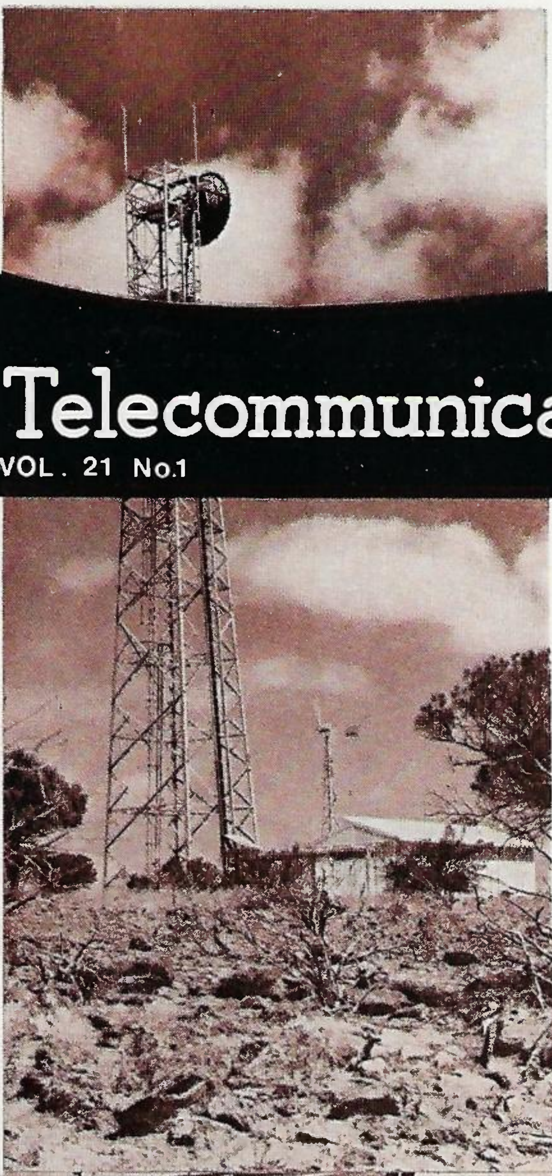
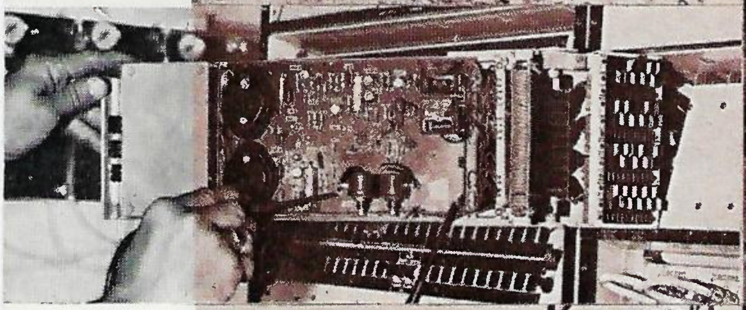


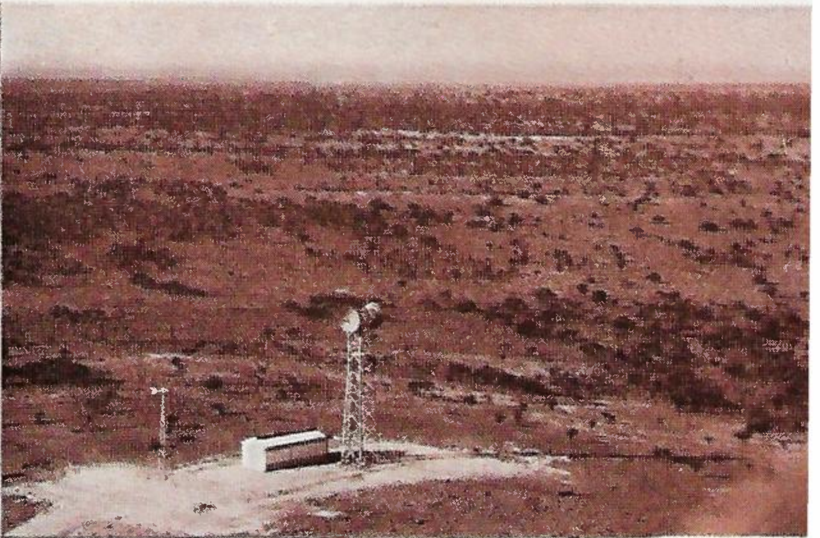
THE Telecommunication Journal OF AUSTRALIA

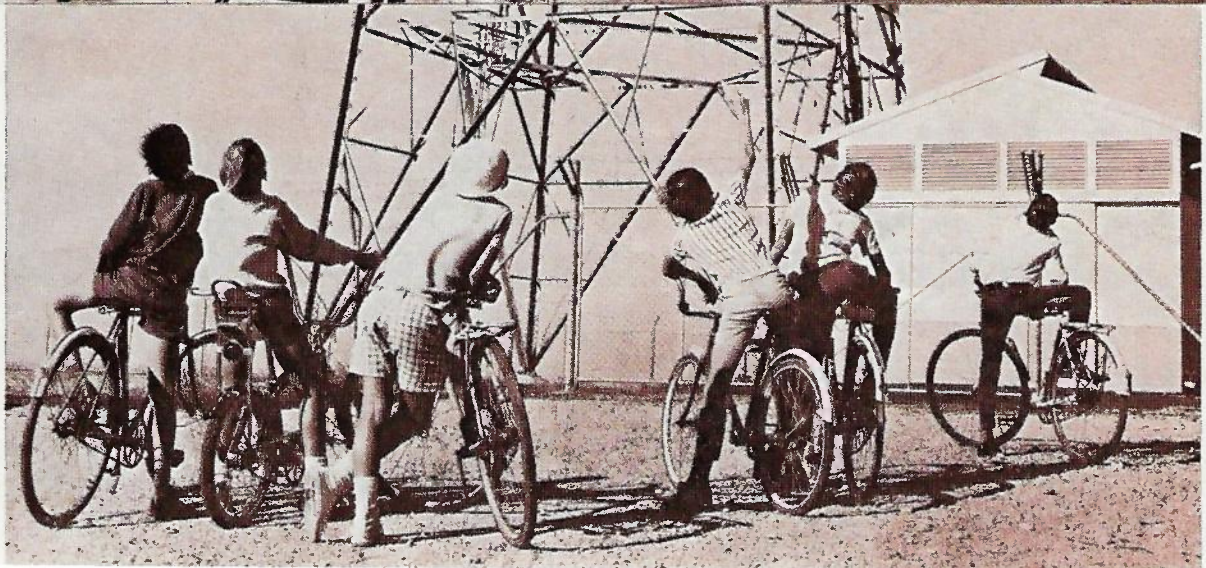
VOL. 21 No.1
FEBRUARY 1971

SPECIAL ISSUE

EAST - WEST MICROWAVE RADIO RELAY SYSTEM







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TELECOMMUNICATION SOCIETY OF AUSTRALIA

THE TELECOMMUNICATION JOURNAL OF AUSTRALIA

VOL. 21 No. 1
FEB. 1971

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Technical News Items

The TELECOMMUNICATION JOURNAL of Australia

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FOREWORD

THIS issue of the Journal records the latest chapter in the development of communications on the East-West route.

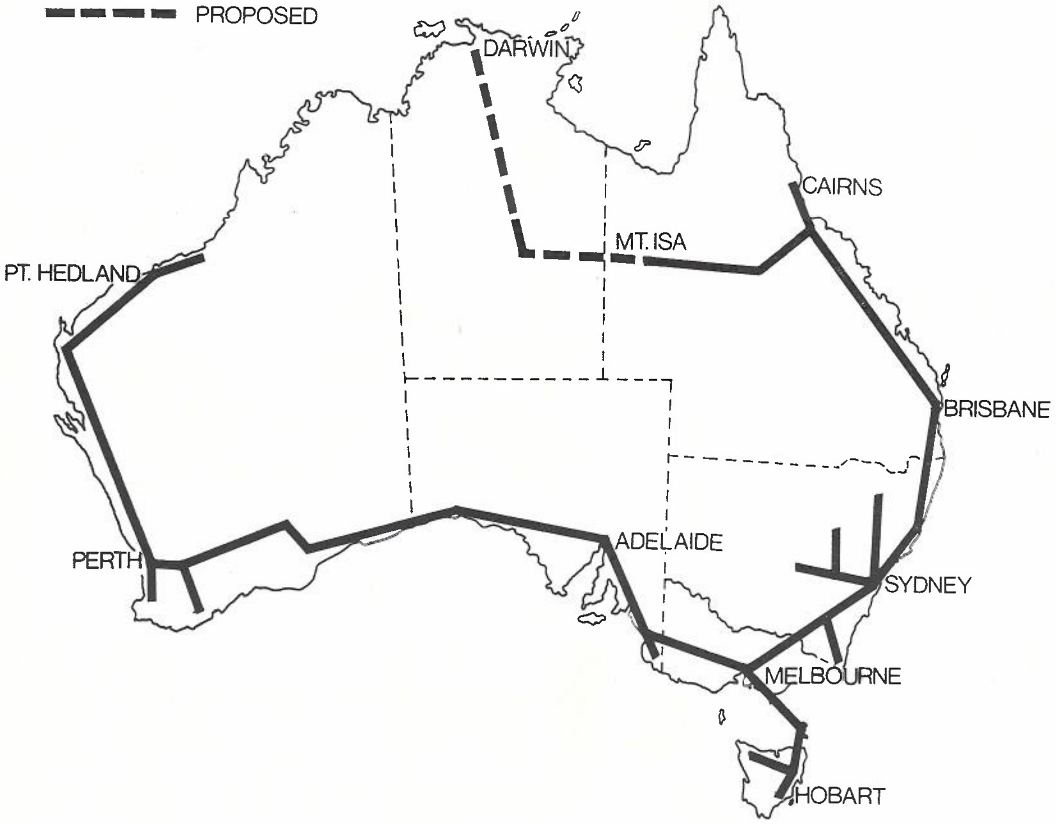
A single telegraph line in the 1870's, a few telephone circuits in the 1930's, and now a 600 channel microwave bearer; these steps outline the ever increasing demands and the ever changing technology of communications.

Although the East-West microwave system is the largest broadband project to be undertaken by the Post Office, its real significance lies in the linking of the broadband networks of Western Australia and the Eastern States and in the many areas of original engineering work which were carried through to overcome the very real difficulties of an inhospitable terrain. It is worthy of mention that apart from station batteries, all other main items of plant were designed and developed to meet the requirements of the route. The extent of this work will be apparent from the specialist articles devoted to each particular activity.

Such is the rate of technological change that already some of the innovations adopted for the new system have become commonplace; such is the nature of engineering that some problems on the route have yet to be completely solved; such is the continuing demand for circuits that engineers are already working out designs for the next system — for the next chapter of the East-West saga.

To place the project in perspective, it is necessary to recall the rate of development of the Australian Broadband network. Beginning with the 550 mile Sydney-Melbourne Coaxial Cable project comenced in 1956, the network was added to by the Melbourne-Bendigo radio system in 1960, by the 1560 mile SEACOM radio and cable system and the 500 mile Melbourne-Adelaide radio system in 1966, and by the Perth-Carnarvon-Port Hedland cable system which will be completed later this year. The Townsville-Darwin radio system has reached Mt Isa and will be completed in about three years. Port Hedland-Darwin is now the only remaining gap in the complete broadband encirclement of Australia. The map below outlines the present stage of the broadband network.

The Journal has featured the earlier projects as they have occurred and now presents details of the largest of the broadband projects — the Adelaide-Perth radio relay system.



THE PRIME CONTRACTOR'S ROLE IN PROJECT MANAGEMENT

*R. W. RICHARDS AND J. DONOVAN**

INTRODUCTION

In any large project there is much liaison and co-ordination effort required on equipment and services which are not normally part of a prime contractor's manufacturing capability, but nevertheless form part of his contractual responsibility. GEC-AEI Telecommunications Limited (the UK-based company responsible for the telecommunications activities of The General Electric Company Limited, of England) was well equipped to act as the essential keystone vital to the success of any large telecommunications project. The East-West system is a typical application of this expertise.

A UK-based project management team, unique to the project, was appointed as soon as the 'Invitation to Tender' was issued, and later supplemented by a Melbourne-based team to ensure maximum communication between customer and suppliers. This article presents the scope of the problem and illustrates the means subsequently used to co-ordinate all aspects of the Contract. Particular reference is made to one contractual responsibility; that of training A.P.O. engineers and technicians in the operation and maintenance of the advanced and sophisticated all-semiconductored equipment supplied.

THE INVITATION TO TENDER

GEC (Australia) Pty Ltd was one of 28 companies invited to tender for the 2400 km (1500 mile) Northam to Port Pirie Microwave radio system for trunk-telephone and television transmission (Fig. 1). The 60-hop system was to provide 1 + 1 bothway 600-circuit telephony bearers between Northam and Port Pirie, capable of carrying television over the standby channel on an occasional basis. A unidirectional television channel was required between Northam and Kalgoorlie. In addition, 'wayside' telephone channels were to be provided for settlements along the Eyre Highway. The requirement for space diversity operation over particularly difficult sections of the route was known, although the details were finalized later. The invitation to tender also

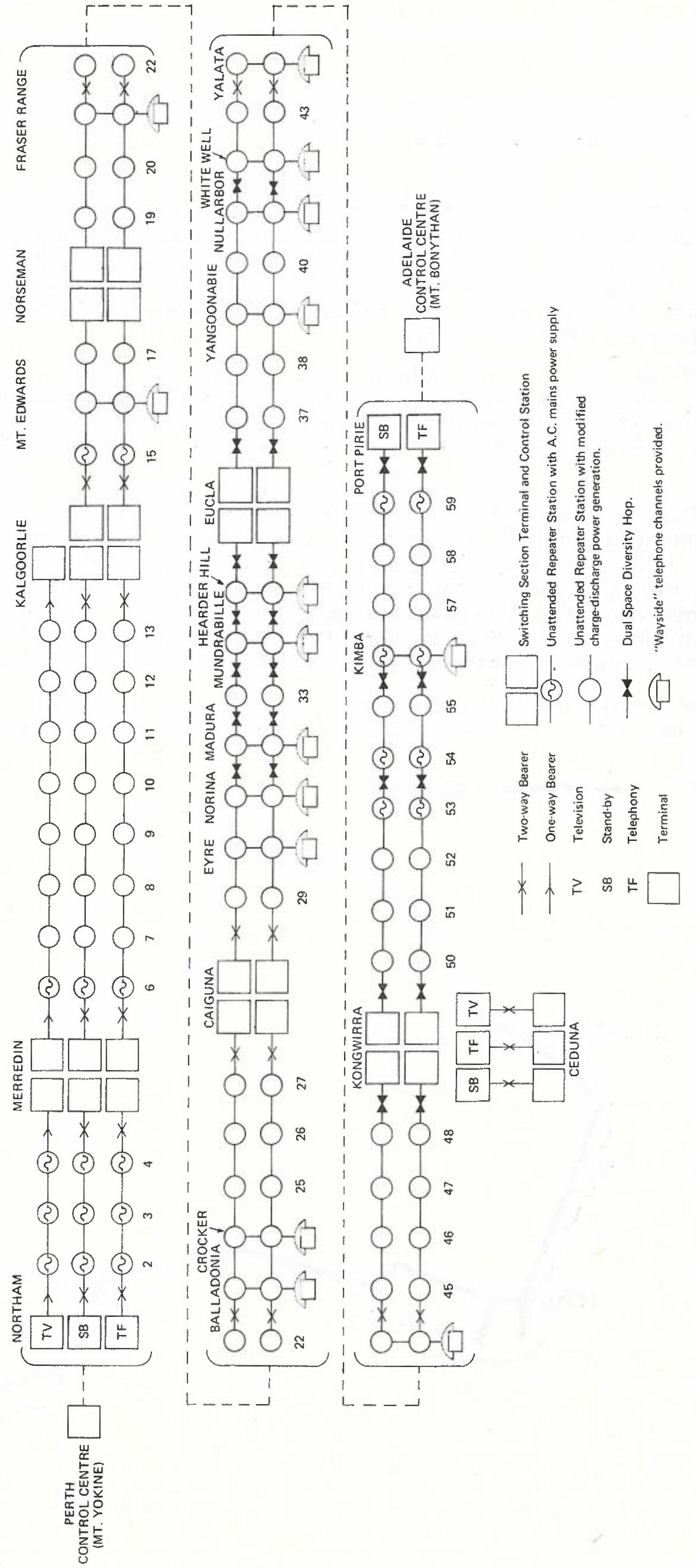


Fig. 1 — Simplified Route Plan

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* Mr Richards is U.K. Project Manager and Mr Donovan is Australian Project Manager, East-West Project, for GEC-AEI Telecommunications Ltd, England.

specified the requirements for shelter and tower foundations, towers, equipment shelters for 51 unattended repeater stations, power-generation plant, antennae and feeders, and the supervisory and control scheme to be operated from control centres near Perth and Adelaide; intermediate control and switching stations were to be provided at Merredin, Kalgoorlie, Norseman, Caiguna, Eucla, and Kongwirra.

1 + 2 bothway telephony and television bearers between the satellite earth station at Ceduna and the adjacent intermediate control station at Kongwirra were added later.

The system had to take into account future expansion of the system up to a maximum of 6 radio bearers in each direction. For example, this influenced the shelter, tower and power generation considerations.

In addition to the technical requirements, the invitation to tender offered a wealth of information on the environment and discussed the problems with which a contractor was likely to be faced, and formed a sound foundation for the resulting tender.

PRE-TENDER INVESTIGATIONS

GEC (Australia) Pty Ltd enlisted the aid of GEC-AEI Telecommunications Ltd, who accepted responsibility for preparing a tender for submission to the A.P.O.

As soon as the invitation to tender was issued a project manager and a team of systems-planning, contract-engineering, and installation and commissioning experts, who were responsible for the complete preparation of the tender working in close cooperation with their colleagues in the Australian company, were appointed.

GEC experts visited Australia to make a comprehensive appraisal of potential subcontractors needed for the supply of ancillary equipment. Due account was taken of the local expertise that would be required, as well as transport considerations and freight economy, and it was decided that towers, shelters, and prime-power generation equipment should be manufactured in Australia. The team of experts also visited the repeater sites proposed by the A.P.O. to elaborate on the information provided in the invitation to tender, thus giving first-hand knowledge of site-access, environmental, and logistics problems.

Information obtained during the investigations, and from concurrent discussions with the A.P.O., was fed back to the U.K. for inclusion in the GEC proposals.

The project team was responsible for the collation of all incoming information and for the co-ordination of all the design and development activities. It was also responsible for co-ordination and liaison between all internal departments, subcontractors, the GEC teams in Australia, and the customer.

As an example of the co-ordination problem involved, it became obvious that all means possible would have to be used to reduce the overall prime power requirement, with minimum degradation of system performance. A.C. mains supply is not available at most of the unattended repeater stations, and these stations would normally be totally dependent on diesel generators. The route is effectively only accessible from the ends, therefore fuel transport costs are high. These factors led to the proposal of a low-power consumption version of the GEC 2 GHz radio system in which the total power consumption of a 1 + 1 bothway unattended repeater, with subtrafficband access, was reduced to about 500 W. This drastically altered the approach to shelter and power-generation design and gave rise to the shelter design that did not need powered equipment to control its environment and the modified charge-discharge system of power generation, the principles of which are described in individual articles.

Thus it will be appreciated that the early appointment of a centralized management team, can provide invaluable liaison and co-ordination between customer and suppliers.

Shortly before the tender was submitted by GEC (Australia) Pty Ltd, the project manager visited Melbourne to co-ordinate the activities of potential subcontractors and compile the comprehensive tender documents.

POST-CONTRACT ORGANIZATION

GEC retained two design consultants, Ove Arup and Partners for towers and foundations, and D. S. Thomas and Partners for the equipment shelters. The companies to whom GEC awarded the various subcontracts were Electric Power Transmission Pty Ltd for foundations and towers, Signal Industries Pty Ltd for equipment shelters, McColl Electric Works Pty Ltd for power equipment, and Andrews Antennas Pty Ltd for antennae and waveguide.

A team was set up in Australia, based in Melbourne, to prepare detailed information on such matters as station layout, site and foreground clearance. The role of the U.K. project management team changed from one of contract negotiation to one of co-ordination of design, manufacture, and supply. At this stage, the final format of the project management teams came into operation. A simplified liaison-path diagram of the Anglo-Australian partnership set up by the company is shown in **Fig. 2.**

The Project Manager in the U.K. had to ensure that each factory department, and U.K. supplier, received sufficient information on planning and progress associated with both U.K. and Australian phases of the project in order that all the committments could be met. He was also responsible for the commercial decisions necessary to maintain close control over the project. He was able to draw on the specialist expertise available at Coventry.

The GEC Project Manager at Melbourne, assisted by a project co-ordinator, was responsible for the co-ordination of all aspects of the project in Australia. Their team included a financial controller, specialist project engineers, field contract controller, sub-contractor's factory inspectors, and field surveillance engineers. The respective responsibilities are shown in Fig. 3.

COMMUNICATIONS

Telex and telephone communications were maintained between the UK-based GEC company, the Melbourne office, the field contract-control office (initially in Adelaide, later moved to Perth), and the field support centres at Ceduna and Northam (later moved to Norseman).

An appraisal of existing means of communication along the route indicated that the increased telephone activity would not overload the local public telephone network at the end sections, but that the public system would not cope on the centre section — the only communication with Eucla was a single-wire earth-return circuit which followed the original telegraph route of 1875.

These facilities were augmented by a temporary HF mobile radio network with base stations at the two field support centres and 21 mobile sets for the teams.

As each microwave radio-relay station became operational, additional communication was provided back to the terminal stations via the supervisory engineers' order wire circuit.

TRAINING

The contract included comprehensive instruction on all aspects of the system and its constituent equipments for the 45 A.P.O. maintenance technicians who were to be assigned to the route. A training establishment was set up at Whyalla (station 59) to

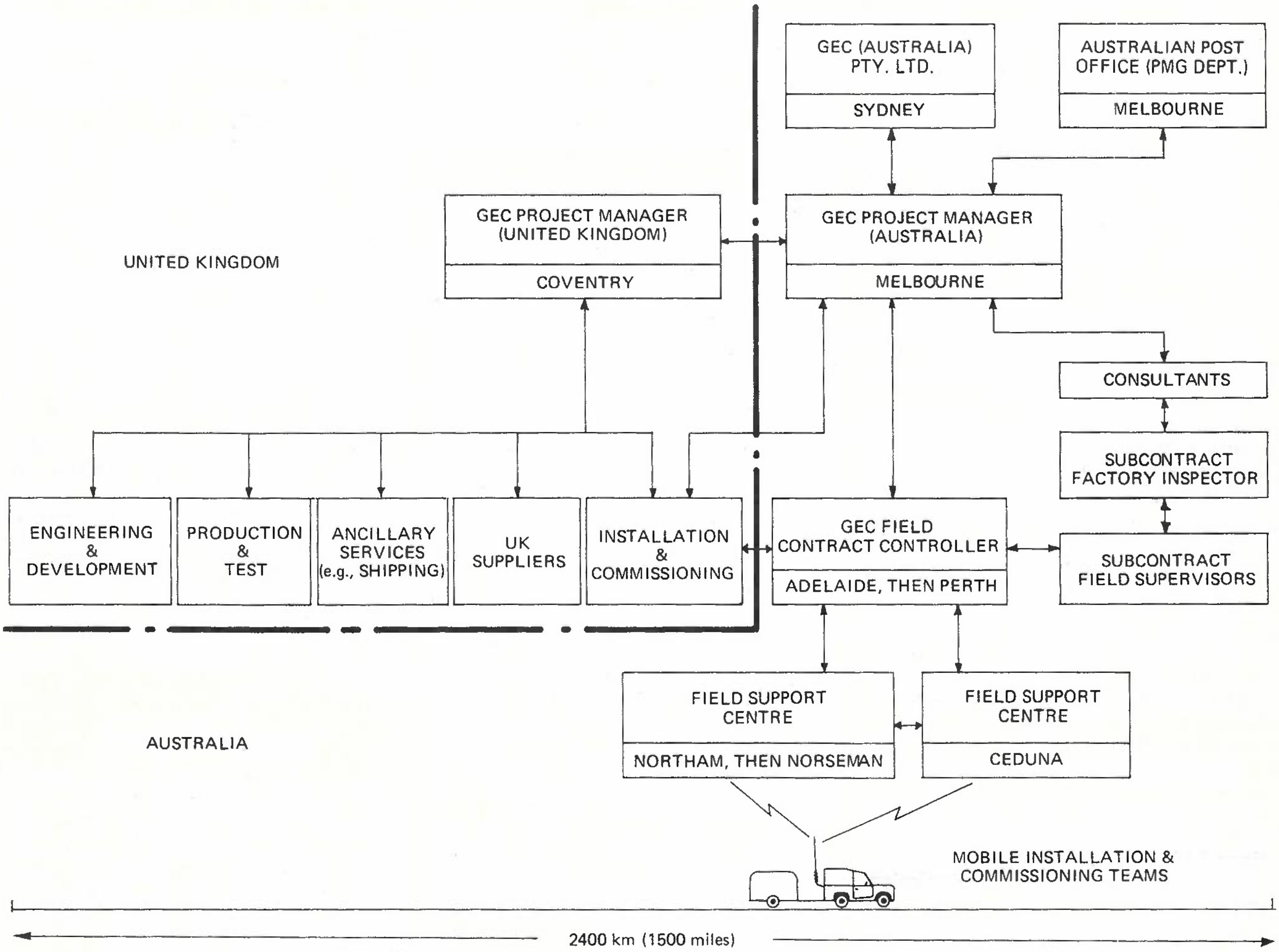
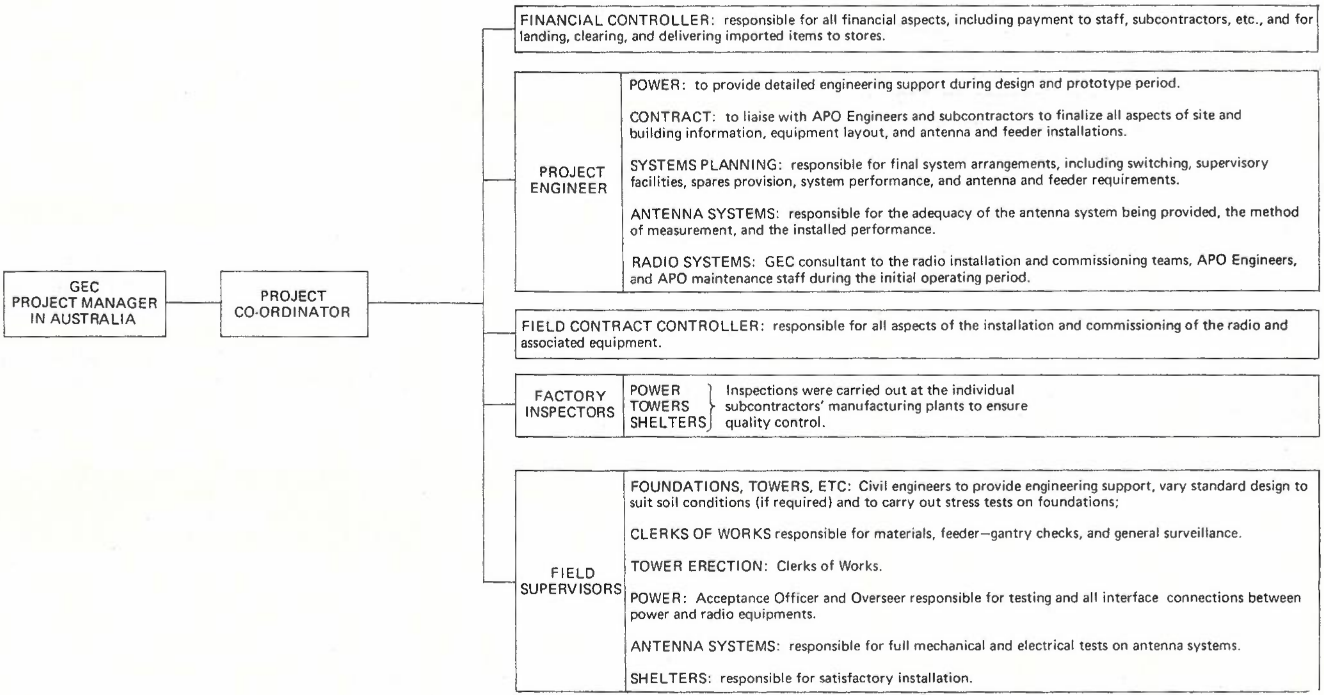


Fig. 2 — Simplified Liaison-Path Diagram of Project Organisation



FINANCIAL CONTROLLER: responsible for all financial aspects, including payment to staff, subcontractors, etc., and for landing, clearing, and delivering imported items to stores.

POWER: to provide detailed engineering support during design and prototype period.

CONTRACT: to liaise with APO Engineers and subcontractors to finalize all aspects of site and building information, equipment layout, and antenna and feeder installations.

SYSTEMS PLANNING: responsible for final system arrangements, including switching, supervisory facilities, spares provision, system performance, and antenna and feeder requirements.

ANTENNA SYSTEMS: responsible for the adequacy of the antenna system being provided, the method of measurement, and the installed performance.

RADIO SYSTEMS: GEC consultant to the radio installation and commissioning teams, APO Engineers, and APO maintenance staff during the initial operating period.

FIELD CONTRACT CONTROLLER: responsible for all aspects of the installation and commissioning of the radio and associated equipment.

POWER
TOWERS
SHELTERS

Inspections were carried out at the individual subcontractors' manufacturing plants to ensure quality control.

FOUNDATIONS, TOWERS, ETC: Civil engineers to provide engineering support, vary standard design to suit soil conditions (if required) and to carry out stress tests on foundations;

CLERKS OF WORKS responsible for materials, feeder—gantry checks, and general surveillance.

