)
- 30 Relays
- Miscellaneous Resistors, Keys, Condensers, etc.

The Morkrum teletype for the purpose used in this apparatus can be briefly described as an electrically operated typewriter. The various characters are printed by the operation of five magnets which singly or in combination set up the numbers to print the desired character. These magnets are operated by an earth pulse via the wipers and bank contacts of 12-16 levels of the motor uniselector. The printer magnet pulse is operated by a start pulse operating the starting mechanism and the desired character is printed. The printing magnets operate on 50 volts and the motor is driven by 200 volts D.C. derived from the A.C. supply by a rectifier. Contact springs mounted on the carriage platform, and operated by fingers on the carriage, control the carriage return, paper feed and column start position mechanism.

Connections from all lamps on the routiner display panel are made to bank contacts of the motor uniselector in the following order:—

Bank 1—Vacant.
Banks 2-3—To rack indicating lamps.
Bank 4—To shelf indicating lamps.
Bank 5—To switch indicating lamps.
Banks 6-7—To bank contacts 4 and 5 levels (first fault marker).
Banks 8-9—To fault indicating lamps.
Banks 10-11—Miscellaneous.
Banks 12-16—To printer magnets 1-5.

Fault indicating lamps also connect to contacts on banks 2 and 3 of the first fault marker switch.

DESCRIPTION OF OPERATION

The actual circuit diagram of the recorder and recorder control is too large for reproduction in this Journal. A simplified diagram, Fig. 6, has been made for the purpose of explaining the principle of operation of the apparatus.

When the routiner alarm delay period of four seconds has expired, in lieu of operating the alarm, the first fault marker switch is started and its wipers stepped to the contact marked by the operated fault lamp. The marker switch camps on this contact until the recording has been completed. The switch sends an earth pulse back to the routiner which

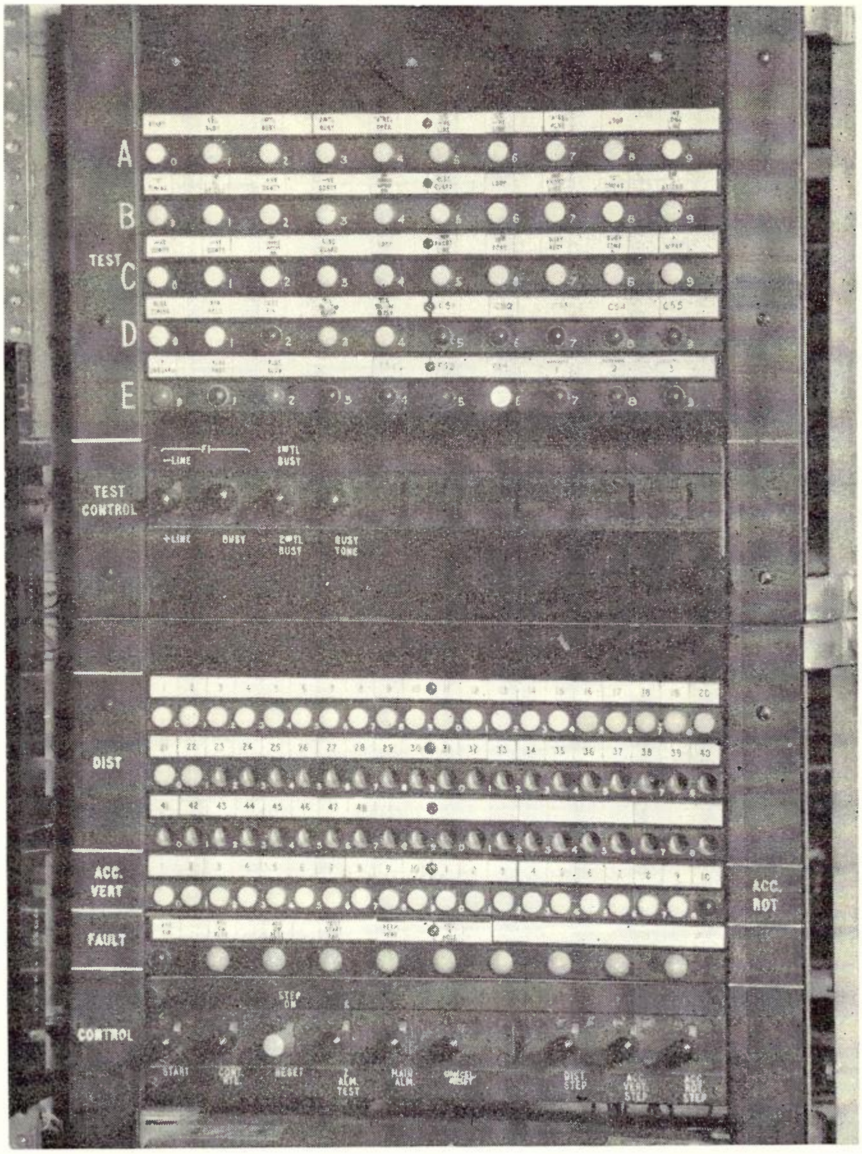


Fig 2.—Photograph of Selector Routiner Lamp Panel.

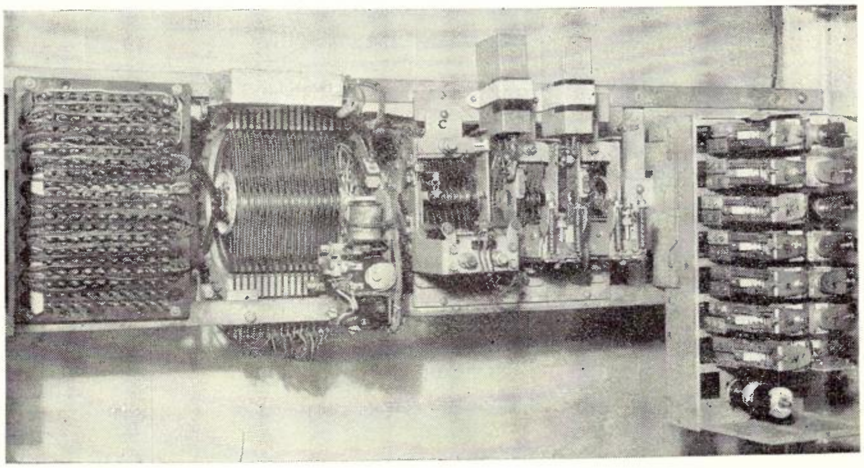


Fig. 4.—Photograph of a Recorder Control.

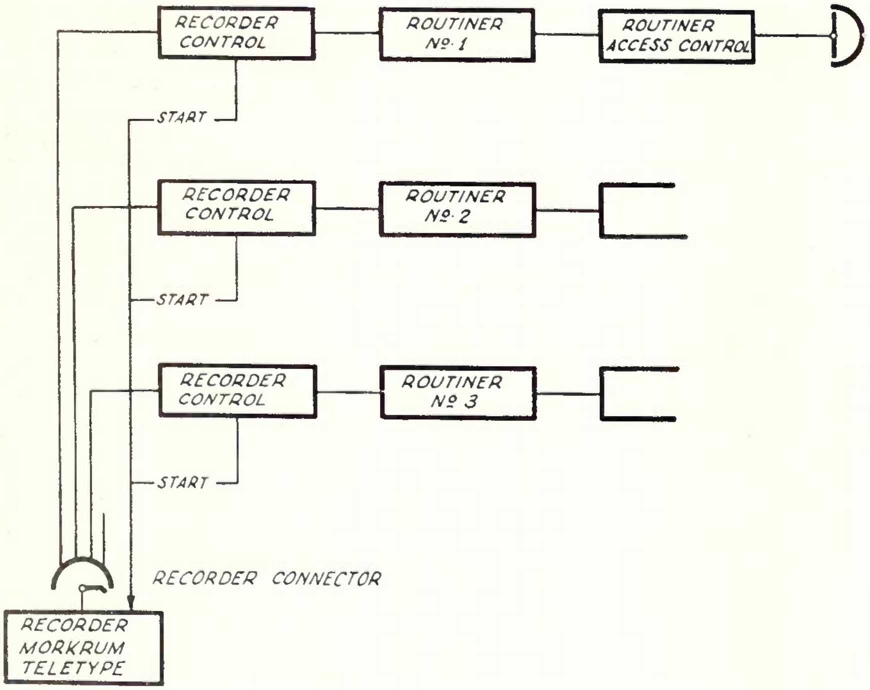


Fig. 3.—Block Schematic of the Scheme.

resets and a second test of the faulty switch is started. When the stoppage is due to the switch being busy a second test is not made.

When the second test of the switch has been completed an earth from the routiner operates the finder start relay and the finder switch wipers step to the outlet corresponding to this routiner. The finder camps on this contact until the recording has been completed. The finder switch hold relay contacts provide an earth to operate the start relay in the control circuit.

The printing is done in four columns across the sheet as shown in Fig. 5. Prior to a recording being printed an earth pulse from the control switch sets the printer carriage at the column start position. Each routiner has its own identifying number 1, 2, 3 and so on. An earth pulse from the control switch, via the motor uniselector, causes this identifying number to be printed as the first figure of every recording.

Operated lamps on the routiner lamp panel indicate rack, shelf, switch and fault numbers. Corresponding to these operated lamps various contacts on the motor uniselector banks will be earthed. The control switch and the motor uniselector now set up an inter-action to

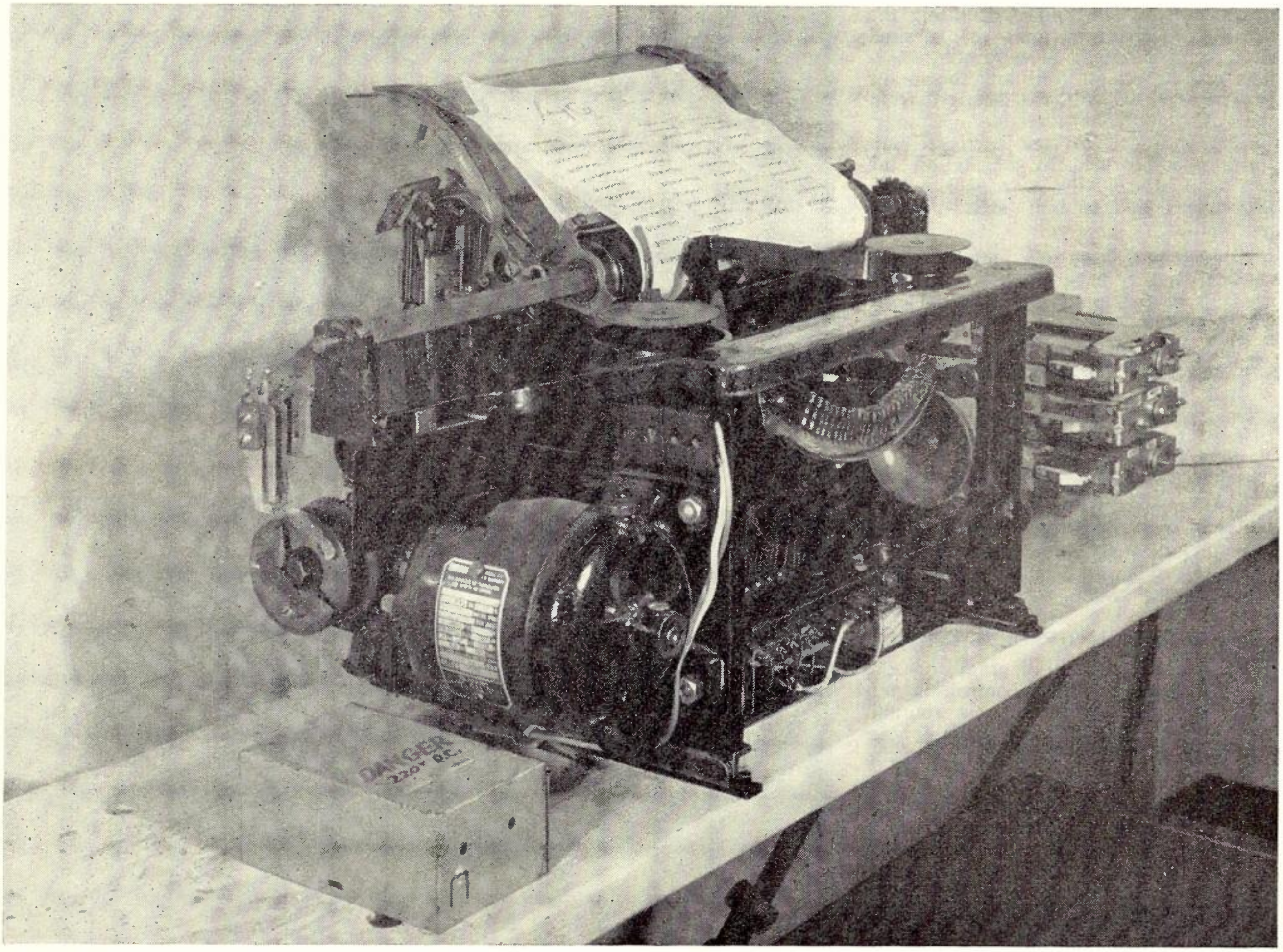


Fig. 5.—Photograph of the Printer and Typical Recording.

search for these marking earths. The motor uniselector starts when the latch magnet by operating, removes the lock on the mechanism and closes the circuit to the motor uniselector motor. The stop relay is connected to wipers 2 and 3 of the control switch. The bank contacts of these levels are connected to the motor uniselector wipers 2 to 10. When the motor uniselector wiper, to which the stop relay is connected, reaches a marked contact the stop relay operates, the latch magnet restores and the motor uniselector stops. Relays A, B and C, controlled by the motor uniselector circuit, cause an earth pulse via banks 12-16 to operate the printer magnets associated with the contacts stopped on, and the appropriate figure is printed. The operation of relays A, B and C also step the control switch forward one step. This removes the stop relay from the earthed wiper of the motor uniselector and connects it to another wiper. The stop relay releases, allowing the latch magnet to reoperate. The search for the marked contact in this bank now proceeds. When the earthed contact is reached the stop-print-control switch step on operation is repeated. This sequence of operations continues until the numbers of all operating lamps have been printed. The miscellaneous characters and the tens figure for double-figure lamp numbers are printed by earthing particular contacts of motor uniselector

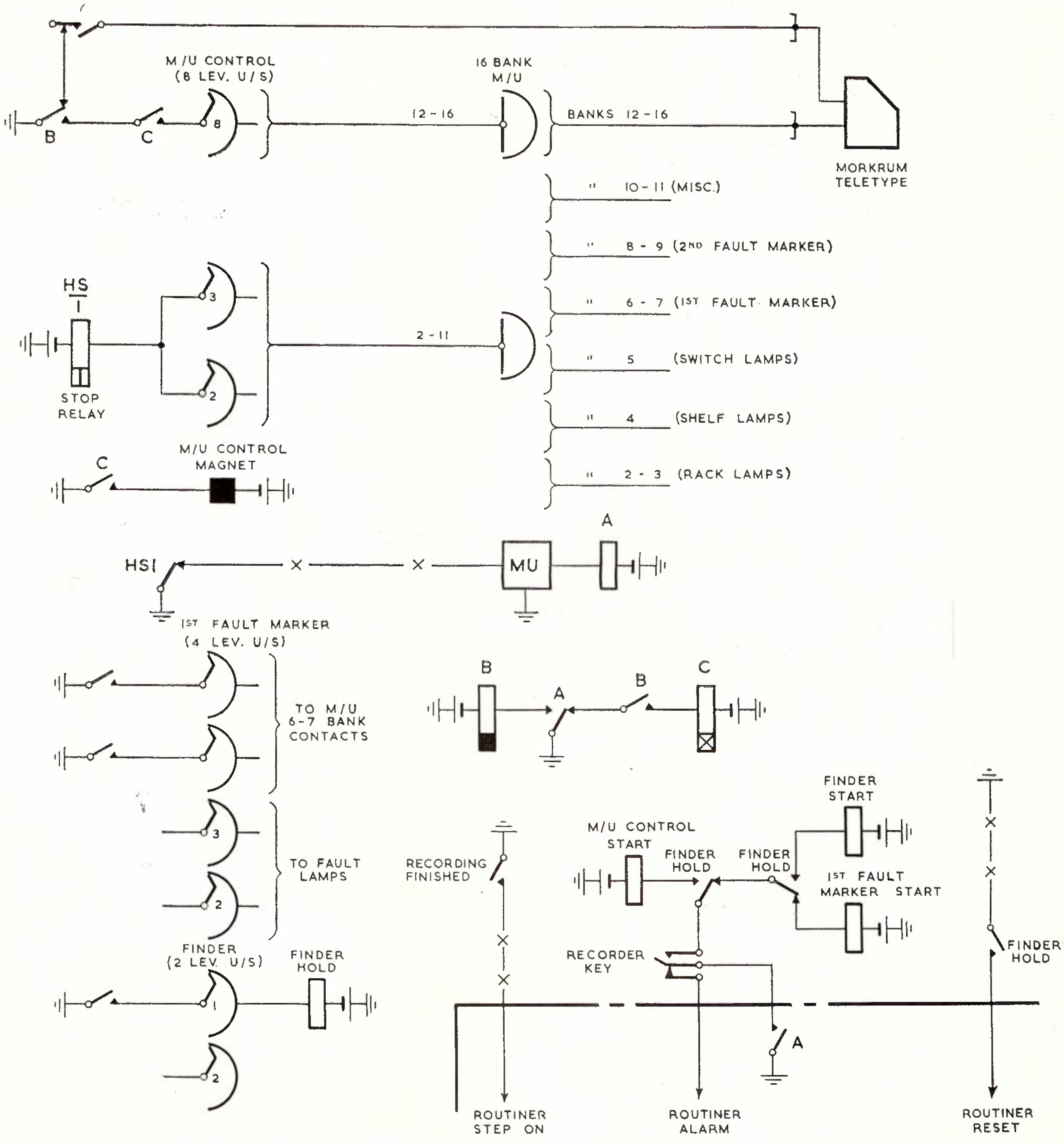


Fig. 6.—Explanatory schematic of main Circuit Features.

bank 10 and connecting the stop relay to motor uniselector wiper 10 at suitable stages of the recording.

The recording is made in the following typical form:—

3/25-2-7-8. 8

These figures indicate the following information:—

3 routiner, number 25 rack, number 2 shelf, number 7 switch, number 8 fault 1st test, number 8 fault 2nd test.

When the switch tests O.K. on the second test the character "&" indicates that test result and is printed in the second test space thus:—

3/25-2-7-8. &

When all particulars have been printed, an earth pulse from the motor uniselector via the control switch steps the routiner to the next switch and testing continues. All control and recording apparatus restores to normal.

Any switch may be tested continuously and the results of the recorded routiner rack shelf and switch numbers are printed, followed by the printed result of every test made whether O.K. or faulty. A typical recording would be in the following form:—

3/25-2-7-3&&& 8 &&& 8&& 25&&& 4&

Test failures are indicated by printing the particular fault number and O.K. tests are indicated by printing the symbol "&". All other routiners are isolated from the printer while this feature operates.

The circuit provides that should a failure occur of the printer motor, motor uniselector, marker, finder or control uniselector, the nine second delay exchange urgent alarm operates. In addition any faulty condition of the routiner or associated apparatus causing a succession of switches to fail on test will operate the exchange three-minute delayed alarm.

Typical recordings of a test run are shown in the printer in Fig. 5. This typical run was obtained in testing a group of approximately 1500 group selectors.

CONCLUSION

The Collingwood trial has demonstrated the practicability and the usefulness of an automatic fault recorder for automatic routiners in exchanges, and work is proceeding to provide a permanent installation in which the one recorder would serve all automatic routiners in the exchange. In the permanent installation a teleprinter will replace the Morkrum printer which was used for the initial installation described in this article.

THE VICTORIA-TASMANIA RADIO TELEPHONE SYSTEM (via Flinders Island)

*W. E. BEARD, B.E.E.**

INTRODUCTION

In November, 1955 a new radio telephone system between Tasmania and the mainland was cut into service, adding six high-grade telephone channels to the Department's communication facilities across Bass Strait. Twelve months later, improvements to the radio equipment permitted the addition of another six channels. The system operates between Wilson's Promontory, Victoria, and Lilydale (near Launceston), Tasmania, with a repeater at Flinders Island. The geographical location is shown in Fig. 1. From these radio terminals, traffic is taken by open wire trunk route to Launceston trunk exchange and in open wire and cable carrier to Melbourne.

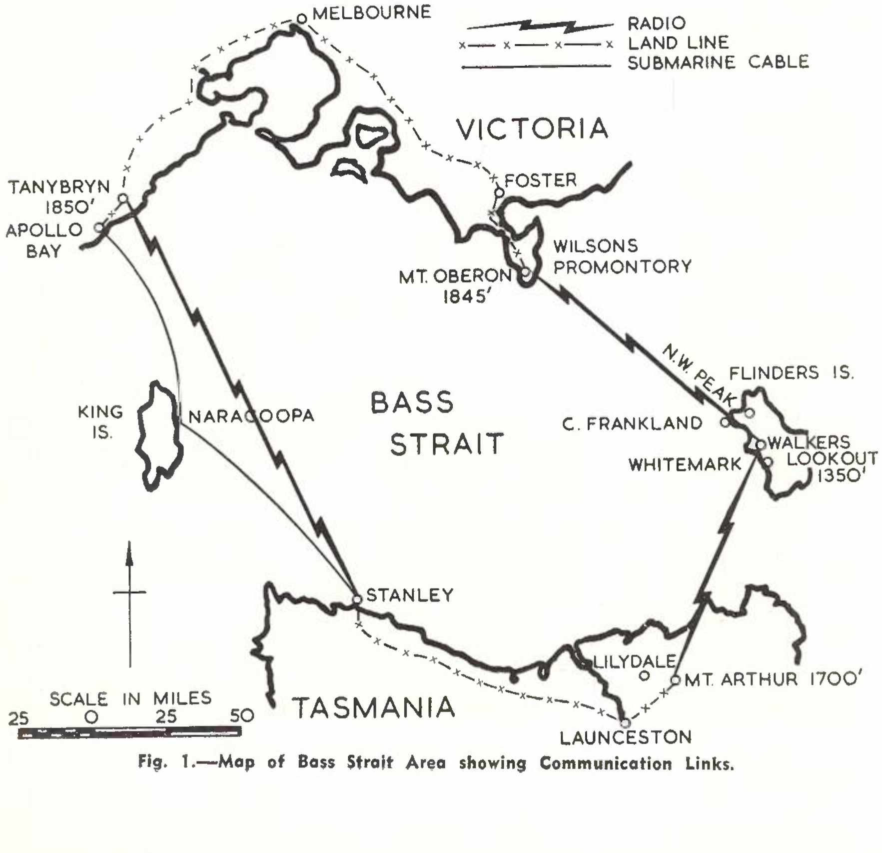


Fig. 1.—Map of Bass Strait Area showing Communication Links.