TOWER ERECTION: Clerks of Works.

POWER: Acceptance Officer and Overseer responsible for testing and all interface connections between power and radio equipments.

ANTENNA SYSTEMS: responsible for full mechanical and electrical tests on antenna systems.

SHELTERS: responsible for satisfactory installation.

Fig. 3 — Project Management Organisation in Australia

simulate a switching-section terminal, and provision was made to transmit to the next repeater along the route (Broadbents Hill) and back. GEC specialists, in co-operation with A.P.O. training officers, conducted two four-week courses in the theoretical and practical aspects of the system, its operation, and its maintenance. Instruction on the power equipment was given by McColl Electric engineers.

CONCLUSION

The article has illustrated one means of contract co-ordination employed by a company that has experience of 'turnkey' contracts in many parts of the world. The diverse requirements of the contract, the high locally manufactured content, and the long distance between prime contractor and customer indicated that best co-ordination would be obtained by appointing two Project Managers, one in the United Kingdom and the other in Australia, with equal general authority but each with overriding authority in his own sphere of activities. This, in conjunction with the tightly knit communications complex between all teams, ensured smooth continuity from the Invitation to Tender stage to the hand over of the complete system to the A.P.O.

TECHNICAL NEWS ITEM

NEW A.P.O. TRAINING COURSES

In April 1970, a decision was taken in conjunction with the Public Service Board and other interested Departments to introduce a completely new tradesman/sub-professional technical staffing structure in the A.P.O. The change took place on 1 December 1970, when the classifications of Technicians Assistant, Technician (Telecommunications), Senior Technician and Supervising Technician, were replaced by new classifications of Telecommunications Assistant, Telecommunications Tradesman, Telecommunications Technician, and Telecommunications Technical Officer.

Following the decision, the design and establishment of new courses of training for the tradesman and sub-professional classifications were commenced. Also, Eligibility Test qualifications for officers to gain entry to the sub-professional Telecommunications Technical Officer grade are being prescribed and the test papers prepared.

Trainees for the sub-professional Telecommunications Technical Officer classification are designated Telecommunications Trainees and their course of training comprises a four year part-time course at an Institute of Technology or Technical College, leading to qualification at the level of the New South Wales Department of Technical Education Certificate, together with in-house training and on-the-job training and experience. On completing the course, trainees will be advanced as Telecommunications Technician pending the accumulation of the required six years experience, including training, before they are advanced as Telecommunications Technical Officer.

Present qualified Technicians (Telecommunications), are translated to the vestibule and holding grade classification of Telecommunications Technician on 1 December 1970. Present Technicians-in-Training will complete their courses in the normal manner and be advanced as Telecommunications Technician. They, and the qualified Technicians, will have the opportunity to qualify as sub-professional Telecommunications Technical Officers, either by transfer to the Telecommunications Trainee course or by passing an Eligibility Test.

Trainees for Telecommunications Tradesmen are designated Apprentice Telecommunications Tradesmen and they undertake a four year course which places greater emphasis on the development of manipulative skills than the previous Technician-in-Training course; however, an adequate level of theoretical instruction will be retained. All of the training for this course will normally be provided within the Department, either in the training schools, in field annexes, or in operational field Divisions.

A.P.O. PROJECT MANAGEMENT

D. S. ROBERTS, M.I.E. (Aust.) and S. M. PUGH, C. Eng. M.I.E.E., M.I.E. (Aust.), M.I.N.E.***

INTRODUCTION.

Telephone density per head of population in Australia has been growing steadily at a rate of five or six per cent. per annum for several decades. Fifty years ago there were four telephones for every hundred people; now with 2.75 million phones in use, the density is thirty per hundred. This rate of growth has, however, begun to increase of late years, particularly in the field of long-distance telephony. During the past three years, rate of growth of the long-distance network has increased from six to eight per cent. per annum to twelve to fifteen per cent. p.a. International calls from Australia have increased at an even more rapid rate; the rate of increase here is now 25 per cent. p.a.

Computer data transmission is also becoming increasingly important. It is estimated that this field will increase by a factor of ten during the years 1969-1974.

Because of this rapid growth in traffic, and particularly in view of the recent increase in rate of growth, it became evident that a new East-West link would soon be essential for Australian communications. A broadband microwave link was decided upon as being the best solution, and early in 1966 route survey work began.

This East-West link (Fig. 1), now in operation, is one of the longest in existence, and is a major undertaking by world standards, particularly in view of the nature of much of the terrain. Sixty steel towers, up to 250 feet high, with associated repeater stations and equipment, stretch over 1427 miles of arid country from Northam in Western Australia to Port Pirie in South Australia. The prime contractor was G.E.C. - A.E.I. (Aust.) Pty. Ltd., operating under the close supervision of A.P.O. engineers.

ROLE OF HEADQUARTERS.

During 1966 a Division, headed by an Engineer Class 3, was set up in A.P.O. Headquarters, Melbourne, to manage the engineering programme (Fig. 2) for the project, and on 25th August, 1966, the inaugural East West Project Engineering Co-ordination meeting was held.

The objects of the co-ordination group were defined at this meeting and are summarised as follows:—

> 'Although the final contract, when it is negotiated, will specify exact details of the facilities to be provided and the target dates for completion of the various sections of the work by the contractor, there will remain a continuing need for close co-operation and co-ordination between the A.P.O. staffs involved in the project at Central Office and in the two States concerned.
>
> 'To ensure that this co-ordination is effectively accomplished over the period of the project, a co-ordina-

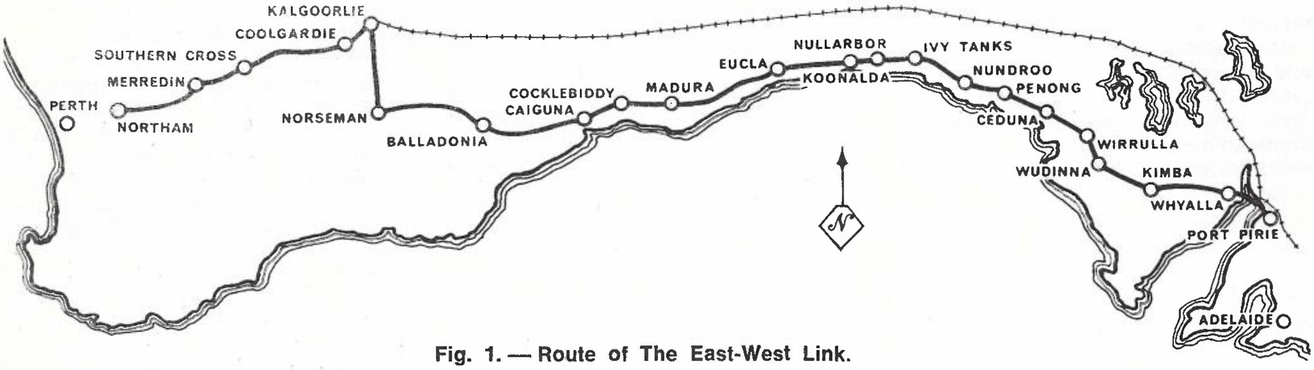


Fig. 1. — Route of The East-West Link.

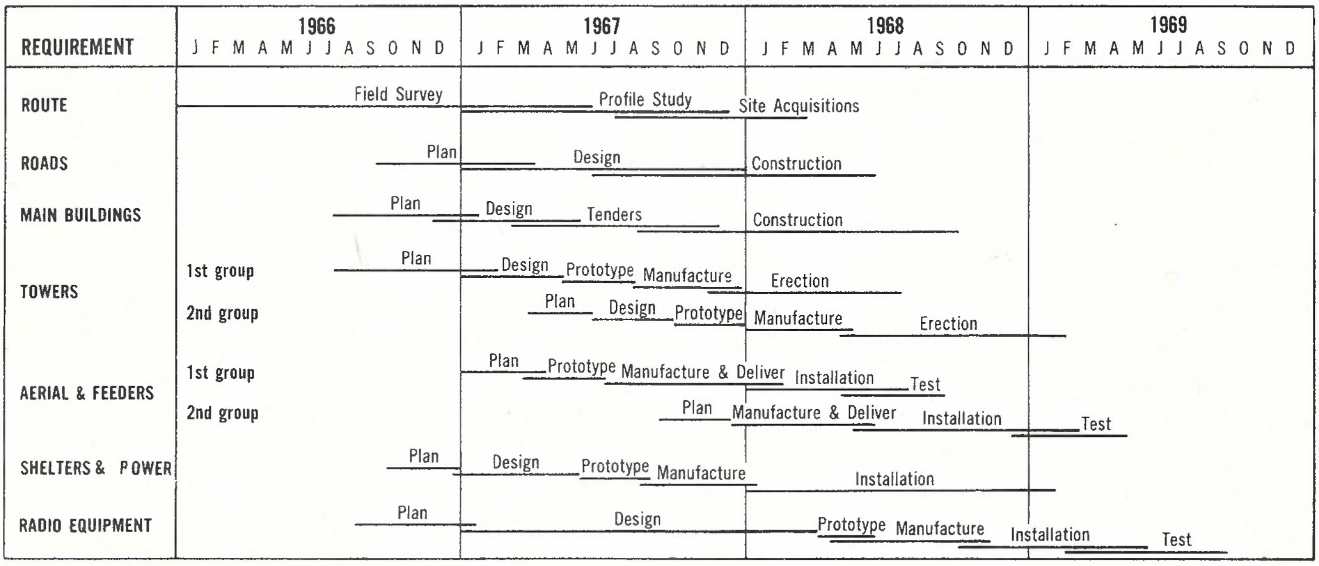


Fig. 2. — Engineering Programme.

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* Mr. Roberts is East-West Project Engineer Headquarters.

** Mr. Pugh is East-West Project Field Engineer, Western Australia.

> tion group has been set up comprising representatives of the various Central Office sections concerned, with the assistance, as required, of representatives from South Australia and Western Australia.
>
> 'The function of this group is to report, on a two-monthly basis, on progress made with the project, highlighting any difficulties which are endangering the achievement of the target dates.
>
> 'The project is conceived as a package deal with minimum Departmental involvement in the supply and installation of equipment. Extensive A.P.O. involvement, however, will be necessary in regard to liaison with the contractor and inspection of equipment and work.'

It was within this framework that sub-sections in South Australia and Western Australia were created with the express intention of carrying out inspection duties on behalf of the A.P.O.

The following extracts from a co-ordination report indicate the problems considered at a typical co-ordination meeting. Representatives were present at this, the sixteenth meeting, from:

Engineering Works Division (Long Line Equipment and Radio Sections);
Engineering Division, South Australia;
Engineering Division, Western Australia;
Public Relations;
Administrative Section:
Services Section (Mechanical and Electrical, Drafting Section);
Planning Branch (Transmission and Line);
Supply Branch;
Finance and Accounting Branch.

Engineering Co-ordination — Report No. 16.

Introduction.—The sixteenth meeting of the group set up to co-ordinate the Departmental aspects of the East-West project was held in the Headquarters Engineering Works conference room in the Parkade Building, Melbourne, on 19th November, 1968.

Summary. — Satisfactory progress is being made with the project, although four areas must be watched carefully to avoid further delays which would be critical:

The Western Australian Police Department prohibition of the long transport vehicle for the shelters has delayed the installation of shelters in W.A. New vehicles are being arranged and the installation is expected to proceed without jeopardising the completion date of the project.

The tightening up of the G.E.C. timetable is giving less and less opportunity for the A.P.O. acceptance tests to be completed to the timetable; there is a danger that this factor alone could delay the 'in-traffic' date by up to six weeks. The problem is dependent upon the efficient scheduling of acceptance tests and this is in hand in the Headquarters Radio Section in negotiation with G.E.C.

The provision of A.P.O. staff housing at Ceduna is falling behind the planned programme and is causing concern to South Australia. Houses are not now expected until July, 1969, and this is

TABLE 1: ESTIMATED COSTS.

Item.	Estimated Cost as at 28.3.68.		Estimated Cost as at 11.11.68.	
	$ Million.		$ Million.	
Survey Contract		0.08		0.125
G.E.C. Contract				
Radio Eqpt. (incl. antenna systems)	2.60		2.66	
Radio spare parts	0.23		0.30	
Radio installation	0.47		0.48	
Project management	0.34		0.34	
Towers (erected)	2.74		2.74	
Power (installed)	1.16		1.18	
Power spare parts	0.04		0.04	
Shelters (installed on site)	0.84		0.84	
Earlier completion date for project	0.14		0.14	
Fencing	0.11		0.11	
Earthing	0.04		0.04	
Sub-total		8.71		8.95
Test Equipment Contracts		0.30		0.32
Associated Radio Costs				
Departmental labour (mostly supervisory and testing)	0.14		0.14	
Incidentals	0.03		0.03	
Stores Administration 1%	0.09		0.09	
Sub-total		0.26		0.26
Contingencies		0.21		0.03
Complementary Works				
Cable tails	0.02		0.02	
Carrier (broadband) equipment	0.51		0.51	
Sites and roads	0.74		0.74	
Buildings (5 Terminal, 1 Repeater)	0.372		0.372	
Residences (4)	0.128		0.128	
Mains Power	0.068		0.068	
Sub-total		1.838		1.838
TOTAL		11.398		11.443

inconvenient, as staff will be brought into the area in January, 1969. Works Programming and Building Sub-section will approach the Department of Works to arrange to have the housing completed by March, 1969, if possible.

The A.P.O. has advised O.T.C. that the earliest possible completion date for the ground station is September, 1969. However, to meet this target the A.P.O. would have to forego testing of the Port Pirie - Kongwirra system, thus invalidating equipment guarantees and jeopardising the performance of the whole system. September, 1969, is not therefore considered to be a suitable date for handing over circuits to O.T.C.

Planning.

Master Plan. The W.A. Telecommunications Division is forwarding a slightly altered plan for the wayside circuits through Headquarters, Telecommunications Division within the next few weeks. The new proposal is along the same lines as before with a slightly different circuit arrangement for Eucla.

Emergency Transportable System. —Discussions were held with G.E.C., who are preparing a quote this month. Headquarters Radio Section looked into the possibilities of obtaining quotes from other companies because of the probable 12-month delay in the delivery of the G.E.C. equipment, but as the G.E.C. equipment is very suitable for the purpose and uses spares already being provided, it represents the most satisfactory solution.

Funds Allocation. A new expenditure sheet is attached (see Table 1). It shows increases in costs of radio equipment, spares and installation with towers, power and the remainder approximately the same. The total cost is now estimated as $11.5 m.

Progress with Project.

Radio Bearer

Propagation Tests: The tests have been completed and the analysis is awaited.

A.P.O. Buildings: The buildings in S.A. are now complete with the Whyalla building having been handed over. The W.A. buildings are now all completed.

Shelters: All 21 shelters in S.A. are now complete, but no shelters have been completed in W.A. because of recent bushfires and the fact that the long Sigal transport vehicle is not permitted on W.A. roads. G.E.C. and the sub-contractors were warned of road limitations very early in the project, so that the present difficulty should not have arisen. Departmental representatives (including Supply Branch) have negotiated with the W.A. Police, but without succeeding in having the ban lifted. The delay in shelters may have an effect on power plant production. New transport arrangements are being made and the first shelter should be completed at Site No. 2 on 12th January, 1969. From that date the shelters should be installed at the rate of one every three days until completion.

Roads: All roads in W.A. and S.A. have been completed and are satisfactory to carry all traffic, but some minor repairs are needed in both States. Repairs in W.A. should be completed by April, 1969, and repairs in S.A. are in progress.

Mains Power: Mains power is now available on all sites in S.A. and W.A., with the exception of Alan Hill (W.A.), which will be completed in February, 1969.

Power Supply Equipment: All S.A. installations except one will be completed by Christmas, 1968, except for wind generators. Eighteen wind generators have been delivered, but only three have been accepted and some have been rejected because of minor component faults. In W.A. installation can be kept to schedule if the shelters come forward at the rate of one every three days as now programmed.

Radio and Supervisory Equipment: The two-month formal testing period of the prototype equipment has elapsed and the first part of the A.P.O. laboratory report on assessment of performance has been issued. Environmental testing by the A.P.O. will commence within a few days and will continue over the next few weeks. Overall, the tests have gone very well with the stability of the equipment being most encouraging. Headquarters would like to retain the equipment until the end of December, if possible, but would make it available for delivery to S.A. for training purposes by mid-December if necessary.

G.E.C. have notified that factory testing in the U.K. will be about two months late, and a firm statement is being awaited from G.E.C., defining the precise date for factory testing, and the effect of the delay on the completion date.

There may be a serious situation developing in regard to field acceptance testing and overall testing of the systems. An acceptance testing specification is currently being negotiated with G.E.C. and it is not yet clear whether the A.P.O tests will be purely supplementary to the G.E.C. commissioning tests or whether some of the G.E.C. tests will have to be repeated. In any case, the tightening up of the G.E.C. timetable is giving less and less opportunity for the A.P.O. tests to be completed to the timetable. There is a danger that this factor alone could extend the 'in traffic' date by up to six weeks. The problem is dependent upon the efficient scheduling of acceptance tests and this is in hand in the A.P.O. Radio Section in negotiation with G.E.C.

Towers: All towers in S.A. have been completed. In W.A. 24 towers have been completed, and seven remain to be constructed, although all foundations have been completed and steel has been delivered. The antenna and feeder programme has been further delayed because of aerial problems; but the situation is now under control.

Long Line Equipment. Event charts have been received from both States showing the installation programme for the carrier equipment. There are no problems in this area.

Cables. No change; installation should be completed in Kalgoorlie between January and February, 1969, and in Norseman by March, 1969.

Vehicles. The prototype unit transit case will be shock and vibration tested in Sydney next week. Word has been received from the States that some units may have to be transported by rail or in various road vehicles not properly equipped for the purpose. This could lead to shock and vibration damage, and W.A., S.A. and Headquarters will confer on this problem.

Contractor Negotiations. G.E.C. still expect to meet the target date (August 31st), but they are becoming harder pressed for time. G.E.C. are now due to produce a revised programme following advice of delays in factory acceptance testing.

Summary. Target Date: The present target date (completion 31.8.1969, and 'in service' 30.11.1969) still applies, subject to the awaited notification from G.E.C. as above.

P.E.R.T. Diagram: A new edition of Drawing CSK.8434 has been prepared.

System Ends (Perth-Northam, Port Pirie-Adelaide).

Carrier Equipment. There are no problems at this stage. In W.A. the video-on-cable arrangements are in hand with L.L.E., who consider that there are no difficulties.

Cable Tails. No problems.

Radio Bearers. Bakewell-Northam T.V. depends upon delivery of the Katanning contract, which is due in February or March, 1969, and which should be satisfactory. S.A. is awaiting Siemens' confirmation of the delivery of modems and switching equipment for the Adelaide-Port Pirie system, which are due in January, 1969, and are necessary to avoid staff overloading in April.

General.

Publicity. A cine and photographic coverage was carried out for three weeks in the field in October, 1968, and many black and white photographs, colour photographs and transparencies were taken on construction. Two films are now being edited and should be ready well before the end of 1969. One is a 30-minute sound and colour film for general public viewing and the other is a 15 minute silent film on technical aspects. More filming is to be carried out during the February-March period on the erection of shelters and antennae (the only areas not yet covered). Copies of all photographs will be made available to senior officers in charge of projects. The black and white photographs will also be used for newspaper supplements and the A.P.O. journal.

A three-minute T.V. film of wind generator and antenna research at Mt. Cottrell is being shown on Australia-wide A.B.C. and commercial stations at peak viewing periods.

The A.B.C. have expressed interest in making a 15 to 20 minute T.V. documentary of the East-West project late in 1969 following completion of the O.T.C. earth station at Ceduna.

One hour is to be set aside at the next meeting for the showing of selected slides taken on the recent field coverage.

Power Training. The States' comments have been received and a draft syllabus prepared for the P2 course. The Department will participate with G.E.C. in the lecturing. S.A. will place an amount on the programme for the purchase of the prototype equipment for use as a training medium when it becomes available.

Staffing Proposals. W.A. are reorganising their staff proposals following the decisions to move the repair centre back to Perth. Staff has been selected in S.A.

Staff Accommodation. In W.A. all housing is complete at Merredin and Norseman, and no problems are foreseen. In S.A. the present situation will cause some difficulties. On present planning, tenders will not be called until March, 1969, which means that the houses will not be complete until July, 1969. As staff will be brought into the area in January, 1969, the Works Programming and Building Subsection will approach the Department of Works to see if housing can be completed much sooner, preferably March, 1969. (Note: Information available since the meeting reveals that the delay in the programme occurred in Engineering Division, S.A., and arose out of an economic study of several alternative methods of provision.)

Other Business.

Satellite Ground Station at Ceduna. An answer from G.E.C. is still awaited with regard to the installation of the ground station link. The A.P.O. has advised O.T.C that the earliest possible completion date for the ground station is September, 1969, but this target could not be met unless the Department was to forego the testing of the Pt. Pirie-Kongwirra system.

Northam-Port Pirie Proposed Signal Strength and Noise Performance Measurements. The report on the proposed measurements has now been forwarded to the States, and has been changed considerably from the previous proposal, reducing the amount of work to be carried out.

Fire Protection at Unattended Buildings. The absence of fences leaves the shelters exposed to flaming wind-blown tumbleweeds at the present time, but as there is no equipment in the shelters and the shelters themselves are reasonably fireproof, there is no real danger. All blocks are cleared and security fences should be erected in the near future. W.A. has requested advice on who carries the responsibility for loss by fire during the construction phase.

PROPOSALS FOR IN-TRAFFIC MEASUREMENTS.

Introduction.

A.P.O. Headquarters is responsible for engineering the route, specifying antenna heights and space diversity requirements and for estimating the expected propagation behaviour. In the course of this work propagation measurements have been carried out by the Research Branch on selected paths along the route, and the results interpreted and applied by the Radio Section. Outages due to propagation are not covered by the contract and must therefore be held within limits by system design action. From this viewpoint, the system design was based on a target outage time of 0.03 per cent. of the year per bearer, so that for the protected system, it is expected that the outage time due to fading is reduced substantially.

The Northam-Port Pirie radio relay system has been designed to operate with an outage time of not more than 0.1 per cent. of any year. From the design viewpoint, the permissible outage time has been arbitrarily divided into 0.03 per cent., 0.06 per cent. and 0.01 per cent. of any year due to propagation deficiencies, radio equipment failure and power plant failure respectively.

Contractually, the equipment reliability is quoted in terms of a fault rate given in the following table:—

Radio Equipment: 0.14 bearer-outage faults per bearer-site per annum averaged over the whole system.

Switching Equipment: 1 resulting directly in a traffic interruption for the whole system.

Feeders: 1 per annum over the whole system.

Power Plant: Nil resulting in a traffic interruption over the whole system, except at Northam, Merredin and Port Pirie.

Additionally, the system has been designed to meet the noise performance recommended by the C.C.I.R. for 80 per cent. of any month, viz., 3pW/Km. The design was based on guaranteed equipment parameters and a fade of 4dB occurring simultaneously on all paths.

During the two-year guarantee period for the system, it will be necessary to measure the system outage time, the equipment reliability and the system performance (noise level not exceeded for 80 per cent. of any month) to confirm that the specifications for the system are being met.

It is proposed that the system performance be measured using a chart recorder at the two ends of the system (Northam and Port Pirie), whilst the equipment reliability and system outage time will require an analysis of the service reports generated by the Maintenance Control in each section.

Furthermore, it is proposed to obtain a measure of outages due to fading on each path by monitoring the operation of the carrier re-insert facilities.

Proposed Measurements.

Established methods can be applied to the recording of equipment reliability and system outage time, and to the periodical measurement of performance. However, the determination of long-term noise performance of the system requires the statistical analysis of continuous records over at least a 12-month period and preferably over a 15 month period.

In addition to measuring statistical behaviour, a close watch on the system will be necessary to locate any unexpected equipment behaviour and to confirm the adequacy of measures to protect the system against excessive fading.

The only satisfactory method of determining the statistical behaviour of the parameters is to obtain correlated recordings of:

(a) signal strength;
(b) operation of carrier re-insert (muting);
(c) noise on a test slot;
(d) protection switching operation;
(e) link pilot continuity.

However, in order to ease the maintenance requirements which would be imposed by recording signal strength on each path, it is proposed to obtain a measure of fading outages by monitoring the operation of carrier re-insert facilities on one bearer per path. This monitoring could be carried out at the line section control stations (Mt. Yokine and Mt. Bonython), since operation of the carrier re-insertion of each transmitter will appear as an alarm indication via the supervisory system. Where a path is shown to exceed the permissible outage time due to fading, it may become necessary to carry out more detailed investigations by means of signal strength recordings.

It is therefore proposed that the measurements be carried out by using pen recorders applied as follows:—

Propagation Outages. At the two line section control stations (Mt. Yokine and Mt. Bonython), record operation of the carrier re-insert facility (muting) on at least one bearer per path.

Interruptions Due to Equipment.

(i) Overall System:

The following parameters will be monitored at Northam and Port Pirie:

1. Incoming radio system pilot (4287 kHz) (Normal amp.).
2. Incoming radio system Channel Noise (4287 kHz) (Average amp.).
3. Input of ac/dc converter (Normal amp.).
4. Output of ac/dc converter (Normal amp.).
5. Incoming pilot (8.5 MHz)—'Normal' amplifier.
6. Incoming Bearer channel noise (8.5 MHz)—'Average' amplifier (Rectilinear pen):
7. Incoming bearer switching 'Normal' amplifier.
8. Modem switching 'Normal' amplifier.

Note: All pens except for Item 6 are to be curvilinear.

(ii) Bearers (Monitored when faulty sections determined).

1. Incoming system pilot (8.5 MHz). 'Normal' amplifier Curvilinear pen 1.
2. Incoming system pilot (8.5 MHz). 'Average' amplifier. Curvilinear pen 2.
3. Odd and Even Bearer channel noise (3.2 MHz). 'Average' amplifier. Curvilinear pens 3 and 4.
4. Incoming bearer switching. 'Normal' amplifier. Curvilinear pen 5.
5. Incoming signal strength. 'Average' amplifier. Rectilinear pen 6.
6. Modem switching. 'Normal amplifier. Curvilinear pens 7 and 8.

Test Instruments Required.

The test instruments required for this series of measurements are as follows:—

(a) four (4) 20-pen event-type recorders, located at each supervisory centre (Mt. Yokine and Mt. Bonython).
(b) Two (2) eight-pen recorders located at Northam and Port Pirie.
(c) Four (4) noise level meters.

The development and manufacture of some small incidental items which may be necessary for interface problems will be undertaken by the A.P.O. Headquarters Radio Section, with possible assistance from the Melbourne Postal Workshops or the State Administrations.

Analysis of Propagation Outage Recordings.

The examination of chart recordings will be carried out by the A.P.O. State Administrations, so that any immediately apparent abnormal system operation can be investigated and, where possible, corrected without delay.

A suggested form of analysis is the examination of six-hourly time blocks on each path and the tabulation for each block of the number of outages and total outage time due to fading. The outage time is to be totalled up on a monthly basis, and the chart recordings and a copy of the tabulations should be forwarded to Headquarters at monthly intervals.

Recording of System Performance.

General: All equipment chart recordings will be run at a speed of one inch per hour. At this speed, interruptions of one m.sec. will be clearly seen when the pen amplifier is set to 'normal,' whilst an interruption of 10 ms will yield a F.S.D. When set to the 'averaging' position, the rise time of the amplifier is slowed so that interruptions in the range 10 ms to 100 ms can be assessed. It should be possible to extend this range to include the 300 ms STD drop out limit by suitably modifying a time constant in the amplifier.

Measurement Programme: The Beckman 8-pen recorders will be installed at Northam and Port Pirie to record overall system outages and mean power in a telephone channel.

This chart recording of system outages is primarily aimed at detecting multiple, short term, interruptions which are caused by equipment factors. Its use will not obviate the need for the reporting of bearer and traffic outages by the usual method of service reporting, but, where practicable, suitable annotations of 'fault-cause' could be made on the chart to facilitate later assessment of the chart.

The recorders will remain at Northam and Port Pirie until a proven record of equipment interruptions has shown the need to 'sectionalise' the trouble. At this stage, then, the parameters 'interruptions due to equipment' set out previously should be recorded.

Analysis of Mean Noise Power Recordings: The analysis of mean noise power recordings will be carried out in each State and the results and charts referred to Headquarters at monthly intervals.

A suggested form of analysis is the examination of discrete time blocks and the evaluation of time below selected levels in these time blocks. At the end of a month, the total time may be summed and converted into a percentage of the total valid recorder time for that month. The mean noise power for any percentage of the month may then be assessed.

Bearer Outages: Should there be a need for 'Bearer' recordings, it may be necessary to consider setting up a small working party to assess the results and consider the action required.

In any case, the number of Bearer-outage faults per bearer site will be derived from the normal service reporting technique and forwarded to Headquarters on a monthly basis.

Summary.

The Headquarters Engineering Branch in Melbourne was responsible for the executive and technical work associated with the establishment of the broadband radio relay system.

These responsibilities included the efficient provision of the radio system in accordance with contracts placed and the approved A.P.O. Works Programme, and co-ordination with all other Departments and Organisations as necessary in matters affecting the provision and commissioning of the radio system.

This office constantly reviewed arrangements proposed by the contractors and prepared recommendations for variations in the material or services to be supplied.

The preparation of detailed specifications for the acceptance of the plant in the factory and in the field, and the development of new or improved testing techniques, were also the responsibility of this Headquarters group.

THE STATE ROLE: WESTERN AUSTRALIA.

Consideration was given to the management of the field aspects of the East-West project in Western Australia and following a submission to the Public Service Board, an East-West

Broadband Radio Bearer Sub-Section was created in February, 1967.

During December, 1966, information concerning the G.E.C. Central Management and Field Organisation for this project was received, and in February, 1967, a tentative programme of work was received from the main contractor. It was then possible to assess the duties and responsibilities of inspectors and the task of obtaining positions for inspection staff was commenced.

In October, 1967, the decision was taken to call for applications from interested officers with a view to the selected applicants transferring to maintenance after the commencing of the system.

The final establishment was as follows:—

Head Office, Western Australia:
- 1 Engineer Class 3.
- 1 Divisional Clerk (Class 4).

Field Staff, Western Australia:
- 1 Supervising Technician Grade 2.
- 2 Supervising Technician Grade 1.
- 10 Senior Technicians.
- 1 Line Foreman Grade 2.

With the addition of a position of Engineer Class 1 on and from September 1, 1969.

The duties of the above staff were basically the overseeing of contractual performance and the acceptance testing on behalf of the Department of all material supplied and equipment installed by the contractor. The Engineer Class 3 was responsible for all field engineering aspects of the system in W.A. relating to roads and buildings, and the oversight of contractual performance of plant installation and commissioning.

The Supervising Technicians Grades 1 and 2 were responsible for ensuring that all material supplied and equipment installed (e.g., radio and supervisory equipment, shelters, power plant, waveguides and antennae) conformed to Departmental standards; they were also responsible for acceptance testing on behalf of the Department of all equipment installed by the contractor. They prepared and submitted to their immediate superior, the Engineer Class 3, interim and final reports on all inspections and acceptance tests and supervised and directed subordinate staff. Under limited supervision, similar duties and responsibilities were carried out by the Senior Technicians. Interim and final reports by the Senior Technicians on inspections and acceptance tests were submitted to the Supervising Technician. It was also part of the duties of the Supervising and Senior Technicians to undertake familiarisation studies of all equipment for future maintenance purposes.

The duties of the Line Foreman Grade 2 were chiefly concerned with inspecting foundation, shelter, and tower constructions to ensure that the standards of workmanship were in accord with the Department's requirements and that general layout, site plans and tower erection were in conformity with specifications and Departmental drawings. Samples of concrete and other materials were taken as specified and submitted for analysis.

Because of the complexity of the work involved, it was considered that a Clerk of Class 4 classification was required. The Divisional Clerk was required to assist the Divisional Engineer in the areas of finance, progress information, material supply and accounting, staff dispositions, accommodation and transport. Since the staff were widely separated geographically, the Divisional Clerk was involved in much extra work in the co-ordination of personnel and in arranging salaries, travel warrants, travelling allowance claims, etc.

Arrangements were made for technical staff to attend unit courses at the Technician's School prior to joining the sub-section, and also to receive training at Whyalla in South Australia at courses run by the G.E.C. on power plant and radio equipment peculiar to the project.

In addition, one of the Supervising Technicians spent several months at the A.P.O. Radio Lab., Melbourne, carrying out tests on the prototype equipment as a member of the combined C.O.-W.A.-S.A. team.

The courses at Whyalla, S.A., were also attended by staff from the Technicians' School, Central (Country) Division, and Building Engineering Service. Arrangements were made for A.P.O. staff to work for the G.E.C. to gain practical installation experience.

Two radio training courses were held. The aims of the first course were to train Departmental inspection staff in the techniques of section and in-station measurements, and to prepare Departmental staff training with the contractor installation team, so that they could immediately carry out duties assigned to them.

The second course was aimed at training the staff of the maintenance control centres in the specialist diagnostic techniques available for the different unit types; to teach the Radio Line Section and Radio Maintenance Control staff the system design concepts; and to train staff for replacement of individuals trained in course 1 but later becoming unavailable for various reasons.

Each course was planned to run for four weeks and to train some fifteen technical staff at each.

The requirements for staff and their starting dates were based on the G.E.C. Field Programme, a list of 'Proposed Staffing Arrangements,' and a list of 'Significant Target Dates.' Among these significant target dates were:—

August 2, 1966: Letter of Intent to G.E.C. (Aust.) Pty. Ltd,

November 9, 1966: Initial issue of contract to cover supply and installation and commissioning of the system.

December 22, 1966: Contractor to be advised of details of system.

January 1, 1967: A.P.O. to provide to G.E.C. site locations, tower details, and antenna positions for Northam-Kalgoorlie and Kalgoorlie - Ceduna (preliminary).
A.P.O. to provide tentative frequency plan, general system details and shelter requirements.

February 1, 1967: A.P.O. to advise G.E.C, of names of A.P.O. State representatives

March 1, 1967: A.P.O. to provide to G.E.C. detailed system requirements.

April 1, 1967: G.E.C. to provide preliminary tower drawings to A.P.O.

May 1, 1967: A.P.O. to provide to G.E.C. site details and route contour information for Northam-Kalgoorlie sections, and draft acceptance test schedule.

June, 1967: G.E.C. to provide prototype shelter and power plant.

August 1, 1967: G.E.C. to provide A.P.O. with final tower drawings.

December 1, 1967: A.P.O. to provide G.E.C with survey and propagation test results.

January 1, 1968: A.P.O. to provide G.E.C. with site locations, tower details, and antenna positions Kalgoorlie - Ceduna (final); to provide G.E.C. with final frequency plan; and to provide site details and route contour information for Kalgoorlie-Ceduna sections.

March 1, 1968: G.E.C. to provide prototype items for test.

June 1, 1968: A.P.O. to provide G.E.C. with acceptance test schedule.

December 1, 1968: G.E.C. to provide A.P.O. with installation instructions.

September 20, 1969: Installation, line-up and testing completion date Northam-Kalgoorlie TV.

October 31, 1969: Installation, line-up, and testing completion date, Northam-Port Pirie telephony.

January 1, 1970: G.E.C. to provide A.P.O. with system handbooks and linen transparencies.

Staff selected for the project were kept informed of progress by means of information bulletins and various Technical Information Bulletins. These

Bulletins were sent also to other interested groups, such as Trunk Service, Long Line Installation, Bearer Provision, etc. These bulletins were in effect progress reports, but Information Bulletin No. 5, issued in June, 1968, restates the objectives of the project in summarised form. This was a valuable interpolation at this stage, in that personnel recently recruited to the project, and particularly members of other interested groups, may well not have been totally informed as to these objectives. Extracts from this bulletin are given below:—

Extracts from Bulletin No. 5.

"The project is still proceeding generally as planned, although further delay in the delivery date for the prototype equipment from G.E.C. will leave little or no margin for trouble. The very dry conditions which adversely affected road-making have now been replaced by very wet conditions, resulting in several roads being badly cut up. Work to repair these roads will commence shortly. The power supply equipment for the first non-mains powered repeater has been commissioned. Tests of the wind-driven generator are still proceeding.

The Project: Essentially, the objective of the project is to provide new telephone circuits between Perth and the Eastern States. The major component of the project is the provision of a microwave radio relay system between Northam (W.A.) and Port Pirie (S.A.), complete with the necessary shelters, power plant and towers. The system will be equipped with the following facilities:

(i) a duplicate 600-channel 1 + 1 telephony bearer;
(ii) a one-way television bearer from Northam to Kalgoorlie;
(iii) provision for occasional interstate television relays in each direction over the standby bearer;
(iv) provision for deriving a few sub-baseband telephone channels at intermediate repeater stations between Kalgoorlie and Port Pirie.

Complementary or ancillary works include:

(i) an additional 960-channel telephony bearer on the existing micro-wave system between Port Pirie and Adelaide. (Similar provision between Perth and Northam is unnecessary as the existing bearer has sufficient capacity.)
(ii) a one-way television bearer from Mt. Bakewell to Northam to connect with an existing television bearer from Perth.
(iii) facilities for the occasional relay of television signals in each direction, where not already provided, over the existing standby bearers between Perth and Northam, and between Port Pirie and Adelaide.
(iv) lead-in cables (new V.F. or carrier cables, or use of spare tubes in existing coaxial cables).
(v) line transmission equipment for lead-in cables (multi-channel or broadband).
(vi) carrier (broadband) equipment at Perth, Adelaide and intermediate stations.
(vii) two transportable emergency radio stations complete with all necessary facilities, for use as either repeaters or back-to-back terminals.

Broadband equipment provision allows for derivation of the following super-groups.

Seven supergroups (Nos. 3 to 9), Perth to Adelaide. Two of these are for extension to Sydney and three for extension to Melbourne. The third Perth-Melbourne supergroup will not be required initially and may be used, if required, to provide a second Ceduna Earth Station to Sydney supergroup.

One Supergroup (No. 10), Perth to Merredin and Kalgoorlie ('leaked off' at both Merredin and Kalgoorlie).

One Supergroup (No. 1): (a) Ceduna to Adelaide for extension from Ceduna to O.T.C. Earth Station and from Adelaide to Sydney (O.T.C.), 'stopped' at Ceduna. (b) Perth-Kalgoorlie, and (c) Kalgoorlie-Norseman. Both 'stopped and replenished' at Kalgoorlie.

One Supergroup (No. 2) 'stopped and replenished' at Northam, Merredin, Kalgoorlie, Ceduna and Port Pirie to provide supergroups (a) Perth-Northam; (b) Northam-Merredin; (c) Merredin-Kalgoorlie; (d) Kalgoorlie-Norseman - Caiguna - Eucla - Ceduna ('leaked off' at Caiguna, Eucla, Ceduna, but circuits will not be derived initially at Eucla or Ceduna); (e) Ceduna-Port Pirie; (f) Port Pirie - Adelaide.

On the subject of propagation tests, it is reported in this bulletin that Research Report No. 6244, Desert Microwave Propagation Studies Report 1, has been issued. This report describes the investigations and discusses the results obtained between April, 1966, and March, 1967. Tests continue on all line-of-sight paths with the exception of the Ivy Tanks, now closed down in favour of the over-the-horizon test between Ivy Tanks East and Wigunda. The direction of transmission over this latter path has been reversed to overcome interference problems. The transmitter is now at Wigunda and the receiver about 75 miles distant at Ivy Tanks East. Plotting the temperature gradient of the atmosphere vertically from the ground up to altitudes of several thousand feet is to be carried out in the first two weeks of June. The measurements, in conjunction with radio propagation measurements made at the same time, are designed to add to the understanding of the meteorological factors affecting radio propagation.

Buildings: The buildings at Kalgoorlie, Norseman, Caiguna and Eucla are nearing completion. The progress at Whyalla and Kongwirra, both in South Australia, is satisfactory.

Equipment Shelters: Shelters have been erected at four sites in South Australia. In Western Australia the first shelter is scheduled for erection at Bulgin Rock during September, 1968.

Roads: Roads have been completed between Northam and Norseman, and between Whyalla in South Australia and Crocker, a site about 25 miles east of Balladonia, in Western Australia. Bulldozed access tracks have been provided between Balladonia and Norseman, and the construction of the final roads is in progress. All roads should be completed by August, 1968.

Power Supply Equipment: Commercial power is available at repeater sites at Bulgin Rock, Tammin, Baandee and Tank Hill and at the terminals at Northam, Merredin and Kalgoorlie. Sites still to be connected are Alan Hill repeater and the terminals at Norseman, Caiguna and Eucla. The primary source of power for non-mains-powered stations on the route is the diesel generator. To supplement these generators, wind-driven generators are to be used. The function of the wind-driven generators is to extend the life of the batteries by reducing the number of cycles per charge/discharge per annum, and to extend the intervals between diesel generator overhauls by reducing the running hours per annum. These two extensions reduce operating and maintenance costs. The expected method of servicing wind generators in the event of failure will be by replacing the hub-assembly and blades as a unit, or by replacing generator, hub-assembly and blades as a unit. Wind surveys are being made at two stations along the route, at Malabie, in S.A. and at Comet Hill, in W.A. Results from the survey should be available for the next meeting of the co-ordination group.

Radio and Supervisory Equipment: Delivery of the prototype equipment has been still further delayed. It will now be arriving during June, July and August, 1968. G.E.C. have made a large-scale amendment to and improvement of the radio equipment. The improvement has been mainly directed towards interchangeability of equipment. The State liasion officers have strongly recommended that if a further engineer is to go to Coventry for the acceptance testing of the production equipment, consideration be given to sending a State officer. The purpose of this would be for someone in the States to gain supplementary knowledge of the equipment.

Towers: Foundations for all 23 sites in South Australia have been completed and the team is about 14 days ahead of schedule. In Western Australia, the team from S.A. has commenced work at Eucla and the W.A. team has completed foundations at 15 sites and is now about seven days ahead of schedule.

The steel work programme has been revised and erection will not commence in W.A. until the middle of July, 1968, when, following the completion of the tower at Dick Plain, in S.A., the E.P.T. team will move to Bulgin Rock in W.A. The rate of erection has increased and all towers up to Kalgoorlie should be erected by early September, 1968.

Antennae and feeders: These are being manufactured and are being inspected before despatch direct to site. The first deliveries are expected to take place during July, 1968. Headquarters Research Section propose to take measurements on a sample of the Andrews antenna at their field site at Mt. Cottrell. The measurements are to include determination of gain and polar pattern, including Front-to-back ratio. Because the research engineer responsible for antenna work will not be available after early June, it is proposed that the testing be under the general guidance of an engineer from Headquarters Radio Section with subprofessional staff from Research Section to carry out the measurements required.

Target Dates: The present target date for completion of the radio bearer by G.E.C. is August 31, 1969, with a corresponding 'in-service' date of November 30, 1969. The guaranteed completion date for the bearer, however, is October 31, 1969, and in the event that the bearer is not completed until that date, the corresponding in-service date will be January 31, 1970.

Training Courses: The first Power course commences on August 5, 1968, at Broadbent Hill Repeater Station; the second course, of two classes of 15 or 16, will be held at Whyalla Repeater Station, the first class to commence on January 20, 1969, and the second on February 3, 1969.

The first Radio course will consist of two classes, the first to commence on February 17, 1969, and the second on March 17, 1969. Whyalla Radio Communications Building will be the base for this course, but training will take place on site between Whyalla and Broadbent Hill.

The second radio course will have a total duration of eight weeks, four weeks in S.A. and four weeks in W.A. Sessions will be held at each Maintenance Control Centre and at the Radio Line Section Control sites of Mt. Bonython and Mt. Yokine. Since training should take place during the three-month G.E.C. 'maintenance' period, the probable timing will be November-December, 1969.

As required by the contract, the instructor in charge of all the courses will be provided by G.E.C. However, since each session of courses P2 and R1 are expected to cater for 15 or 16 students, there is a need to provide assistance to the G.E.C. instructor. This will be done by pre-training (to a certain extent) suitable Departmental personnel prior to the initial session of each course. This pre-trained staff will then act as assistants throughout each session of a course. In the case of the P2 course, the 'assistants' are expected to be the Technician's School representatives attending the P1 course from W.A., S.A. and Headquarters. For the R1 course, the 'assistants' involved must be given training in the Headquarters radio laboratory, using the prototype radio equipment The 'assistants' should be completely familiar with normal broadband routine test equipment and procedures, and should attend throughout the first four weeks of the prototype testing. (Note: After this period, detailed investigations will be proceeding on individual problems whch may not be suitable for training purposes.)"

General.

Field staff were provided with Grundig tape recorders and spare cassettes so that field reports could be recorded and then transcribed and typed in due course at Head Office. Sufficient spare cassettes were issued to ensure that the field staff always had one available.

Inevitably in a project of this magnitude, with supply lines thousands of miles long, many changes occurred between conception and completion. Because of this the commencing dates for Departmental staff had to be revised from time to time and indeed the number of staff required at any one time became a very variable quantity.

SUB-CONTRACTORS AND CONSULTANTS

That part of the contractor's management team controlling the work of their sub-contractors and consultants was based in Melbourne and since the Departmental field inspectors had no authority to challenge or direct the sub-contractors, the sequence of events required to pass formal comments on work standards, etc., was quite lengthy since the lines of communication passed through the A.P.O. Project Engineer based in Perth and the G.E.C. Project Manager based in Melbourne. In the case where there was a G.E.C. inspector continually in the field this problem did not arise to the same extent, although problems did arise with the antennae sub-contractors and the power plant sub-contractors when there was only one G.E.C. inspector and work was in progress by the sub-contractor at more than one site.

When installation of equipment by the G.E.C. commenced in W.A., the G.E.C. Field Contract Controller was based in Adelaide, S.A., thus again creating communication problems as instructions to G.E.C. field staff had to pass through the Field Contract Controller. This situation improved when the G.E.C. Field Contract Controller (F.C.C.) moved to Perth late in 1969 and was further improved when a sub-office was set up at Norseman, WA., early in 1970.

However, since the G.E.C. control of subcontractor activity was still based on Melbourne, Victoria, problems regarding power plant, shelters, and antennae and feeders had to pass through that office, and in general no action in these areas of work was taken by the G.E.C. F.C.C. or his staff. There was a lack of understanding by the F.C.C. of the contractor's responsibility for maintenance up to final system acceptance, due in part to the failure of the G.E.C. Melbourne office to send copies of correspondence between the company and the A.P.O. to the F.C.C.

CONCLUSION

The A.P.O. responsibilities were restricted to the route survey, provision of cleared and levelled sites, roads, a.c. mains in areas where a commercial supply had been established, batteries, buildings at nine of the 60 sites, and of course sufficient supervision to ensure that standards and specifications were being met by the contractors during all phases of the project.

The project posed many interesting management problems and highlighted the fact that for the 'package deals,' a different form of Schedule should be issued and in particular such a Schedule must include either very detailed specifications for every aspect of the work or a broad specification covering final performance only.

TESTING THE PROTOTYPE EQUIPMENT

*A. Z. BYCZYNSKI, M.E.E., C.Eng., M.I.E.E., F.I.N.E.**

INTRODUCTION.

The magnitude of the order for radio equipment for the East-West project made it possible to modify the equipment production where necessary to suit the A.P.O. requirements. In order to make the most of this opportunity, the contract included provision for testing a sample of the production equipment type SPO-5504, which formed the basis of the design for the East-West project. The contract indicated that particular attention would be paid to:

(a) components operating outside manufacturer's ratings;

(b) components of unacceptable quality;

(c) performance outside specification of sub-assemblies and complete items;

(d) performance aspects marginally within specification, but which were irregular, unrepeatable, unstable and impracticable to achieve by normal maintenance methods;

(e) access to units for maintenance purposes which was unnecessarily difficult;

(f) weakness in component mounting and wiring with predisposition to failure in service.

The contractor agreed to rectify all defects of a qualitative nature provided that he was notified within three months of receipt of the equipment in the Radio Section Laboratory. Thus, this period of testing and evaluation provided a unique opportunity for the Department to express its comments and to have them taken into account by the manufacturer in the final design of the East-West equipment to be submitted for test later.

TEST FACILITIES.

The test facilities available for appraisal testing of the equipment SPO-5504 in the Radio Section laboratory were very limited and some essential test instruments such as group delay derivative test set, level measuring set, etc., had to be borrowed from other Departmental laboratories.

By August, 1968, shortly before the prototype equipment was airfreighted to Australia, the laboratory had been equipped with the most advanced test equipment, namely: microwave sweep set-up, link analyser, baseband sweep set-up, S.H.F. frequency counter, spectrum analysers, etc. Also, a very efficient and versatile environmental chamber had been constructed by one of the senior staff of the laboratory. The unit was designed to accommodate up to four standard racks of equipment and this resulted in a valuable reduction in the time taken for temperature tests.

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*Mr. Byczynski is Engineer Class 3, Radio Section, Headquarters.

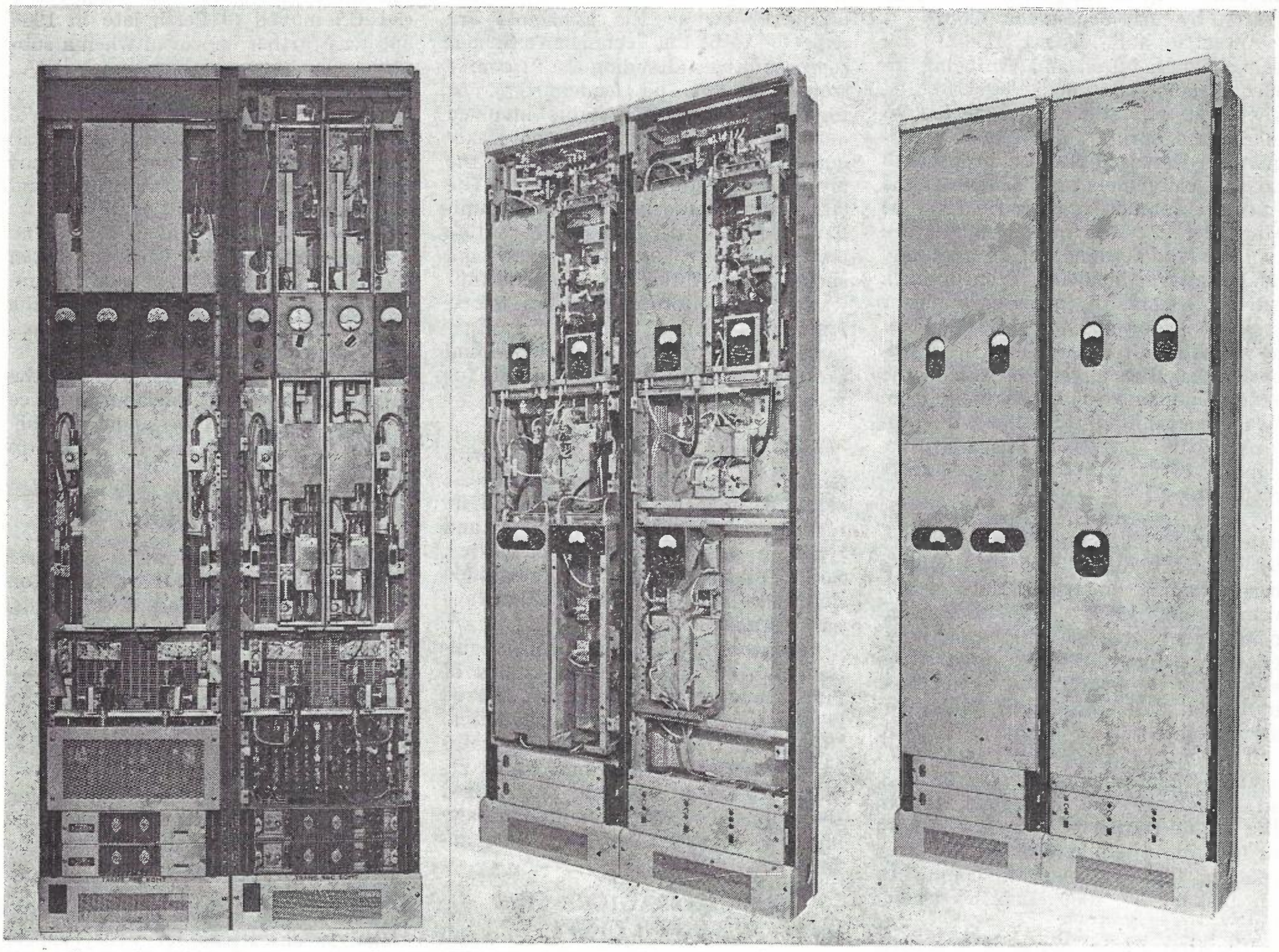

Fig. 1. — Radio Rack Equipment: (a) SPO-5504 Equipment; (b) and (c) Prototype Equipment (one transceiver and one diversity rack).

EQUIPMENT TYPE SPO-5504B.

Mechanical Inspection.

The equipment consisted of two modulator-demodulator shelves and two radio racks, each rack comprised two transmitters, two receivers and two branching networks. An initial inspection of the equipment indicated that the mechanical layout of the transmitter (shown in Fig. 1a) would require an extensive modification as replacement of any component of the transmitter appeared to be very difficult and required realignment of the transmitter in situ. This method did not comply with the agreed principles of service of the East-West route. Also, removal and replacement of the receiver unit (shown in Fig. 2a) was unreasonably difficult because of its weight, size and method of mounting on the rack.

The use of C.A.S.E. (Card Assembled Shelf Equipment) construction for the modulator/demodulator equipment did not make use of the standard facilities available with this type of construction. As a result, the units and cards could not be withdrawn without first disconnecting several BNC type connectors at the rear of the rack.

Concurrently with the mechanical inspection of the racks and shelves, an examination was made of components and manufacturing practices used in the equipment. On all aspects the opinion and comments of a wide range of Departmental staff were obtained, including officers from South Australia and Western Australia who would be concerned eventually with the maintenance of the East-West route.

Electrical Tests.

After an initial inspection of mechanical features, a brief check was made of all equipment to ascertain whether any major defect had developed in transit from the G.E.C. factory. A minor fault was found in the transmitter power supply and this was corrected by the replacement of one damaged transistor. All other equipment was in good working order. Electrical tests on the equipment were carried out in three stages.

Ambient temperature tests, stage 1: In this series of tests the modulator and demodulator shelves were set up following exactly the procedure given in the 'In Station' section of handbook 5610E. Similarly, the transmitters and receivers were set up following exactly the procedure given in the 'Rack' section of handbook 5504B. Adjustments were made only when the specified performance was not obtained from a particular test, and were again in accordance with the handbook procedure. On completion of in-station testing, the modulator-demodulator shelves, transmitters and receivers were connected as a one-hop system. Tests were then carried out following the procedure in the 'System' section of handbook 5504B.

Owing to late arrival of factory test information from the contractor, the arrangement of units on the modulator and demodulator shelves for these tests was different from that used in the factory. However, it was expected that the equipment performance would still be close to the specification shown in the handbooks. An initial brief test showed that this assumption was correct, with the exception of amplitude responses, group delay responses and overall NPRs (noise power ratios) which were outside specification. It was decided, therefore, to carry out the 'In-station' test procedure set out in the handbook on the assumption that only minor adjustments would be required to meet the specifications.

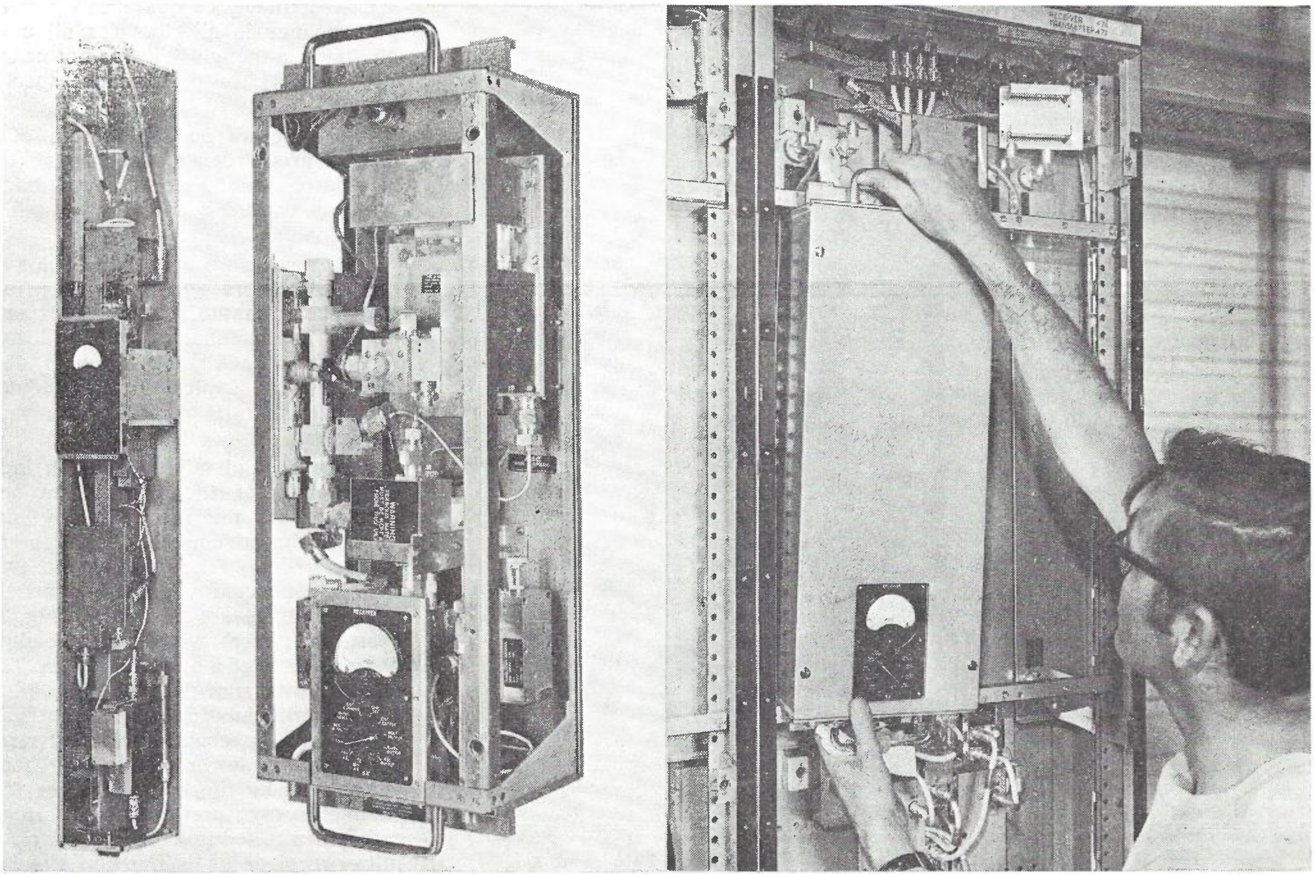

Fig. 2. — Receiver Unit: (a) SPO-5504 Equipment. (Dimensions 55 5/8 x 5⅜ x 7¾ in; Weight 47 lbs). (b) Prototype Equipment. (Dimensions 24½ x 8 x 6 in; Weight 34 lbs). (c) Replacement of the Receiver Unit.