The new link thus provides a traffic route completely alternative to the existing cable and radio links at the western end of Bass Strait. Communication between the States is now more reliable, being less dependent on the vulnerable trunk route along the Tasmanian coast between Stanley and Launceston. Further improvements to the radio equipment are being actively pursued and will eventually give the radio bearer an even greater traffic carrying capacity.

PLANNING

Planning for this new service commenced in 1947 when an investigation was started to find a suitable radio telephone route across Bass Strait which would give better performance than the Tanybryn-Stanley system which was already established at that time. Possible routes were investigated at the western end of the Strait, including provision for a repeater station at King Island, and at the eastern end with a repeater at Flinders Island. Sites were surveyed and a theoretical prediction was made of received signal levels. These predictions indicated that a route at the eastern end of the Strait would offer the best radio path performance.

With not a little difficulty and with great credit to the staff involved, test stations to test these predictions were set up during 1948-49 on Wilson's Promontory, Flinders Island, and at Mt. Arthur in Tasmania. The site at Wilson's Promontory was about 1845 ft. above sea level, and was close to the summit of Mt. Oberon, which overlooks Tidal River

---

* Mr. Beard is a Divisional Engineer in the Research Section, Central Administration.

settlement, 40 miles from Foster. On Flinders Island a station was set up at Walker's Lookout, a cleared hill, 1350 ft. in height, which was fairly accessible by jeep. It is near the centre of the island and about 7 miles from Whitemark, the main township. The radio path between these stations was 116 miles long and non-optical, so it was expected that severe fading would be experienced at times. The site in Tasmania was chosen at what was known as Kelp's Paddock, about 1700 ft. up the slopes of Mt. Arthur, and 17 miles from Launceston. Mains power was available to this station and a road went right to the site. The southern path from Flinders Island to Tasmania was 92 miles long and optical.

Propagation measurements conducted over this path and the alternative western route proved that the Flinders Island scheme would produce a superior circuit, moreover, with the use of higher frequencies for which smaller aerial systems were possible. This route was therefore recommended. To minimize the effects of deep fading encountered over the Wilson's Promontory-Flinders Island link, it was recommended further that a diversity system with different frequencies be employed. A full description of this early survey and propagation work is given in Ref. 1.

Even though this propagation survey had shown that the Mt. Oberon-Flinders Island-Mt. Arthur path would provide a high grade circuit, many other factors had to be examined before a firm proposal could be advanced for development of the route. Roads and buildings would have to be provided and an open wire trunk line taken from Foster to the top of Mt. Oberon and from Mt. Arthur to Lilydale. Provision would be necessary on the main South Gippsland trunk route in Victoria for the extra bearers required for the proposed system. The location of the stations, remote from centres of population and main power reticulation, would involve problems of maintenance and local power generation.

Early in the planning stage it was advocated that stations should be unmanned, except for periodic visits by maintenance staff. This concept immediately made more important the provision of reliable radio and power equipment with standby facilities and automatic changeover. Adequate fuel storage would be needed to cover the emergencies which might cause disruption to regular deliveries.

Investigations were started at once into the power supply problem, especially that of automatic starting of standby plant, and the experience of other administrations and authorities was drawn upon freely. Provision of standby radio equipment was automatically covered when frequency diversity operation was decided upon. An efficient alarm system indicating faults to the remote exchanges was required and some effort was devoted to that problem. Even though the station would be unmanned, accommodation would still be necessary for staff kept at the station over night on installation or maintenance work or who might be stranded by such emergencies as an impassable road or bad weather. Not the least of the problems was the provision of sufficiently high performance radio equipment. It had to be decided in the light of what equipment was available and the results of propagation tests how many channels should be provided, and what performance would be expected.

LAND, ROADS AND BUILDINGS

As soon as it could be seen how these problems could be overcome, a decision was made to develop the route. The sites chosen for the installation were those used during propagation tests, and land was purchased at Flinders Island and made available at Mt. Oberon by the Victorian Government. At Mt. Arthur the site chosen was already on Departmental property, having been purchased for the terminal of a single channel link to Flinders Island. A new road was built between Tidal River and the summit of Mt. Oberon, of a grade and width to take an oil tanker, and a shorter length of road was built between Walker's Lookout and the end of the road to Whitemark. The station sites were built up and levelled at the same time. Good weatherproof buildings were required at all three radio sites and a new long-line equipment building was required at Foster. The first building at Mt. Oberon, of foam concrete construction, suffered badly from storms in the Spring of 1954 and water penetrated to a severe degree. Later in the same year one wall was damaged by fierce winds, as a result of which the exterior walls were replaced by brick construction. Special methods were employed to seal

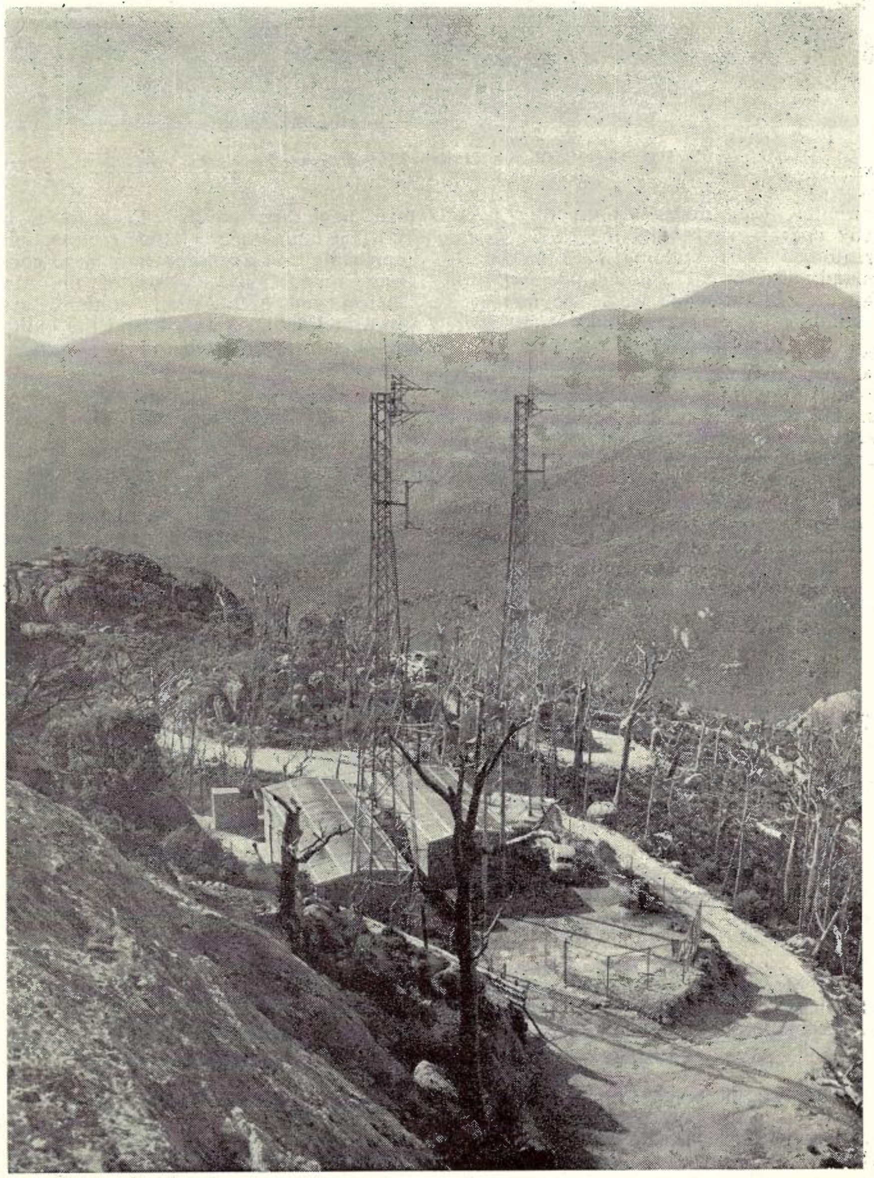


Fig. 2.—Mt. Oberon Radio-Telephone Station.

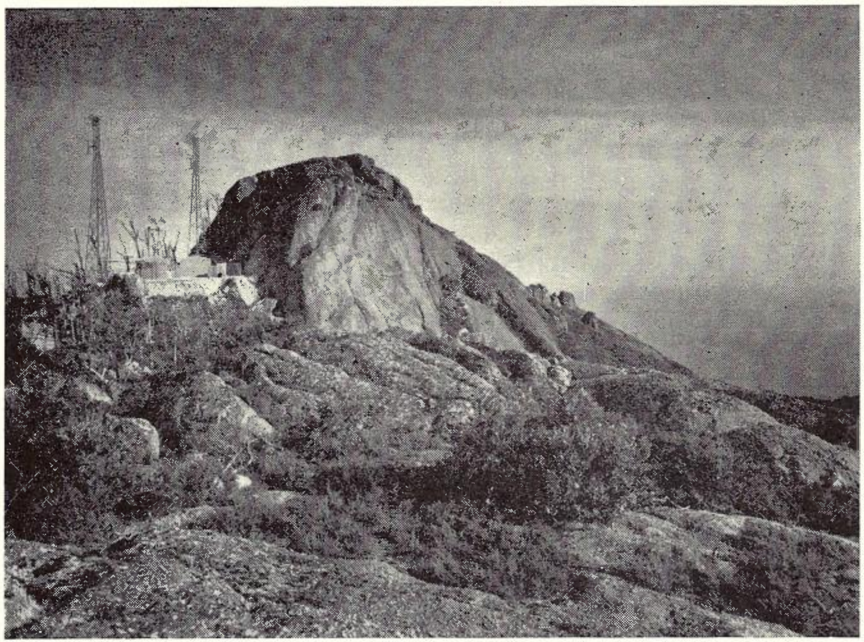


Fig. 3.—Mt. Oberon Station Viewed from the North.

windows and doors against rain swept by updraft winds, and the roof was reinforced. The building at Flinders Island, also in an exposed position, was treated in the same way. The improved buildings have been found very satisfactory after two years' occupation.

Although differing in details, all three radio buildings are arranged in the same general way. A separate engine-room which may accommodate a workshop, is connected by a short covered passage to the equipment room alongside. The engine-room is large enough to house three diesel alternators with service tanks and switchboards. Low-level double windows in front of each engine allow adjustment of air flow through the room and control of room temperature. The space between the two main rooms is partly occupied by covered water tanks. The equipment room is divided with partitions into equipment room proper, kitchen, store and bunk-room. Large fire-proof double doors to equipment and engine-rooms allow the heavy equipment to be brought in. To minimize noise transmission between the two rooms, fire-proof doors have been put in at each end of the connecting passage. Ducts have been provided in the floors of both rooms for electric wiring cables, and exhaust from the engines is also taken out through the floor ducts.

At Mt. Arthur, where mains power is available, the engine room is smaller. 3,000 gallon underground oil storage is provided at Mt. Oberon, sufficient for 6 months' operation whilst at Walker's Lookout 1,500 gallon storage is provided in an enclosure above ground as all fuel is supplied in 44 gallon drums. Two aerial towers have been provided at each station. These were provided with the radio equipment and are designed to take Yagi type aerials. Each tower is 100 feet high, square lattice section, self supporting and anchored into large concrete foundations. Views of the Mt. Oberon and Mt. Arthur stations are given in Figs. 2, 3 and 4, and the building layout at Mt. Oberon is shown in Fig. 5.

POWER EQUIPMENT

Reliable power plant is essential so it was decided to instal a group of three diesel alternators in each of the stations at Mt. Oberon and Flinders Island. Only one machine of the group supplies power to the radio equipment at any one time, with one other machine as a standby. In this way there would always be one standby machine and another available for overhaul. A typical engine room is shown in Fig. 6. The units are Lister 3 cyl. 25 h.p. diesel alternators, rated at 12.5 KVA at 240 volts and were originally supplied to the Department as standby equipment for mains operated plant. They are designed to start up automatically and take over the load upon failure of the main supply, so for this purpose each engine has its own control panel. Each machine has its own 24V. starting battery and starter motor which is driven as a battery charging generator once the engine is operating normally. The charging rate is controlled from each control panel. The three machines are interconnected via a fourth control panel which provides for any one machine to be selected at will as main and another to be selected as standby. Interlocked main switches between each alternator and the main bus bar allow the operating machine to supply power to the load without risk of parallelling machines. Provision is made for the third machine to supply power to certain outlets such as the kitchen stove when there is a danger of the extra kitchen load overloading the main machine. When full load tests are required on this machine its power may alternatively be switched to a dummy load.

Unattended operation of the machines required certain refinements to the installation to improve reliability and keep maintenance visits to a minimum. Each engine has its own fuel service tank filled by electric pump from the main storage, from which service tank fuel is supplied to the engine by gravity feed. Header tanks for cooling water are installed above each engine and the water level is automatically made up from rain water tanks with the aid of a pump. Sump oil make-up tanks are installed on each engine and the sump of an idle engine is kept warm by

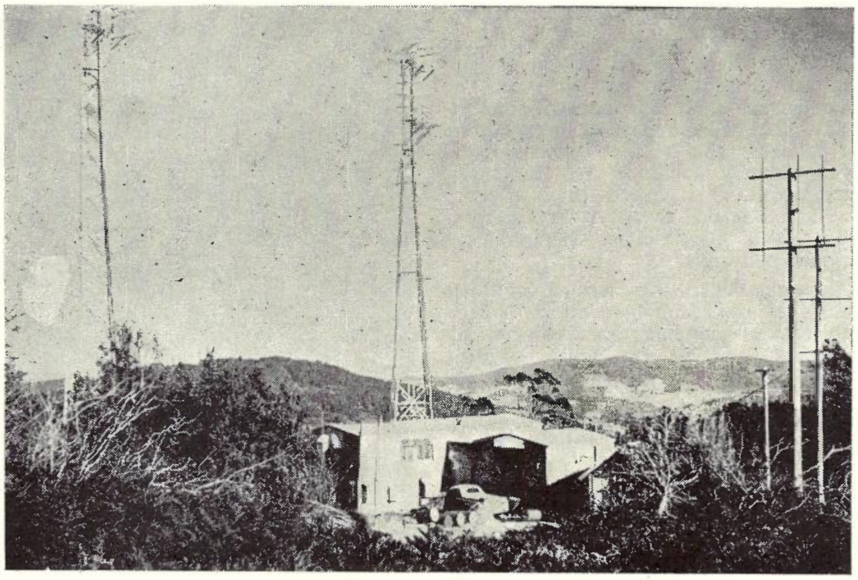


Fig. 4.—Mt. Arthur Radio-Telephone Station.

thermostatically controlled heaters. Alarms, which operate on low water and oil level, excessive engine temperature and excessive movement of the engine governors occasioned by possible engine faults or sudden load changes, will shut down the engine and bring in the standby machine. Engine shut down is indicated by alarms which appear at the exchange. The power installation at Mt. Arthur is simpler than described as mains supply is available and one only standby machine is installed.

THE RADIO PATH FREQUENCY DIVERSITY SYSTEM

The original propagation tests were carried out on frequencies of 160 Mc/s and 60 Mc/s. Analysis of records taken over the north path showed that both the 160 Mc/s and 60 Mc/s signals fell 10 db below their median values for percentages of time up to 6%, but simultaneous fading of both signals below their medians occurred for less than 0.1% of the time. It was therefore expected that considerable performance improvement would be brought about if both frequencies were used simultaneously and automatic means provided for selecting the circuit with the better signal-to-noise ratio.

The nearest band to 60 Mc/s that could be exploited was the 80 Mc/s band. Except for the theoretical difference of path attenuation it was not expected that propagation phenomena at 80 Mc/s would be much different from those at 60 Mc/s. Frequencies in the 160 Mc/s band were available and

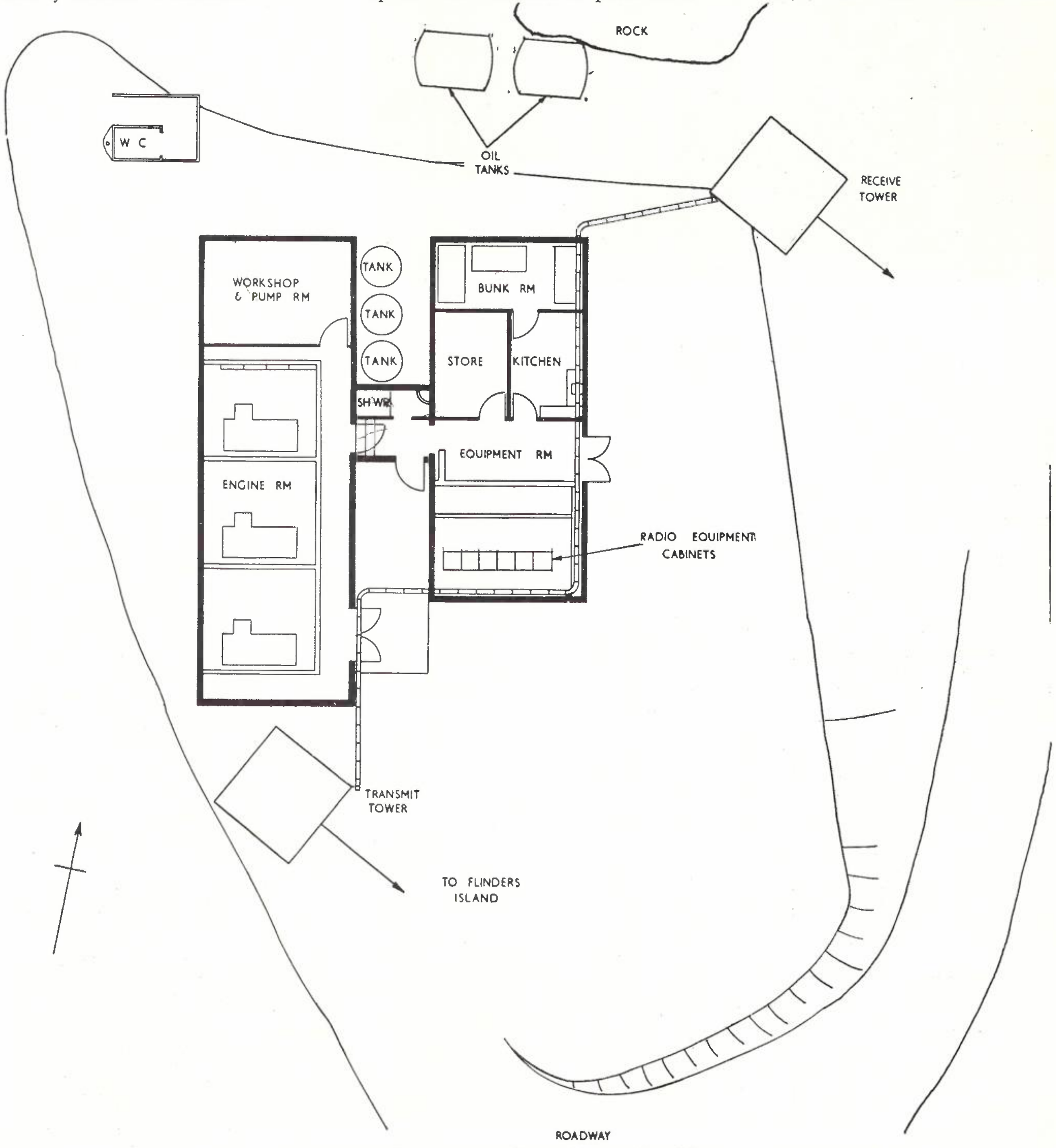


Fig. 5.—Mt. Oberon Radio Station—Site Plan.

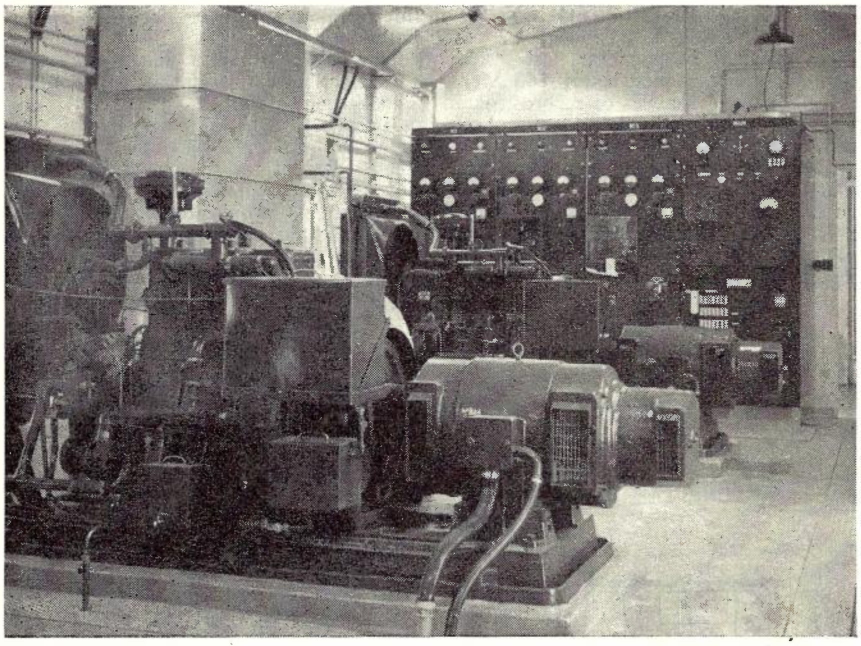


Fig. 6.—View of Engine Room—Mt. Oberon.