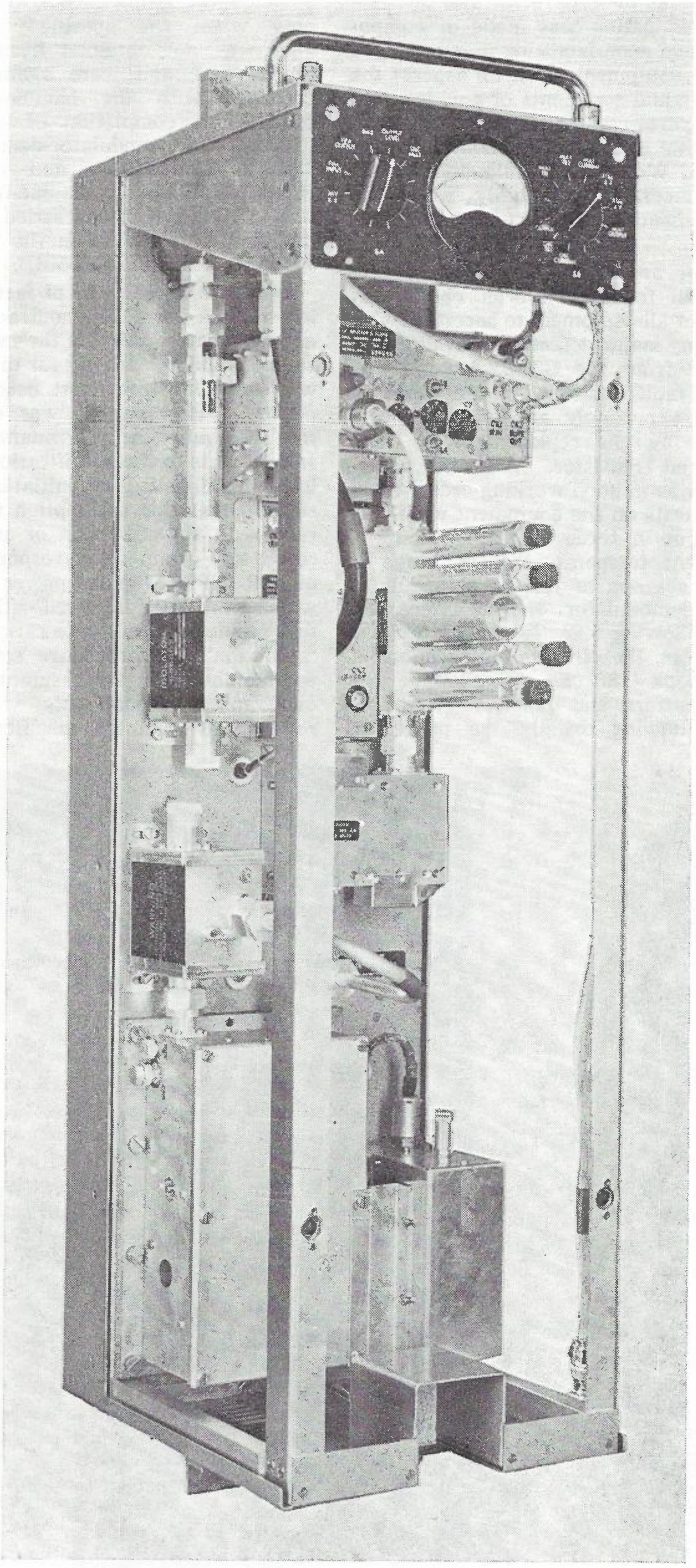

Fig. 3. — Prototype Transmitter Unit (Dimensions 28½ x 8 x 10½ in; Weight 40 lbs).

Ambient Temperature Tests, Stage 2: It was felt that the unsatisfactory characteristic exhibited in the first series of tests might have resulted from individual unit performance being outside specification. Accordingly, it was decided to check each basic unit of the baseband equipment and the transmitter-receivers against the unit performance specified in the handbooks.

Each of the basic units making up one modulator shelf and one demodulator shelf was tested and adjusted on bench in accordance with the relevant unit section of the handbook 5610E. Some component values were changed, where necessary, to achieve the specified performance. The units were then re-assembled on the shelves and tested again following the procedure in the 'In-station' section of the handbook. The noise power ratios of both modems (modulator demodulator) were well within specification in the 2438 kHz and 3886 kHz slots, but derivative response had to be tilted slightly to bring the 70 kHz slot within specification. Compatibility between the two modulators and two demodulators was found to be much better than in the Stage 1 tests. A slight adjustment of the group delay equaliser was made to obtain optimum performance in all slots for all combinations, although this was not necessary to meet the performance specificaton.

Fig. 4 shows an oscillogram of a typical group delay response of the modulator-demodulator shelves, back-to back, while Fig 5a shows a white noise loading characteristic.

Unit tests were also carried out on the transmitters and receivers in accordance with the relevant unit section of the handbook 5504B, followed by further 'Rack' system tests. Fig. 6a shows a typical group delay response IF-to-IF of the radio rack equipment.

The tests and adjustments on individual units of the transmitters and receivers did not result in any significant improvement in IF to IF characteristic. The equipment was then re-connected as a one-hop system and overall tests were made. Fig. 7a shows a typical white noise loading characteristic of a one hop system. The tests results showed that both basic and intermodulation noise contributions of the baseband equipment were substantially lower than had been guaranteed by the contractor for 960 channel system performance. However, when tested together with a transmitter-receiver as a one-hop system, the overall performance was no better than would be expected with the

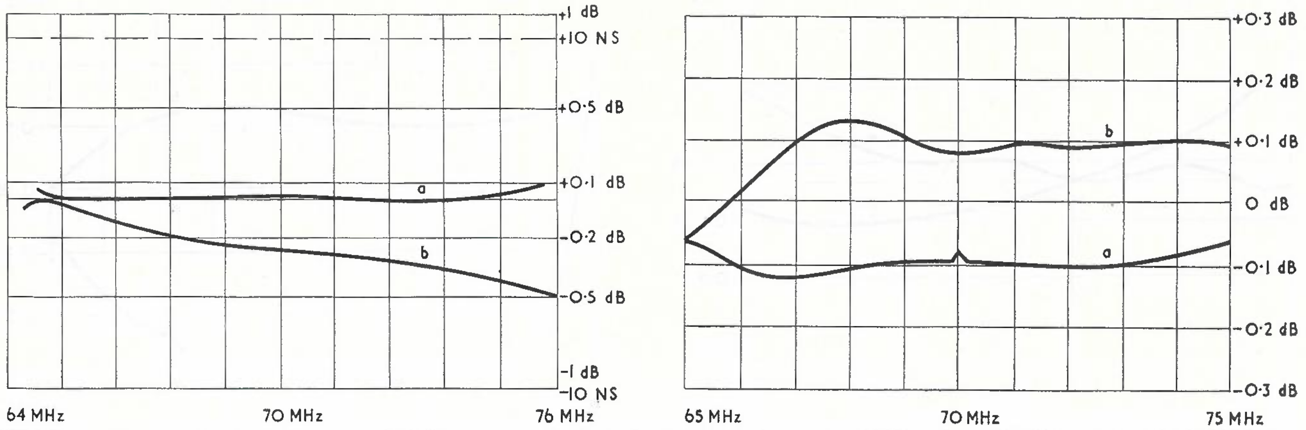

Fig. 4. — Modem Equipment. (a) SPO-5504 Equipment; Curve a — group delay; Curve b — linearity. (b) Prototype Equipment. Curve a — group delay, calibration: 1.0 ns/cm. Curve b — linearity, calibration: 0.1dB/cm.

guaranteed noise figures in which modulator-demodulator noise predominates. This indicated that the transmitter-receiver was contributing far more basic and intermodulation noise than had been guaranteed. This was a crucial issue, since in the East-West system the overall noise performance would be dominated by the repeater noise.

Environmental Tests: In this series of tests, the equipment was subjected to high and low temperature conditions in environmental chambers. Two separate test chambers were constructed for tests, one capable of maintaining a temperature of +55 deg. C, the other adjustable for any temperature between ambient and 0 deg. C. The equipment SPO5504B was designed to operate within the specification over a temperature range from 0 deg. C to +45 deg. C, and with slight degradation in performance up to +50 deg. C. Limitation in time available made it necessary to restrict the heat test to two extreme temperatures of 0 deg. C and +55 deg. C in order to obtain a general indication of the behaviour of the equipment under the worst possible conditions encountered on the East West route. Prior to the heat tests, the group delay and signal-to-noise ratio of one-hop system were measured and compared with the results of previous tests. During the first part of heat test, the modulator-demodulator equipment was placed in the environmental chamber and subjected to air temperature of +55 deg. C, while the radio rack equipment was maintained at ambient temperature. During the second part of test, the radio rack equipment was subjected to high temperature, while the modulator-demodulator equipment was held at ambient temperature. At least two hours of temperature soaking was allowed before commencement of measurements. In each case, three heat cycles were carried out to ascertain the reversibility of changes in the system performance over the temperature range. A similar procedure was adopted during the tests at a temperature of 0 deg. C. It was noted that the temperature variations had very little effect on the performance of the modulator-demodulator equipment. The frequency stability of the equipment SPO5504B was good, the UHF to IF response remained substantially unaltered, spurious responses and image rejection of the receiver were greater than 85 dB. The output power of the transmitter dropped approximately 0.4 watt at the high temperature limit of +55 deg. C. However, degradation in the noise factor of the receiver unit and gain of the intermediate frequency amplifier was greater than expected.

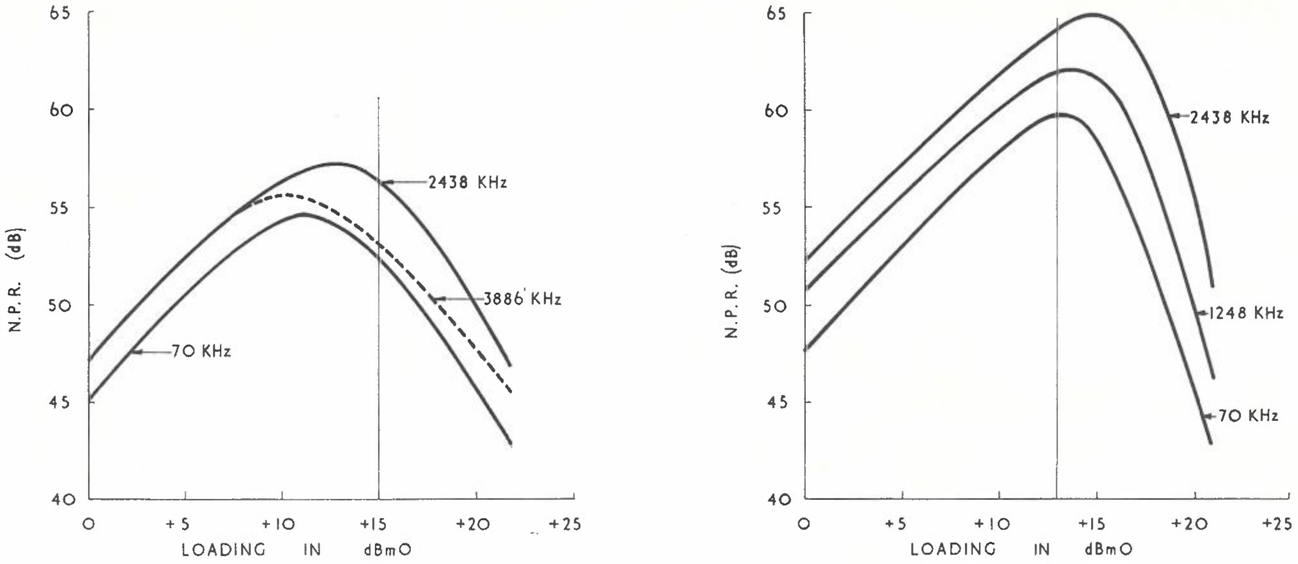

Fig. 5. — Noise Loading Characteristic of the Modem Equipment. (a) SPO-5504 Equipment, 960 channel system. (b) Prototype Equipment, 600 channel system.

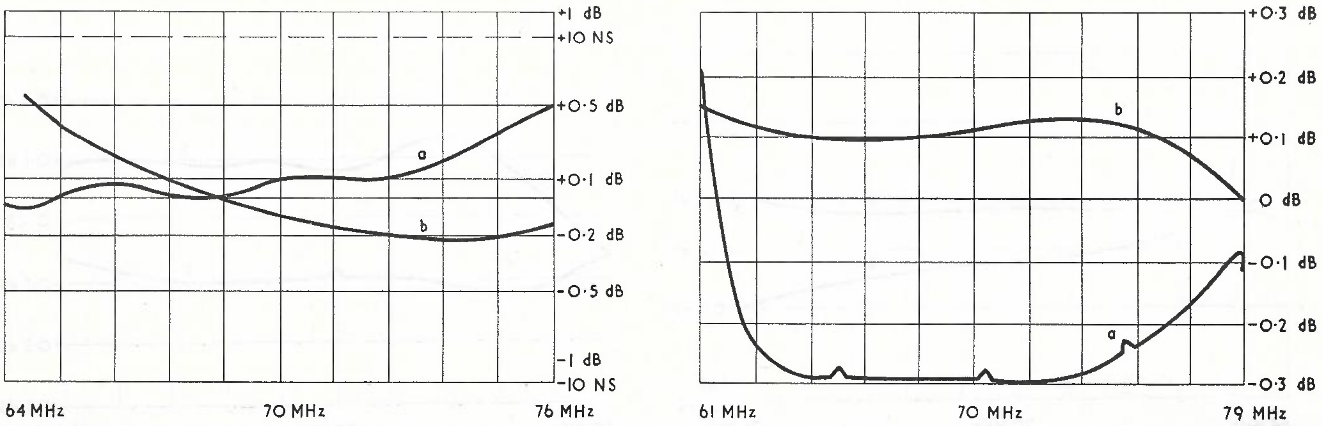

Fig. 6. — IF-to-IF Response of One-Hop System: (a) SPO-5504 Equipment; Curve a — group delay, Curve b — amplitude response. (b) Prototype Equipment; Curve a — group delay, calibration: 1 ns/cm, Curve b — amplitude response, calibration: 0.1dB/cm; (Sweep 70 ± 9MHz, Markers 70 ± 5MHz).

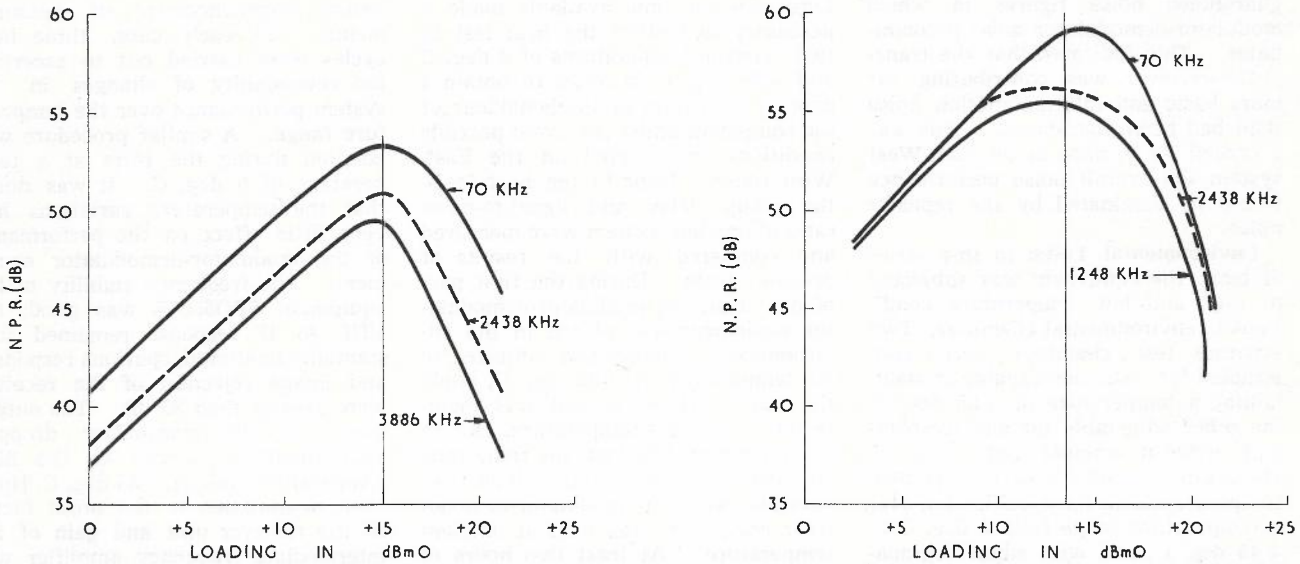

Fig. 7. — Noise Loading Characteristic of One-Hop System. (a) SPO-5504 Equipment, 960 channel system; (b) prototype, 600 channel system.

Conclusion: The mechanical and electrical tests on the equipment SPO5504B showed that it required a number of extensive modifications into the final design of the corresponding equipment for the East-West system in order to meet the agreed specifications and the Departmental philosophy of service and maintenance of the system. The extent of those modifications and all other matters relevant to the design and construction of the East-West prototype equipment were agreed during mutual discussions between the Department and the contractor.

THE EAST-WEST PROTOTYPE.

Mechanical Inspection.

The assessment tests on the East-West prototype equipment were carried out in the Radio Section Laboratory at Jolimont between 14th September and 9th November, 1968. The object of these tests was to ascertain whether its mechanical and electrical standards complied with the specifications, and to assess the effect of transportation by comparing the test results obtained in the laboratory at Jolimont with those obtained at the G.E.C. factory in Coventry prior to airfreighting of the equipment to Australia.

The prototype equipment consisted of one repeater (comprising one C.A.S.E. rack, one main radio rack and one diversity rack) and one terminal (comprising two C.A.S.E. racks, one main radio rack and one diversity rack). The C.A.S.E. rack of the repeater station contained the sub-baseband equipment and supervisory equipment, while those of the terminal station contained supervisory equipment, sub-baseband equipment, IF switching, and modulator-demodulator equipment. Each main radio rack contained two receivers, two transmitters, with associated power supplies, and miscellaneous equipment. Each diversity rack comprised two diversity receivers with associated miscellaneous equipment.

The inspection of the prototype indicated that the equipment was of a new design and that a great deal of thought had been given to the mechanical layout and construction of the radio rack equipment. It appeared that particular attention had been paid to the reliability and simplicity of the equipment. The most noticeable improvement had been achieved in construction of the transmitter unit, which could now be aligned on the bench independently of the transmitter power supply. Also, its group delay and amplitude response could be adjusted independently of the hop equaliser. The transmitter and receiver units, shown in Figs. 1b, 2b and 3, are constructed in form of modules which after alignment in the maintenance depot can be delivered to the station and replaced by one technician using only a screwdriver.

Also, the telephony and television modulator-demodulator equipment was of a new design. Each type of modem consisted of two shelves, each shelf comprised two modulator or demodulator units with associated input-output cards and switching unit. The old and new types of modem units were compatible in terms of physical size and mechanical arrangement for front access to all interconnections for maintenance purposes. Special attention had been paid to the stability of the equipment at high temperature, interchangeability of the units, unbiassed switching system and independence in alignment of the units from each other.

In case of unforeseen deficiencies detected during the inspection, the contractor agreed to rectify them, providing they were notified within two months of receipt of the equipment in the laboratory at Jolimont. The extensive vibration tests on the equipment carried out in the factory and subsequent mechanical modifications to various parts of the units indicated that the equipment would meet the Departmental philosophy of service and maintenance. It is expected, therefore, that each unit, after being aligned in the maintenance depot, can be delivered to the station and inserted in the rack without need for adjustment to any part of the equipment and, also, without any noticeable degradation in performance of the system.

Ambient Temperature Tests.

Electrical tests were simultaneously carried out on the radio rack equipment and C.A.S.E. racks by the staff of the laboratory and technical officers delegated by the States concerned with the service and maintenance of the system. The whole equipment was tested as received from the factory without adjustment to any part of the system. The equipment was initially assembled and tested as a one-way system over eight simulated hops, and then as two 4-hop systems and as four 2-hop systems (one main and one protection channel). The tests were conducted in two phases, at ambient and elevated temperature. During the first phase, the tests were initially carried out without adjustments to any part of the equipment and then with hop equalisers adjusted for the best group delay responses. During the second phase the repeater and the terminal were placed in an environmental chamber, one by one, and tested at +50 deg. C and +55 deg. C. respectively. No adjustments were made during this phase.

All the individual units were inspected before being inserted in the appropriate shelf. Following an initial warm-up period of at least one and a half hours, checks were made of d.c. levels, line up levels, modulator frequency stability, modulator deviation sensitivity, IF input and output levels and return loss of both modulator and demodulator units. All results were within the handbook specifications. Group delay and linearity of each telephony modulator-demodulator combinations were checked over the frequency range of 70 MHz ±5 MHz and 70 MHz ± 10 MHz, a typical response is shown in Fig. 4b. No spurious signals in the frequency range of 1 kHz to 9 MHz were noticed. The only spurious signals observed were those due to local medium wave broadcasting stations at a level of about –86 dBm, and those were isolated to the test equipment, and did not originate in the equipment under test. Each combination of modulator-demodulator equipment was tested for basic and intermodulation noise. A typical response is shown in Fig. 5b. It appeared that all modem combinations had a margin of at least 5 dB compared with the guaranteed figures.

Tests on television modulator-demodulator equipment showed that the results were within the handbook specifications, with the exception of the overall frequency responses and unweighted random noise. However, as deviation from the specification, in each case, did not exceed 1 dB, it was considered that it could be caused by slight retuning of some units during the inspection. Tests on the main equipment in the factory confirmed this assumption.

A standard sound modem equipment was supplied with normal provision for main and standby sections; however, only one set of units was available for tests. Tests performed on the equipment included: transfer levels, gain, frequency response, distortion, channel noise, sound subcarrier frequency stability, output levels and frequency deviation. The test results were within the handbook specifications and similar to those obtained in the factory.

Radio Rack Equipment: Electrical tests on the radio rack equipment indicated some noticeable improvement in performance of the individual subassemblies. For example, the gain and noise factor of the tunnel diode amplifier appeared to be more uniform up to the input signal level of –43 dBm as shown in Fig. 8. Above this level degradation in the noise factor was approximately 1 dB per 5 dB increase in the input signal level. Also the group delay and amplitude responses of the transmitter and receiver intermediate frequency amplifiers showed much less dependency upon the input signal levels than the SPO-5504 units.

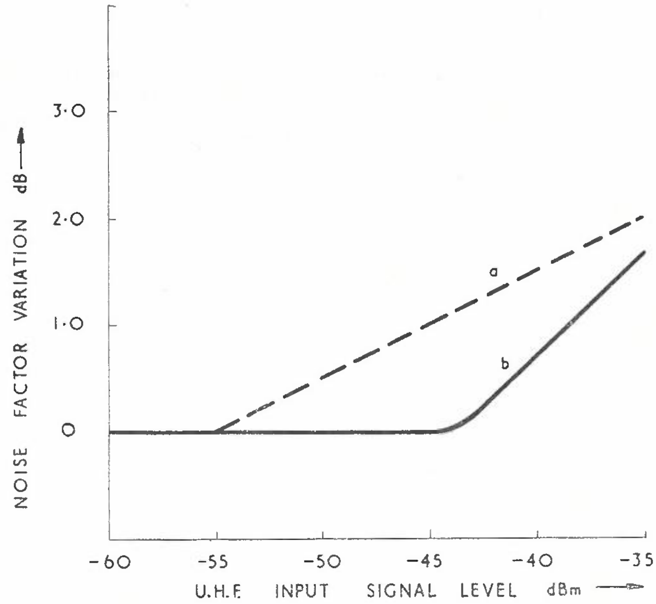

Fig. 8. — Noise Factor Variation. Curve a — SPO-5504 receiver unit; Curve b — East-west prototype receiver unit.

However, the group delay and amplitude responses of each one-hop system indicated certain anomalies in the group delay equalisation. Analysis of the results suggested that some errors were probably made in final alignment and packing of the equipment in the factory. Further tests proved that the slope equalisers were not required. The results of white noise tests on one-hop, two and four-hop systems were 2 to 5 dB worse than expected; however, after re-alignment of the hop equalisers, all group delay responses and noise power ratios met the contractor's specification and were very similar to those obtained in the factory. A typical group delay response and noise loading characteristic of one-hop system are shown in Figs. 6b and 7b respectively. It was noticed that IF switching equipment caused degradation of 0.2 dB in the 70 kHz slot and about 1 db in the 2438 kHz slot. In the main equipment the IF switching unit will be compensated for flat group delay response.

Sub-baseband Equipment: Tests on the sub-baseband equipment indicated that the equipment was generally satisfactory. Tests performed on the equipment included: frequency responses, signal levels, basic noise, distortion, return loss and overload characteristic. The tests results were within the handbook specification with the exception of audio output levels and signalling levels. These two discrepancies had been brought to the notice of the contractor.

Supervisory and IF Switching Equipment: The object of tests on the supervisory and IF switching equipment was to assess their operational philosophy, and functioning of the manual and automatic controls. All possible switching conditions involving manual and automatic operations were simulated and the results compared with the handbook descriptions. Tone frequencies, levels and sensitivities were also checked and agreed with the handbook specifications. Test on the supervisory equipment revealed some discrepancies between time constants of the fault register and auto reset circuit. It appeared that any disturbance of duration longer than the recognition time of the fault register but shorter than the time constant of the auto reset circuit would be indicated as a permanent fault requiring a maintenance visit to the site to reset the alarms. Although in the main equipment these time constants were made equal, it appears that false operation of the supervisory circuit is still likely to occur and some further modifications to the fault register or auto reset will probably be required.

High Temperature Tests.

Limitation in time available for the prototype testing made it necessary to restrict the heat tests to those which would give a general indication of the behaviour of the equipment at high temperature. Prior to the heat test the system group delay and signal-to-noise ratio were measured at ambient temperature and compared with previous tests. Heat tests on the two-hop system were carried out by subjecting the terminal end to an air temperature of +50 deg. C, while the repeater end was maintained at ambient temperature. Heat was then applied to the repeater end at +55 deg. C while the terminal end was held at ambient temperature. On system tests, two heat cycles were carried out to ascertain the reversibility of changes in the system performance over a temperature range.

Generally, the tests results obtained in the laboratory did not agree with those obtained in the factory. The heat tests on the two-hop systems indicated that in some cases the system performance was degraded considerably at high temperature. However, when the equipment was allowed to cool to ambient temperature, the system performance recovered to its initial state. Although the sample of transmitters and receivers was too small for a clear evaluation, there was a strong indication that the repeater intermodulation noise rose excessively at temperatures of the order of 50 deg. C and might prevent the achievement of the guaranteed system noise performance at elevated temperatures. The noise performance of the modem used in the system tests was acceptable on its first high temperature test but showed a large degradation when measured after going through several heat cycles during the system tests. One modulator unit, not associated with the system tests, produced a grossly irregular linearity curve when heated to 50 deg. C. The performance of the sub-baseband equipment was generally good at ambient and elevated temperatures except for the minor misalignment of some carrier and signalling tone levels. The IF switching equipment displayed poor reliability at higher temperatures. A number of intermittent and permanent faults developed on the control and power supply cards and caused false operation of the IF switch. The T.D.M. equipment was generally satisfactory at 50 deg. C except for the very poor temperature stability of the FSK receiver, which was understood to be in the process of being re-designed. The faults were brought to the notice of the contractor for modification in the production equipment.

In early 1969 the design of some panels had been revised and additional environmental tests on the equipment carried out in the factory. The test results were very satisfactory and similar to those obtained earlier in the factory prior to air freighting of the East-West prototype to Australia.

INSPECTION.

Under the contract agreement, the Department reserved the right to carry out inspection and testing of material at the G.E.C. Works. In early 1968 it had been suggested that such an inspection might be undertaken by the B.P.O. Inspection and Test Branch using their facilities already established at Coventry. It appeared that the B.P.O. had a great interest in development of the East-West equipment and, after some preliminary discussions, the B.P.O. agreed to undertake the inspection work on behalf of the Department. The inspection was in accordance with the B.P.O. standard practice. This took the form of mechanical and visual inspection of components, networks, cards, units and shelves for quality of workmanship and conformity to standards as well as certification of the factory test forms. Electrical testing of the radio rack equipment was carried out jointly by the B.P.O. and A.P.O. Inspecting Officers at the G.E.C. Works.

CONCLUSION.

Assessment tests on the East-West prototype equipment were carried out in the Radio Section Laboratory between 14th September and 19th December, 1968. Initially the equipment was tested as received from Coventry, i.e., without any adjustments. On arrival all equipment functioned correctly and in general the factory test results were reproduced immediately. In view of the large quantity of equipment involved in the test, this indicates that the equipment is inherently stable and not subject to faults and mistuning due to transportation. Only one failure occurred during the tests.

During the second phase of testing hop equalisers were re-adjusted to correct for a packing error in the assembly of the equalisers. The resulting performance was again similar to the factory test performance. The test results indicated that the prototype equipment performed to specification at ambient temperature. The modem performance was particularly notable in that there was a very large margin for all combinations relative to the tendered specifications. High temperature tests showed that degradation in performance of the equipment was higher than expected. However, further improvements and environmental testing carried out in the factory indicated that the equipment was capable of meeting the agreed specification.

Most of the unit adjustments were within specification and experience has shown that the equipment could generally be aligned to a closer tolerance than the handbook figures, indicating that unit interchangeability should not be a problem. All important parameters were within the specification as received. Operational philosophy of IF switching and T.D.M. supervisory equipment was found to be satisfactory. Overall the prototype tests indicated that the equipment was satisfactory, and had no apparent defects which would prevent the achievement of the guaranteed system performance at commissioning and during operation.

TECHNICAL NEWS ITEMS

NEW STANDARD FREQUENCY AND TIME SIGNAL SERVICE

New equipment for the Departmental Standard Frequency and Time Signal Broadcast Service from VNG, Lyndhurst, Victoria, has been commissioned at Lyndhurst Radio. VNG provides precise time signals for use by surveyors, seismic and geophysical exploration teams and observatories, academic groups, private industry and Government Departments in Australia and the Territories. The new service has been accepted as a subsidiary standard of measurement of time interval and frequency under the Commonwealth Weights and Measures Act, 1960-1966, and its promulgation as such awaits the issue of documentation by the National Standards Commission.

The fractional accuracy of both the carrier frequencies and the time signal intervals, as emitted, is 1 part in 10^{10} relative to nominal and meets the specification of C.C.I.R. Recommendation 374-1 for standard frequency and time signal services. The VNG time signals are maintained within 100 micro-seconds of the co-ordinated time scale maintained at the Research Laboratories.

RESTYLED TELEPRINTER INTRODUCED

In 1969/70, a restyled teleprinter was introduced by the Post Office for telex services. The actual mechanism is the well-established Siemens Model 100, incorporating a number of design changes aimed at improving its reliability or facilitating its manufacture. However, the cover has been completely redesigned so that it now houses inside the main cover the tape transmitter and tape reperforator attachments and the telex control unit. Coupled with a change from curved to square styling and a change in colour from brown to blue, the effect has been to produce a machine more in keeping with current office decor.

At the same time, the keyboard was changed from a three row to a four row layout. The advantage of the four row layout is that it more closely approaches that of the typewriter and, as the operators of telex services usually have other duties such as typing, they are able to undertake teleprinter operating more readily on the four row keyboard.

THE DESIGN AND DEVELOPMENT OF THE RADIO AND ASSOCIATED EQUIPMENT

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INTRODUCTION.

The development during the early 1960's of transistors and variable-capacitance semi-conductor diodes capable of handling the necessary bandwidths and powers for wideband telephony and television transmission systems made possible the development of all-semiconductored microwave-radio equipment. For the first time, it became economically possible to generate powers in excess of 5 W (unmodulated) and in the range 1.5 to 2 W (modulated) at 2 GHz. This was achieved by the use of variable-capacitance diodes as efficient frequency multipliers of energy generated by high-power VHF transistor oscillators and amplifiers, in conjunction with high-level variable-capacitance-diode converters in which the microwave energy could be mixed with a modulated IF carrier. Tunnel diodes were used in the development of economical low-noise radio-frequency pre-amplifiers.

These developments permitted satisfactory system performance to be achieved for 600/960 circuit telephony operation and were the keystone to the equipment design approach for the Northam to Port Pirie system.

System Design Considerations.

For systems traversing remote regions where maintenance problems are severe, and where mains primary power-sources are often non-existent, all semi-conductored microwave equipment is particularly advantageous compared to valved equipment because of:

(a) the high reliability of semi-conductor devices, generally low operating temperatures of associated components, and the low operating voltages of the circuits;

(b) improved stability and repeatability of transmission characteristics arising from the relative stability of device properties during equipment life;

(c) reduced power consumption, at low DC voltages, which may be derived from power sources utilising batteries to ensure continuity of supply; and

(d) reduced size of equipment, resulting in reduced equipment shelter dimensions.

The East-West route is unusually onerous for civil telecommunications equipment, particularly in respect of the maximum temperature, and of the diurnal and annual ranges of ambient air temperature. Therefore particular attention had to be given to the thermal design of the shelters and to minimising the total power consumption at repeater stations, in order to reduce as far as possible the maximum ambient temperature in the equipment shelters; this was limited to 55 deg. C (131 deg. F) without the use of power-consuming environmental - control equipment.

Considerable attention had to be paid to the operating conditions of components, and to the stability of circuit performance over the temperature range to ensure satisfactory operation in the above conditions. As far as possible, units dissipating high power were positioned to obtain good access to the surrounding air, thereby reducing heating of surrounding components.

Another advantage obtained from the low power consumption of repeater equipment is that fuel delivery costs are reduced, a significant factor on this very long route. (Fuel costs are further reduced by the maximum utilisation of wind-generated power.)

Because long sections of the route traverse very sparsely populated and inhospitable country, the support of installation, commissioning, and maintenance personnel, with all associated living and working facilities at the very remote repeater stations is difficult and costly. The reduction of on-site operations to a reasonable minimum was therefore an important objective. Any maintenance procedure has as its objective the earliest possible restoration of the availability of the standby channel after an equipment failure. On the East-West system it was required that all repairs be carried out at base centres. These requirements dictated the approach to equipment design.

A modular concept was essential so that any faulty unit could be replaced in the shortest possible time with each unit easily accessible and replaceable: for example, a complete UHF transmitter is retained by four captive screws and all electrical connections are by plugs and sockets.

Failed units have to be unambiguously identified at control stations, to avoid unnecessary transportation of spare units, and easily confirmed by maintenance personnel upon arrival at the remote station. This was achieved by grouping various sub-units into larger modules and providing a comprehensive range of fault indications from all the interface points to lamp panels both at the control centre and the remote station (this was in addition to built-in metering for significant signal conditions, for example, transmitter power, and IF transfer levels).

The ability to assemble a complete system from individually tested units, without compensating adjustments also assists factory testing, installation, and commissioning, because of the added flexibility this confers.

Since all repair operations are carried out at base maintenance centres, which means that spare and repaired units have to be transported over considerable distances, particular attention was required in mounting individual components. Excessive built-in stresses, excessive vibration forces, and random movements of critical components had to be avoided.

An additional feature of the equipment design is its ability to operate over a particularly wide range of supply voltage (—21.5 to —32 V d.c.) at repeater stations. The storage battery capacity can thus be utilised to the maximum, thereby ensuring the maximum available repair time in the event of complete failure of all prime power generation.

Overall Radio Equipment Complex.

Figs. 1 and 2 are block diagrams showing the radio equipment at a terminal and a repeater; the overall baseband transmission characteristics are given in Table 1, together with a precis of prototype test results. The overall complex is made up of the following equipment categories:—

(a) UHF (2 GHz) radio equipment, which translates the IF signals to and from the 2 GHz band and combines the various UHF channels for connection to the antenna (the method of reception for space diversity operation is shown in Fig. 3);

(b) IF (70 MHz) switching equipment, which provides automatic protection against failure of the radio equipment;

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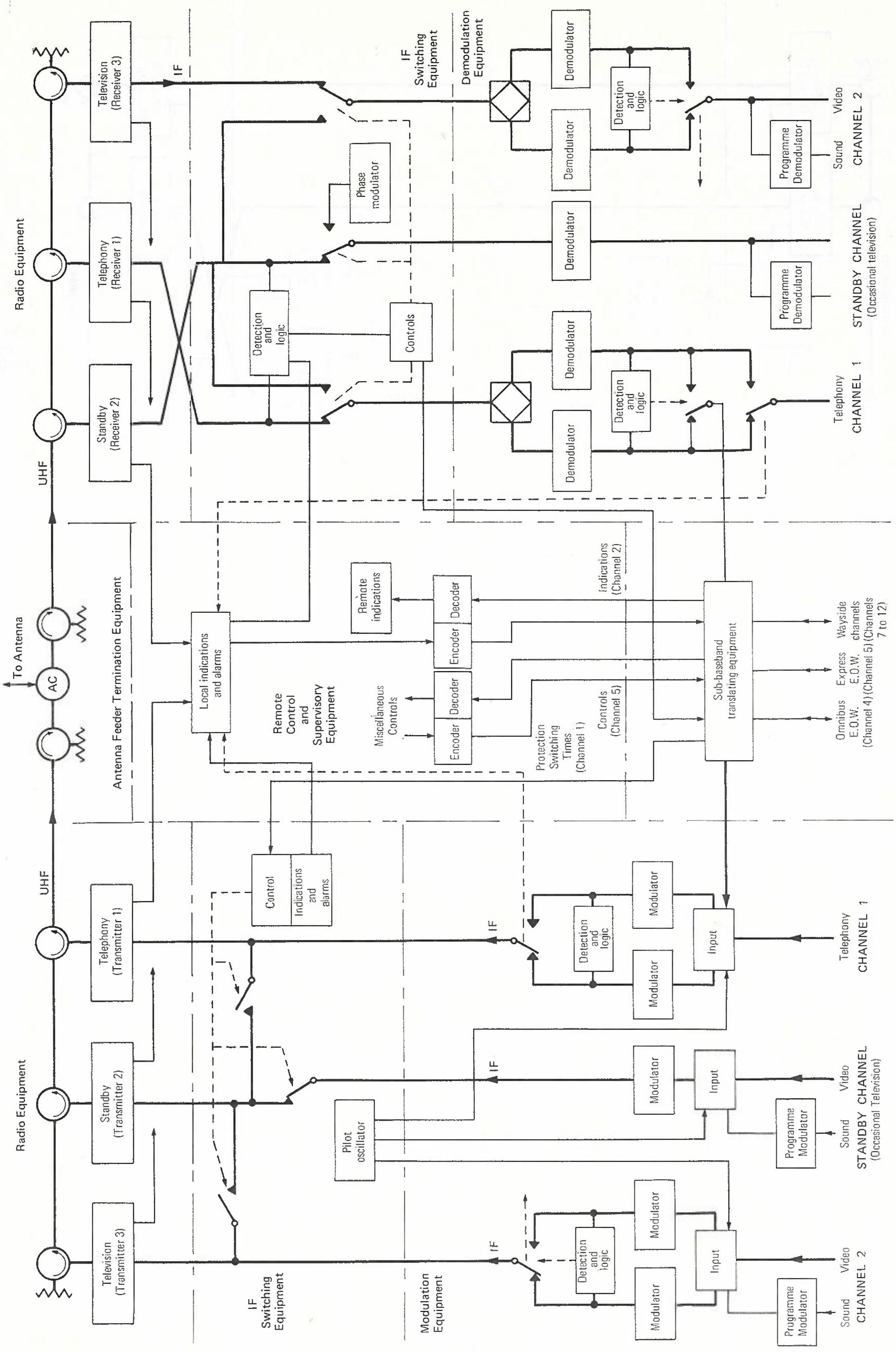


Fig. 1: Block Diagram of a Radio Terminal.

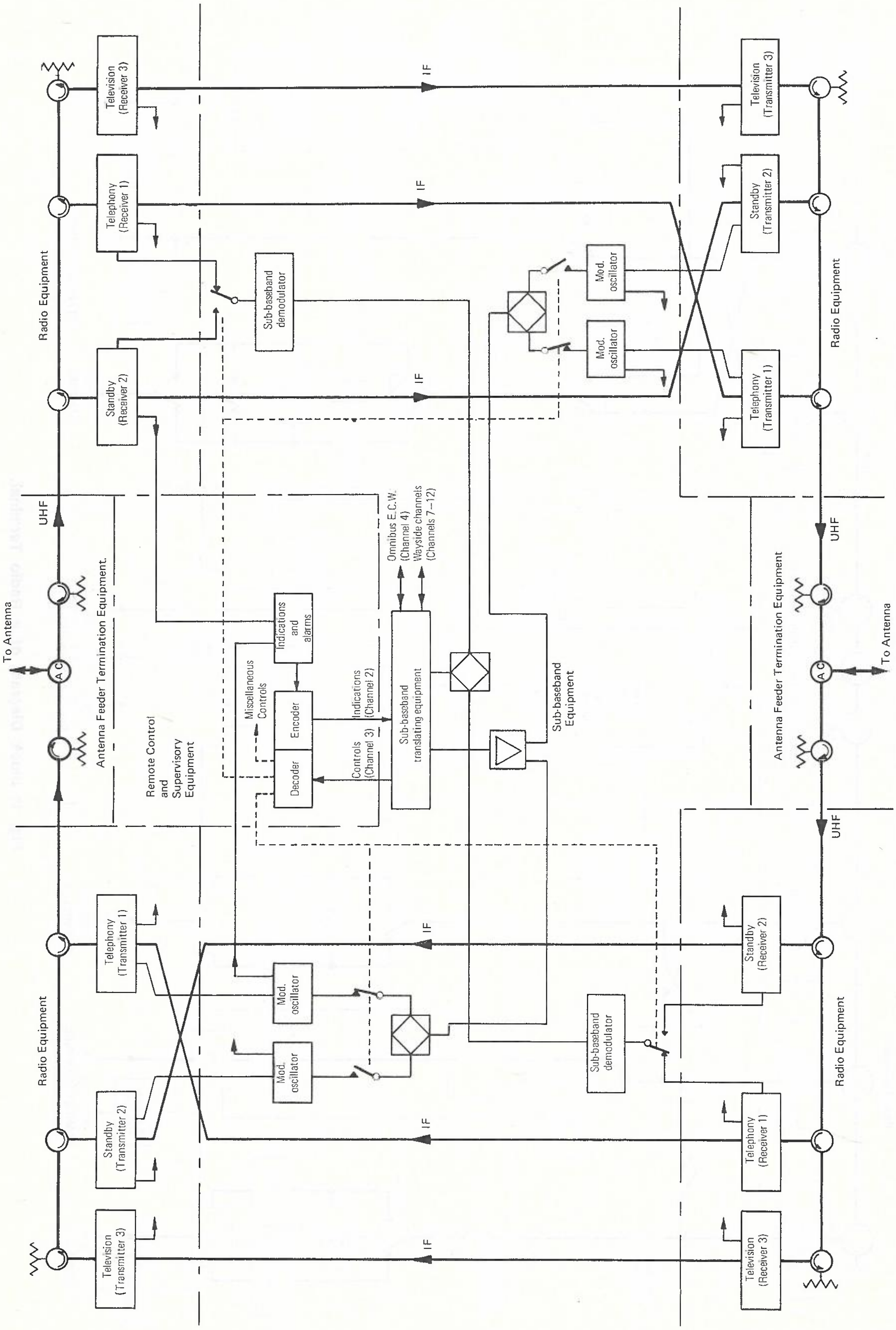


Fig. 2: Block Diagram of a Non-Demodulating Repeater with Sub-Baseband Access.

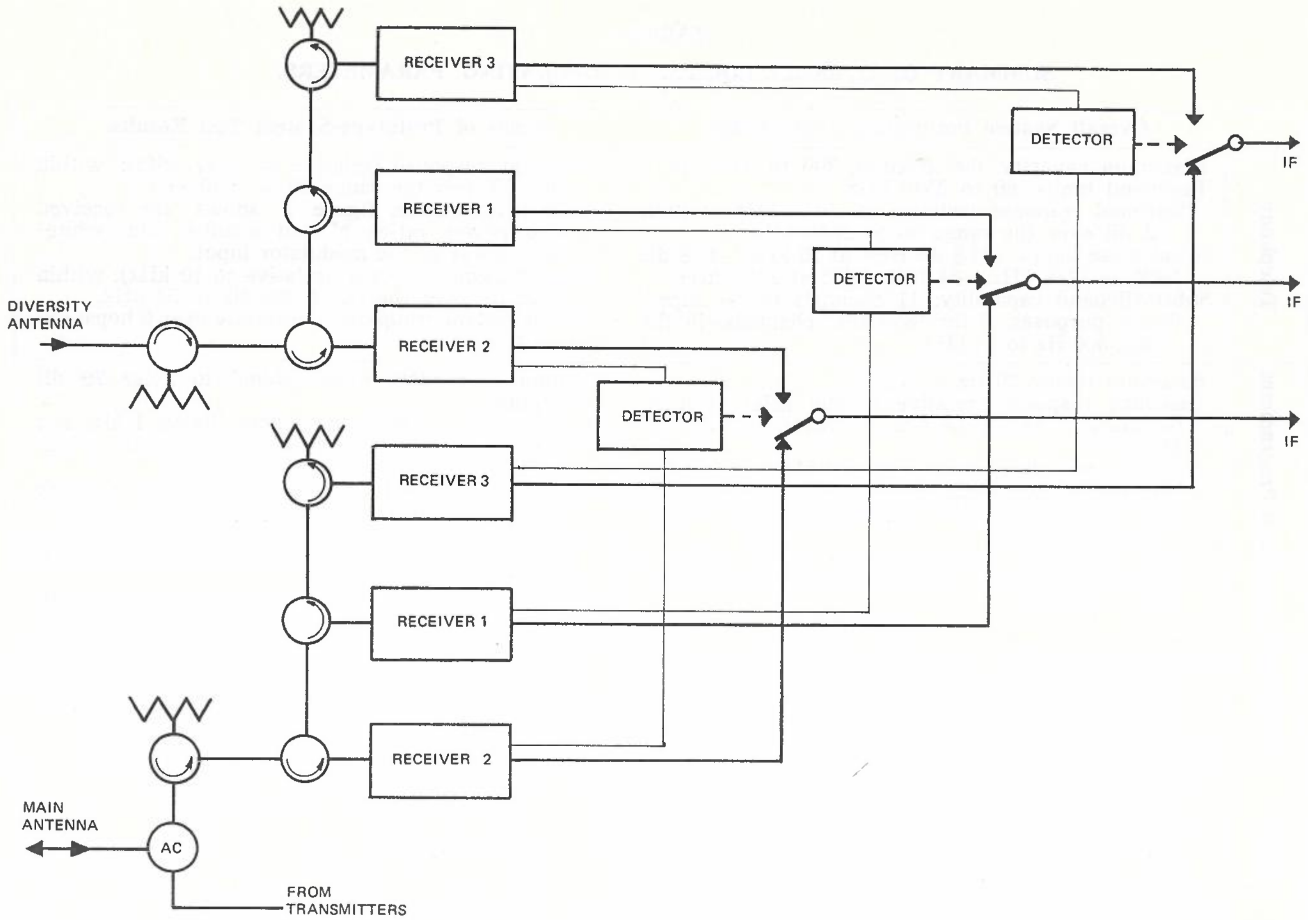


Fig. 3: Block Diagram of a Diversity Reception System.

(c) frequency modulation and demodulation equipment, including automatic protection against failure;

(d) sub-baseband modulation and demodulation equipment for non-demodulating repeater stations, together with frequency division multiplex equipment for sub-baseband speech channels;

(e) control and supervisory equipment for encoding the condition of the numerous equipment indications for transmission to remote stations, for decoding these conditions at the receive station, and for control and display facilities;

(f) antenna-feeder termination equipment, which separates the received from the transmitted signals, and provides an accurate impedance match for the antenna feeder;

(g) antenna-feeder equipment (the equipment is described in another paper, but the basis for the electrical specification is discussed later in this article).

Development Programme.

Throughout the development, close liaison was maintained with the Australian Post Office engineers, to ensure that the equipment supplied was fully in accord with the overall system operational planning. In the case of the radio transmitter/receiver equipment, an established design existed which could be developed to meet the specific requirements of the East-West system. The development was decided after a detailed evaluation of this design, including tests carried out by the A.P.O. engineers on sample racks. In this way the development objectives were clearly defined and understood by user and designer.

The development programme included tests intended to simulate conditions at the environmental extremes to be encountered. Units and sub-units were checked over temperature ranges from about 0 deg. to 60 deg. C, and fully equipped racks and frameworks over a range from —2 deg. to 55 deg. C, including extended periods of operation at 55 deg. C.

The ability of the equipment to withstand shock and vibration was investigated by taking representative units from the various equipment categories and subjecting them to a bump test of about 4000 bumps at 10 G magnitude. This was followed by a resonance search over a frequency range of 10 Hz to 150 kHz at 1 G. At each resonance frequency located, an extended period of vibration was applied to ensure that no damage occurred.

As development approached completion, one prototype of all equipment for a terminal and a repeater station was made available to the A.P.O. engineers for their independent assessment. A second was retained for further evaluation at the GEC development laboratories in Coventry. This included comprehensive tests over the 39 km (24 mile) GEC test hop from Coventry to a repeater site at Sibford Heath. Antenna-feeder systems were used which closely simulated those used on the final system. The two sites of the test link were equipped as follows: Coventry development laboratories, 46 m (150 ft.) self-supporting tower with a 3.7 m (12 ft.) diameter focal-plane paraboloid reflector and 55 m (180 ft.) EW17 elliptical

TABLE 1.

SUMMARY OF OVERALL EQUIPMENT OPERATING PARAMETERS.

	Overall System Performance Parameters.	Precis of Prototype-System Test Results.
Telephony.	Maximum capacity: 600 circuits, 300 to 3400 Hz. Baseband limits: 60 to 2540 kHz. Baseband response (relative to 1617 kHz): within ±2 dB over the range 60 to 2540 kHz. Total noise limits: –34.8 dB NPR at 70 kHz; –33.8 dB NPR at 1248 kHz; –34.0 dB NPR at 2438 kHz. Subtrafficband capability: 11 channels (5 for supervisory purposes, 6 for 'wayside' channels) in the range 300 Hz to 54 kHz.	Baseband response (relative to 1617 kKz): within ±0.5 dB over the range 60 to 2540 kHz. Noise performance: figure 5 shows the received noise power ratios plotted against total white-noise power at the modulator input. Subtrafficband response (relative to 10 kHz): within ±0.25 dB over the range 300 Hz to 54 kHz. Overall system group-delay response over 6 hops: see Fig. 4.
Television and Sound Programmes	Baseband limits: 30 Hz to 5 MHz. Baseband response (relative to 200 kHz) of main Northam to Kalgoorlie bearer: within ±1 dB at 5 MHz. Baseband response (relative to 200 kHz) of standby Northam to Port Pirie bearer; within ±3 dB at 30 Hz; within ±1.5 dB, 1 kHz to 1 MHz; within ±3 dB at 5 MHz. Linear waveform distortion: main bearer within 1 per cent. K rating; standby bearer within 4 per cent. K rating. Programme channel transmitted by modulation of a video subcarrier at 7.5 MHz: frequency limits, 30 Hz to 14 kHz; response (relative to 1 kHz), within ±1 dB over the range 30 Hz to 14 kHz.	Continuous random noise: signal to noise 70 dB weighted. Periodic noise: sum of components below 1 kHz not measurable; no single frequency between 1 kHz and 5 MHz is greater than –60 dBmO. Programme channel response (relative to 1 kHz): within ±0.5 dB over the range 30 Hz to 14 kHz. Programme channel signal-to-noise ratio: 71.25 dB with video terminated; 70.5 dB with video loaded with CCIR test signal 2. Programme channel non-linearity distortion: –48 dB 2nd harmonic content and –55 dB 3rd harmonic content relative to a test-tone level of +9 dBm at 1 kHz (equivalent to 200 kHz peak deviation); the harmonic contents are –50 dB and –53 dB respectively if the test-tone level is increased to + 15 dBm.
Power.	Approximate power consumption from a nominal –24 V d.c. supply, and assuming a main and standby bearer in each direction, duplicated telephony modems, IF protection switching equipped 1 + 1, and all subtrafficband supervisory channels equipped: typical repeater, 450 W; end terminal, 370 W; intermediate (demodulating) terminal, 700 W; intermediate (non-demodulating) terminal, 650 W.	

waveguide; Sibford Heath repeater (30 m (100 ft.) self supporting tower with a 3.7 m (12 ft.) focal-plane paraboloid reflector and 37 m (120 ft.) EW17 elliptical waveguide. Each station was equipped with transmitters and receivers to provide three bearers in each direction. IF connections were made between bearers to simulate a 6-hop radio system. All the baseband equipment was installed at the development laboratories, from where all the overall tests were conducted.

These prototype tests established the ability of the equipment to meet system performance objectives and operational requirements; they also enabled commissioning and production procedures and tests to be finalised. Test and commissioning personnel participated to gain familiarity with the equipment. Prototype construction and testing provided the basis for finalising engineering information for full-scale production.

During production two fully-equipped radio racks were diverted from the scheduled production process and subjected to further tests in temperature controlled chambers. As well as sustained operation at 55 deg. C, these tests included a long period of consecutive days during which the ambient temperature was cycled 30 deg. C and 50 deg. C.

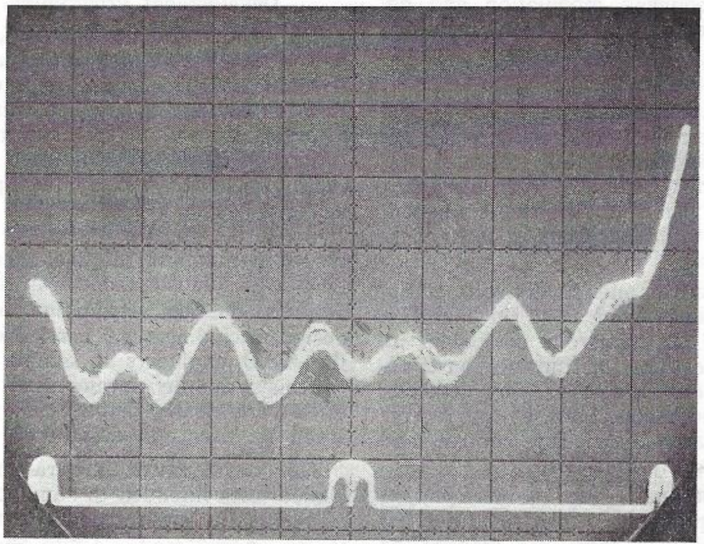


Fig. 4: IF Group Delay Response of a 6-Hop System (Vertical sensitivity, 2ns/division; frequency markers at 64, 70 and 76 MHz).

RADIO EQUIPMENT.

The radio transmitters and receivers operate in the 1.9 - 2.3 GHz band. The transmitters accept a frequency-modulated intermediate - frequency

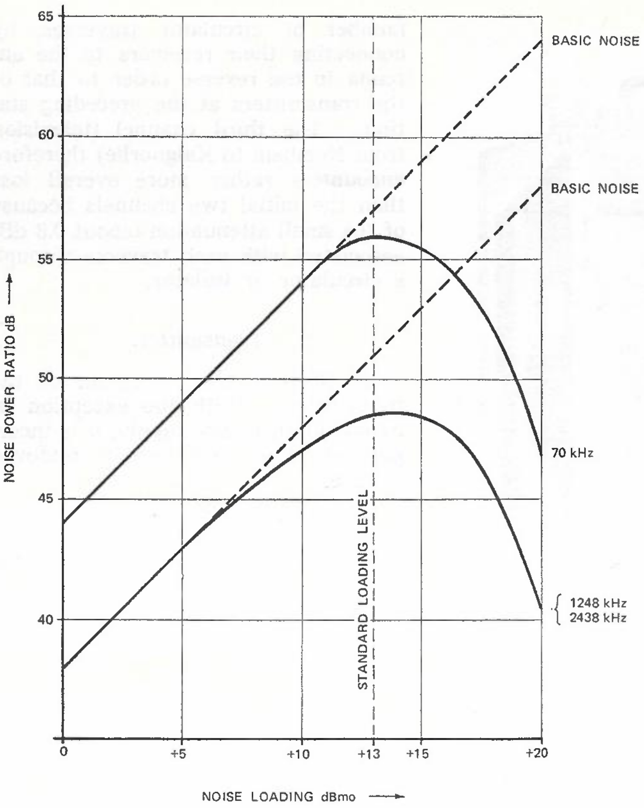


Fig. 5: System Noise Performance.

signal and the receivers deliver an intermediate-frequency signal in accordance with CCIR recommendations, and are suitable for the transmission of 600 telephone channels or television to high-quality transmission standards.

Two transmitters and two receivers are accommodated within a UK standard 'type 51' rack framework (Fig. 6); three diversity receivers are also accommodated within a single framework. The transmitters and receivers are constructed as modules (Fig. 7) retained in the rack framework by four screws and any module can be readily removed without interrupting the operation of the other modules in the rack. The rack also accommodates the power supplies, and passive units (such as the microwave channel filters and multiplexing circulators and isolators).

All UHF interconnections are made via 50 ohm 'type N' coaxial connectors; IF interconnections use 75 ohm BNC connectors.

RF Multiplexing.

Antenna-feeder Terminations. — Up to six bi-directional radio channels can be equipped in the 1.9 - 2.3 GHz frequency band using two monopolar antennae. Fig. 8 illustrates diagrammatically the antenna-feeder termination arrangements. To obtain the best possible feeder termination, the antenna circulator AC is connected directly to the feeder coaxial-to-elliptical waveguide transition by a large diameter EIA coaxial socket mounted above the equipment racks and fed by semi-rigid coaxial line. The combined outputs of up to three transmitters operating in one-half of the frequency band pass via the isolator and antenna circulator to the antenna feeder. The composite received signals pass via the same antenna circulator and a second isolator to feed up to three receivers operating in the other half of the band.

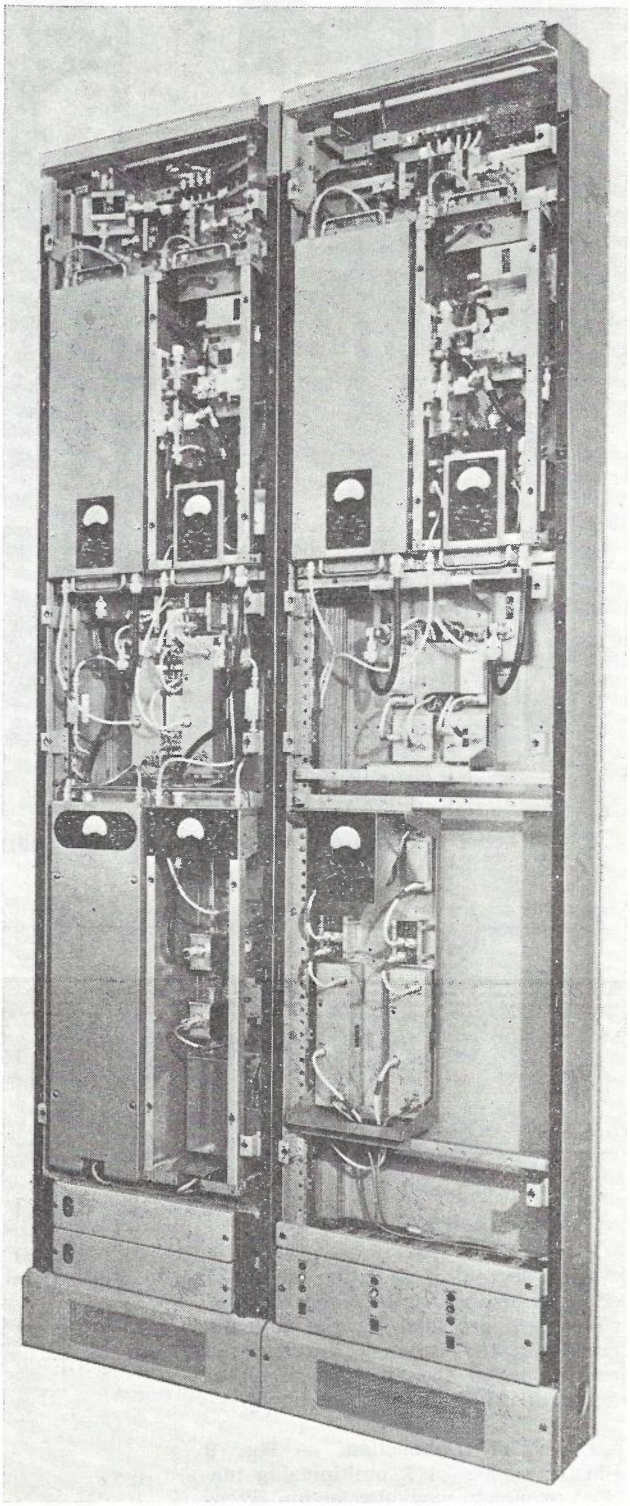


Fig. 6: 2-GHz Radio Racks with Covers Removed. The left-hand rack houses duplicated transmitters and receivers; the right-hand rack houses up to three diversity receivers.