Table 1

	160 Mc/s	80 Mc/s
Transmitter Power	20W.	20W.
Type of Modulation	F.M.	F.M.
Modulation Band	300 c/s - 212 kc/s	300 c/s - 212 kc/s
Max. Freq. Deviation	± 300 kc/s	± 200 kc/s
Receiver Noise Factor	< 10 db	< 7 db
Aerials	(a) 17 db/dipole (Yagi) (b) 21 db/dipole (Rhombic)	11 db/dipole (Yagi)
Feeder Loss	(a) 1.1 db (AS57) (b) 2.25 db (UR17)	0.8 db
Receiver Aerial Filter Loss	2 db	2 db
Input Signal for Max. Dev.	− 30 dbm	− 30 dbm
Output Signal for Max. Dev.	+ 20 dbm	+ 20 dbm

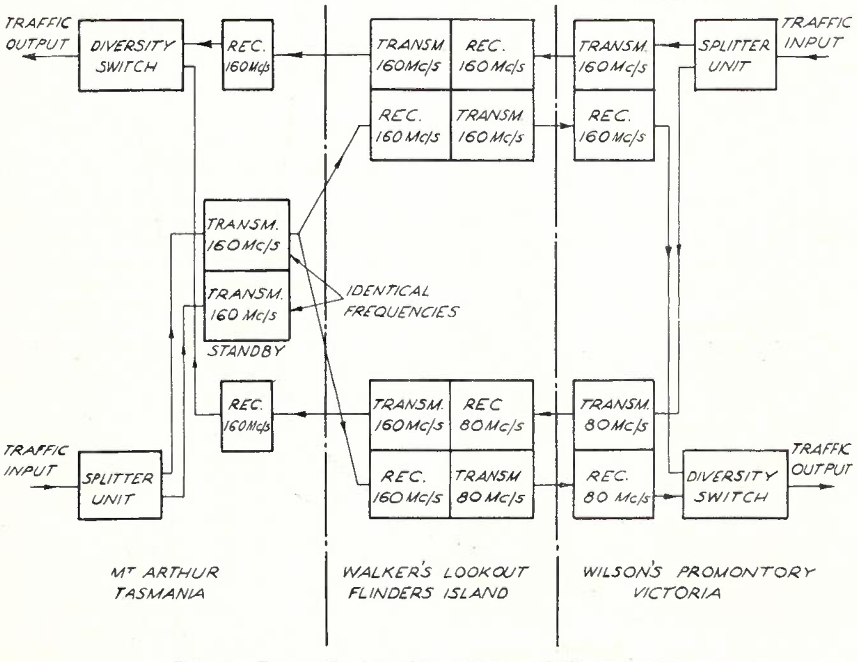


Fig. 7.—Frequency Diversity Scheme—Block Schematic.

accordingly the north path uses frequencies in the 80 Mc/s and 160 Mc/s bands.

Over the south path, some fading was experienced but the lower path attenuation provided a much larger margin of signal-to-noise ratio than was obtainable over the north path. Diversity over this path was accordingly not necessary and frequencies in the more open 160 Mc/s band were chosen. A frequency diversity plan was worked out which operates in the following manner. Sending from Victoria, the 80 Mc/s and 160 Mc/s transmitters are modulated by the same traffic signals and radiate simultaneously as shown in Fig. 7. The repeater at Flinders Island re-transmits the received signals separately over two frequencies in the 160 Mc/s band without demodulation and the frequency deviation is preserved. At the Tasmanian terminal the receiver outputs are monitored automatically and the one with the lower noise is switched through to the line. In the opposite direction only one transmitter is used in Tasmania which is received by both repeaters at Flinders Island, one retransmitting in the 160 Mc/s band, the other in the 80 Mc/s band. As in Tasmania the signal from the better path is selected to line upon reception in Victoria. A standby transmitter is provided in Tasmania operating on the same frequency as the main transmitter. A total of 7 frequencies was reserved in the two bands for this system and a second set of frequencies was also reserved in the event of another system being installed.

RADIO EQUIPMENT

At the time the decision was made to develop the route (1950), the only supplier of suitable radio link equipment from Sterling sources, who would be able to make deliveries within the time desired, was the Marconi W.T. Co. Negotiations were commenced with the company to effect a specification, and ultimately a contract was let. The specified characteristics of the equipment ordered are given in Table 1.

All aerials used, except the 160 Mc/s north directed rhombic aerials at Flinders Island, were Yagi arrays. The 160 Mc/s arrays were 6 element Yagis stacked 2 x 2 and each array had a nominal gain of 17 db. The 80 Mc/s arrays were 2 stack, 4 element Yagis, with a nominal gain of 11 db. 100 ft. towers upon which the arrays were mounted (see Fig. 2) were ordered from the Marconi Co.

The rhombic aerials were developed in the Research Laboratories of the Department and had three tiers with a leg length of 14 wave-lengths. The measured gain was 21 db referred to a dipole, this figure being necessary to give an adequate signal over the North Path. The nature of the site at Mt. Oberon precluded the use of rhombic aerials there. Feeders for the rhombic aerials were polythene insulated UR17 coaxial cable which has a greater loss than the air-spaced AS57 cable supplied with the Yagi aerials.

Because this equipment is operating in diversity, the Tasmanian transmitter would be restricted to a maximum frequency deviation of ± 200 kc/s instead of its designed maximum of 300 kc/s, to prevent overloading of the 80 Mc/s equipment on the north path.

PREDICTION OF RADIO PATH PERFORMANCE

The equipment is designed for 48 channels in the band 12-204 Mc/s, but initially the system was to be loaded with six channels only in the band 12-36 kc/s. At this stage it was possible to make a prediction of path performance. Propagation measurements and calculations gave reasonable agreement for the median signal level and the known characteristics of the radio equipment could be applied to give a figure for channel signal-to-noise ratio. The channel signal is taken to be the channel line-up tone, transmitted at 0 dbm from the trunk test board. This tone was required to produce a modulation level 12 db below maximum frequency deviation (±200 kc/s) for best compromise between intermodulation noise and thermal noise performance. Noise level in a channel is take to be the weighted level (1951 C.C.I.F. weighting) measured over a 4 kc/s band. In a frequency modulation system the level of thermal noise power appearing in a channel is not independent of the channel frequency but is proportional to the square of channel frequency. Thus the 6th channel centred on 34 kc/s will be the worst, and calculations were made of the noise appearing there.

For the aerial gains used, the powers transmitted, and feeder and filter losses, the measured median received signal levels over the various paths are shown in Table 2. From these signals the signal-to-noise ratio expected if an amplitude modulated system were used with line up tone producing 100% modulation, is given by $10 \log \frac{C}{N_{2fa}}$ where C is received carrier power, N_{2fa} is noise power in the 2fa band where fa is the channel bandwidth. Frequency modulation F.M. has an advantage over A.M. with respect to signal-to-noise ratio, given by $20 \log \frac{\Delta F}{fc}$ where ΔF is the max. frequency deviation and fc is the centre frequency of the channel (whose bandwidth is considered small in comparison). Weighted noise is 3.5 db less than flat noise, and 12 db must be deducted to allow for the channel line-up level.

Taking the North Path at 160 Mc/s as an example.

Received Power — 98.4 dbw.
Thermal Noise in 8 kc/s band — 165 dbw.
Noise Figure of Receiver 10 db.
∴ A.M. S/N ratio (100% Mod) — 98.4 — (—165 + 10) = 56.6 db.
F.M. advantage (at 36 kc/s) = 15.4 db.
Line-up level — 12 db.
Weighting Factor + 3.5 db.
∴ S/N ratio in channel 6 = 56.6 + 15.4 — 12 + 3.5.
= 63.5 db. (median)

Signal-to-noise ratios for the various paths are also shown in Table 2.

Table 2

Frequency	Median Received Signal	Received Power	A.M. S/N Ratio	F.M. S/N Ratio
North Path				
80 Mc/s	68 μV, 70 ohms	—101.8 dbw.	56.2 db	63.1 db
160 Mc/s	101 μV, 70 ohms	— 98.4 dbw.	56.6 db	63.5 db
South Path				
160 Mc/s	950 μV, 70 ohms	— 78.9 dbw.	76.1 db	83.0 db

These figures show that over the complete system the conditions prevailing over the north path will almost always govern the system performance, as the noise contribution from the south path is approximately 20 db below that produced from the north path. The system median signal-to-noise ratio is thus 63 db (approx.) and as it was expected that simultaneous fades of 10 db depth would occur less than 1% of the time, it was expected that the signal-to-noise ratio obtained in the worst channel would exceed 53 db for 99% of the time.

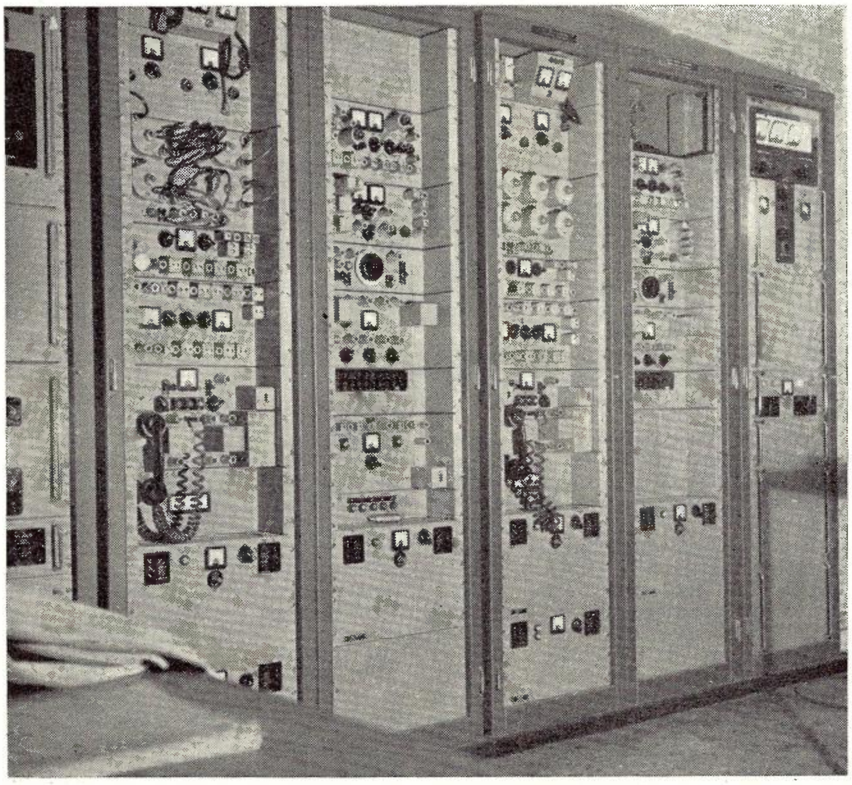


Fig. 8.—Radio Equipment, Mt. Oberon. From Left, 160 Mc/s Power Amplifier, Transmitter, Receiver, 80 Mc/s Transmitter, Receiver, Power Amplifier.

TRUNK LINE ARRANGEMENTS

Since a radio link inherently has separate go and return paths a cable carrier system is the natural choice where frequency division multiplex equipment is used. A cable carrier system was chosen for the section between Foster and Launceston but the distance, 40 miles Foster to Mt. Oberon and 17 miles Mt. Arthur to Launceston, precluded the laying of a cable. Open wire lines were used instead and were very carefully transposed and equalized up to a frequency of 60 kc/s. Any small amount of crosstalk remaining would not be troublesome as it appears only as side-tone to the talker. Intially, 6 channels were provided and these channels were demodulated to voice frequency at Foster and Launceston. At Launceston they were split into a Launceston group and another group for re-transmission to Hobart. At Foster the six channels fed into a twelve-channel open wire carrier

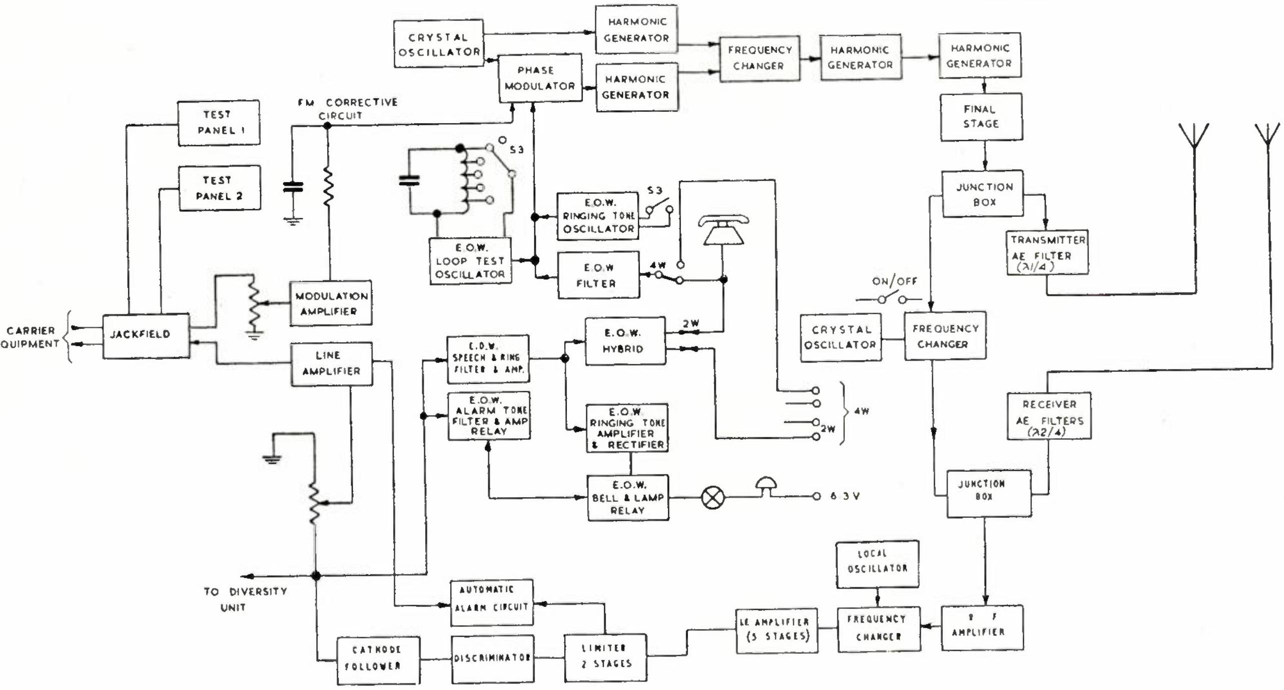


Fig. 9.—Terminal Equipment—Block Schematic.

system to Dandenong with a repeater at Korumburra. Six channels were origially held in reserve at Foster, but later on when the radio bearer was able to take a twelve-channel group these channels were cut into service. At Dandenong the 12 channels are group connected to a cable carrier system to the Melbourne trunk exchange. Transmitting and receiving amplifiers are not required at the radio terminals, as the radio equipment can be fully modulated with an input signal of —30 dbm, and an overall gain of 50 db is possible.

RADIO EQUIPMENT DETAILS

Terminal Equipment: This is housed in 7ft. cabinets, and the equipment at Mr. Oberon is shown in Fig. 8. Power supplies are placed at the foot of the cabinets and generally the path of the signal is downward in the receiver cabinet and upward in the transmitter cabinet. A block diagram of the terminal equipment is shown in Fig. 9.

Transmitter: The equipment is crystal controlled throughout and the modulator permits production of low distortion F.M. without the need for automatic frequency control. Two inputs are combined at the modulator, one from the traffic band 12-204 kc/s, the other from the order wire panel. The modulator is actually a phase modulator and F.M. is produced by passing the traffic signal through a simple R-C network producing a fall in response of 6 db/octave above 7 kc/s. Below 7 kc/s the modulation is partly phase and partly frequency but from 12 kc/s upward the modulation is nearly pure F.M. The modulator tube amplifies the signal from the oscillator but a feedback network between anode and grid causes a phase shift which changes in sympathy with the modulating signal applied to the grid. This phase deviation is kept very small to reduce distortion, and in order to bring the degree of modulation up, a chain of frequency multipliers follows. In the case of the 160 Mc/s transmitter the frequency generated is in the region of 4.5 Mc/s and after modulation the frequency is multiplied 9 times. A separate output from the oscillator is multiplied 8 times without modulation applied, and the two multiplied signals are combined in a mixer. The difference signal taken out is thus at the original crystal frequency but the frequency deviation is multiplied 9 times. From then on a chain of multipliers of increasing power multiply the signal 36 times and the final signal appears at a level of 20 watts approximately with a full deviation of 300 kc/s. The deviation produced by an input signal is controlled by a gain control in the line amplifier preceding the modulator. The output signal passes through an aerial filter to eliminate unwanted products and is sent to the aerial through a 70 ohm coaxial cable.

Receiver: The receiver is a superheterodyne and has a low noise "cascode" input stage. The signal from the aerial cable, after passing through an aerial filter, is applied to a transformer at the input stage whose ratio is arranged to match the cable impedance. After amplification, the signal is mixed with the locally generated signal from the crystal oscillator and then amplified considerably in the I.F. chain. The I.F. amplifier has a bandwidth of ± 0.5 Mc/s and a gain of approximately 60 db. Next the signal goes through 3 stages of limiting to remove any A.M. and is demodulated in a Foster-Seeley discriminator very carefully designed and adjusted for linearity. The I.F. amplifier gain is controlled by an attenuator between the 1st and 2nd I.F. stages; automatic gain control (A.G.C.) is not used and the gain control is set to give a gain convenient for the median received signal. The limiters ensure that an input signal ± 20 db from the median level varies by less than 1 db by the time it reaches the discriminator. The discriminator is followed by a cathode follower stage where the outputs to the order wire and the diversity switching unit are taken off. The traffic signal passes through a high pass filter and a gain control to the input of the line amplifier whose output is sent to line. The receiver has an alarm circuit which operates on either low signal, high noise or both. A sample of the limiter grid current (controlled by the input signal) and the D.C. output from a narrow band noise amplifier and detector centred on 250 kc/s (above the traffic band, hence controlled by noise) are combined through a manually controlled potentiometer. This potentiometer can be set to give a signal which will operate a trigger circuit at any desired ratio of the signal and noise inputs. The trigger circuit, operating on the desired signal-to-noise ratio will in turn operate a relay bringing in an alarm. This alarm indicates a possible distant transmitter failure, aerial failure, receiver fault or deep fading of the signal, which bring up the noise level.

Order Wire Facilities: Housed in the transmitter cabinet is the engineers order wire (E.O.W.) panel which provides all the facilities for communication between stations. The output of the receiver to the E.O.W. panel passes through a 300 c/s - 2 kc/s filter, then through an amplifier to the listen side of a 4-wire handset. The handset sends to the transmitter modulator through a transmit amplifier and filter. Provision for party line operation between exchange-terminal-repeater-terminal-exchange is arranged with a hybrid transformer in the panel which permits extension of the order wire by a 2-wire line. Ring tone is generated in the panel and is fed through the order wire transmit amplifier. Another tone can also be transmitted whose purpose is to loop a repeater back to the transmitting terminal for fault location tests. Separate control of tone levels and speech levels is made via manually adjusted semi-fixed controls. The receive amplifier is arranged to split off signals to two frequency selective amplifiers, one for the ring tone and the other for a repeater alarm tone. Received speech level and received ring and alarm tone levels are adjusted also by semi-fixed controls. Levels of speech and alarm tones are well below normal traffic channel line-up level.

Test Facilities: The receiver cabinet houses in-built test equipment in the form of two test panels. The first panel comprises a signal generator which can also be made to operate as a wavemeter. Two bands are covered, one in the range of the transmitter drive circuits, the other in the receiver I.F. range. This panel can be used to line up tuned circuits or detect the presence of a signal and is used in the standard line-up test to measure full deviation by the carrier zero method.

The other test panel houses a sensitive transmission measuring set (T.M.S.) capable of detecting levels down to —80 dbm. A 6.93 kc/s oscillator is built in also, and is used to carry out line-up adjustments and distortion tests. The T.M.S. can be used as a vacuum tube voltmeter to read the actual level of input to the transmitter or output from the receiver, or to check the output level from the 6.93 kc/s oscillator. It can be used to read noise level from the receiver, when it is preceded by a filter of bandwidth 10-100 kc/s. With the use of built-in band pass filters at 14 kc/s and 21 kc/s, it is used to measure the level of second and third harmonic distortion of the test tone.

Line up is effected by taking the output of the test tone oscillator at —30 dbm and applying it to the transmitter. At its particular frequency and at a level which will produce full deviation, the spectrum of the modulated wave has a zero component at carrier frequency. The gain control ahead of the modulator is adjusted until this zero appears, as measured by the other test panel. After reception, the modulating tone level is measured at the output to line and is adjusted by the gain control in the receiver line amplifier to give +20 dbm on full deviation. This overall system gain is 50 db and the transmitter frequency is deviated fully by a —30 dbm signal. If necessary channel line-up tones can be measured going in and out of the radio equipment.

Line up of a terminal can be carried out from one end only by looping portion of the transmitted signal back through to the receiver via a built-in frequency changer. Distortion in a terminal or excessive transmitter noise can also be measured using this loop.

The Repeater: The repeater is housed in two cabinets, north-south in one and south-north in the other. A block schematic circuit of the repeater equipment is shown in Fig. 10. The receivers are substantially the same as for the terminal but the traffic signal is not demodulated. Instead the signal is further amplified and limited and after passing through a high level mixer to which a high level locally generated oscillator signal is applied, the signal after further amplification is transmitted in the correct band at a level of 20 watts through aerial filters to the aerial. There is a discriminator however for the order-wire circuit which with its associated limiters is tapped off the main signal route. Modulation of the carrier by the E.O.W. handset takes place by phase modulating the frequency of the receiver local-oscillator. The engineers order wire panel, in most respects similar to that of the terminal has provision for selecting the path (north or south) over which communication is desired. A three position switch, normally paralleling both paths to the handset, if operated disconnects the unwanted modulator and de-modulator. This provision is necessary if one path happens to be noisy and communication in the other direction is desired. The order wire is extended to the local exchange by a four-wire circuit, the speaker circuit being parallelled to all paths, but the one diversity path only is used for listening. Failure of this path switches the circuit to the other path. A tuned amplifier in the order wire panel, selective to the tone (the loop tone) transmitted from one terminal (say the north) operates a relay which applies heater current to a frequency changer valve and oscillator placed between the south directed transmitter and receiver. Portion of the south-bound transmission is thereby looped back into the receiver and re-transmitted to the north terminal.