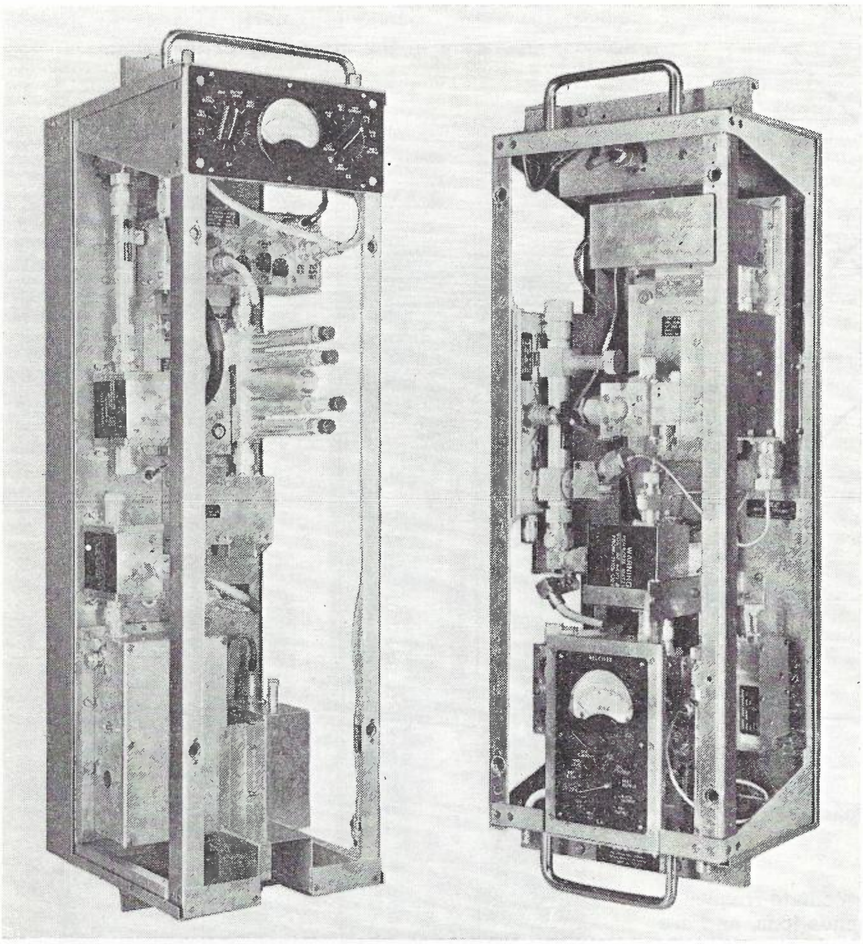


Fig. 7: Active Elements of a Complete Transmitter (left) and Receiver (right).

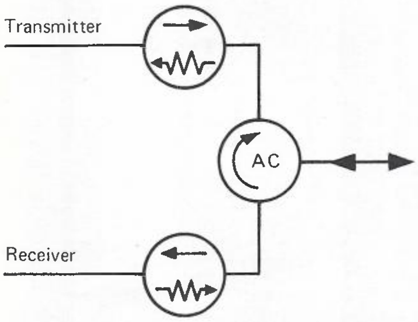


Fig. 8: Antenna Multiplexing.

A high degree of isolation, about 27 dB, between transmitted and received signals, is provided by the antenna circulator; the isolators improve the return loss at the antenna circulator input (about 30 dB over the band).

Order of Connection. — Fig. 9 illustrates the UHF multiplexing method in which channel-rejection filters are used in conjunction with isolators and circulators. It is arranged that the two main telephony and standby radio channels make an equal total number of circulator traverses, by connecting their receivers to the antenna in the reverse order to that of the transmitters at the preceding station. The third channel (television from Northam to Kalgoorlie) therefore encounters rather more overall loss than the initial two channels because of the small attenuation (about 0.3 dB) associated with each traverse through a circulator or isolator.

Transmitter.

Fig. 10 is a block diagram of the transmitter. With the exception of its stabilised power supply, it is incorporated in a single easily removed module.

Transmitter Unit.—The IF input signal to the rack originates either from an IF modulator (via protection switching equipment) at a terminal, or from a UHF receiver at a repeater, adjusted to a standard input level of 0.3 V r.m.s.

IF Input. — An all-pass network equalises the group delay of the transmitter and an amplifier provides an IF output level of 0.25 V r.m.s. to the high-level mixer incorporated in the input unit.

In addition, an IF output is derived via a hybrid network and connected when required to a separate demodulator on an ancillary rack to extract supervisory wayside channels from the through IF signal at repeaters.

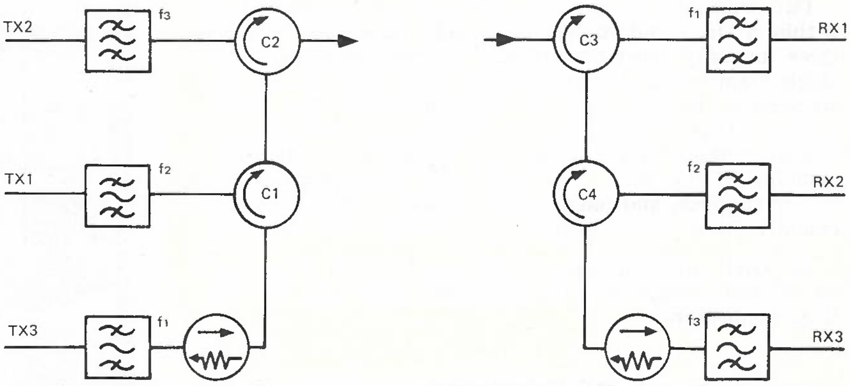


Fig. 9: Transmitter Multiplexing (Left) and Receiver Multiplexing (Right).

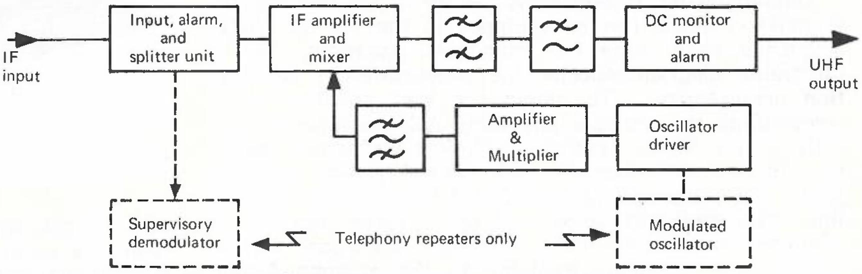


Fig. 10: Block Diagram of a 2 GHz Transmitter.

If the input level falls by 4 dB or more a Schmitt trigger circuit actuates a reed relay to provide local and remote alarm indications.

IF amplifier and high-level mixer: The IF signal is amplified to about 8 V r.m.s. and fed to a high-level mixer incorporating a varactor diode; d.c. bias supply for the varactor is also included. A local-oscillator signal at a level of about 5 W is applied to the high-level mixer at a frequency 70 MHz above or below the final transmit frequency depending on whether the particular channel is in the upper or lower half of the band.

The high-level mixer is terminated at its input by an interdigital bandpass filter which reflects all components other than local oscillator energy. At its output a similar filter passes the wanted sideband but reflects all other components. Adjustable stubs set the optimum conditions at the diode for maximum power conversion to the wanted sideband, together with the required bandwidth. Typical mixer output powers are in the range of 1.6 to 2.0 W.

At terminal stations, and at repeater stations for TV bearers, the local oscillator energy is derived from a crystal-controlled oscillator operating at about 120 MHz. The signal is amplified to about 2 W and fed via a narrow-band coupling network to a 2-stage 20 W amplifier. Three varactor-diode multipliers follow in which the frequency is multiplied by 18. A good termination for this source unit is provided by an isolator at its output.

Since the source unit dissipates most of the power supplied to the transmitter, particular care is taken to prevent excessive temperature rise. Large fins project into a space at the rear of the transmitter unit, which forms a cooling chimney.

Telephony repeaters use the oscillator unit as an amplifier to give a frequency modulated output. It is driven from a separate crystal-controlled oscillator frequency modulated with the sub-baseband signals carrying supervisory information and 'wayside' traffic channels. The frequency modulated oscillator is mounted on the ancillary rack.

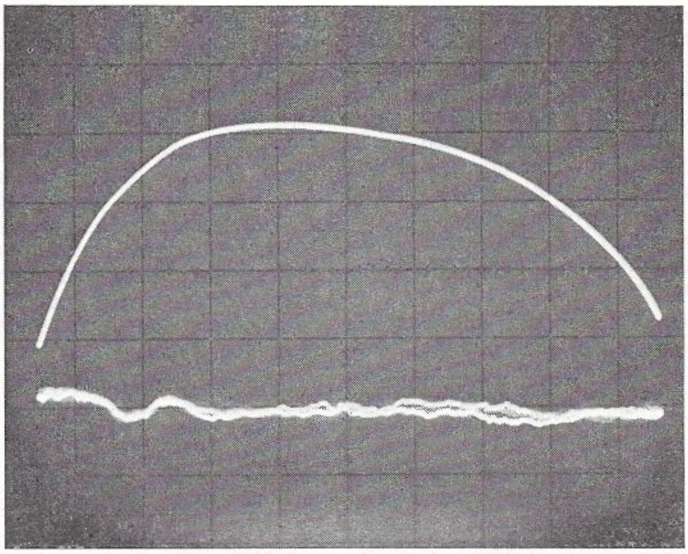


Fig. 11: Typical Transmitter Amplitude (Top) and Group Delay (Bottom) Responses. (Horizontal sensitivity, 2 MHz/division; vertical sensitivity, 0.2 dB/division on top trace and 1 ns/division on bottom trace.)

Following the wanted-sideband filter, a low-pass filter reflects harmonics and an isolator provides a good mixer termination. The d.c. output from a transmitter output power monitor is connected to an alarm circuit, which gives local and remote indications when the transmit unit output power drops to 0.5 W.

Fig. 11 gives typical amplitude and group delay responses (IF/UHF) of the transmitter unit.

Receiver.

The receiver is divided into two sections. The first (receiver unit), shown in Fig. 7, incorporates a tunnel-diode pre-amplifier, local oscillator, frequency changer, and an IF amplifier. The second section (miscellaneous unit) consists of a limiter and carrier re-insertion unit, group delay equalisers, and a final IF amplifier, mounted on a sub-framework within the rack. The IF output signal is taken to a socket at the rack top, either for connection to demodulating equipment or to the following transmitter at a repeater. Fig. 12 is a block diagram of the receiver.

Receiver Unit.

Tunnel Diode Amplifier: The UHF input signal appropriate to the receiver is applied to a tunnel-diode amplifier via a coaxial low-pass filter to reduce local-oscillator harmonic energy at the receiver unit input and reflect any transmitter harmonics and any extraneous signals above the 2 GHz band.

The tunnel diode amplifier comprises a five-port circulator, together with a diode mounting block. The block incorporates a strip line, with the tunnel diode mounted across it. A bias voltage is fed to the diode from a circuit mounted on the block and the strip line is terminated by an RF resistor shunted by an open circuited quarter wavelength stub to prevent out-of-band oscillation. The tunnel diode reflects incident signals at an increased power level and the strip line is connected by a coaxial plug

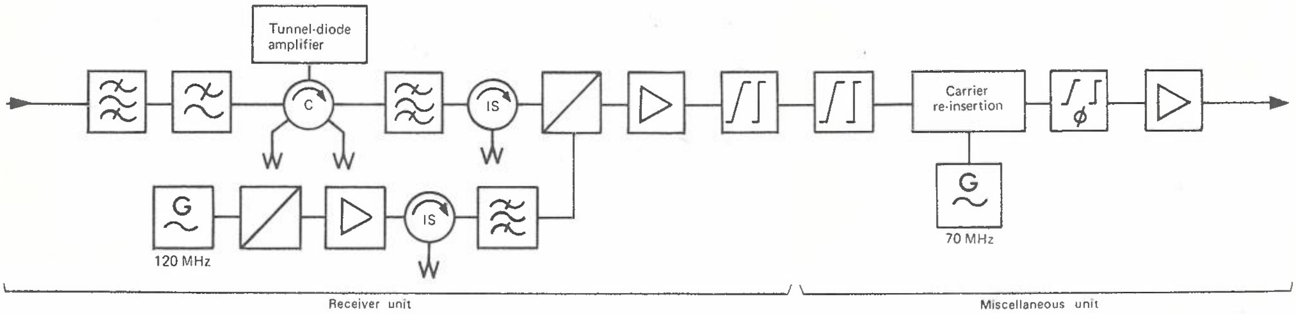


Fig. 12: Block Diagram of a 2 GHz Receiver.

and socket to a circulator which separates the incident and reflected signals. To eliminate further reflections, isolators are used at the input and output of this circulator, the whole unit being constructed as a single five-port circulator assembly. The amplifier has a low level noise factor of about 5.5 dB and an overall gain of about 13.5 dB. Its bandwidth is about 180 MHz to the 3 dB points.

Receiver Mixer: The amplified signal is applied via an inter-digital bandpass filter and an isolator to a single-ended coaxial mixer employing a germanium point-contact diode. The filter rejects noise at the receiver image frequency and the isolator terminates image frequency signals generated by the receiver mixer.

The local oscillator signal at a frequency spaced 70 MHz from the received-signal frequency is applied to the mixer diode at a level of a few milliwatts via a coaxial loop directionally coupled into the input line. The local oscillator frequency is either above or below the signal frequency depending on whether the channel is in the higher or lower half of the frequency band. The local oscillator is generated by frequency multiplying the output of a crystal-controlled oscillator operating at about 120 MHz. This is first amplified and then fed via a narrow bandpass filter (to reduce noise sidebands) to a step-recovery diode in turn coupled to a 2 GHz resonant cavity. Multiplication of 17 or 18 times in one stage is thereby achieved. The cavity output is well terminated over a wide-band by an isolator; an interdigital bandpass filter further reduces the level of any unwanted components. The source unit output level is about 100 mW.

IF Amplifier: The 70 MHz signal at the mixer diode output is amplified in a broadband unit whose response is defined by two bandpass filters. The UHF/IF amplitude response is controlled within close limits and adjustments are provided to set the receiver unit IF output to nominally 0.5 V r.m.s. The maximum amplifier gain is 74 dB and amplitude limiting commences when the output signal level reaches 0.3 V r.m.s. As the input level increases, successive stages towards the receiver input enter limiting conditions and the gain at normal received signal level falls to about 30 dB. Diode detectors included at three points along the amplifier chain each develop a d.c. voltage proportional to the signal level at that point with a maximum voltage corresponding to the appropriate limiting level. The voltages developed by each of the three detectors are added in series so that the voltage sum varies linearly with the input signal. This d.c. voltage is amplified and applied to the receiver unit meter.

Where space diversity reception is used, the d.c. output voltages from the receivers are connected to their respective meters and also to the associated control units; the two voltages are compared in the control unit, which actuates an IF diversity changeover switch in favour of the stronger signal.

The main IF amplifier is followed by a group delay equaliser for the overall UHF/IF group delay characteristic of the whole receiver unit. A typical example of such a characteristic is given in Fig. 13.

Miscellaneous Unit.

Tilt Equaliser: The IF output from the receiver unit is first fed to a fixed group-delay equaliser to compensate for linear variations of group delay with frequency ('tilt') introduced by dispersive propagation in the waveguide antenna feeders and also for any channel filter response asymmetry. About 6 ns variation over 18 MHz is typical.

Limiter and Carrier Reinsertion Unit: A limiter stage is included in the signal path in which two series-connected and biassed diodes alternately conduct when the IF voltage exceeds the bias voltage, to reduce IF amplitude fluctuations by about 20 dB. An amplifier then restores the output level to 0.5 V r.m.s. The IF signal amplitude at the input is detected and if it drops by more than 6 dB (due for example to failure of the receiver unit) a Schmitt trigger circuit causes the through signal path to be interrupted by applying a bias voltage to a transistor in the signal path. Simultaneously a 70 MHz crystal-controlled oscillator is switched on and injected at the transistor output within 20 μs of signal loss. A reed relay is also actuated to provide local and remote indications of receiver unit output failure. IF carrier reinsertion prevents the transmission of wideband noise through a failed radio channel which could result in interference with adjacent channels. All IF and RF levels in the succeeding equipment remain normal, but since the received continuity pilot disappears at the terminal station, the IF protection switching automatically switches the interrupted traffic on to the standby channel.

Channel Filter Equalisation: An adjustable group-delay equaliser connected between the carrier reinsertion unit and the output IF amplifier corrects the parabolic component of group delay introduced by the UHF components, particularly the waveguide channel filters, between the preceding transmitter unit output and the subsequent receiver input.

Both this and the 'tilt' equaliser are passive networks not requiring any readjustment when active units are replaced.

Output IF Amplifier: The output signal from the adjustable group-

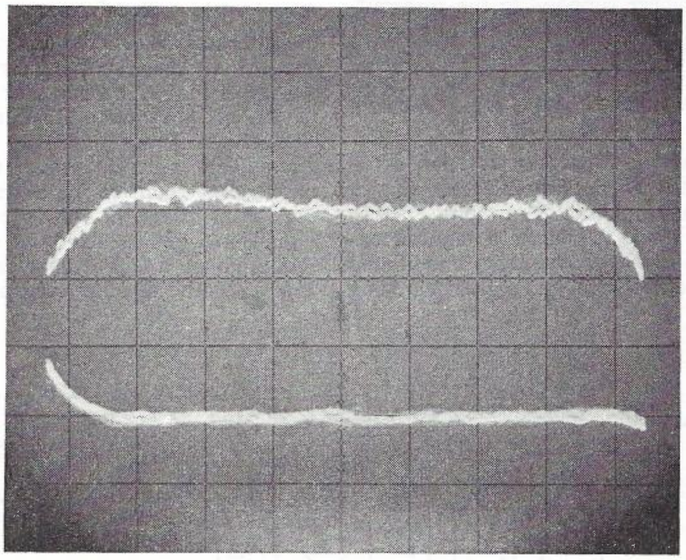


Fig. 13: Typical Receiver Amplitude (Top) and Group Delay (Bottom) Responses —Receiver in Amplitude Non-Limiting Condition. (Horizontal sensitivity, 2 MHz/division; vertical sensitivity, 0.1 dB/division on top trace and 1 ns/division on bottom trace.)

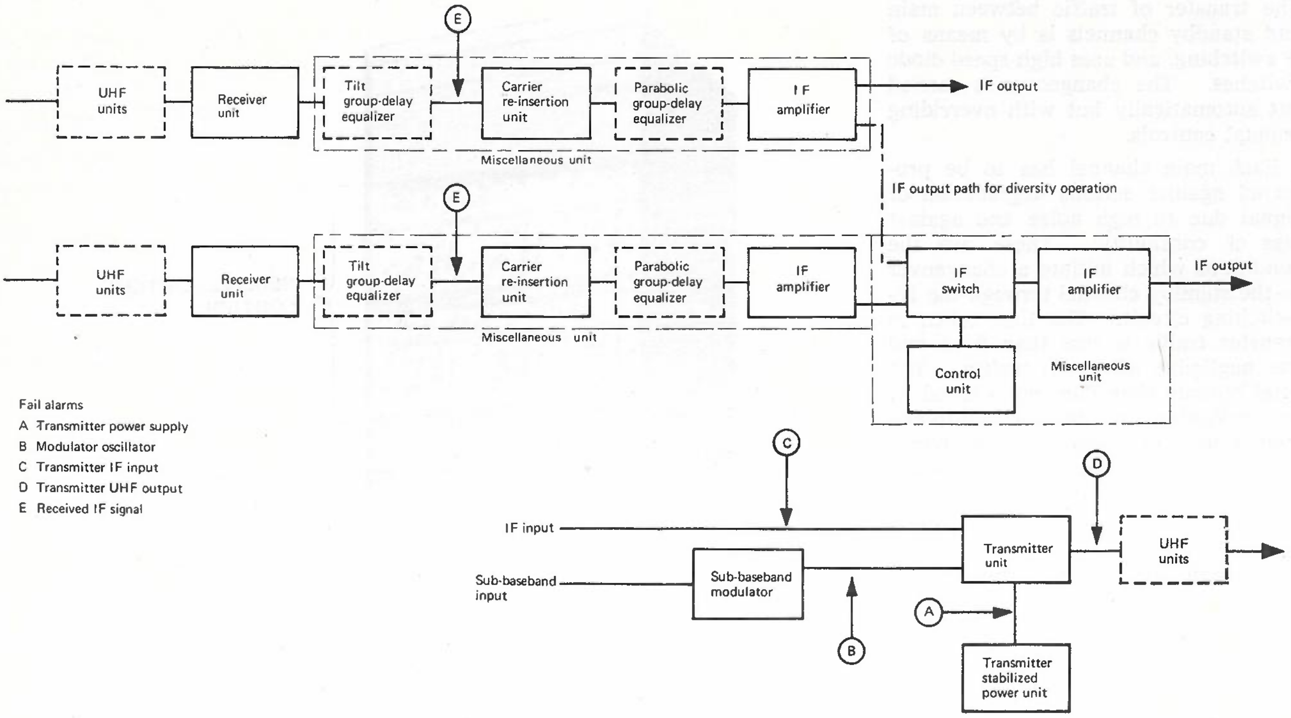


Fig. 14: The Active (Solid Line) and Passive (Dotted Line) Elements of a 2GHz System.

delay equaliser is further amplified to give a final nominal IF output level of 0.5 V r.m.s. at the rack output.

Diversity Receiver.

Space diversity operation is provided at 18 stations covering 12 hops and utilises a second diversity receiver rack which can mount up to three receivers of identical design to the main receiver connected together in RF multiplex to the diversity antenna feeder.

The IF outputs from the main receiver and the appropriate diversity receiver are connected to a semiconductor-diode IF changeover switch on the diversity receiver rack. The switch transit time is about 5μs. D.C. voltages, derived from the main and diversity IF main amplifier and which are a function of the respective received signal levels as described above, are applied to a d.c. sensing circuit in the IF switch control unit. When a d.c. voltage corresponding to a difference of about 6 dB between the two receiver input signal levels is detected, the control unit operates the IF switch to accept the higher received signal. The switch output is fed via an additional IF amplifier (to compensate for the loss occurring in the IF switch and cabling) to the rack output for connection to subsequent equipment. A switch on the control unit enables either receiver to be selected manually.

Technical Summary.

Operating frequencies:
in the band 1.9 to 2.3 GHz.

Transmitter.

Output power (2 GHz):
1.3 W minimum at high-level mixer output.
Output impedance:
50 ohms unbalanced.
Input level (70 MHz):
—6 dB relative to 0.5 V r.m.s.
Input impedance:
75 ohms unbalanced: return loss 26 dB.
Frequency deviation:
(see Modem technical summary).
Frequency stability:
< 1 part in 10^5 (0° to 50°C).

Receiver.

Input impedance (2 GHz):
50 ohms unbalanced.
Output level (70 MHz):
0.5 V r.m.s.
Output impedance:
75 ohms unbalanced: return loss 26 dB.
Noise factor:
5.5 dB (nominal) at tunnel diode amplifier input.
Bandwidth:
40 MHz to the —3 dB points.
Image response:
more than 70 dB below the wanted signal.
Mute level:
—110 dBW (nominal).

Power consumption:

Power supplies:
—24 V d.c. (nominal) (range —21.5 to —32.0 V).
Transmitter:
2.8 amps approx.
Receiver:
0.7 amps approx.
Diversity receiver:
1.2 amps approx.

IF PROTECTION SWITCHING.

To ensure a high degree of reliability the main (working) channels are protected by a standby (protection) channel. The latter will carry occasional traffic under normal conditions, but provides an alternative circuit should a main channel be required for maintenance checks or become unserviceable due either to equipment failure or frequency-selective fading. In principle, changeover can be effected to include the baseband modulators and demodulators, or protect the radio equipment only: the two types are termed baseband switching and IF switching respectively. The standby channel provides protection for terminal transmitters and receivers of a system and also for all the repeaters of a switching section. Baseband equipment is protected by duplicating the critical elements of the circuits and providing separate changeover-on-fail switches.

One standby radio channel can protect up to seven main radio channels.

The transfer of traffic between main and standby channels is by means of IF switching, and uses high-speed diode switches. The changeover is carried out automatically but with overriding manual controls.

Each main channel has to be protected against serious degradation of signal due to high noise and against loss of continuity. These are the conditions which initiate a changeover to the standby channel through the IF-switching circuit. The time taken to transfer traffic is less than 5 μs and has negligible effect on traffic. The total operate time does not exceed 30 ms, excluding the time for end-to-end transmission of tones. A second noise-fail level is also used. This is above the level of noise normally experienced and gives the same indication as a pilot fail.

UK standard type-62 construction practice is used throughout (Fig. 15). The extensive use of plug-in units means that the system can be expanded with additional units as required.

Fig. 16 shows a simplified 1-for-1 IF-switching system between two terminal stations: radio repeater stations have been omitted. The traffic, together with the main-channel continuity pilot, is applied to the main-channel modulators. The resulting IF signal is taken to the main-channel transmitter via the IF-switching equipment. The standby continuity pilot, at a different frequency to the main pilot, is applied to the standby-channel modulator and the IF signal is then taken via a separate path through the switching equipment to the standby-channel transmitter. A standby-channel demodulator is provided at a receive terminal so that television programmes may be transmitted over the standby channel.

At the receive-end of the section the IF outputs from all receivers are applied to the switching equipment, where the pilots are demodulated and monitored by the detection equipment to decide whether a changeover shall take place.

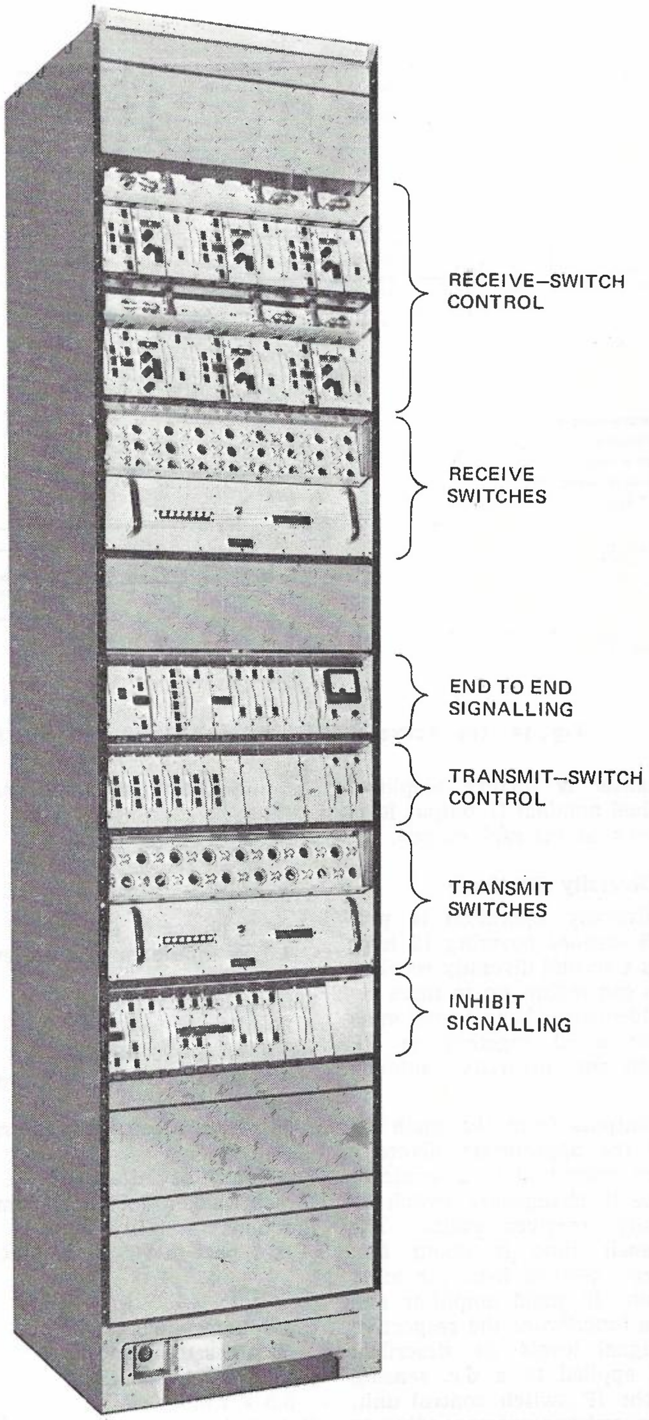


Fig. 15: Typical IF Protection Switching Rack, Fully Equipped for a 1-for-7 System.

Detection and Logic.

Fig. 17 shows the detection-and-logic circuits. The received IF signals are demodulated to extract the continuity pilots and noise signals in the band between about 8 and 9 MHz; the pilot frequencies used are 8.5 MHz for the main channel and 8.0 MHz for the standby channel. In the normal condition the output from each main-channel pilot demodulator is its pilot, and that from the standby-channel pilot demodulator is the standby-channel pilot. When main channel traffic is switched to standby the output from the standby-channel pilot demodulator is at the main-channel pilot frequency.