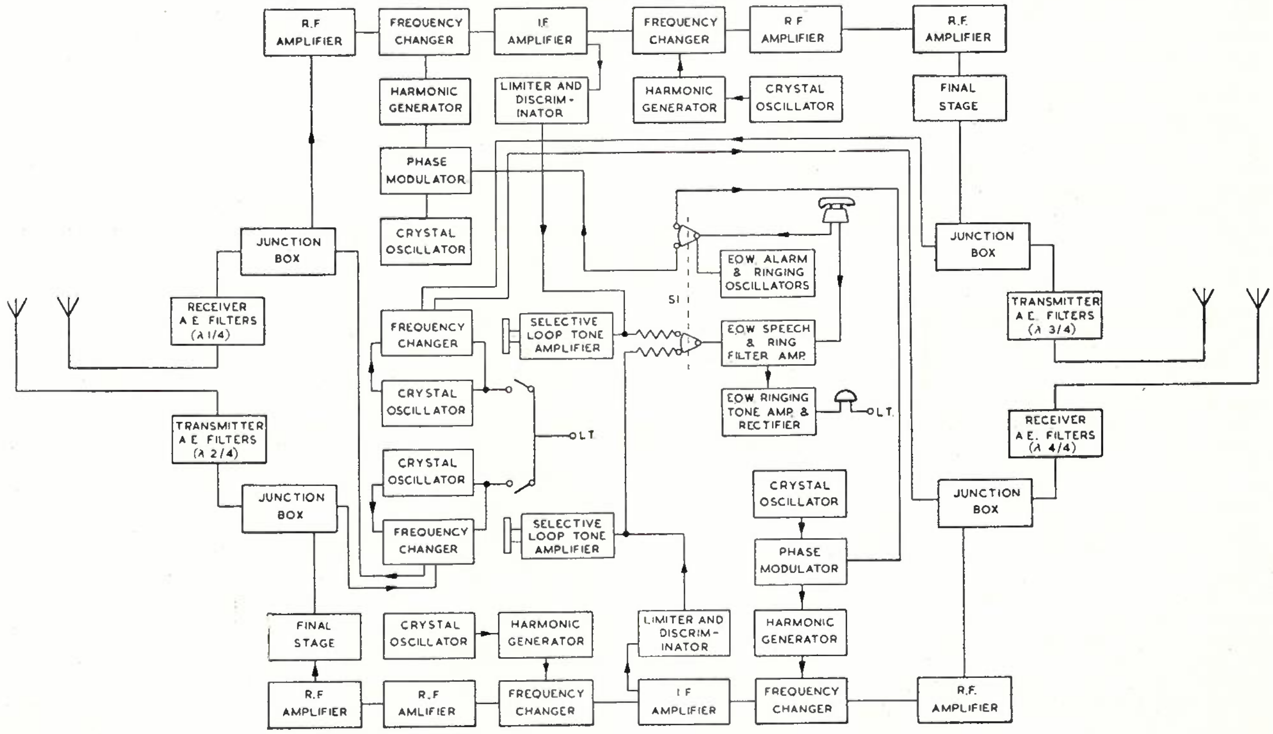


Fig. 10.—Repeater Equipment—Block Schematic.

This loop can be used for fault location tests. Action of one looping relay locks out the one at the opposite end of the repeater, preventing a loop around the internal circuits. Since in Tasmania a common transmitter is used for both diversity paths, two loop tones are used, a different one for each path.

Diversity Switching Unit: The diversity switching unit at each terminal is very simple in principle. From the discriminator of each receiver an output is taken to a narrow band amplifier, centred on 250 kc/s, above the traffic band. These two noise amplifiers are designed to operate over a wide range of input level with the assistance of an A.G.C. line and are adjusted to maintain equal gains over this range. The amplifiers feed into diode detectors arranged in such a way that an output D.C. signal is obtained proportional to the difference between the input signals (that is received noise level) to the two amplifiers. This D.C. signal is applied to a trigger circuit which in turn operates the diversity relay. Line up of the diversity unit is carried out by the following procedure. A signal generator is applied to one receiver and the inputs to the two noise amplifiers are parallelled to this receiver. The signal generator output is varied over the full range of received signals and the A.G.C. and the gain controls of one of the amplifiers are adjusted to apply zero resultant D.C. signal to the trigger circuit over this range of input signal. Symmetry and "backlash" of the trigger circuit are adjusted by semi-fixed controls, with the inputs to the noise amplifiers in the normal condition. In general "backlash" of ± 1 db can be achieved with an asymmetry of less than ½ db. The relay operated by the trigger circuit has changeover contacts which switch the traffic and E.O.W. lines to one receiver or the other. The selected path is indicated by lamps on the unit.

At the Tasmanian terminal where only one transmitter is used, the standby transmitter comes in automatically upon failure of the first. This is achieved by a reflectometer unit placed in the aerial cable of the main transmitter. The reflectometer monitors both forward power to the aerial and reflected power, and by combining suitable proportions of these two signals in the correct sense, a resultant is obtained to operate a relay through a magnetic amplifier. The unit operates on low forward power or too much reflected power caused by a faulty cable or aerial. The relay switches H.T. to the standby transmitter which has its own separate aerial system.

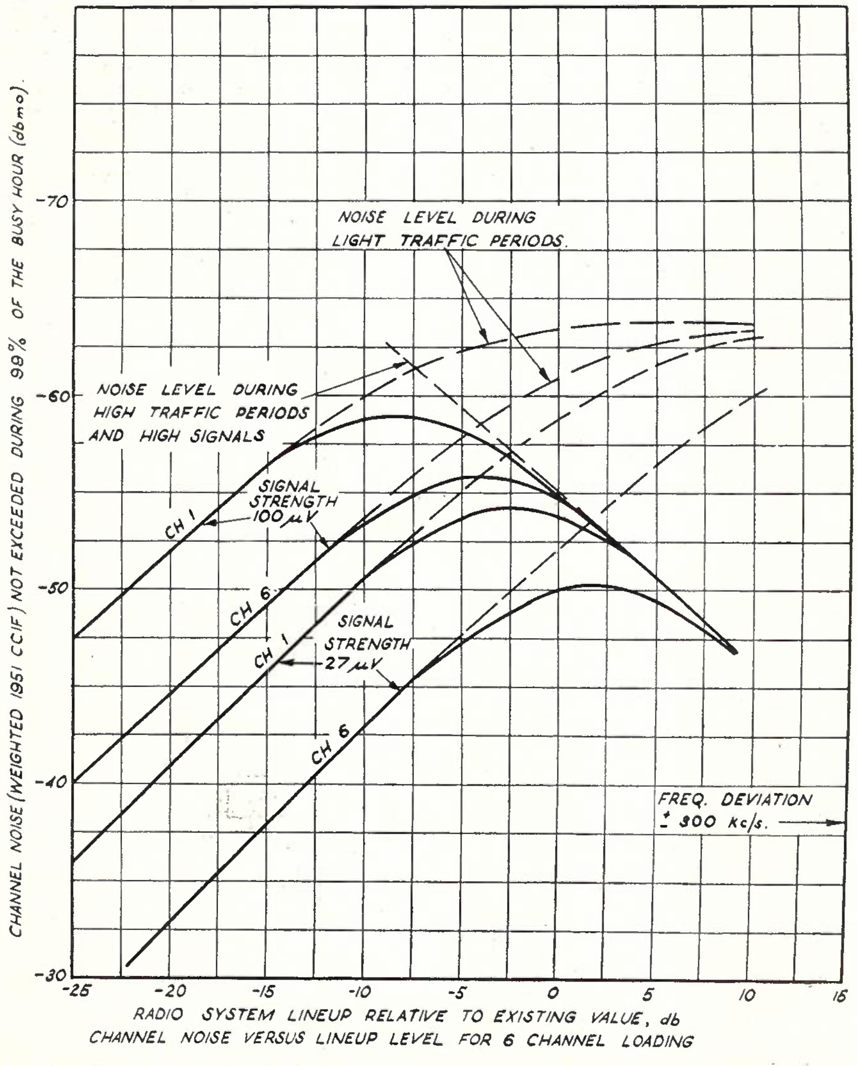


Fig. 11.—Channel Noise Levels shown as a Function of Signal Strength and Modulation Level.

EQUIPMENT PERFORMANCE TESTS

The radio equipment underwent rigorous performance tests in the laboratory and in the field as a result of which some improvements were made. The frequency response of the system was quite satisfactory for 6 channel operation but a fall-off in the response above 150 kc/s indicates that improvements or equalisation may be necessary if more than 24 channels are to be carried. The power output of the transmitters was generally below the 20 watts specified and when the aerial filter loss is taken into account the power fed to the aerial cable is about 14 watts for the 80 Mc/s transmitters and 10 watts for the 160 Mc/s equipment. Receiver noise figure was quite satisfactory, being about 7 db for both 80 Mc/s and 160 Mc/s receivers.

Distortion as measured on the test panel (7 kc/s tone) showed figures slightly worse than the manufacturer specified. However, these figures are not a good guide as the test tone is outside the traffic band and moreover distortion in one place may be cancelled out by distorion of opposite phase in another when single tone tests are used. A more comprehensive series of distortion tests was carried out, using noise generators simulating a multi-channel traffic signal. This noise may be generated over a wide band simulating 24 or 48 channel working or may be generated by separate noise generators applied to each channel for 6 and 12 channel operation. Both these methods were used. Statistical data has been obtained (Ref. 3) indicating the total speech and signalling tone power transmitted in a multichannel speech circuit under 99% busy hour conditions. A thermal noise signal of the same power over the same bandwidth can be used to simulate the traffic signal. If portion of the band is stopped and the noise intermodulated into that portion is measured after passage through the system, we have a very good indication of the intermodulation distortion present in the system. The results of these tests are graphed in Fig. 11 for a range of line-up levels. Thermal noise from the radio receiver is shown also and this is dependent on the received signal level. The tests were performed not only to measure the intermodulation performance, which could indicate the traffic carrying capacity of the system, but also to allow the determination of an optimum line-up level for the number of channels used. This was stated earlier to be 12 db below maximum frequency deviation but there is an optimum figure where the intermodulation noise level exceeded for only 1% of the busy hour equals the receiver noise exceeded for only 1% of the time. This optimum is given when the intermodulation noise curve crosses the 1% receiver noise curve. The 1% receiver noise level can be found only from long term propagation measurements, which actually were carried out after the link went into service.

The Yagi aerials fell short of the specified performance. The 160 Mc/s Yagi arrays were measured to have a gain of only 12.6 db instead of 17. This would cause the received signal to be lower than those expected over the 160 Mc/s paths and was due to individual Yagis being stacked too close together. It was found that to achieve maximum gain the Yagi aerials should be at least 1¼ wavelengths apart as against the original of much less than 1 wavelength. Other troubles were also experienced; water penetrated transformers in the cable harness feeding the aerials and wind vibration caused elements of the aerials to fatigue and break and caused open circuits inside the transformers attached to the driving dipole. The aerial impedance created too high a standing wave ratio on the coaxial cable, giving rise to serious intermodulation caused by phase distortion, and corrective matching adjustments had to be carried out in the field. After a long period of field work on the towers in wintry weather, the minor problems were overcome but the major one of low gain remained because of doubts as to whether the strength of the towers would permit larger arrays of the same design to be used.

PATH PERFORMANCE

The equipment was put into service in November, 1955, and during the first twelve months of operation continuous records of received signal level were taken on both paths at Mt. Oberon and on the south path at Flinders Island. At the same time noise records were taken. The noise level in channel 8 (40-44 kc/s) was monitored by a bridging filter and amplifier applied to the line, the amplifier output being rectified and applied to a recorder. Action of the diversity switch was also monitored simultaneously. Analysis of the records is not quite complete but the 80 Mc/s north path records show that the signal level at the receiver exceeded for 99% of the time is 20 μV as shown by Fig. 12. This is better than expected and corresponds to a signal/thermal noise ratio of 52 db in channel 6. The 160 Mc/s performance is well below this figure, due to smaller than expected aerial gains and lower transmitted power. These factors do not account for all the difference however, and it is thought that ground reflections producing a multipath signal have caused the actual gain of the rhombic aerial at Flinders Island and possibly the Yagi aerial gain at Mt. Oberon to be less than that measured under plane wave conditions. Rough height-gain measurements taken at both sites have proved the presence of a field pattern which changes with the propagation conditions.

Under these conditions where one path is so much (about 12 db) below the other, diversity working produces little benefit (only 2 db) and the system performance is substantially that of the 80 Mc/s path. Yagi arrays of a new and improved design are being developed in the Research Laboratories and it is expected that these and lower loss aerial cables will bring the 160 Mc/s path somewhere close to parity with the other.

Another cause of noise noticed since the system went into service is so-called precipitation static. This static occurs sometimes during thundery weather and severe storms and appears to be due to a silent corona discharge from the aerials or some neighbouring point, or the actual bombardment of the aerial by charged rain or hail particles. The noise is quite severe and under certain conditions can make a path unworkable. However, this noise occurs infrequently. Investigations have commenced into the phenomenon and counter-measures are being tested, but it is too early yet for any worthwhile conclusions to be made.

EXTENSIONS

In December, 1956, high power amplifiers were added to the transmitters on the north path. The power output was increased to 200 watts and as the aerial filters are now on the drive side of the amplifier the power gain is at least 12 db. The extra power enables six more channels to be applied and twelve channels are now operating with intermodulation distortion being the prime limiting factor in their performance. The amplifier for the 80 Mc/s path was supplied by the Marconi Co. and the 160 Mc/s power amplifier was built in the Research Laboratories. Both amplifiers use the tubes Type QB3-300 and the limitation on power output is mainly due to insufficient driving power. The tubes are arranged as push-pull Class C amplifiers, the 80 Mc/s circuit using lumped coils and capacitors for tuning, and the 160 Mc/s amplifier using lecher lines. Efficiency is about 50% for the 160 Mc/s amplifier and 60% for the 80 Mc/s amplifier. Full protection and automatic starting facilities have been incorporated in both types of transmitters.

At the present moment the Department is actively engaged in finding out the ultimate capacity of this system. New aerials are being built and better feeder cables will be installed. The records obtained over twelve months of operation on low power are under analysis,

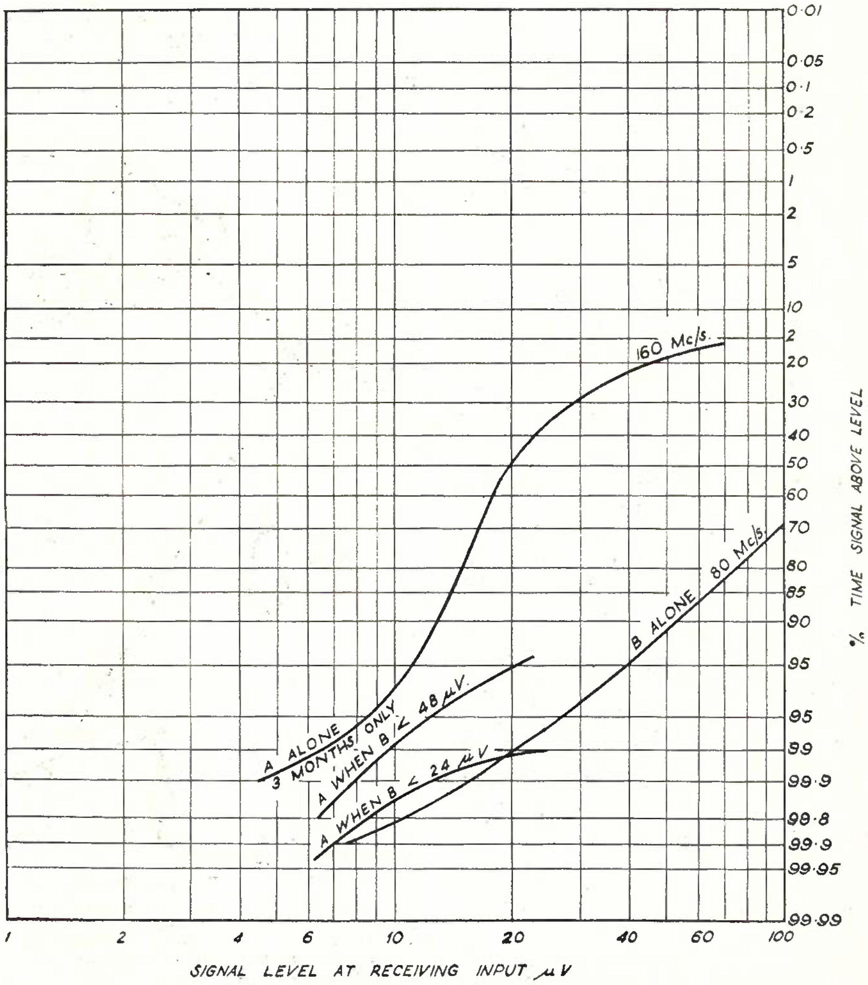


Fig. 12.—Received Signal Analysis, showing Probability that a Particular Level will be Exceeded —Two Diversity Paths.

the results of which will now be modified by the improvement in radiated power brought about by the power amplifiers and the new aerials and cables. Improvements in linearity and frequency response may be necessary, and with this possibility in mind the intermodulation performance of the system using the power amplifiers will shortly be measured in the field by the noise intermodulation techniques described earlier. The results of the signal strength analysis and the intermodulation tests will allow an accurate prediction of performance for any number of channels to be made. It is noteworthy that when the Bass Strait cable failed, the system was connected in tandem with a developmental 900 Mc/s radio system between Melbourne and Mt. Oberon, and carried 24 channels, giving very good service over a three-week period. If the necessary improvements can be brought about over the 160 Mc/s path and the record analysis shows that a reasonable degree of independent fading over the diversity paths occurs, then it is possible that even more than 24 channels may be carried over a single diversity system. If this can be brought about and if the link can be duplicated, the problem of communications across Bass Strait will be eased greatly for some years to come.

REFERENCES

1. Projected New Radio-Telephone Link from the Mainland to Tasmania—Propagation Measurements; O. M. Moriarty, Telecommunication Journal of Australia, October, 1949.

2. The Calculated Performance of the Proposed Radio-Telephone Link between Wilson's Promontory and Tasmania via Flinders Island; N. S. Feltscheer, P.M.G. Research Laboratory Report No. 3807.

3. On the Testing Level to be used in Noise Intermodulation Tests on Multichannel Telephone Systems; D. A. Gray and A. W. Thies, P.M.G. Research Laboratory Report No. 4054.

4. Intermodulation Measurements on the Victoria-Tasmania V.H.F. Radio Telephone System via Flinders Island; M. W. Farmer, P.M.G. Research Laboratory Report No. 4255.

BASS STRAIT TELEPHONE CABLES, 1957 REPAIR: FAULT CONDITIONS AND TESTING.

S. DOSSING, M.Sc.E.E., M.I.F.[*]

INTRODUCTION

The insulation resistance of both the Northern and the Southern Bass Strait Cables had been deteriorating for some years, and a complete failure of the Southern Cable occurred on Sunday, 17th March, 1957. This article describes the development of the fault conditions on the two cables, this development being of such a nature that a location of a fault at sea on the Southern Cable could be made and the necessary repair operations organised before the actual failure of that cable occurred. A description is also given of the special fault location methods employed, the three shore-end repairs, the provision of emergency and order-wire circuits needed during the period the Southern Cable was out of service, the proof testing of the cables and the restoration of service.

SYMPTOMS OF THE 1957 FAULT CONDITIONS

The two cables, namely the Northern Cable between Apollo Bay (Vic.) and King Island, and the Southern Cable between King Island and Stanley (Tas.), were laid in 1935.

The cables are of the coaxial type, and each is approximately 80 Nauts long (1 Naut = 1 Nautical Mile = 1 Geographical Mile = approximately 1.15 Mile), and whilst it had not been necessary to carry out any repairs on the Northern Cable, the Southern Cable had failed three times, namely in 1938, 1940 and 1943. In each case the failure had occurred practically without any warning and the cable had failed completely within a matter of hours, or at the best within a few days. All these failures were, when repair was undertaken, found to be due to abrasion of the cable by the rocks of Sea Elephant Shoal (see Fig. 1), and by abrasion of the cable against itself (where loops or kinks of the cable had been formed due to excess slack).

The southern cable is laid across the Shoal over a distance of approximately 4-8 Nauts from King Island, and the three faults were all located in this section of the cable. Other abrasions which

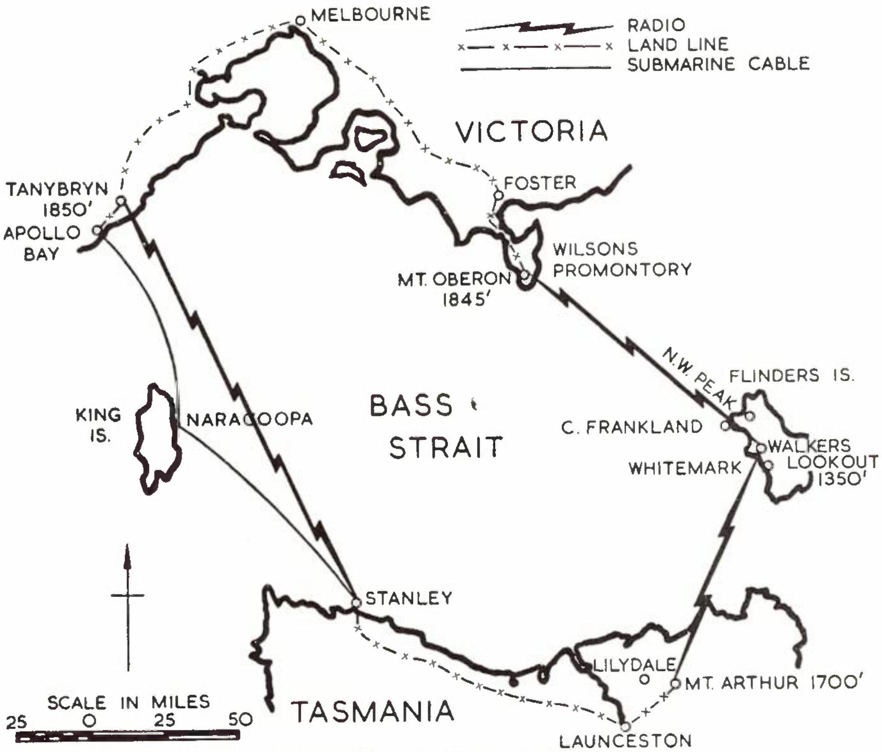


Fig. 1.—Victoria-Tasmania Communication Systems.

The Southern Submarine Cable crosses the Sea Elephant Shoal over a distance of 4 to 8 Nauts from Naracoopa. The communication channels normally provided are:—

Vic.-Tas.: Submarine Cables: 15 Telephone and 1 reversible Programme Channel. Tanybryn-Stanley, Radio: 2 x 6 Telephone Channels. Mt. Oberon-Mt. Arthur, Radio: 12 Telephone Channels.

Vic.-King Island: Submarine Cable: 1 Telephone Channel.

Tas.-King Island: Submarine Cable: 1 Telephone Channel.

---

[*] Mr. Dossing is a Divisional Engineer in the Long Line Equipment Section, Central Administration.

had occurred in this section had necessitated the replacement of long lengths of cable; thus in 1943 a length of about 4 Nauts had been replaced.

Due to this abrasion it had been proposed at one stage to remove the King Island repeater station from Naracoopa to Sea Elephant River enabling the cable course to be diverted around the northern end of the Shoal. Such a diversion would undoubtedly have resulted in reduced fault-liability of the cable, but would also have resulted in an increase in the length of the Southern Cable, which would have adversely affected a proposal for an increase of the channel capacity of the cable. For this and other reasons the cable was not diverted, but the lengths of cable purchased for the diversion project were useful for the 1957 repairs.

The insulation resistance of each cable, in good order, is of the order of 500-2,000 Mohms. Late in December, 1945, the insulation resistance of the Southern Cable dropped suddenly to a low value. The actual value is not known, but the probable order is 40,000-100,000 ohms. As distinct from previous occasions no further immediate deterioration occurred. It was well known that the application of a DC-Voltage to a submarine cable normally results in an increase of insulation resistance due to "polarisation" effects. It was consequently decided to apply a "polarising" potential to the centre conductor in order to restore the insulation resistance, as far as possible, to the original value.

The polarising potential, applied on the 1st January, 1946, was obtained from a 22.5 Volts battery applied to the centre conductor through a resistor of 2 Mohms, the centre conductor being DC—separated by means of capacitors from the equipment at the cable stations. The effect of the polarising voltage was most satisfactory, resulting in the insulation resistance being increased to about 100 Mohms, and it was maintained in the 5-100 Mohms range for 5½ years, when a sudden drop to the range 1-10 Mohms occurred. This range was maintained for 5 years (up to November, 1956), and a 0.25-5 Mohms range was maintained until the 14th January, 1957, when a further violent decrease occurred.

As consequence of this, the polarising current was increased to 45V through 100 kohms. This did produce an improvement, but at irregular intervals very low insulation resistance, that is of the order of a few hundred ohms, occurred.

The Northern Cable commenced to show signs of deterioration in August, 1949, but a really serious drop in insulation resistance did not occur until late in June 1950, when a decrease from the order of 800 Mohms to the range 0.1-10 Mohms occurred. As a consequence a polarising voltage was applied on the 2nd July, 1950, resulting in the insulation resistance being maintained in the 5-170 Mohms range up to August 1954 and in the 0.5-10 Mohms range from this date until the repair in April 1957.

For the purpose of maintaining a continuous watch on the condition of the cables, the polarising currents were recorded by D.C. recorders during most of the time the low-insulation conditions prevailed. The insulation improving effect of the polarising potential was confirmed by the unmistakable decrease of insulation resistance which occurred if the polarising potential was disconnected.

THE FAULT LOCATION PROBLEM

The exact nature of the mechanism by which the polarising current helps to improve the insulation resistance is not known, nor was the nature of the fault(s) known.

In order to obtain a location of the fault(s) it is necessary that the insulation resistance should be low, the actual upper limit being dependent on the method used, as discussed later. In view of the uncertainties about the mechanism of the polarising action and the nature of the fault(s), it was considered that a removal or reversal of the polarising current for a period of time sufficient to cause the insulation resistance of the cable to drop sufficiently to permit a fault location to be made, might bring about such conditions that the insulation resistance could not be restored by a re-application of the polarising potential. If this did happen, it would be nearly certain that the cable would fail completely, and it would not be possible to restore service until after a repair had been made. If the fault was at sea, and this was considered the most likely case in view of previous experience, a cable ship would be needed for the repair. The cable ship to be used is not normally staffed, and the time taken to obtain a crew, make the ship ready for departure and make the voyage from New Zealand (Wellington being the home port) to Bass Strait was estimated at not less than three weeks. This would mean that at least four weeks would elapse before the cable and the much needed traffic channels could be restored. As an alternative the cable ship could be obtained and be ready for repair when the fault location was attempted. The cost of chartering the ship and associated expenditure would be in the order of £1,000 a day, and it was necessary to consider this expenditure in the light of the possibility that the services of the ship would not be required if there were no faults at sea, and that a fault location might not be possible if the insulation resistance could not be sufficiently reduced.

It was consequently most desirable to be able to establish whether or not a fault existed at sea prior to a complete failure and without removal of the polarising voltage.

Due to the reasonably high insulation resistance values obtaining up to mid-January 1957, there was no hope of locating the fault(s) without removal or reversal of the polarising voltage and resort had to be made to "intelligent guessing". It was generally considered that the fault on the Southern Cable would be in the section crossing the Sea Elephant Shoal, and this could also be the case with the Northern cable which skirts the shoal. It was also known that both the Southern and Northern Cables had been exposed to the weather for some time on the beach at King Island, due to removal of sand by the sea. This also applied to the Northern Cable at Apollo Bay where it had been exposed due to a change of the course of Wild Dog Creek. These exposures could conceivably have resulted in a deterioration of the insulation, but the likelihood of this was considered small. Faulty cable terminations were considered as a third possibility, and as a result both ends of the Southern Cable and the southern end of the Northern Cable were reterminated in 1950, but unfortunately without any improvement being obtained.

With the violent decrease of the insulation resistance of the Southern Cable, in the middle of January 1957, a location of the fault(s) became a possibility. A number of different methods were considered for this purpose, and these are discussed in some detail below.

METHODS OF FAULT LOCATION

There are many well established methods of locating faults in lines and cables, and Ref. 1 gives a reasonably detailed description of most of the known methods. Due to the long length of each cable, approximately 80 Nauts, and the fact that one single-conductor cable only is available in each of the two sections, most of these methods cannot be applied. The applicable methods may be classified into four types: Intermodulation Tests, DC Tests, Impedance Tests and Pulse Echo Tests.

The possible application of each of these four types of test was considered for the purpose of initial fault location, that is in the presence of the polarising voltage, as well as for fault location purposes during repair operations when the polarising voltage could be removed. Each of the four types of test have certain advantages and disadvantages. These are discussed in some detail below, together with certain refinements in testing techniques which may be used to reduce or eliminate some of the disadvantages.

Intermodulation Tests

There are no known cases of fault location based on intermodulation tests. However sometimes during conditions of low insulation resistance, say 3-10 kohms, excess interchannel intermodulation interference occurred on the channels of the carrier equipment operated over the cables. From an analysis of this interference it was possible to deduce that an "intermodulating element" existed on the southern cable at or within a reasonable distance from King Island. However in order to obtain an actual location, it would be necessary to develop and build quite a complicated test set-up, and the method was discarded for this reason and since it did not appear to possess any significant advantages over the other methods. An intermodulation test could readily be applied in the presence of the polarising voltage.

DC Tests

In the early days of very long submarine telegraph cables, such as for instance the Transatlantic cables, the one and only way to locate a fault was by means of DC tests. If a return cable is available so that a loop may be formed, a loop test such as a Murray or Varley test may be made with a reasonably accurate result. If a loop cannot be established a reasonably accurate location becomes difficult, unless the fault is very severe, due to the interfering effects of earth currents and due to the fact that the fault resistance depends on the measuring current and generally increases with the length of time the current is applied (compare the action of the polarising current described previously). A large number of different refinements aimed at reducing the inaccuracies due to these variables have been used (Mance's Test, Cann's Test, Blavier's Test, Lloyd's Test, Black's Test, the Overlap Test, etc.), but there appeared to be little doubt that, for cables of 80 Nauts length as is the case with the Bass Strait cables, the DC tests would be inferior to the other methods for fault location purposes, wherever the fault(s) might be situated and whatever type of fault.

DC tests cannot be applied without interference with the polarising voltage. They are furthermore unsuitable if there are two or more faults of reasonably the same magnitude and at different places in the cable.

DC tests were therefore not considered as a desirable method. They were employed for check purposes during the repair, but with poor results, thus confirming their inadequacy. The one outstanding feature of a special DC test, namely the DC insulation test, is that it will reveal whether or not an insulation fault exists.

Impedance Tests

The impedance test is one of the best known methods of fault location. In its simplest form this test is carried out as follows:

The far-end of the line is terminated in an impedance as similar as possible to the characteristic impedance of the line, and an impedance versus frequency characteristic is taken (at the near-end). If there is a severe enough fault not too far away, this characteristic will display peaks and troughs at regular frequency intervals. The distance to the fault is then usually determined by the formula:
Distance to Fault

$$(1) = \frac{\text{Velocity of Propagation}}{2\ (f_1 - f_2)}$$

where f_1 and f_2 are the frequencies associated with two successive impedance peaks or troughs. However, Reference 2 shows that the more accurate formula

$$\text{is } l = \frac{V_1 V_2}{2\ (V_1 f_2 - V_2 f_1)}$$

where V_1 and V_2 are the velocities of propagation at the frequencies f_1 and f_2 respectively. For this test the actual impedance may be represented by different quantities such as magnitude of impedance or the resistive or the reactive (including sign) component of the parallel or series representation of the impedance. In this connection it should be mentioned that a representation in terms of return loss is not well suited.

The impedance test in the simple form just described is suitable only for location of rather severe faults reasonably close to the testing point, since a less severe fault at a greater distance would not cause sufficiently distinct peaks and troughs to enable them to be distinguished from the peaks and troughs always present due to "normal" irregularities in the cable. If however the impedance characteristic under the fault condition is "subtracted" from the characteristic applicable to the fault free cable (both characteristics being measured with precision testing instruments, preferably the same instruments in both cases) then the peaks and troughs of this difference - impedance characteristic should be representative of the fault. The distance to the fault may then be determined using the formula mentioned above. Employing this technique, it is possible to obtain a location on a fault much further removed and of much higher insulation resistance than with the simple method.

The formula given for the distance to the fault is not exact if the fault is so remote that the peaks and troughs at the low-frequency end (say 0-10 kc/s) only are discernible. This is mainly due to the fact that it is assumed, in the derivation of the formula, that the angle of the cable impedance is zero, and this assumption is incorrect at low frequencies. There are also other factors which may cause inaccurate locations, but the occurrence of these factors should be relatively rare and they will therefore not be discussed here.

The impedance method of fault location is obviously not suitable if two or more faults exist and are of such magnitude and location as to cause peaks and troughs of the same order of magnitude.

The simple impedance test may be applied to "swinging" faults, provided the fault is severe enough to cause substantial peaks and troughs, since it is possible with a quick-responding impedance indicator, such as a Transmission Measuring Set bridged across the output of an oscillator feeding into the cable, to "tune in" to the peaks and troughs of the modulus of the impedance in the same manner as a wireless receiver may be tuned in to a strongly fading radio station. The difference - impedance method however is difficult to apply to a swinging fault, since the precision testing instruments used require so much time to operate that it is difficult, if not impossible, to obtain readings at each frequency at the same point of the fault-cycle.

The simple impedance test can be applied in the presence of the polarising current, since the impedance may be measured through a DC blocking capacitor. The same possibility exists if the method of precision measurement of the difference-characteristic is employed, but the practical difficulties encountered in order to maintain a high degree of precision under this condition appear to be so great that no attempt to apply this test in the presence of the polarising voltage was made.

A fault location by means of the simple impedance method may be made in the course of a few minutes. A precision measurement of the impedance characteristics, using the testing instruments available at the stations for this purpose, takes of the order of six hours which is equivalent to an expenditure of approximately £350 if the cable ship is held up waiting for the result of the location. In order to permit the difference-impedance method to be used for fault location purposes, a precision measurement of the impedance characteristic is always made after each repair. In this connection it should be mentioned that this method can usually be used for the location of the first fault only, since the repair of this fault will result in a change of the cable impedance, and there is therefore no reference characteristic with which the impedance-characteristics for the second and subsequent faults may be compared.

No complete analysis of the possible maximum insulation-resistance which allows a fault location to be obtained has been made, but there is little doubt that the pulse-test method described below is superior in this respect even to the difference-characteristic method.

Pulse Echo Tests

This method, which is based on the same principles as echo-sounders and radar instruments, is one of the newcomers in the field of fault location, see Refs. 1-6. A number of pulse echo test sets have been in use for some time for location of faults on open-wire lines. Some of the sets had occasionally been used on balanced pair cables, but with limited success due to the high attenuation per mile of the cable pairs. The pulse test method, if applicable to the Bass Strait Cables, would however possess four very important advantages over the other methods, namely:

(i) it would not interfere with the polarising voltage (by applying the test signal through a DC blocking capacitor),

(ii) fault location would be practically instantaneous and if a number of fault locations had to be made, this would enable the maximum use to be made of the cable ship,

(iii) any number of faults (out to and including the first short or open-circuit) would be displayed simultaneously, again enabling the maximum use of the cable ship to be made,

(iv) it would be particularly suitable for location of "swinging" faults (the 1938, 1940 and 1943 faults had all been "swinging" up to the moment of complete failure).

The fact that this test method could be used readily in the presence of the polarising voltage was most important since it opened up the prospect of determining, before actual failure of the cable, whether a fault existed at sea, and as outlined earlier this had to be known in order that the most economic planning of the repair operations could be made.

None of the pulse echo test sets available in the Department were directly suitable for location purposes on the Bass Strait Cables, but an examination of them revealed that the Alan H. Reid Type F.L.O.S. locator, if modified and used with auxiliary apparatus which had to be developed, should be suitable. A further consideration in the choice of the type of locator to be used, was that at least four locators had to be available for the project during the repair operations.

Further details of the pulse echo method are given in Appendix I, together with a description of the circuit used for location purposes on the Bass Strait Cables. Many of the points discussed in the Appendix are of interest for the general application of pulse echo test sets. The development of the circuit was greatly facilitated by the existence of two sections of cable, one 12 and one 17 Nauts in length, in tanks at Port Melbourne. By joining these together a 29 Nauts length of cable was obtained and various "artificial" faults, introduced at the junction of the two cables, could be observed on the Pulse Echo Test Set.

PRELIMINARY FAULT LOCATION

The discussion of the pulse echo test method given in Appendix I shows that it is possible under favourable circumstances to locate insulation faults of as much as 30 kohms. Thus when the insulation resistance of the Southern Cable dropped in the middle of January, 1957, the possibility of a location came within reach. Early in February large variations in insulation resistance occurred due to "natural" causes, thus favouring a pulse echo location. Such a location was carried out during the early hours of the 10th February, when the trace was watched under conditions of 100 kohms insulation resistance, and a sudden deterioration to 3 kohms occurred. Simultaneously with this deterioration an echo from a point 4.8 Nauts from the King Island Repeater appeared, and there was thus no doubt that a fault existed at that point.

It had thus been established that at least one fault existed at sea, and consequently a cable ship was required for the repair. This finding enabled the planning of the most effective arrangements for the repair to be made, and since it was apparent that the complete failure of the cable might not be far off, a decision was made to proceed with the repair.

EMERGENCY CHANNELS AND ORDER-WIRE FACILITIES

As soon as the decision had been made to proceed with the repair, arrangements were made to provide adequate emergency channels as a substitute for the channels which would be out of service during the cable repairs. The normal channels available are indicated on Fig. 1.

Improvements were being made at the time to all the radio systems, and this work was speeded up to ensure that more reliable and satisfactory channels were available before the cable was taken for repair. An additional 12 channels were provided over the Mount Oberon-Mount Arthur radio link by the installation of higher powered transmitting amplifiers. These channels were extended from Mt. Oberon to Melbourne on a micro-wave radio link which was in the process of being installed for experimental purposes. In order to make the necessary carrier telephone equipment available for the additional Mount Oberon-Mount Arthur channels, recoveries of equipment from other existing installations were necessary, and in some cases special arrangements were made with contractors for top priority deliveries. Thanks to the willing co-operation of the contractors concerned, and to the enthusiasm of the Department's own staff, the work was so well advanced that, when the Southern Cable failed in the morning of Sunday, 17th March, the emergency arrangements could be practically completed early on the following day. The Engineering Division can be duly proud of the large amount of administrative, design, construction and other work performed in the short time available.

The provision of the 12 extra Victoria-Tasmania radio channels compensated to a large extent for the loss of the 15 cable channels. It was not practically possible to provide an emergency channel to compensate for the loss of the King Island-Tasmania channel, and the traffic carried normally by this channel was therefore routed via Melbourne, thus putting an additional load on an already heavily loaded channel. A further heavy load on this channel was to be expected, due to the stationing of two fault-testing engineers on the island during the repair. This additional load was, however, considered too much, and a simple carrier terminal to work in with the normal carrier equipment at Apollo Bay was therefore made and installed at King Island to carry this additional traffic. Communications between the engineers at King Island and the ship were provided by VHF "taxi" type radio transmitters and receivers. The island thus became the centre of the repair communications, and at times the emergency channel was in continuous use for many hours on end. It is now evident that the provision of this channel was a most important detail without which the repairs could not have been performed so smoothly.

REPAIR OPERATIONS

Prior to the arrival of the ship on the 27th March, all the fault location methods described, except the intermodulation method, had been applied to confirm the location of the fault, which had been located by the pulse-echo method on the 10th February at a distance of 4.8 Nauts from the King Island repeater station. During the confirmation tests the fault was severely "on" but "swinging" with a period of 20-30 sec. The results obtained may be summarized as follows:—

DC Tests: These gave inconsistent results, varying from 2 Nauts "inland" to 8 Nauts out. Minimum fault resistance was in order of 50 ohms.

AC Tests: Impedance tests from King Island gave the distance to the fault as 4.63 Nauts, whereas impedance tests from Stanley gave a distance of 74 ± 2 Nauts from Stanley; that is 8 ± 2 Nauts from King Island. The reasons for this error in location have been mentioned earlier.

Pulse Echo Tests: When the swinging fault exhibited the best transmission properties, the far end of the cable could be seen readily. After careful adjustment of the pulse echo test sets for minimum zero-error, the length of cable corresponding to one marker-unit was established by counting the number of units for the full length of cable. Due to slight inaccuracies in the marker-sections of the sets, a figure must be established for each set. An average figure is 2.71 Nauts/marker unit. Tests from both King Island and Stanley placed the fault at 4.69 Nauts from King Island. The pulse echo trace as copied by the transparent mirror method is shown in Fig. 2a.

The location of the fault, as determined by the cable ship during the picking-up operation was 4.65 Nauts. It will thus be seen that the DC tests were not very satisfactory. The same applies to the long-distance impedance test from Stanley, whereas the short-distance impedance test from King Island gave an accurate location. Both the short-distance and the long-distance pulse tests gave accurate results.

The initial repair operation carried out by the cable ship involved picking-up the cable from a distance of approximately 3 Nauts to 8 Nauts from King Island. In doing so the "fault" at 4.65 Nauts and other sections of badly damaged cable were picked up. However, the insulation resistance of the remaining King Island and Tasmanian Sections was found to be in the order of 100 kohms only. In the hope of achieving an improvement, the cable terminations were cut off at both stations, but no improvements resulted. Due to the high value of the fault resistance a location of the faults by any of the known tests was not possible. In an attempt to locate the fault(s) in the King Island section of the cable, the ship commenced picking-up this section whilst the insulation resistance and the pulse echo trace were continuously watched. No changes were however apparent, and the ship had to stop due to lack of sufficient depth of water at 0.3 Nauts from King Island. The cable was then cut at this point and it was found that the low insulation resistance was in the remaining 0.3 Nauts sections.

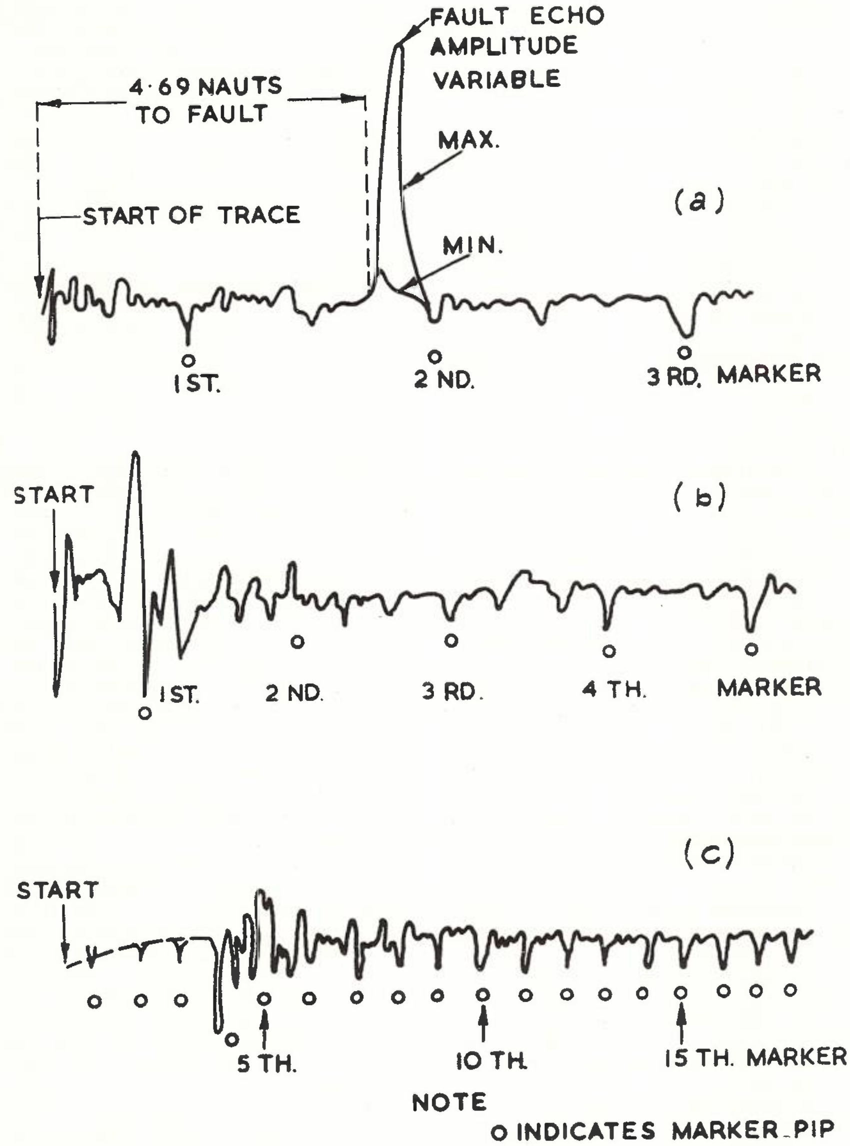


Fig. 2.—Pulse Echo Traces (Southern Cable):

(a) Trace at King Island showing echo from fault at 4.69 Nauts on 22/3/57.
(b) Trace at King Island after repair using a range setting of approximately 15 Nauts.
(c) As (b), but using a range of approximately 45 Nauts, and higher receive gain. The trace has not been shown in the 0-8 Nauts range, since this range is covered under (b).