The pilot demodulator outputs are applied to individual pilot receivers, which detect the pilots and the noise in a narrow band around each pilot. If a pilot fails by the pre-set amount, a pilot fail is indicated; similarly if the noise rises above the pre-set figure a noise fail is indicated.

The main channel pilot and noise fail outputs are applied to override units which control the relative priorities of access to the standby channel by the various main channels. All pilot failures are given priority over high

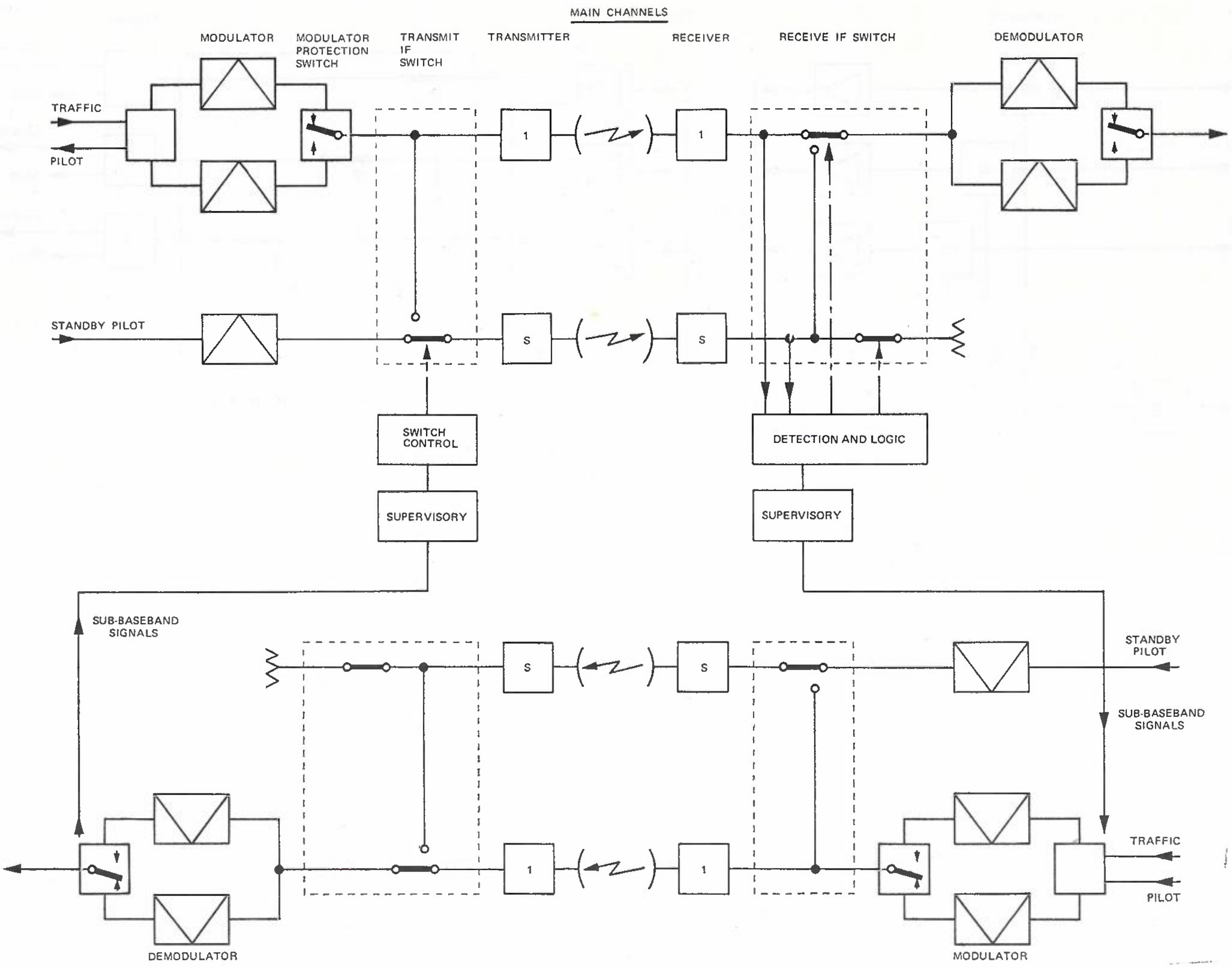


Fig. 16: Block Diagram of a Simplified 1-for-1 IF Protection Switching System.

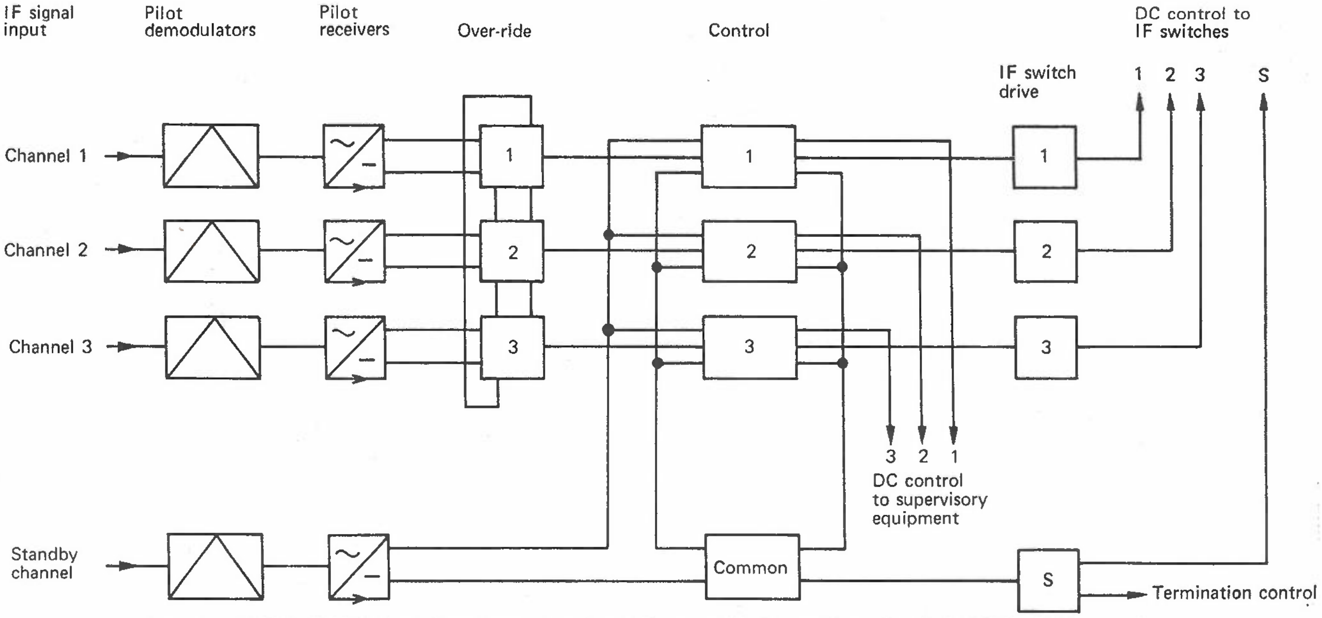


Fig. 17: Block Diagram of the Detection and Logic Circuits Applied to a 1-for-3 Configuration.

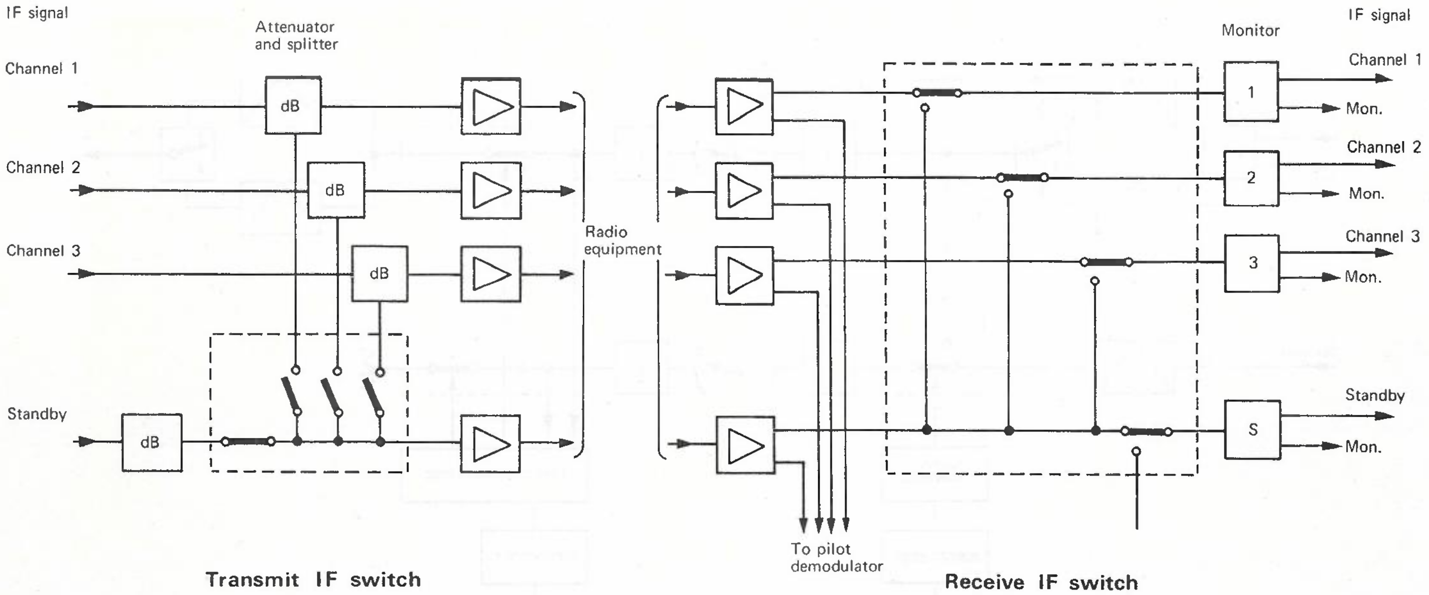


Fig. 18: Block Diagram of the IF Switching Circuit Applied to a 1-for-3 Configuration.

noise fails, and all changeover requests have priority in the order channel 1, channel 2, channel 3, etc. The channel fail signals initiate a changeover. The appropriate channel control then applies a d.c. voltage to the supervisory equipment. Tones are generated by the supervisory equipment and sent back to the terminal transmitter station over sub-traffic-band speech channel. At the same time, the control common unit inhibits all other channels from gaining access to standby.

At the terminal transmitter, the standby radio channel is then connected in parallel with the failed main channel.

The presence of the pilot is detected at the receiver and causes the receive IF switch to change over and connect the standby channel receiver output to the appropriate main channel demodulators.

The transmit changeover switch does not disconnect the input signal from the main-channel transmitter; when the main channel returns to normal, the reappearance of its pilot is detected at the receive end of the section and the receive IF switches return to normal. This event is returned to the transmit end, via the supervisory link, and the appropriate IF switch restores the standby modulator to its radio channel. Thus the traffic path is disconnected only during the switching action of the receive-end IF switch.

Intermediate Frequency Equipment. Fig. 18 shows the IF-switching equipment for both transmit and receive-ends of a switching section. For clarity only three main channels have been shown.

At the transmit-end of the switching section the main-channel IF signal is applied to an adjustable attenuator-and-splitter unit, which can accommodate input levels within the range —6 dB to +1 dB relative to 0.5 V.

The splitter unit has directional (hybrid) properties so that any signal reflected back into one of the outputs does not appear at the other output. One output is amplified to give a main-channel output at a level of 0.5 V. The second output is applied to the transmit switch and is terminated by the switch in 75 ohms.

The standby-channel IF signal is applied to an attenuator unit and then to the transmit switch. In the normal condition the switch selects the standby-channel input and applies it to a broadband IF amplifier. This amplifier, which is similar to that used on the main channel, is adjusted to give an output level of 0.5 V. The transmit switch consists of one fast-acting on/off diode switch for each channel.

The control circuits provide a separate d.c. control voltage for each switch so that only one switch will be operated at any time. When the transmit IF switch operates, the standby-channel switch input is terminated in 75 ohms, and the appropriate main-channel switch connects the output from the main-channel attenuator-and-splitter unit to the standby-channel IF output.

The receive-end inputs are applied to IF amplifiers each with two outputs. The main output is taken, via the receive switch to the main-channel demodulators. The second output is taken to the pilot demodulators in the detection-and-logic circuits. The receive IF switch consists of two-way channel-switch units (one for each channel) and each can either select the signal from the standby receiver or from its own channel.

Diode Switch. Fig. 19 shows the basic circuit of the fast-acting diode switch. When a positive voltage is applied to the d.c. control input, diodes D1 and D2 are forward biassed and provide a low-impedance IF path. In this condition the loss through the switch is less than 1 dB. If the d.c. control input polarity is reversed, D1 and D2 are reverse biassed and present a high impedance to the IF signal but diodes D3 and D4 are then forward biassed and, with capacitors C2 and C3, provide a very low impedance path to earth, giving a very high insertion loss of the order of 80 dB.

Express Switching Tones.

Audio tones are used to signal from the receive switching terminal to the transmit switching terminal of a switching section. Six tones are used: one tone is the guard tone transmitted when no changeovers are requested. The remaining five tones are used to provide a 2 out-of-5 code to signal a changeover to standby for each channel of the transmit switch.

Fig. 21 shows a block diagram of the express-switching-tone equipment. The d.c. control signals from the detection and-logic equipment are applied

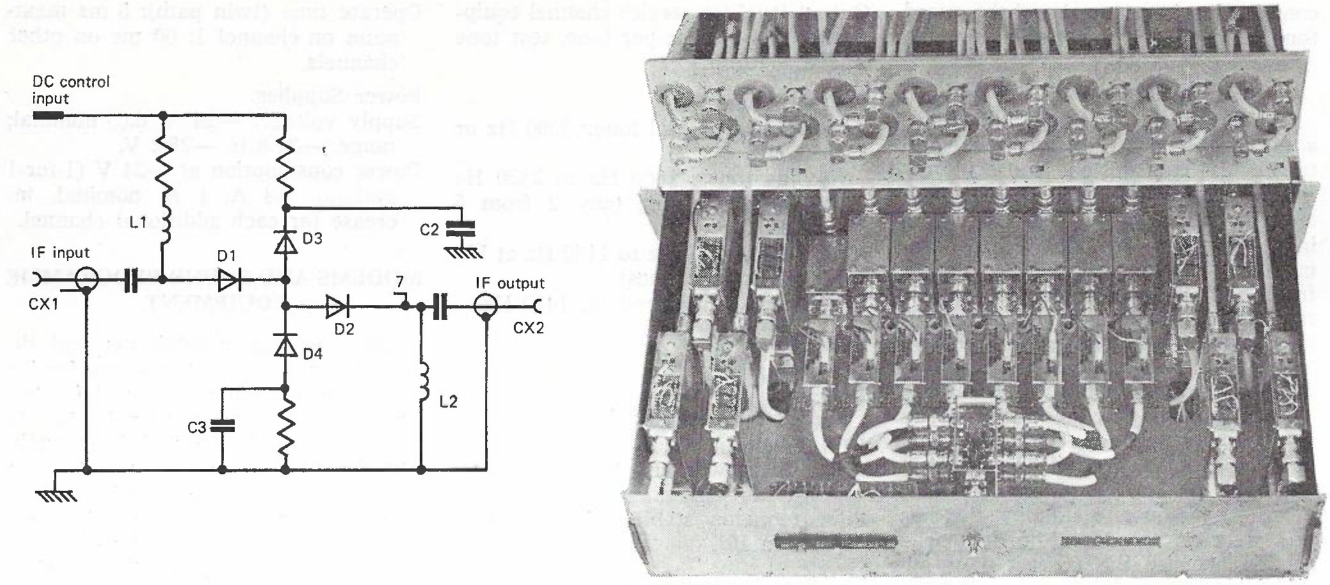


Fig. 19: IF Switch: Simplified Circuit of One Switch and Fully Equipped 1-for-7 Transmit Switch Shelf.

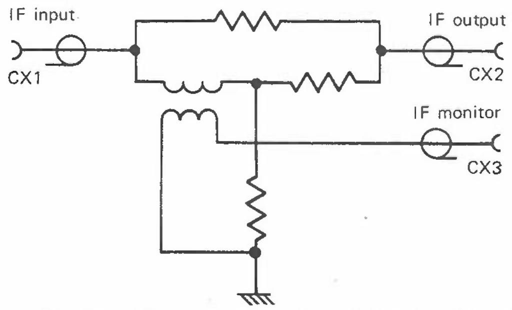
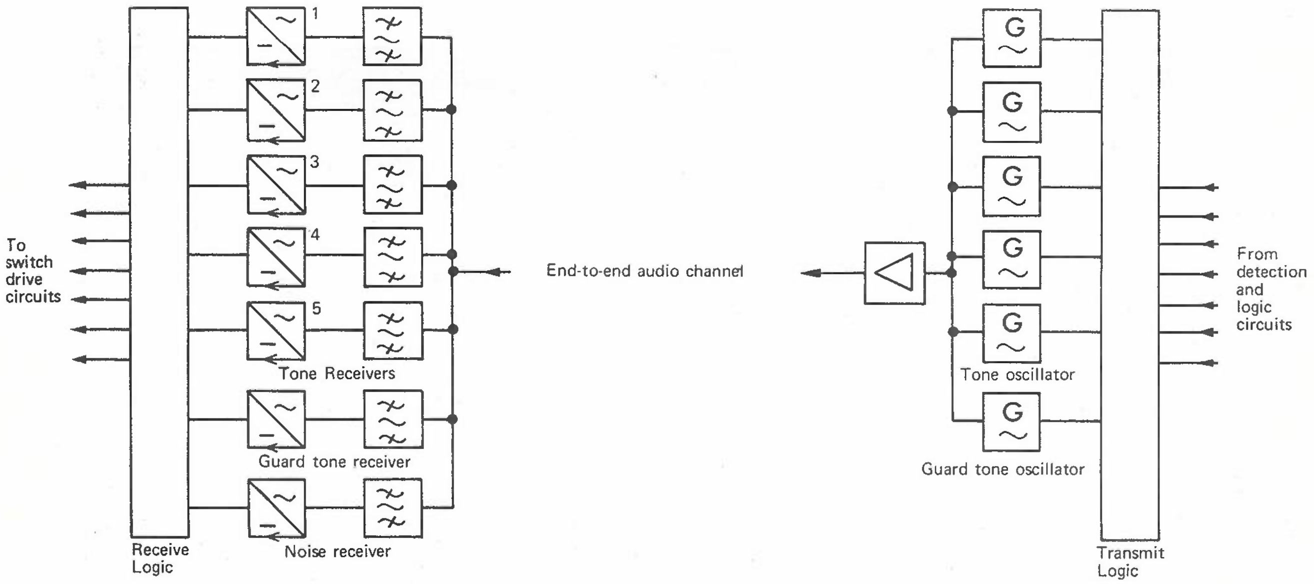


Fig. 20: Simplified Circuit of the IF Monitor Hybrid.

to the transmit logic unit. At the transmit terminal the tones are detected and the resulting d.c. signals applied to a receive logic unit which converts the two-tone combinations into separate control outputs for each main channel in the switching system. The control outputs are applied to the switch drive circuits and thus control the transmit IF switches. The tone receivers and logic circuits have their own built-in protection against false switching due to wrong tone combinations and high noise. The supervisory system will only return to normal when the two-tone



Transmit terminal **Receive terminal**

Fig. 21: Block Diagram of the Express Switching Tone Transmission Circuit.

combination is removed and the guard tone received at the transmit terminal.

Switching Sections in Tandem.

The East-West system is divided into a number of switching sections, and traffic is transmitted consecutively from one switching section to the next. Normally the IF signals at the switching stations are demodulated to baseband and the pilot and noise signals from the first switching section are extracted before the signal is remodulated on to the following section using a new pilot. Thus the sections are independent. At Merredin, the television channel is through connected at IF to the following section, with the pilots and noise also carried through. If either of the Northam-Merredin channels changes over to standby, this has no effect on the Merredin-Kalgoorlie section because the correct pilot appears at the appropriate following main-channel input. If, however, the second channel also failed, the corresponding channel on the Merredin-Kalgoorlie section would attempt to change over because it would recognise an apparent fault condition. False changeover is prevented by applying a d.c. voltage to the appropriate transmit-switch circuits and by transmitting a tone forwards to the following receive detection-and-logic equipment to cancel the apparent failure.

Technical Summary.

IF Connections.
IF centre frequency: 70 MHz.
IF impedance: 75 ohms unbalanced.
Return loss (except for Tx output): 26 dB from 56 to 84 MHz.
Return loss transmit IF output: 26 dB from 60 to 80 MHz.

Input Levels:
Receive switching equipment: 0.3 V r.m.s.
Transmit switching equipment: 0.3 V r.m.s.

Output Levels:
Receive Switching equipment: main output, 0.5 V r.m.s.; monitor output, —16 dB on 0.5 V r.m.s.
Transmit switching equipment: 0.5 V r.m.s.
Amplifier response: within 0.2 dB from 55 MHz to 85 MHz.
Relative group delay: 1 ns from 61 MHz to 79 MHz.
Rejection of unwanted channel: 75 dB minimum at 70 MHz.

Service Channel Connections.
Impedance: 600 ohms unbalanced.
Frequency band: 300 Hz to 3.4 kHz.
Input level (from service channel equipment): —10 dBm per tone, test tone level 0 dBm.
Output level (to service channel equipment): —10 dBm per tone, test tone level 0 dBm.

Control Tones.
Service band control tone: 3060 Hz or 3180 Hz.
Switching tones: 1860 Hz to 2820 Hz at 240 Hz spacing (any 2 from 5 used).
Inhibit tones: 420 Hz to 1140 Hz at 120 Hz spacing (7 tones).
Noise monitor: centred on 1440 Hz.

Pilots.
Pilot Frequency:
Working channel: 8.5 MHz.
Protection channel: 8.0 MHz.
IF Deviation:
8.5 MHz (worker), 8 MHz (protection): 140 kHz r.m.s.
Pilot frequency stability: better than 5 parts in 10^5.

Basis of Changeover.
Pilot Degradation:
—2 dB to 8 dB (adjustable).
Noise Degradation:
Telephony: nominally 25000 pW (—46 dBmop) in the 2438 kHz slot.
Television: nominally 65000 pW (—42 dBmop) in the 2438 kHz slot.
Protection: nominally 65000 pW (—42 dBmop) in the 2438 kHz slot.
Manual operation: remotely operated.
Lock out operation: remotely operated.

Changeover Times.
Transfer time: 5 μs maximum.
Operate time: 30 ms maximum (excluding time for end to end transmission of tones).
Operate time (with override): 60 ms maximum.
Operate time (twin path): 5 ms maximum on channel 1; 60 ms on other channels.

Power Supplies.
Supply voltage: —24 V d.c. nominal; range, —21.8 to —28.2 V.
Power consumption at —24 V (1-for-1 system): 3.4 A; 1 A, nominal, increase for each additional channel.

MODEMS AND SOUND-PROGRAMME EQUIPMENT.

The frequency modulation and demodulation (modem) equipment for the East-West system is equipped for 600 telephone channels, with a further 11 supervisory and/or 'wayside' channels, although the design is suitable for applications involving up to 960 or 1800 channels. Alternatively television signals with a sound programme channel may be transmitted. Continuity pilots at 8.0 MHz and 8.5 MHz are employed. The equipment is designed to comply with all relevant CCIR Recommendations.

Semi-conductor devices are used throughout and high-performance standards, coupled with high-reliability of operation are achieved. The equipment is considerably more compact than earlier valved designs and a complete modulator or demodulator equipment can be accommodated within a UK standard Type 62 framework in a height of 203 mm (8 in.), as shown in Fig. 23. This incorporates duplicate modulators (or demodulators) and automatic means for switching traffic through the standby in the event of a failure of the operating equipment.

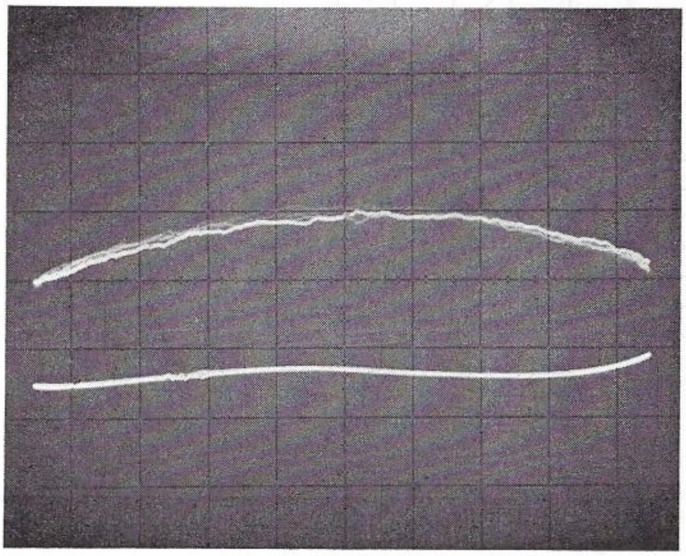


Fig. 22: Typical Amplitude (Top) and Group-Delay (Bottom) Responses of Transmit and Receive Switching Equipment Connected Back to Back at IF. (Horizontal sensitivity, 2 MHz/division; vertical sensitivity, 0.1 dB/division on top trace and 1 ns/division on bottom trace.)

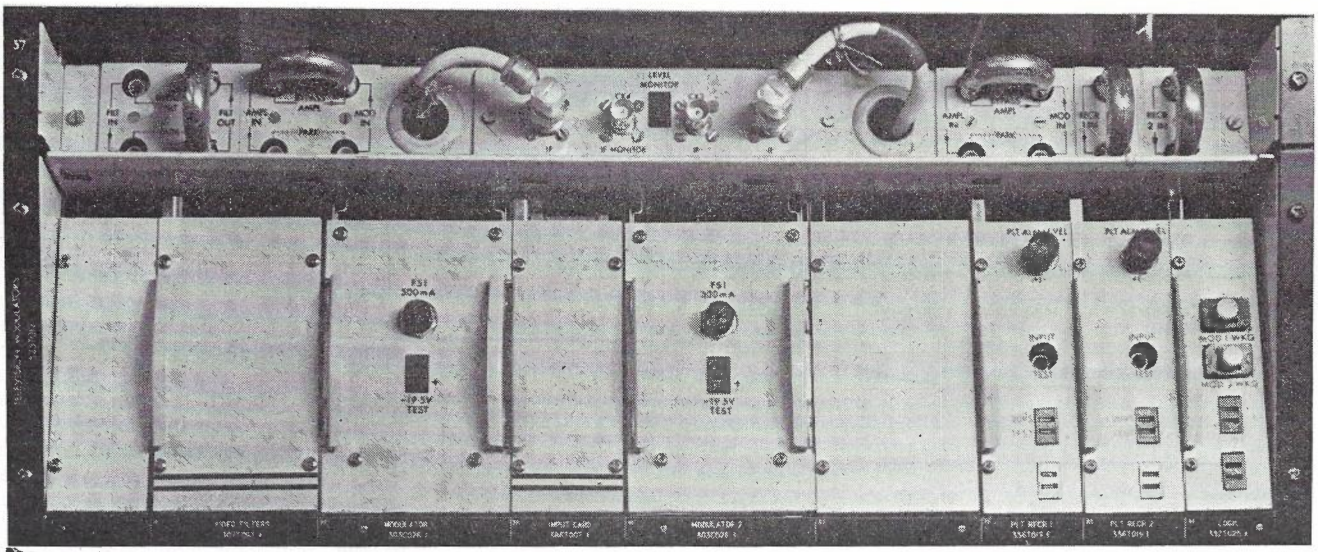


Fig. 23: Duplicated Modulator and Pilot Receiver Equipment with Associated Interconnection Panel.

Modulators and demodulators may be independently pre-adjusted, so that the requisite overall performance limits are achieved without further adjustment when they are interconnected.

Modulation Equipment.

Telephony traffic is transmitted in the band 60 to 2540 kHz, with supervisory and 'wayside' channels in the band 300 Hz to 54 kHz. The equipment accepts a baseband input level of —42 dBr and provides a modulated 70 MHz IF output level of 0.5 V r.m.s., at 75 ohms impedance.

Two frequency modulators are fed in parallel (Fig. 24), and an IF switch selects the output from one of them. This ensures continuity of transmission from baseband input to IF output in the event of failure of any active device, and allows maintenance operations on a modulator without interrupting traffic.

Input Circuit. — The baseband signal is fed to an attenuator, used for setting a standard input level to the modulators, followed by a pilot-stop filter tuned to the continuity pilot frequency 8.5 MHz. This filter prevents incoming energy in the region of 8.5 MHz from interfering with the pilot receivers at the system output. A hybrid combines the baseband signal with the continuity pilot and a further hybrid provides identical outputs for the duplicated modulators.

Pre-emphasis Circuit. — Each modulator includes a pre-emphasis network (Fig. 25) to shape the overall frequency deviation characteristic to that recommended by the CCIR (Recommendation 275-1). The network has an amplitude response in which the output at the highest baseband frequency is 8 dB above that at the lowest. A loss of 5 dB in the total power level of the baseband signal is introduced (represented as a 'white noise' spectrum) but an associated amplifier compensates for this loss to produce a 'test tone' deviation of 250 kHz r.m.s. at the 'crossover' frequency (0.6 times the maximum modulating frequency), 2dB above the standard deviation recommended by the CCIR. This was chosen to reduce the overall system basic noise. The pilot deviation is 140 kHz r.m.s.

Frequency Modulator. — The modulator uses a modified Colpitts oscillator (Fig. 26) operating at 70 MHz; its frequency is controlled by a 'varactor' diode.