At this juncture the ship left for Melbourne to unload and load cable for the repairs. At least three faults, that is one or more faults in each of the two remaining sections of the Southern Cable and one or more faults in the Northern Cable were as yet unlocated. The speedy location of these faults was of course of great importance for the proper planning of the ship's movements. Consequently, this task was commenced immediately upon the departure of the ship. The insulation resistance of the 0.3 Nauts section at King Island was just over 100,000 ohms, and it was attempted to "break-down" the fault by the application of 500 volts DC with regular changes of polarity. In this manner the insulation resistance was reduced to about 40,000 ohms, but this was still too much for a location to be carried out. It was consequently decided to locate the fault by sectionalising the cable. The cable had originally been laid with "slack" just above the high-water line, and in order to facilitate possible resplicing, the first cut was made at this point. After several unsuccessful attempts to find the cable by digging, a cable tracer was improvised from available instruments and components, and the cable was duly located and cut. When tested the fault was found to be between the cut and the repeater station (150 yards). An attempt could now be made to locate the fault by applying Varley and Murray DC tests to a loop consisting of the centre conductor and a return conductor established by means of jumper-wire, but the attempt was not successful. A further cut was then made about 30 yards away from the station, and when the fault was proved between this cut and the station, yet another cut was made approximately 4 yards from the station end of the cable.

Tests revealed that the fault was in this 4 yard length of cable. Although the cable appeared in good condition when inspected from outside, further subdivision revealed that the paragutta insulation had deteriorated, probably due to ingress of moisture and air through the cable termination which did not provide a hermetic seal. Investigations have since been made to ascertain the exact cause of the deterioration and to find a means of preventing similar future deteriorations. These investigations will form the subject of an article in a future issue of the Journal.

The experience thus gained at King Island led to a decision to cut the Stanley section of the cable also at 4 yards from the station end. Consequent tests and examinations proved the fault to be in the 4 yard length, and that it was of the same nature as the fault in the 4 yard length at King Island. Sufficient slack cable was available at Stanley to make up for the loss of the faulty 4 yard length. The 0.3 Nauts length of good cable remaining at King Island was so short that it was decided to discard it, and the cable ship operation required to complete the repair of the Southern cable was thus the laying of approximately 8 Nauts of new cable from the King Island repeater station to the buoyed-off end of the Stanley section of the cable.

As mentioned earlier, it had been decided that fault location on the Northern cable should not be commenced until the repair of the Southern Cable had been completed. It did not seem unlikely however, that the insulation at the cable ends would have deteriorated in the same manner as at the ends of the Southern Cable. Investigations were therefore commenced to determine the amount of available "slack" cable at both ends and since sufficient slack was available, work was commenced to facilitate the speedy cutting of the cable at points 4 yards from the ends at such time as the fault location was to proceed. This necessitated manipulation of the cable end at King Island. As a precautionary measure the insulation resistance of the cable was observed continuously on a recording instrument which had been inserted in August, 1954, to provide a record of the insulation resistance. The manipulations did not impose any great stresses on the cable, but they nevertheless caused the insulation resistance to fall far below any value recorded previously, and in order to prevent a possible complete failure of the cable an "emergency amputation" of the cable end was made as a matter of urgency. In order to avoid interruption to traffic the outer and the inner conductors were jumpered to the repeater station equipment from a point approximately 4 yards from the end before removal of this length. As in the case of the two ends of the Southern Cable, this 4 yard length was faulty, and its removal

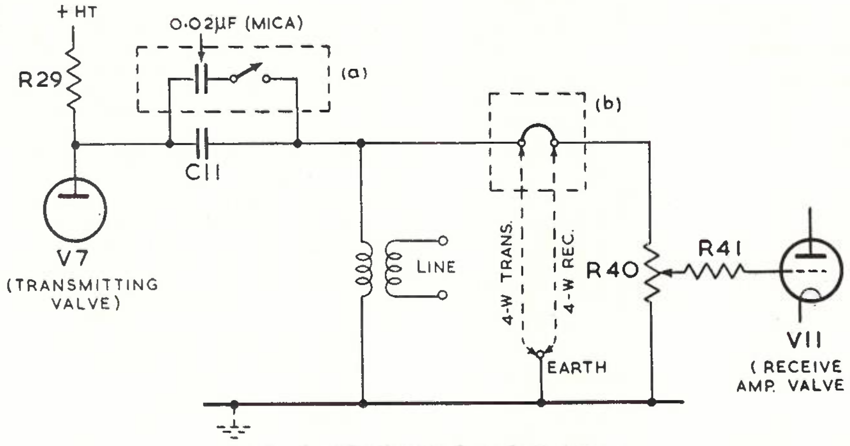


Fig. 3.—Modifications to FLOS Fault Locator.

(a) This modification provides choice of "normal" or "high-powered" transmitted pulse.
(b) This modification provides separate access to Transmitter and Receiver for 4-Wire operation (see Fig.4b). The normal "Line" terminals are not used in this type of operation.

resulted in a restoration of the insulation resistance of the Northern Cable to the original installation values, the cable end at Apollo Bay apparently being in good order.

At this time the ship was about halfway through the loading of cable for the repair of the Southern Cable, and the fact that the Northern Cable had been repaired meant that the ship's operations could now be planned without having to cater for a possible fault at sea on the Northern Cable. This resulted in a considerable saving of time and money.

PROOF TESTING OF CABLES AND RESTORATION OF SERVICE

The laying of the new 8 Nauts length of cable needed for the repair of the Southern Cable, the associated splicing at sea and the re-termination of cables at the repeater stations were completed at 6 a.m. on the 8th March, permitting the proof testing of the cables and the necessary work to restore service to commence.

To determine the insulation resistance the cable is polarised for 40 seconds, and five readings of the current flowing into the cable are then taken at 10 second intervals, that is at 40, 50, 60, 70 and 80 seconds. The insulation resistance is obtained by dividing the average of the five current readings into the applied voltage. At 80 seconds the inner conductor is connected to the outer for a 1 minute discharge, and the potential is thereupon applied in reverse to the cable and five more current readings are taken after a further 40, 50, 60, 70 and 80 seconds. In this manner a "positive" and a "negative" insulation resistance are obtained. The readings vary greatly due to disturbing earth currents. Thus on the Southern Cable readings in the range 620-1760 M ohms were obtained over a three day period, whilst values in the range 775-2600 M ohms were obtained on the Northern Cable over a seven day period.

Samples of Pulse Echo Traces applicable to the Southern Cable after repair are shown in Figs. 2b and 2c.

Further proof tests required are CR-tests (conductor resistance), capacitance-tests and a precision measurement of impedance. This latter test is, as described earlier, also desirable for future fault location purposes.

Due to the change, caused by the replacement of the 8 Nauts section, in impedance characteristic of the King Island end of the Southern Cable, new cable-balancing networks (Ref. 7) had to be made to replace the existing networks.

In connection with the repair work several incidental alterations were made at King Island. Thus the existing earth-electrode system was discarded due to risk of electrolysis, and a new system established, and in order to improve the noise on the carrier channels some alterations were also made to the general earthing scheme for the repeater station equipment.

Finally, all channels normally carried by the cable were relined right through from end to end, and traffic was transferred back to normal at 11 p.m. on the 10th March.

CORRELATION OF SYMPTOMS AND CAUSES OF FAULTS

The symptoms of the 1957 fault conditions may be compared with the causes to see whether any new information may be derived.

The three earlier faults, 1938, 1940 and 1943, resulted in complete failure of the cable within a matter of hours or at the best within a few days after the first symptoms had become evident. The failures were due to abrasions on the Sea Elephant Shoal sections, and the failures occurred at times of heavy seas on the Shoal. It seems reasonable that abrasion failures on the Shoal should occur in this manner, and under this assumption the abrasion which led to the 1957 failure did not become serious enough to affect the insulation resistance of the cable until the 14th January, 1957, when the seas were heavy on the Shoal and the insulation resistance dropped suddenly from about 250,000 ohms to a few hundred ohms, the cable failing completely on the 17th March. If this assumption is correct, it follows that, up to that date, the polarising voltage on the Southern Cable had improved the

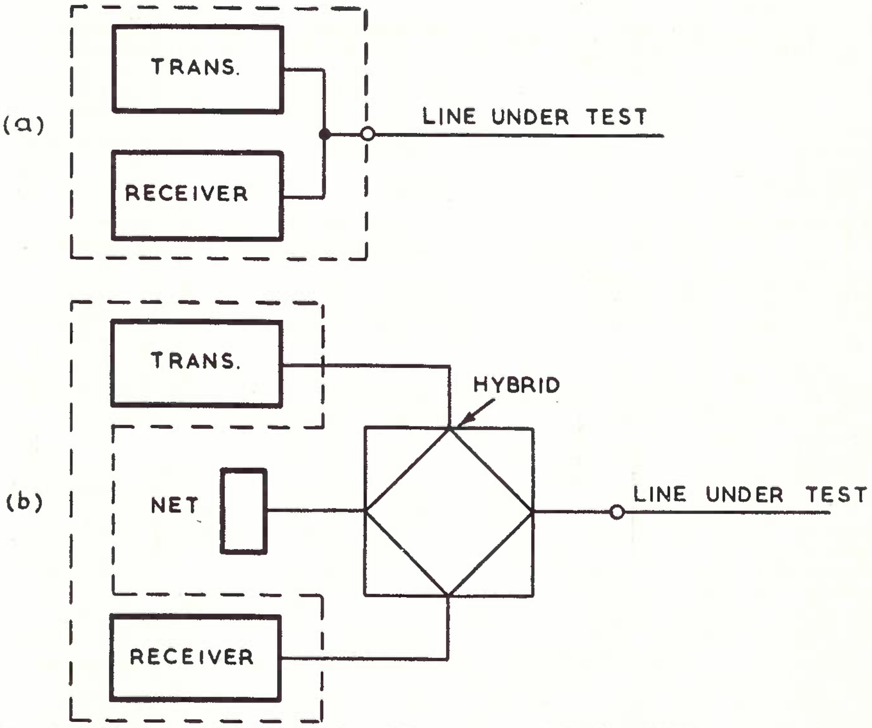


Fig. 4.—2-Wire and 4-Wire Connection of Transmitter and Receiver (FLOS apparatus shown inside dotted line).

(a) 2-Wire: Transmitted Pulse enters Receiver directly.
(b) 4-Wire: Transmitted Pulse heavily attenuated by the balanced Hybrid before entering Receiver.

insulation resistance of the faulty cable ends only. It was shown during the repair that it was not possible, even with voltages of up to 500 v, to reduce the insulation resistance of the ends to less than about 40,000 ohms, and it may thus be concluded that, unless the polarising voltage retarded the deterioration of the paragutta, the cable would not have failed before January 14th even if a polarising voltage had not been applied.

Considering the conditions after the 14th January, there is little doubt that the polarising voltage effectively helped to keep the insulation resistance above the lower limit necessary for satisfactory operation.

If the assumption is made that the abrasion fault which led to the failure of the Southern Cable, did not cause any drop in insulation resistance until the 14th January, it may be concluded that the time lapse from the first symptoms of an abrasion fault on the Shoal to complete failure is usually a matter of hours or a few days (the 1938, 1940 and 1943) but may under favourable conditions (1957) be up to two months. This illustrates that it is important to maintain a continuous watch of the insulation resistance of the cables, and that immediate action should be taken to organise repair if at any time the insulation resistance drops to say 1,000 ohms or lower.

REFERENCES

1. Institution of P.O.E.E. Printed Paper No. 192, 1948. The Location of Faults in Lines and Cables, by A. C. Timmis.

2. Western Union Technical Review, Vol. 11, July 1957; Fault Localisation in Submarine Telegraph Cables, by R. A. Goodman and P. A. Pawson.

3. Bell Laboratories Record, Vol. 23, October, 1945; The Lookator, by J. T. Schott.

4. Electrical Engineer and Merchandiser, June 16, 1947; Fault Location on Transmission Lines.

5. The Telecommunication Journal of Australia, Vol. 7, No. 3, February, 1949; The Application of Pulse Techniques to the Location of Faults on Telephone Circuits, by P. M. Hosken.

6. Telecommunications (India), Vol 5, December, 1955; Indo-Ceylon Cable Repair Operations, 1955, by T. K. Mahadevan and T. V. Malasubramian.

7. The Telecommunication Journal of Australia, Vol. 10, No. 6, February, 1957; Bass Strait Submarine Cable, 9-Channel Extension Carrier System, by D. A. Gray and E. Rumpelt.

APPENDIX I

Development of Pulse Echo Tests for Fault-location on Coaxial Type Submarine Cables.

INTRODUCTION

At the time the investigation of the suitability of pulse testing methods for location of faults on the Bass Strait Submarine Telephone Cables was commenced, there was no published material describing the application of pulse testing to cables of comparable length. A Victorian made instrument (the B. Miller locator at City West) had been applied experimentally to the cables in 1950 and 1952, but the insulation resistance had not been low enough to permit a location to be made. However, some of the experience gained during these tests proved valuable for the development of the equipment used during the 1957 operations. During the development work an article (Ref. 6) was published, describing the application of a Reid Type F.L.O.S. locator (probably unmodified) for faults on the Indo-Ceylon cable, this cable being of the same type as the Bass Strait cables. The Indo-Ceylon cable is, however, 28 Nauts long only, and the two faults, one at 12.5 and the other at 17.5 Nauts, had been severe, that is nearly short circuits, and the article implies that it was just possible to "see" an open or a short-circuit at the far end of the cable. For the Bass Strait application it was desirable to be able to "see" through cables of approximately three times the length of the Indo-Ceylon cable. Furthermore, it should be possible to obtain a location of faults exhibiting high values of insulation resistance up to distances of at least 40 Nauts and preferably over the full length of the cables (approximately 80 Nauts.).

CIRCUIT DESCRIPTION AND PRINCIPLES OF LOCATOR

The desired objectives were achieved by suitable modifications to a Reid F.L.O.S. locator and the development of external auxiliary apparatus. Thus the following modifications were made to the F.L.O.S. locator.

(a) **Extension of Time-base Brightening Pulse:** The longest brightening pulse in a normal instrument permits 27 marker units to be displayed, corresponding to 135 miles of open-wire line. When used on the Bass Strait Cables one marker unit corresponds to approximately 2.71 Nauts of cable, which means that at least 30 marker-units are required for the display of the echoes from the full length of the cable. A 500pF mica capacitor was added in parallel with the existing capacitor C1, resulting in an extension of the time base to a maximum of 33 units.

(b) **Increase in Duration of Transmitted Pulse:** The pulse normally generated by the transmitting section has a very steep front followed by an exponential decay. The nominal time-constant of this decay is 0.6 microseconds. Due to this very short pulse length the transmitted power is small. A pulse of higher power may be obtained by paralleling the existing capacitor C11 with a 0.02

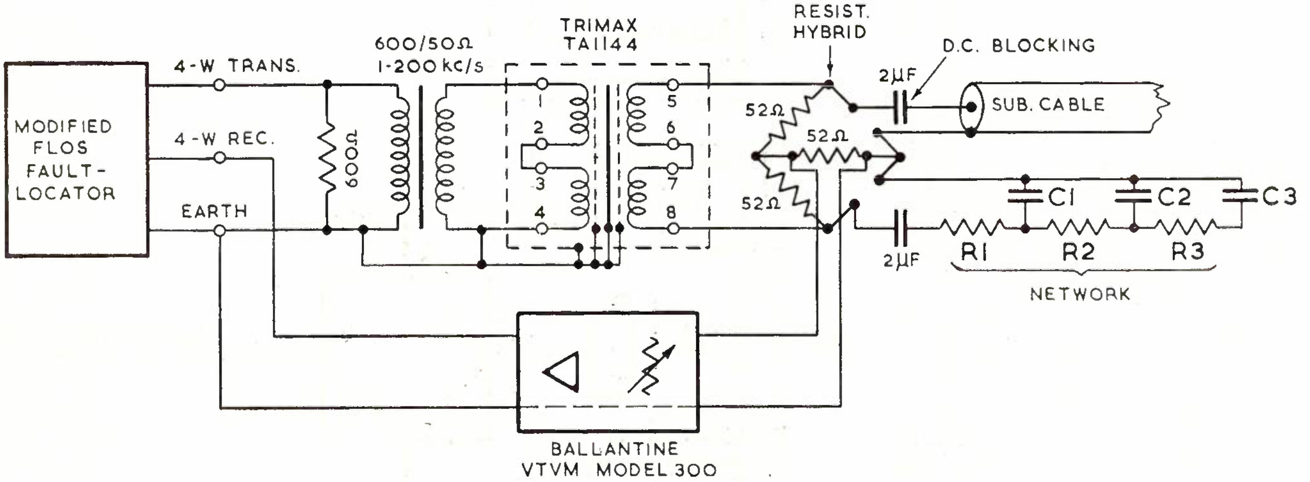


Fig. 5.—Pulse Echo Testing Apparatus for Fault Location on Bass Strait Submarine Telephone Cables.

The optimum network components differ for the four cable ends. The extreme values (after the repair) are:

R1:52.00/53.52 Ω, NR
R2:10.5/18.0 Ω, NR
R3:85/98 Ω, NR
C1:2.7/3.9 μF, NI
C2:3.0/4.4 μF, NI
C3:7.3/9.5 μF, NI

A compromise network having fixed components was used. Components must be so arranged that they can be interconnected by short direct wiring to prevent unwanted resonance effects.

microfarad capacitor (mica) in series with an on-off switch (see Fig. 3). This additional capacitor will widen the transmitted pulse from a nominal of 0.6 to a nominal of 6 microseconds duration. The power contained in the longer pulse is 20 db higher than that in the shorter pulse. Consequently the longer pulse "reaches" further. The shorter pulse gives better resolution than the longer. The instrument in its normal state generates an unwanted pulse which is just discernible as a small "bulge" on the trace of the cathode ray tube in the vicinity of the fourth marker unit. An increase in length of the transmitted pulse increases the amplitude of this bulge, and care is necessary to ensure that an inexperienced operator does not interpret this bulge as a fault.

(c) **Provision of Hybrid:** The F.L.O.S. locator is normally a 2-wire instrument as indicated in Fig. 4a, that is the transmitter, the receiver and the line under test are connected in parallel. To achieve the objectives of fault location as stated above, it is necessary to increase the total receive gain very substantially. Since the transmitted impulse (approximately 300 Volts peak) enters the receiver directly, the desired increase in receiver gain would result in the receiver amplifier being overloaded and paralysed. To prevent this a hybrid arrangement is necessary (and is shown in Fig. 4b, and described in detail later). To enable the transmitter and the receiver to be connected in the desired fashion to this hybrid, the transmitter output and the receiver input were arranged so that access to these points could be obtained separately (see Fig. 3).

The external auxiliary apparatus required consists of the equipment outside the dotted line in Fig. 4b supplemented by an additional amplifier in the receive path. The details of the final arrangement employed are shown in Fig. 5.

The main features of this arrangement are:

(a) The transmitter and the receiver are connected to the cable via a hybrid in which the cable impedance is balanced by a "cable impedance network". It is of paramount importance that the very best balance possible should be obtained to permit a large amount of additional receive gain to be used without the receiving amplifier being paralysed by that fraction of the transmitted pulse which passes the hybrid and enters the transmitter.

(Note: A hybrid and a balancing network exist at each cable end as part of the normal carrier equipment, but they do not cover the required frequency range, and they are therefore not suitable for this purpose.)

It requires experience to determine whether the transmitted impulse penetrates to such an extent that the gain-characteristics of the receiving amplifier are affected by it. Perhaps the simplest test which can be applied to ensure proper operation is a reversal of the polarity of the transmitter. This should result in the C.R.O. trace being turned upside down, but otherwise no change of shape. If the shape of the trace is altered, operation of the receiving amplifier outside its linear range is indicated.

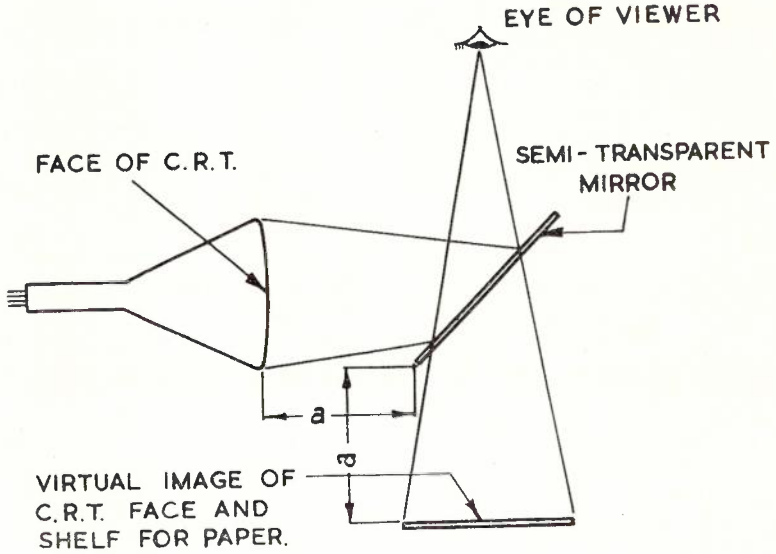


Fig. 6.—Semi-transparent Mirror Method of Recording and Comparing Pulse Echo Pictures.

Other symptoms of overload are:

(i) The trace is fully or partially blanked; that is echoes are not displayed or displayed at too small an amplitude.

(ii) Oscillations of the receive amplifier during one or more stages of its recovery. This will cause a "wavy" trace and suppression of echoes during these stages.

(iii) Reduced sensitivity of receiver.

(b) The impedance of the apparatus as "seen" by the cable is very nearly equal to the impedance of the cable itself. This feature is necessary to prevent misleading effects due to "multiple echoes" from the nearer or more severe cable irregularities.

This phenomena may be explained as follows:

Assume that a pulse is sent into the cable and that part of it is reflected from an irregularity at say 2 Nauts. Upon return to the fault locator some of the energy will enter the receiver (resulting in a deflection on the trace at the 2 Naut point), but if an impedance mismatch exists between the apparatus and the cable, part of the energy will be reflected back into the cable, travel out to the 2 Naut irregularity, where some of it will be reflected back towards the fault locator with the result that a second misleading deflection of the trace is caused at the 4 Naut point. By repeat processes further misleading deflections occur at the 6, 8, 10 etc., Naut points.

(c) High total receive gain approaching the maximum gain possible without undue interference due to cable noise (mainly thermal noise).

PERFORMANCE

An "open" or a "short" at the far ends of the 80 Nauts lengths of cable was readily discernible using the normal pulse length. Using the longer pulse a large echo from the far end could be observed. The estimated accuracy of fault-location, provided the instrument used is carefully adjusted, is ± 0.1 Naut ± 0.5% of the distance to the fault. If the fault is not sufficiently severe to prevent the far end of the cable from being "seen" and used for calibration purposes, a superior accuracy, say ± 0.1 Naut ± 0.2%, may be expected.

As in the case of the impedance tests, the ability of the pulse echo test to locate high insulation-resistance faults is reduced by the presence of "normal" impedance irregularities due to manufacturing tolerances and mechanical deformation during handling and laying. With very few exceptions these normal irregularities do not cause reflections of magnitudes greater than the reflections which would be caused by a 5-10 kohms leakage resistance at the same location. However, in several cases reflections due to these irregularities have been equivalent to an estimated 2-3 kohms leakage resistance. If no information is available in respect of the "pulse echo picture" of the cable in good condition, it is thus necessary, if a certain fault location is to be made, that the insulation resistance of the fault should be well below 2 kohms.

If a pulse echo picture of the cable in good condition is available for comparison with the picture obtaining under the fault condition, the location of faults of 10 kohms or, in favourable circumstances, up to 30 kohms may be carried out successfully. A permanent record of a pulse echo picture and the subsequent comparison of this with another trace on the cathode ray tube may be made in a very simple and convenient fashion by means of a semi-transparent mirror. An indication of the principle involved is given in Fig. 6. Due to the action of the mirror, the screen of the cathode ray tube appears as a virtual image on the paper shelf, and since the paper on the shelf may be seen through the mirror, the trace on the screen of the cathode ray tube appears to coincide with the surface of the paper. Consequently a copy of the trace can be drawn readily on the paper. If it is desired to compare the trace on the cathode ray tube with a trace drawn previously, the drawn trace is placed on the shelf and since the trace on the cathode ray tube and the drawn trace are seen simultaneously, a direct comparison may be made.

In case of varying (and "swinging") faults even better results may be obtained, since the echo due to the fault will vary in magnitude whilst the echoes due to the normal impedance irregularities will remain of constant magnitude. If the variation is rapid, locations of leakage faults in the order of 40 kohms are possible. In this connection it should be mentioned that in some circumstances it is possible to cause a variation of a leakage fault by suitably changing or reversing the polarising current.

PROVISION OF UNDERWATER CABLES—GRAFTON DIVISION

*J. A. SKINNER**

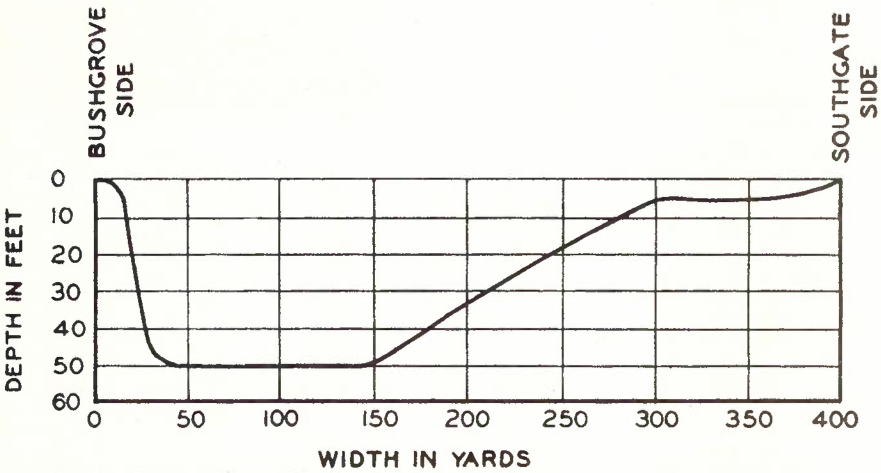


Fig. 1.—Cross-section of the Clarence River between Brushgrove and Southgate.

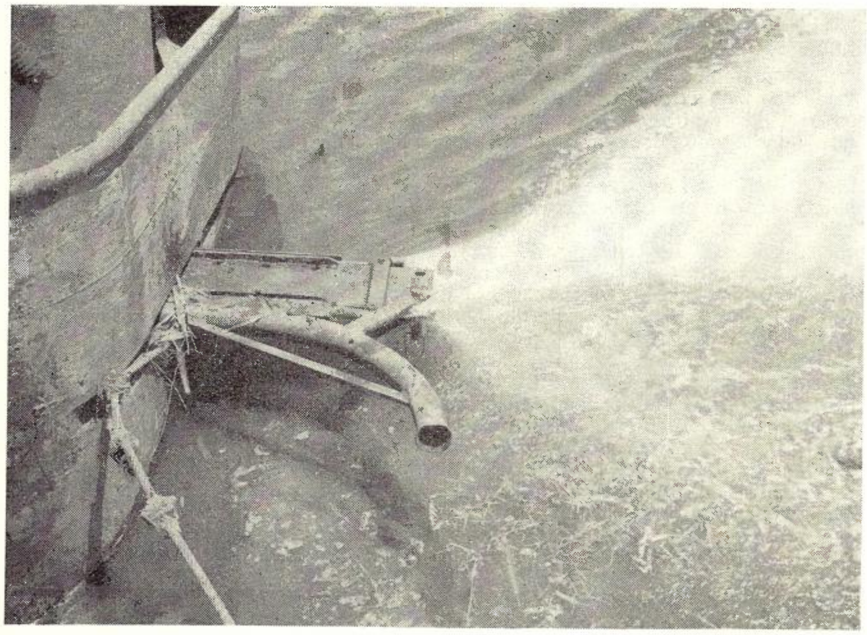


Fig. 2—Skid Type Mole Plough.

Introduction: The Clarence River is the largest of the N.S.W. coastal rivers. It is navigable for coastal shipping as far up stream as Grafton where it is still almost half a mile wide. It is a river of many islands, the largest being Woodford Island, which is twelve miles long and six miles wide. Many of these islands are highly fertile and support a large number of permanent residents. The main development in the area is along the river banks and on the islands. To provide telephone service to an area of this type many underwater cables are required. A total of 24 cables exist at present ranging from one and two pair lead in cables for island residences to 100 pair junction and trunk cables. These cables were provided by laying them directly in the river, either from a barge or by floating them across on drums and releasing them to the bottom of the river, no attempt being made to bury them in the river bed. This method was reasonably satisfactory at some points where the bottom was soft as the cable would sink into it and be protected, but at others cables have been carried away during floods, resulting in considerable inconvenience, loss of revenue and high replacement costs. It was decided to bury all new underwater cables in the river bed where possible to minimise this loss and to provide a more reliable service.

During October, 1956 five cables were provided by various methods in this Division.

(a) Across the Clarence River between Brushgrove and Southgate.

A cable was washed away at this crossing during a flood in 1955. It had provided service for 16 subscribers and three trunk lines. Temporary service was given by connecting the residents to the distant exchange on the trunk lines until the cable could be replaced.

(b) Across the mouth of the Evans River at Evans Head.

A 14/10 SWA cable was laid at Evans Head to give service to waiting applicants and to allow an existing aerial crossing to be dismantled. The

---

* Mr. Skinner is Divisional Engineer, Grafton, New South Wales.

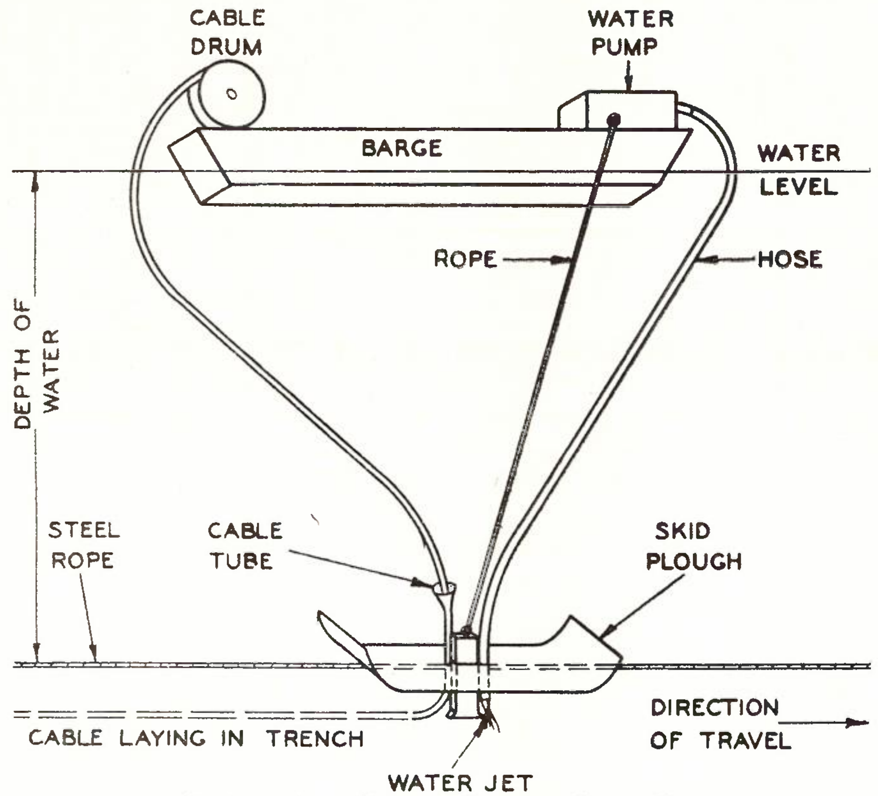


Fig. 3.—Method of Laying Cable across Clarence River.

aerial crossing consisted of 3 pairs of 118 CC wires and could not be further extended unless higher poles were provided.

(c) Across the Richmond River at Broadwater. A 38/10 STA cable was provided to give service to waiting applicants and to meet future development.

(d) Across the Richmond River at Coraki. A 54/10 STA cable was provided to meet future telephone development. Different methods were used to provide this cable due to the presence of existing cables.

(e) Across the Clarence River at Grafton. There were five cables varying in size from a 7 pr. to 54 pr. already laid at this crossing to carry trunk, junction and subscribers lines between Grafton and South Grafton. All existing pairs were occupied and it was decided to provide a new 100/20 SWA cable. Care was required while laying this cable to ensure that the existing cables were not damaged.

These crossings differed in regard to width and depth of the river, and the type of bottom and shape of banks, and it was necessary to devise different techniques to suit each one. The various methods used at each of the crossings are described in the following paragraphs.

Clarence River between Brushgrove and Southgate: A cross-section of the river bed is shown in Fig. 1. The channel near the Brushgrove bank is 50 ft. deep and it was here that the cable had been washed away during the 1955 flood. The main items of plant used at this crossing were:—

(a) A skid type mole plough.
(b) A barge capable of carrying a load of 2-3 tons.
(c) A D8 and D4 Caterpillar tractor.
(d) A 4 inch water pump powered by a petrol engine and associated hoses, etc.
(e) 2,500 ft. of ¾ inch diameter steel wire rope.

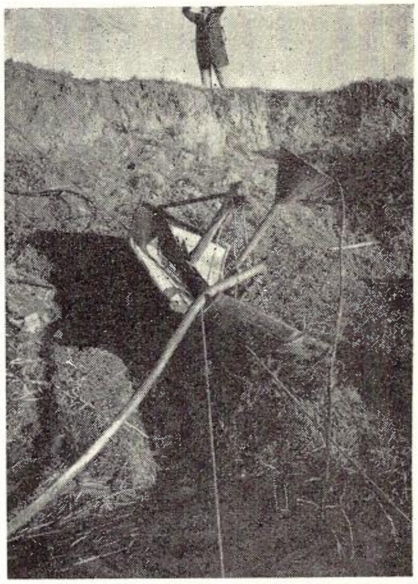


Fig. 4.—Skid Plough Entering River.

The skid type mole plough was made of sheet steel. It is 10 ft. long and 4 ft. wide and curved at both ends to prevent it digging into the bottom when drawn across the river. The plough has a blade 4 ft. long to which two water jets were connected, and a cable tube made of 3 inch G.I. pipe was attached to the rear of the plough blade. The top of the cable tube was made cone shaped with a top diameter of 2 ft. 6 inches to allow the cable to feed freely into the tube and to prevent it fouling the plough while the cable laying operations were in progress. Fig. 2 is a view of the bottom of the plough showing the plough blade, water jets and cable tube.

A type D8 tractor was used for the cable ploughing and a type D4 for pulling the plough back as required. It was

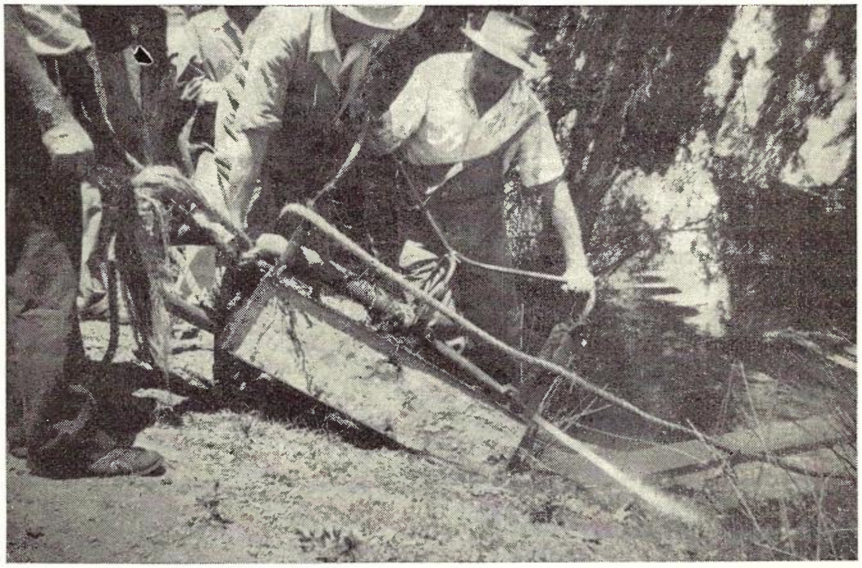


Fig. 5.—Weight with Cable Rings, Hose and Water Jets.

found that the smaller tractor could not pull the plough with the blade fitted. A tractor of at least 60 h.p. and equipped with an efficient winch is needed to pull the plough and bury the cable. A 4 inch centrifugal pump driven by a Ford V8 engine and developing a pressure of 75 p.s.i. was used to provide water pressure for the jets. It was mounted on the barge and connected to the jets on the plough by 60 ft. of canvas hose. The wire rope was taken across the river and attached to the plough. A trial run was then made across the river with the plough blade fitted to prove that there were no obstructions on the bottom. The plough was then returned to the other bank and cable laying operations commenced.

The method used to bury the cable is illustrated in Fig. 3. The drum of cable was mounted on the barge with the pump and the end of the cable fed through the tube on the plough. The plough was then drawn slowly across the river by means of the winch on the tractor. As the plough was drawn across, the cable was run out from the barge, care being taken to see that it was kept tight enough to prevent it forming a loop and fouling the plough. It took 1½ hours to plough the cable across the river. Fig. 4 is a view of the plough entering the river and shows the canvas hose attached to the water jets on the plough blade and also the 38 pr. S.W.A. cable passing through the cable tube. An inspection in the shallow water showed that the cable had been buried 3 ft. deep. A later inspection by a diver proved that the cable was buried at all points except for approximately 40 ft. on the steep edge of the channel near the Brushgrove bank. This was buried by hand. From the above it will be seen that this method is not entirely satisfactory where steep banks are encountered.

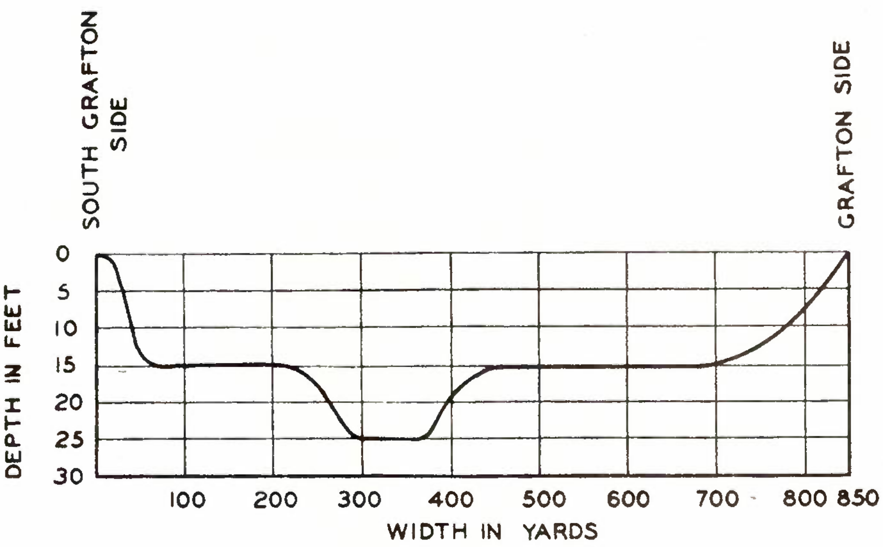


Fig. 7.—Cross-section of the Clarence River at Grafton.

Eight men are required to lay a cable by this method. These include a tractor driver and assistant to draw the plough and barge across the river, five men on the barge to turn the drum, grease and also feed the cable over the side of the barge, and operate the pump. A supervisor is also required to watch the complete operation.

Crossing the Mouth of the Evans River at Evans Head. The river is approximately 300 yards wide, with a sandy bottom and a maximum depth of 10 ft. At low tide a sand bank extends half way across the river. It was not possible to hire a barge at Evans Head so the water pump could not be used and the drum of cable could not be taken across the river. A further difficulty was that it is impossible to get a motor vehicle on to the southern bank of the river so the skid plough had to be drawn across the river by feeding the wire rope through a pulley block attached to a large mangrove tree on the southern bank. A trial run was made to prove that there were no obstructions. The cable drum was then mounted on the northern bank and the cable laid out across the river by manpower at low tide, assistance being given by the Division's flood boat to get the cable across the channel.

The end of the cable was fed through the cable tube on the plough at the southern bank, sufficient being pulled through to reach to the proposed cable pole. The tractor on the northern bank was then attached to the wire rope. As the plough was pulled back across the river, the cable was under-run with a raft constructed from 44 gallon drums and fed into the cable tube on the plough. Ploughing proceeded without incident to within 40 ft. of the northern bank where a section of soft rock prevented the plough from burying the cable. This section is exposed at low tide and it was dug in by hand. The plough buried the cable approximately 2 ft. deep. A greater coverage would have been obtained if it had been possible to use the water jets. However, it is expected that the cable will be protected from any damage in the future by the cover that was provided.

Crossing the Richmond River at Broadwater. This crossing did not present any difficulty. The river banks sloped gently to a depth of twenty feet, this depth being maintained for the complete crossing which was 250 yards. The river bed is composed of soft silt. The skid plough assisted by water jets was used to bury the cable in a similar manner to the method used for the Brushgrove-Southgate crossing. No difficulties were experienced and a later inspection by a diver showed that the cable was well buried for its complete length.

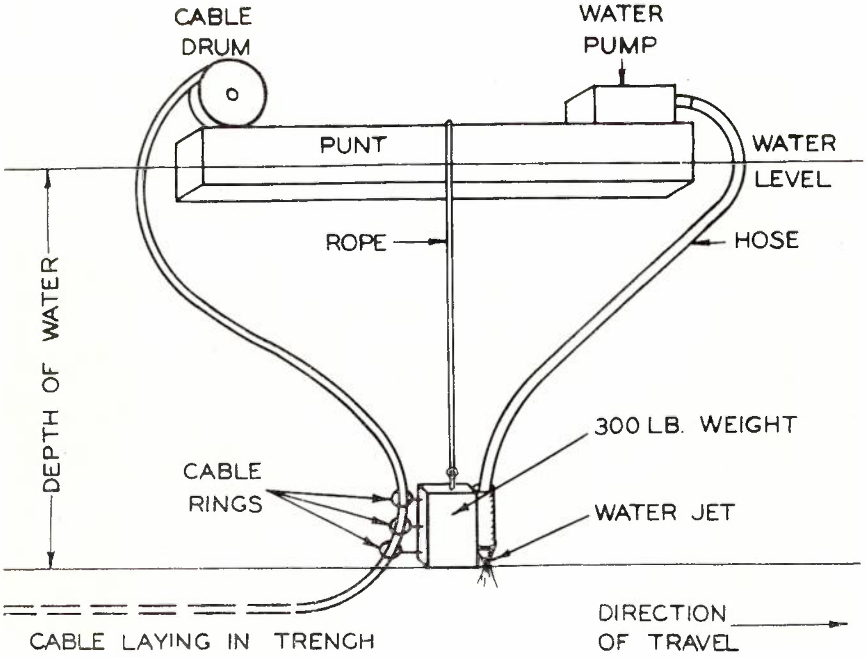


Fig. 6.—Method of Laying Cable across Richmond River.

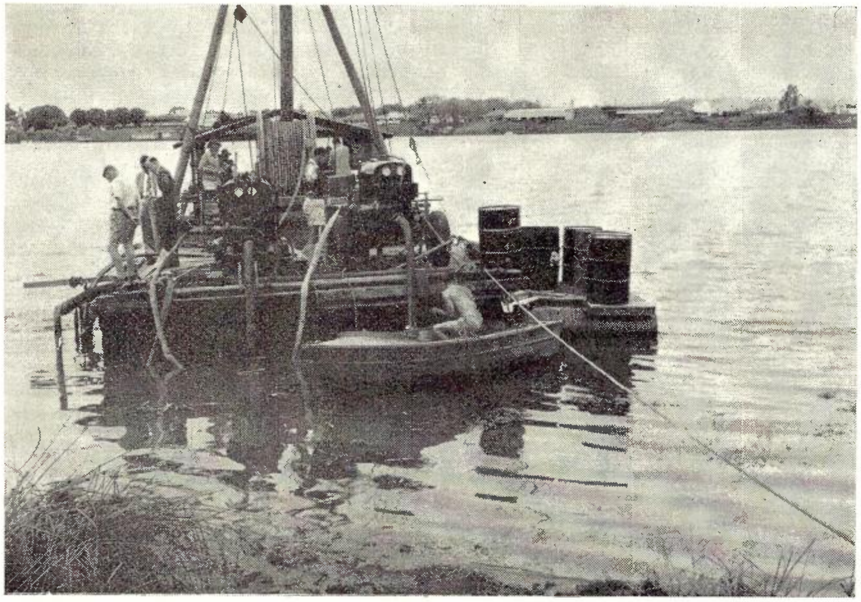


Fig. 8.—Preparing to lay Cable at Grafton.

Crossing the Richmond River at Coraki. The presence of two existing cables at this crossing prevented the use of the skid plough method, because of the likelihood of the plough damaging the cables. The method used to cut a trench at this crossing was to attach a hose nozzle to a 300 lb. weight and lower it to the bed of the river with a rope. The rope was used to raise or lower the weight so that the hose nozzle was suspended immediately above the bottom of the river. The cable was fed through three steel rings attached to the weight thus ensuring that it was laid in the trench cut by the water jets. Fig. 5 is a view of the weight showing the cable rings, hose, and the water jets.

A small vehicular type ferry was hired and connected by means of a wire rope attached to the banks over the course where it was proposed to bury the cable. The water pump and drum of cable were mounted on the ferry and the end of the cable was taken through the cable rings on the weight. The ferry was then wound slowly across the river and the weight was lowered until the hose nozzle was suspended above the river bed. The water jet cut a trench approximately three feet deep when held in this position. Feeding the cable through the rings on the weight ensured that it was laid in the trench. A drawing of the method used is shown in Fig. 6. It was necessary to take the ferry very slowly across the river to give the water jets time to cut an effective trench. Two men were used to raise or lower the weight by means of a rope as the depth of the river varied. This ensured that the hose nozzle was just off the bottom and in the correct position to cut a trench in the river bed.

A trench 2-3 feet deep was cut by this method. The cable was proved to be in the trench by testing with a length of G.I. pipe, the river being only 16 ft. deep. A subsequent inspection by a diver showed that the cable was not buried for a distance of 20 feet near one bank. It is thought that the canvas hose had become kinked and the water pressure was lost over this distance. Kinking of the hose was experienced frequently during the operations, and to avoid this trouble it is intended to use rubber hose in future operations.

Crossing the Clarence River at Grafton. The provision of this cable was more difficult than the previous ones. The river was almost half a mile wide and a much larger cable had to be laid. A cross-section of the river bed is shown in Fig. 7. The bottom slopes gently down from the Grafton bank to a depth of 16 ft. There is a 24 ft. channel approximately half way across after which a depth of 16 ft. is maintained almost to the South Grafton bank.

A method similar to that used at Coraki was also used to lay this cable. Two water pumps were available so it was decided to attach a hose nozzle to the front and rear of the weight in order to cut a deeper trench. When the weight was used at Coraki it had been filled with concrete and weighted approximately 300 lbs., but as two hoses were to be used at this crossing, and a much larger cable laid, the concrete was removed and 500 lbs. of lead was melted into the frame. A barge capable of carrying the 8 ton drum of cable, the two water pumps and associated apparatus was hired locally. A wire rope was provided across the river where it was proposed to lay the cable and anchored securely on each bank. This rope was used to keep the barge on the desired course and also as a means of propulsion. The barge was propelled across the river by taking one turn of this rope round the drum of a hand winch mounted on the deck. A power winch would have been more suitable if one had been available. However, the method did allow the punt to be taken slowly across the river, thereby giving the water jets time to cut a deep trench in the river bed.

Fig. 8 shows the pumps and drum of cable in position on the barge. The weight to take the water jets to the bottom can be seen on the left hand side of the barge. The rope along which the barge is propelled is on the right hand side. Due to the size, weight

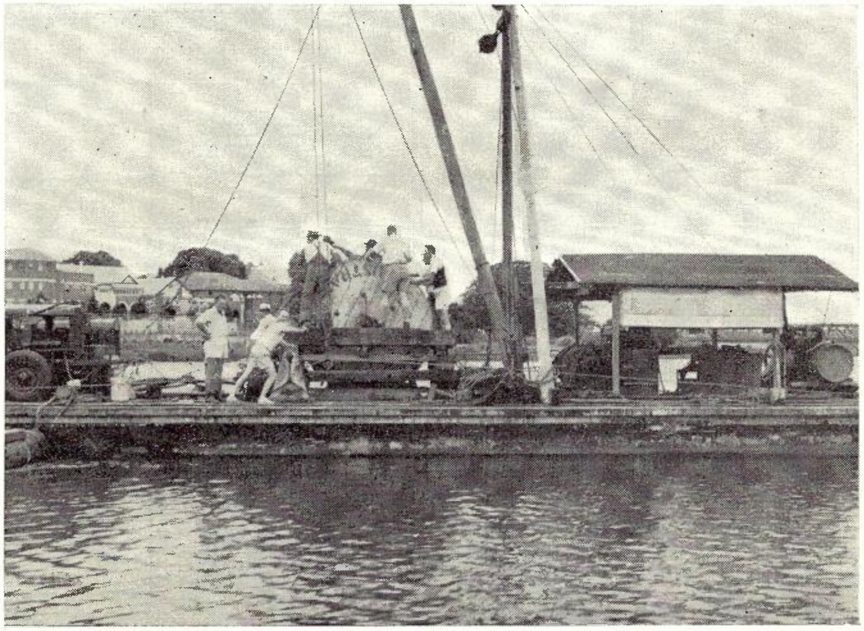


Fig. 9—Cable Laying in progress at Grafton.

and inflexibility of the cable being laid, a 500 lb. weight was required to keep the jets suspended immediately above the bottom. If a lighter weight had been used the rigid nature of the cable would have caused it to slide back along the cable and the water jets would not have been held directly above the river bed. Fig. 9 shows the barge being taken across the river by means of the hand winch while the cable laying was in progress.

Six to eight men were required to turn the drum of cable. It took 4 hours to propel the barge across the river, a distance of 800 yds. A trench 3 ft. deep was cut by the water jets and the cable was laid directly in the trench.

Conclusion: While numerous difficulties were encountered in providing these five underwater cables, they were all laid successfully and are now in service. The difficulties encountered have shown the need for very detailed planning, and adequate and suitable mechanical aids. Both the methods used were satisfactory. The skid plough method is suitable for small cables at crossings where there are no existing cables. The "weight" method is ideal where there are existing cables as there is no chance of damaging them, or in deep water where other trenching methods may be difficult. Either method will bury a cable to a depth of 3 ft. where the river bed consists of silt or sand. If a greater depth than this is required other methods would be necessary. A diver should inspect the cable at both banks of the river, and also at any point where there is a sharp variation in the depth of the river to ensure that it has been buried.

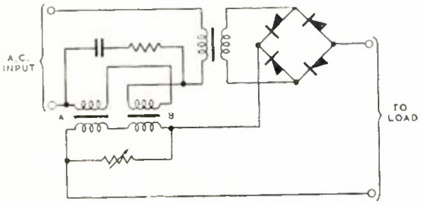
ANSWERS TO EXAMINATION PAPERS

Editorial Note: Instead of providing complete answers to all questions of some Examination Papers, this and future issues of the Journal will include answers to a few questions only from a number of recent papers. The questions selected for inclusion will be those answered poorly, or of special interest, or of a type not covered in other recent issues of the Journal.

Examination Nos. 4445, 4446 and 4465: Senior Technician, Telephone, Research and Radio and Broadcasting. July, 1956.

Q.10.—Describe with the aid of a simplified circuit the operation of a power rectifier unit the output of which is controlled automatically by a saturated reactance.

A.—



Q.10—Fig. 1.

The two choke coils A and B each has two windings. One winding of each is in the AC supply to the transformer and the other winding of each is in the DC output of the rectifier. The choke is designed so that the core is saturated when the DC output current is a maximum. When the output is low the core is not saturated and the choke offers a higher impedance to A.C., reducing the voltage applied to the rectifier. As the D.C. output increases, the iron core of the chokes saturate reducing their impedance and increasing the voltage applied to the rectifier.

The two parts of the choke coils have a reversed connection in the A.C. circuit to prevent the A.C. being induced in the D.C. circuit. Manual control of the output is by means of the resistor and capacitor which shunt the D.C. choke coils and the A.C. coils.

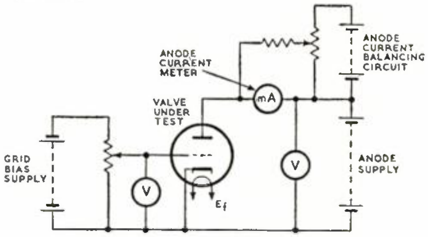
Examination No. 4504: Senior Technician, Research, 1957.

Q.1.—Give two methods of measuring the mutual conductance of a radio valve

(a) a method suitable for use in a commercial valve tester.

(b) a more precise method suitable for laboratory use.

A.—(a)



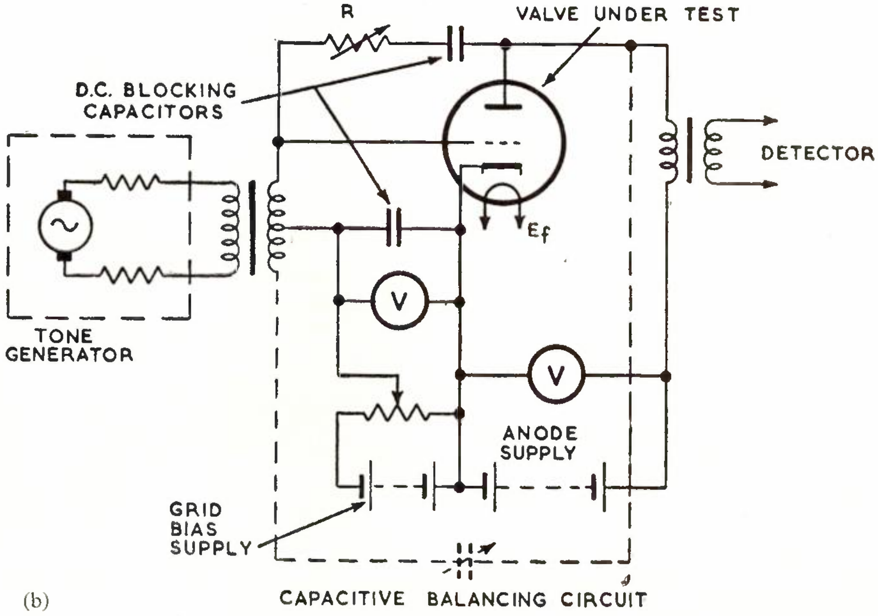
Q.1.—Fig. 1.

The Incremental Method.

The testing circuit (see Fig. 1) supplies the valve with suitable electrode voltages. For example, if the mutual conductance (gm) of a valve is to be compared with a value given in a valve manual then the electrode voltages should be as specified in the manual. The gm may be found using the relationship $gm = \frac{\Delta Ia}{\Delta Eg}$ where Ia is the change in anode current caused by changing the grid bias by a small amount Δ Eg. All electrode voltages other than the grid bias must be constant. By using the anode current balancing circuit and increasing the sensitivity of the anode current meter the change in anode may be read with more accuracy.

The Bridge Method

One circuit using this method is shown in Fig. 2. The tone generator supplies a small alternating voltage to the grid of the valve under test and also to a variable resistor R which may conveniently be a decade resistance box. When R is adjusted for a minimum at the detector



(b)

Q.1.—Fig. 2.

the alternating anode voltage is a minimum and the mutual conductance of the valce is equal to $\frac{1}{R}$ mhos. To obtain a clear minimum the alternating grid voltage should be small and the detector may be tuned to reject harmonics generated by the valve. A capacitive balancing circuit shown dotted may further improve the minimum.

Q.8(a) Define the term "insertion loss".

(b) Calculate the insertion loss in decibels of a blocking capacitor of 0.01 μF capacitance when connected between the output of a cathode follower amplifier having an internal impedance of 500 ohms and a load resistor of 10,000 ohms. The frequency to be considered is 1000 c/s.

A.—(a) The term "insertion loss" of a network connected between a source and load of given impedance is an expression for the ratio:

$$\frac{\text{Power in load when connected directly to the source}}{\text{power in load when connected via the network to the source.}}$$

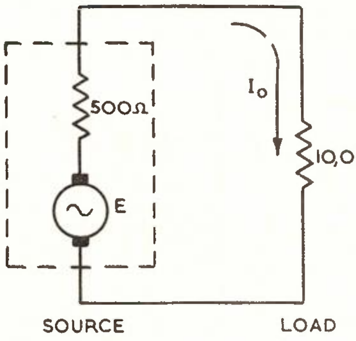
Its value in decibels may be calculated from the expression—

$$\text{Insertion loss} = 20 \log_{10} \frac{I_0}{I_1}$$

where I_0 is the current in the load when it is connected directly to the source and I_1 is the current in the load when it is connected to the source via the network.

These definitions apply whether or not the source and load impedances are matched to each other or to the characteristic impedances of the network.

(b) First calculate the current in the load when it is connected directly to the source:—



Q.8.—Fig. 1.

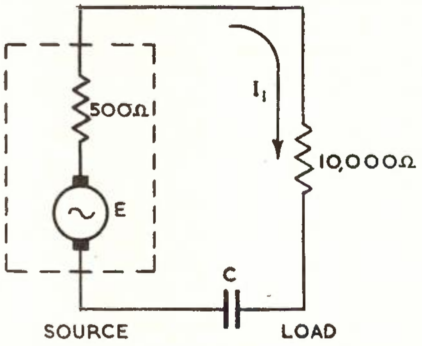
$$I_0 = \frac{E}{10{,}000 + 500} = \frac{E}{10{,}500} \text{ amp.}$$

The reactance of the blocking capacitor can be calculated from the expression:—

$$X_c = \frac{1}{2\,\pi\, fC}$$

giving 15,900 ohms for C = 0.01 μF and f = 1000 c/s.

Next calculate the current in the load with the blocking capacitor inserted:—



Q.8.—Fig. 2.

$$I_1 = \frac{E}{\sqrt{10{,}500^2 + 15{,}900^2}} = \frac{E}{19{,}070}$$

(The total circuit impedance is obtained by vectorial addition of the reactive and resistance components.)

The insertion loss

$$= 20 \log_{10} \frac{I_0}{I_1}$$

$$= 20 \log_{10} \frac{E}{10{,}500} \times \frac{19{,}070}{E}$$

$$= 20 \log_{10} \frac{19{,}070}{10{,}500}$$

= 5.2 decibels.

Examination Nos. 4503, 4504, 4505 and 4506. Telecom. Principles, Senior Technician, All Sections, 1957.

Q.10—Two moving coil voltmeters may have different "ohms per volt" ratings; for example, one may have 100 ohms per volt, the other 10,000 ohms per volt

(a) Assuming the meters are of equal quality, which would be preferred for accurate measurement of voltage across a fairly high resistance source? Explain the reason for your answer as briefly as possible.

(b) What is the basic difference between the two meters and why is there a need for both types?

A.—(a) The 10,000 ohms per volt meter is to be preferred. Voltage is measured by placing the meter in parallel across the source of voltage. For accurate measurement it is important that as little change as possible be made to the high resistance source by the shunting of it by the meter, and, therefore, it follows that the 10,000 ohms per volt meter is selected since for any given voltage range it will offer a higher resistance and hence a smaller shunting effect than the 100 ohms per volt meter. Since both meters are of equal quality their calibration accuracy will be similar and the only inaccuracies that can occur in making the measurement will be due to a change in circuit resistance values by the introduction of the meter.

(b) The basic difference between the two meters is in their sensitivity; the 100 ohms per volt meter requiring 10mA for F.S.D. while the 10,000 per volt meter requires 100μA. The 100μA movement is constructionally and electrically more "delicate" and although both meters be of equal quality, inferring that both conform to certain calibration and manufacture standards, the 100μA movement would normally be used in the "laboratory" type of instrument where it can be expected to receive less rough usage by handling, transport and mis-use. The 10mA movement, being more robust, is used in the "field" type instrument; it can withstand minor overloads and similar mis-use.

Examination No. 4503. Senior Technician, Telephone, 1957.

Q.9.—The R.M.S. voltage measured across the input terminals of a carrier amplifier having 600 ohm input and output impedances is 0.07 volt. To what value should the input voltage be varied if it is desired to increase the output power by 12 db?

A.—Assuming the amplifier gain versus output power characteristic to be linear over the range specified in the question, a 12 db increase in output power requires a 12 db increase in input power. To achieve this the voltage across the input terminals must be increased. When the circuit impedance is constant—

$$\text{db} = 20 \log_{10} \frac{E_2}{E_1}$$

$$12 = 20 \log_{10} \frac{E_2}{0.07}$$

$$0.6 = \log_{10} \frac{E_2}{0.07}$$

$$\text{antilog } 0.6 = \frac{E_2}{0.07}$$

$$E_2 = 0.07 \times \text{antilog } 0.6$$
$$= 0.07 \times 3.98$$
$$= 0.278 \text{ Volts (approx.)}$$

(**Note:** A figure of 4.0 is a commonly used approximation of the value of the antilog of 0.6 and answers of .28 volts obtained using this figure would be sufficiently accurate for the purpose of the examination.)

A.—The input voltage would have to be increased to 0.278 volts R.M.S. to increase the output power by 12 db.

Q.15.—A fault is reported on a physical trunk circuit consisting mainly of aerial construction, but with short sections of entrance cable at each end of the circuit. Voltmeter tests show that the circuit is earthed on one side. Office records at the testing station show that the length of the aerial section is 52 miles and that the loop resistances from the trunk test board to the normal test points are as follows:—

To nearest cable head	**62 ohms**
To distant cable head	**520 ohms**
To distant trunk test board	**548 ohms**

A Varley reading of 266 ohms with 1 : 1 ratio bridge arms is obtained at the testing office. What is the distance to the fault from the cable head near the testing station? (The location should be accurate to the nearest tenth of a mile.)

A.—With equal ratio arms the formula for Varley Bridge calculations is—

$$X = \frac{L - R}{2} \quad \text{where } X = \text{single wire resistance to the fault.}$$

L = circuit loop resistance
R = reading of the Varley Bridge

$$X = \frac{548 - 266}{2} = 141 \text{ ohms.}$$

The single wire resistance to the nearest cable head is 31 ohms ∴ the single wire resistance to the fault from the nearest cable head is 110 ohms. As the single wire resistance between cable heads is greater than this value the fault must be in the open wire section.

As the length of the open wire section is 52 miles and the single wire resistance of this section is 229 ohms simple proportion gives the distance to the fault thus:—

$$D = \frac{52}{1} \times \frac{110}{229}$$
$$= 24.97 \text{ miles.}$$
$$= 25 \text{ miles accurate to nearest tenth of a mile.}$$

(Note: Although in faults of this nature it is usual to conduct the tests with a loop given at the distant trunk test board, the question is a little ambiguous. By the method given above, but using the loop resistance to the distant cable pole instead of that to the distant trunk test board, a distance to the fault of 21.8 miles is obtained. Either answer could be regarded as correct.)

Examination No. 4505. Senior Technician, Radio, 1957.

Q.5.—The characteristic impedance of a two-wire balanced line is given by the expression—

$$Z_o = 276 \log_{10} (S/r) \text{ ohms.}$$

where Z_o = characteristic impedance
S = wire spacing
r = wire radius

What line spacing should be used to construct a 500 ohm line from 0.1937 inch diameter wire? What peak R.F. voltage exists between the line wires at 100 per cent modulation when it is used to connect a 10kW, A.M., broadcasting transmitter to its aerial system?

A.—(i) $Z_o = 276 \log_{10} (S/r)$ ohms
solving for S,

$$S = r \text{ antilog } (Z_o/276) \text{ inches}$$

when $Z_o = 500$ ohms
$r = 0.1937/2 = 0.0968$ inches
$\therefore S = 0.0968 \text{ antilog } (500/276)$
$= 6.25$ inches

(ii) $E_{rms} = \sqrt{P.Z.}$
when $P = 10{,}000$ watts
$Z_o = 500$ ohms

$E_{rms\ of\ carrier} = \sqrt{10{,}000 \times 500} = 1000\sqrt{5}$

$E_{peak\ of\ carrier} = E_{rms} \times \sqrt{2} = 1000\sqrt{10}$

$E_{peak\ 100\%\ mod.} = E_{peak} \times 2 = 2000\sqrt{10}$
$= 6324$ volts

The following notes on voltage, current and power relationships between unmodulated and amplitude modulated waves and the derivation of expressions used in (ii) above may be helpful to students.

Peak—R.M.S. Voltage

When the formula $E = \sqrt{P.Z}$ is applied to any conditions of alternating voltages the value of E is the r.m.s. or effective voltage and is some value less than the peak amplitude. The relation between the r.m.s. voltage and the peak voltage depends on the waveform and it may be shown for a sine wave that

$$E_{peak} = \sqrt{2}.E_{r.m.s.}$$

The practical significance is that a direct voltage of amplitude equal to E r.m.s. will deliver the same heating power into a resistance as an alternating voltage of sinusoidal waveform whose peak value is $\sqrt{2}.E_{rms}$. For this reason the r.m.s. voltage is more generally used than the peak value and most meters read r.m.s. values directly. However, the peak value becomes significant when the voltage breakdown of a component is being examined.

Peak Voltage after Modulation.

The expression of any sine wave voltage is:—

$$e_{instantaneous} = E_{peak} \sin 2\pi f_c t$$

When this wave is amplitude modulated by another sine wave the amplitude of E_{peak} is added to the modulating waveform and the expression for the instantaneous voltage of the modulated wave becomes—

$$E_{instantaneous} = (E_{peak\ of\ carrier} + E_{peak\ of\ audio} \sin 2\pi f_a t) \sin 2\pi f_c t.$$

or more conveniently put,

$$E_{peak\ of\ audio} = m.E_{peak\ of\ carrier}$$

where 'm' may be defined as the modulation depth.

Then $e_{instantaneous} = E_{peak\ of\ carrier} (1 + m \sin 2\pi f_a t) \sin 2\pi f_c t$

For conditions of 100% modulation (when m = 1) the maximum instantaneous voltage is given when both $\sin 2\pi f_a t$ and $\sin 2\pi f_c t$ are equal to 1.

or

$$e_{instantaneous\ maximum} = E_{peak\ of\ carrier} (1 + 1) 1$$
$$= E_{peak\ of\ carrier} \times 2$$
$$= E_{r.m.s.\ of\ carrier} \sqrt{2} \times 2$$

It is interesting to note the relation between the r.m.s. value of current to the peak current for the modulated wave as the wave is no longer a pure sine wave and the value of $\sqrt{2}$ is not valid.

By taking the average value over a cycle of the carrier wave it can be shown that the relationship is

$$I_{peak} = \sqrt{1.5}\, I_{r.m.s.}$$

This means that with modulation although the peak power rises 4 times the r.m.s. power rises only 1.5 times and the r.m.s. current $\sqrt{1.5}$ or 1.225 times.

Summarising the relationship, we have for a pure sine wave

$$E_{r.m.s.\ carrier} = \sqrt{P.Z.}$$
$$E_{peak\ carrier} = \sqrt{2}.E_{r.m.s.}$$

and for a pure sine wave modulated 100% by a second sine wave

$$E_{instantaneous} = E_{peak\ carrier} \times 2$$
$$I_{instantaneous\ maximum} = \sqrt{1.5}\,.\,I_{r.m.s.}$$

The Ruskin Press
123 Latrobe Street
Melbourne