Oscillation occurs at the series resonant frequency of the components Cd and L. The varactor capacitance Cd is a function of the diode junction voltage. For a multi-channel telephony signal to be transmitted without excessive inter-modulation, it is essential that the oscillation frequency is an accurately linear function

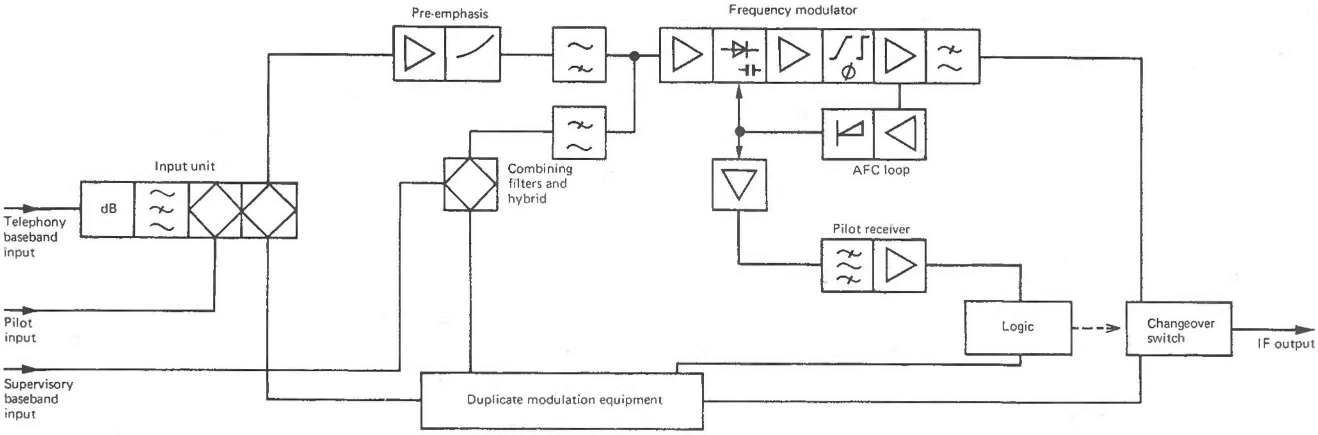


Fig. 24: Block Diagram of a Telephony Modulator.

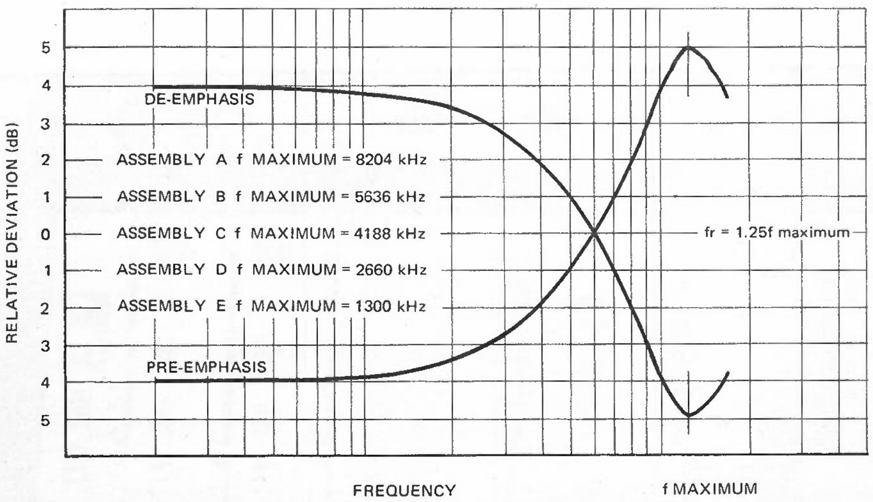


Fig. 25: Telephony Pre-Emphasis and De-Emphasis Characteristics.

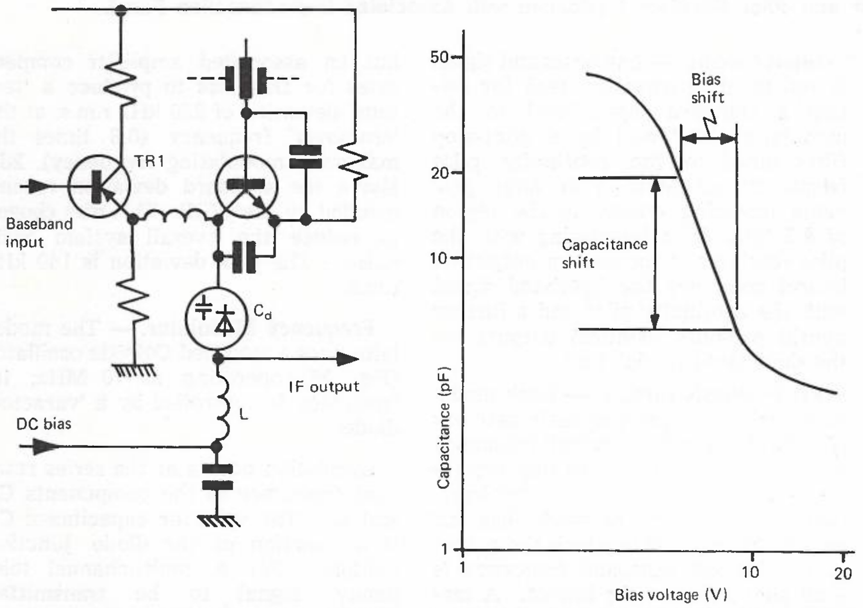


Fig. 26: Simplified Circuit of Varactor Modulator and Relationship Between Capacitance Change and Applied Voltage.

of the input voltage Vd and this is obtained when Cd is inversely proportional to Vd^2. This relationship is realised over a limited range of voltages by use of a hyper-abrupt junction varactor diode.

The baseband signal is applied to the varactor via an emitter follower TR1 and thus frequency modulates the natural frequency of oscillation (controlled by a d.c. bias). The emitter follower ensures adequate low-frequency response and is particularly advantageous when handling television signals.

The modulated output is applied, via an IF buffer amplifier, to an all-pass network, to equalise the modulator group-delay characteristic, measured from baseband input to IF output. Further amplification follows this equaliser, to feed the IF signal to the output connector via a low-pass filter, which reduces the output IF harmonic level. A strappable attenuator is provided before the output stage for setting the IF output level.

The carrier frequency can be maintained within 300 kHz over a 50 deg. C temperature range by suitable selection of feedback components. Automatic frequency control, further controls this drift to within 100 kHz.

Automatic Frequency Control. — Oscillator AFC is provided by means of a feedback circuit from the main IF output. This consists of a limiting IF amplifier and a balanced frequency discriminator whose crossover frequency is set to 70 MHz. The detected d.c. output from the discriminator is applied to the varactor in series with its d.c. bias supply to reduce departures of the oscillator frequency from 70 MHz. Suitable time constants are employed to ensure the AFC does not respond to the modulating signal. The discriminator also provides a means for demodulating the continuity pilot, which is fed via a bandpass filter and an amplifier to a pilot output socket.

Changeover. — The pilot outputs from the two modulators are applied to separate pilot receivers which incorporate narrow bandpass 8.5 MHz filters. Schmitt trigger circuits, actuated by a drop in pilot level of 4 dB or more, provide control voltages to a changeover-logic circuit which determines the position of an IF changeover switch and initiates changeover to the duplicate modulator with a switch transit time of less than 5 μs The switch will remain in this condition until such time as the continuity pilot from the second modulator output fails and the first has restored.

Demodulation Equipment.

The frequency-modulated 70 MHz signal from the radio equipment, via IF protection switching, is accepted at a nominal level of 0.5 V r.m.s. and delivers the baseband signal at the CCIR recommended level, for 600 telephone channels, —23 dBr. Two sets of demodulation equipment are parallel fed from the IF signal, and a baseband switch selects the output from one of them (Fig. 27).

Demodulator. — The IF signal is applied to a low-pass filter, which rejects IF harmonics, a buffer amplifier, and an all-pass network to equalise the overall demodulator IF group delay. The IF signal is then amplified by a series of wideband grounded-base transistor amplifiers followed by a pair of limiter stages with an interposed amplifier stage. The limiters consist of a parallel pair of diodes followed by a series pair, which compress any amplitude modulation components in the IF signal. A subsequent bandpass filter rejects harmonics generated by the limiter. The signal is then applied to a discriminator, which converts the FM signal to amplitude modulation; a high degree of amplitude/frequency linearity is achieved in a single network with a response peak at 55 MHz and a null at 85 MHz. A single diode detects the amplitude modulation to reproduce the baseband signal. A low-pass filter, a feedback pair amplifier and a strappable attenuator (to set the baseband output level) are included before the baseband signal is applied to a pair of signal-separating filters.

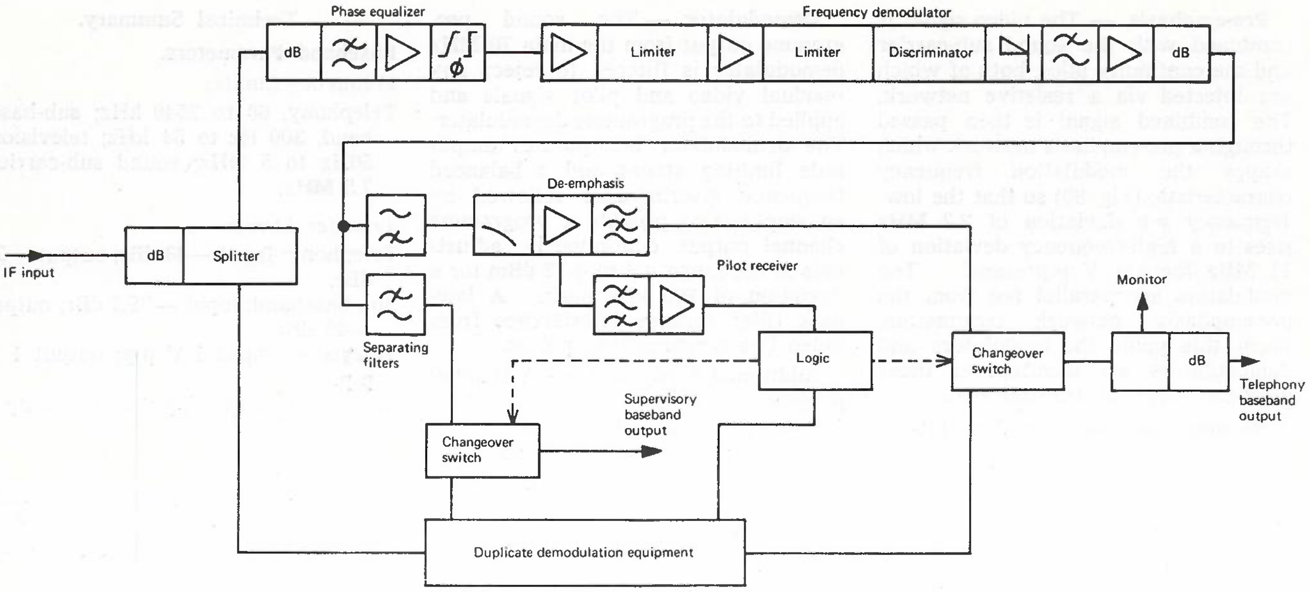


Fig. 27: Block Diagram of Telephony Demodulator.

De-emphasis. — The de-emphasis network restores the baseband amplitude/frequency characteristic to uniformity, and, together with an amplifier, provides the necessary output level as recommended by the CCIR. A band-stop filter at the main baseband output attenuates the level of the continuity pilot appearing at the system output. The amplifier also has an additional output for the continuity pilot.

Changeover.—The pilot output from each amplifier is taken to a pilot receiver identical to that used in the modulator. Schmitt trigger circuits provide control voltages to the logic unit, which determines the position of the baseband changeover switch. A fall in continuity pilot level of 8 dB or more is taken to indicate failure.

The demodulator changeover switch has a similar function to its modulator counterpart, except that it utilises mercury-wetted reed switches to provide a 'hitless' changeover.

Television and Sound Programme Transmission.

The equipment is also used for the transmission of television signals (with some variations in the associated baseband units). The modulators, demodulators and protection equipment are identical to those used for telephony, but the baseband input and output differ in a number of respects, as shown in Figs. 28 and 29.

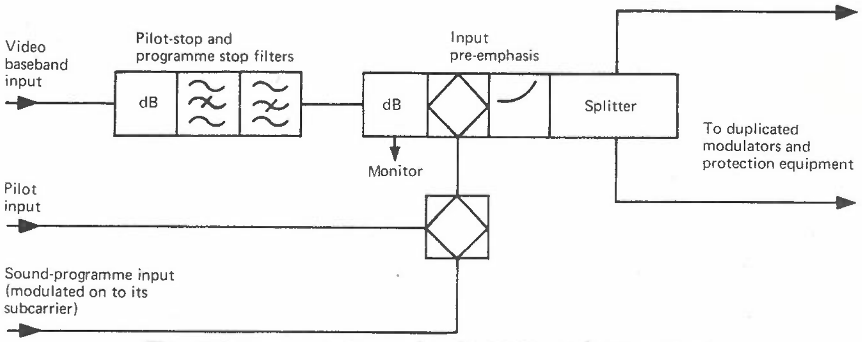


Fig. 28: Block Diagram of Television Modulator Input.

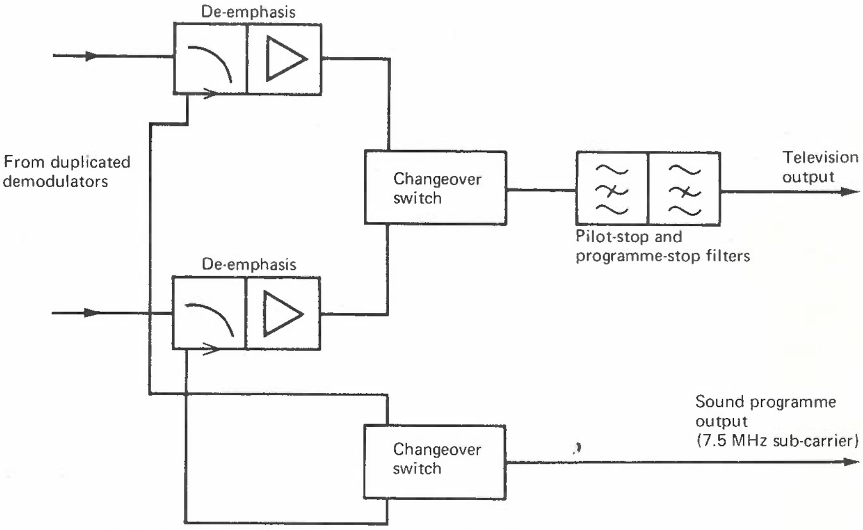


Fig. 29: Block Diagram of Television Demodulator Output.

The video baseband extends to an upper frequency limit of 5 MHz and above this range a sound programme channel may be transmitted, by a frequency modulated 7.5 MHz sub-carrier, together with the 8.5 MHz continuity pilot.

Filter. — The video and sound-programme sub-carrier signals are applied to band-stop filters centred at the sound sub-carrier and continuity-pilot frequencies to prevent interference from pilot frequencies transmitted from preceding sections of the system. An attenuator provides adjustment over the range -3 dBV to +3 dBV.

Pre-emphasis. — The video signal is combined with the sound sub-carrier and the continuity pilot, both of which are injected via a resistive network. The combined signal is then passed through a pre-emphasis network which shapes the modulation frequency characteristic (Fig. 30) so that the low-frequency p-p deviation of 2.2 MHz rises to a high-frequency deviation of 11 MHz for a 1 V p-p signal. The modulators are parallel fed from the pre-emphasis network termination. From this point the modulators and demodulators are identical to those used for telephony transmission.

De-emphasis. — The demodulator output is applied to a de-emphasis network and amplifier, which restores the overall television baseband amplitude frequency response to uniformity. It also provides the gain necessary to deliver a 1 V p-p signal. Separate outputs are provided for the programme sub-carrier and the continuity pilot.

Sound Programme Equipment.

A 7.5 MHz sub-carrier is frequency modulated by the sound channel with modulating frequencies in the range 30 Hz to 14 kHz before application to the 70 MHz modulator. Fig. 31 shows the block diagram of a sound-channel modem equipment.

Modulator. — The incoming audio signal modulates a single transistor oscillator by means of a varactor diode in a similar fashion to the main 70 MHz modulator. An input attenuator provides adjustment for input levels in the range 0 to 19 dBm to produce the standard sub-carrier deviation of 200 kHz peak. The oscillator output is amplified to a level of 0 dBm at the unit output before connection to the main 70 MHz modulation equipment.

Demodulator. — The sound programme output from the main 70 MHz demodulator is filtered to reject any residual video and pilot signals and applied to the programme demodulator. The demodulator incorporates amplitude limiting stages and a balanced frequency discriminator followed by an amplifier to provide a programme channel output continuously adjustable in the range +4 to +17 dBm for a deviation of 200 kHz peak. A low-pass filter reduces interference from video line-synchronising pulses.

Additional Equipment. — A standby programme channel is provided; a manual patching arrangement enables it to substitute for the working channel. A monitor unit may be switched to either audio inputs or outputs and incorporates a VU meter, together with a loudspeaker.

Technical Summary.

Baseband Parameters.

Frequency Limits:

Telephony, 60 to 2540 kHz; sub-baseband, 300 Hz to 54 kHz; television, 50Hz to 5 MHz; sound sub-carrier, 7.5 MHz.

Transfer Levels:

Telephony: Input —43 dBr; output —23 dBr.

Sub-baseband: input —39.5 dBr; output —45 dBr.

Television: input 1 V p-p; output 1 V p-p.

Sound sub-carrier: input 0 dBm; output —25 dBm.

IF Deviation:

Telephony 250 kHz (r.m.s. channel); sub-baseband 50 kHz (r.m.s. channel); television 2.2 MHz (p-p low fre-

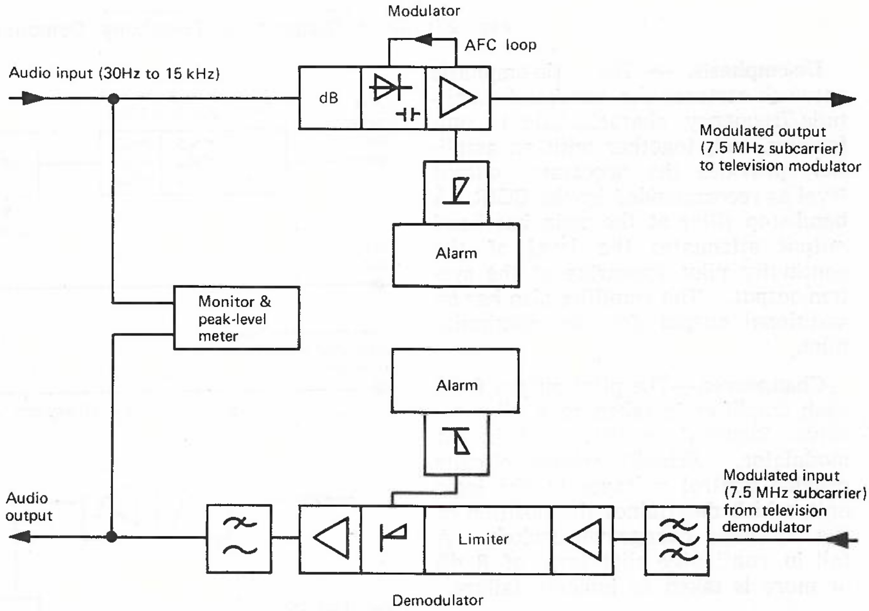


Fig. 31: Block Diagram of a Single-Channel Sound-Programme Modem.

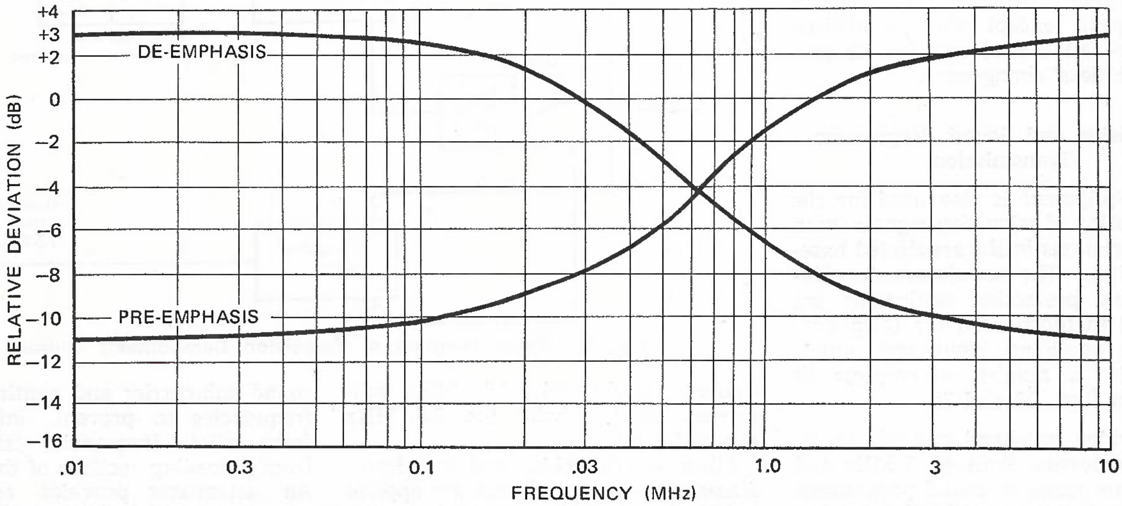


Fig. 30: Television Pre-Emphasis and De-Emphasis Characteristics for a 625-line system.

quency); sound sub-carrier 300 kHz (r.m.s.).

Impedance:
Telephony: 75 ohms unbalanced; 24 dB return loss.
Sub-baseband: 600 ohms; 20 dB return loss.
Television: 75 ohms unbalanced; 30 dB return loss.
Sound sub-carrier: 75 ohms unbalanced; 20 dB return loss.

IF Parameters.
Intermediate frequency: 70 MHz.
Input level (to demodulation equipment): 0.5 V r.m.s.
Output level (from modulation equipment): 0.5 V r.m.s.
Linearity and group delay: see Fig. 32.
Input and output impedance: 75 ohms unbalanced.
Return loss: 26 dB ±10 MHz.

Sound Channel Parameters.
Frequency limits: 30 Hz to 14 kHz.
Transfer levels: input to modulator, +9 dBr; output from demodulator, +9 dBr.
Deviation of sub-carrier: 200 kHz peak.

Power Supplies.
Supply voltage range: —21.8 to —28.2 V d.c.
Telephony power consumption: protected modulator, 1.2 A; protected demodulator, 1.2 A.
Television power consumption: protected modulator, 0.9 A; protected demodulator, 1.6 A; unprotected modem 1.2 A.

Performance Parameters.
Telephony: baseband response, 60 kHz to 2540 kHz within ±0.4 dB; noise performance, the accompanying table contains typical measured figures; together with specified limit figures in brackets.

Measuring Frequency.	Intermodulation Noise.	Basic Noise	Total Noise
70 kHz	40 pWop (80)	13 pWop (27)	53 pWop (107)
1248 kHz	12 pWop (80)	5 pWop (14)	17 pWop (94)
2438 kHz	7 pWop (80)	4 pWop (14)	11 pWop (94)

Television: baseband response: 30 Hz to 5 MHz within ±1 dB; 50 Hz waveform response within 0.5% K rating; 15 kHz 2T pulse and bar, within 0.5% K rating.
Sound channel: frequency response (30 Hz to 14 kHz) within ±1 dB; basic noise, better than —65 dB relative to output signal corresponding to 200 kHz peak deviation; harmonic distortion, better than 1% for frequencies in the range 30 Hz to 14 kHz.

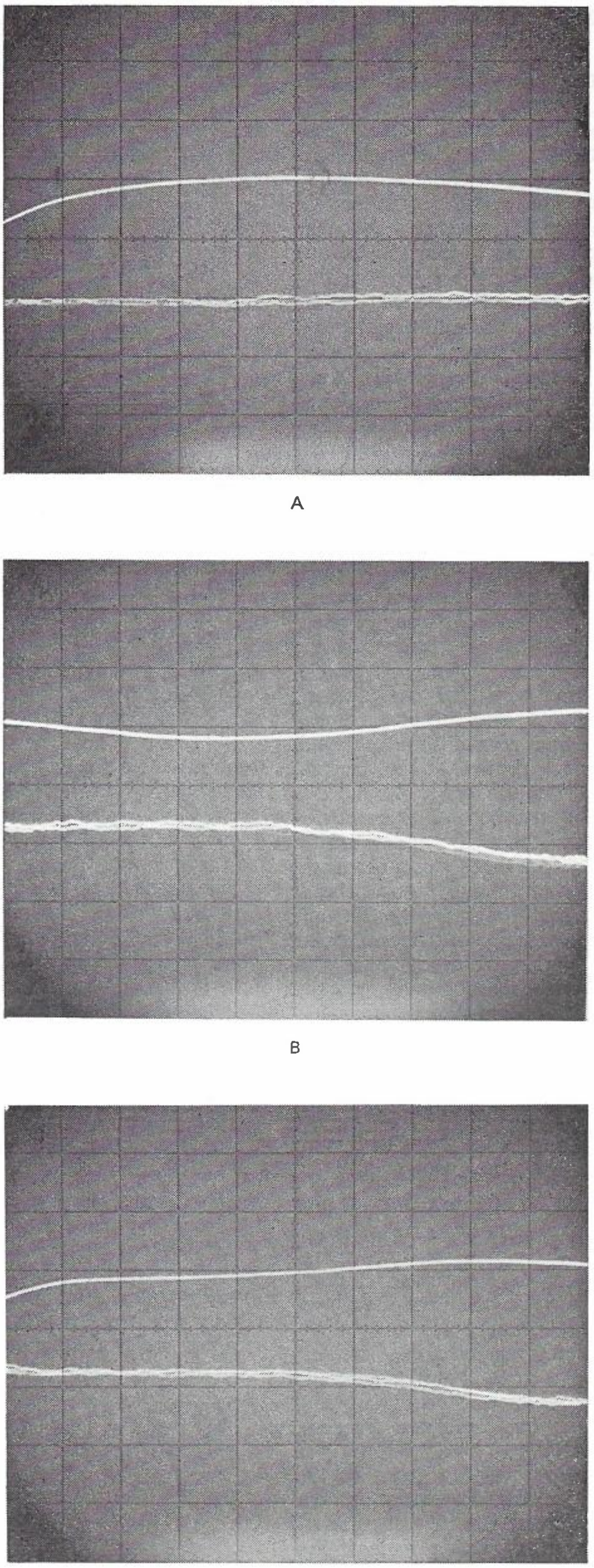

A
B
C

Fig. 32: Typical IF Linearity (Upper Trace) and Group-Delay (Lower Trace) Responses of (a) Modulator, (b) Demodulator, and (c) Modulator and Demodulator Connected Back to Back. (Horizontal sensitivity is 1 MHz/division and vertical sensitivity is 0.3 dB/division on the upper trace and 1 ns/division on the lower trace).

SUB-BASEBAND MODEM EQUIPMENT.

In addition to supervisory signals, speech communication is also transmitted between terminal control stations and between repeater stations (engineers-order wire), and a small number of speech channels ('wayside' channels) to the settlements along the route. These communications are provided by the 'drop-and-insert' method at repeaters, in which this additional information is modulated on to the main telephony bearer at frequencies below the traffic baseband (sub-baseband modulation). Since the main-bearer signals are transmitted through the repeater equipment at IF special equipment is required to modulate the through signal at repeater stations.

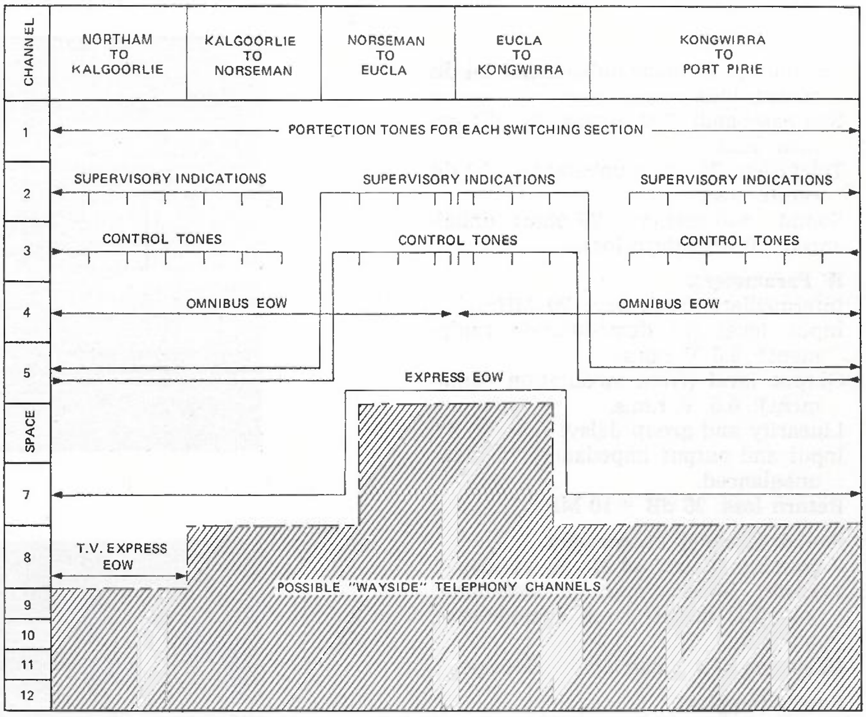
Compared with other methods, such as the use of auxiliary-radio bearers, the drop-and-insert system has a number of advantages which are particularly important in the context of the East-West system. The power consumption is very low, equipment volume is small, and initial costs are low. Also, high reliability is achieved, particularly for the end-to-end switching tones. On the other hand, it is necessary to ensure that intermodulation products from the main traffic modulation into the sub-baseband range, and from the sub-baseband modulation into the main traffic, are sufficiently low, and that thermal noise generated by the sub-baseband modulation equipment does not degrade the main traffic performance.

The equipment meets these requirements and provides facilities for the transmission of up to 11 speech circuits frequency division multiplexed into the frequency range 300 Hz — 54 kHz.

Equipment Description.

Figs. 1 and 2 illustrate the sub-baseband modulation and demodulation process at a terminal and at a repeater. Table 2 shows the channel allocations used on the Fast-West system. Protection tones for the switching section are transmitted over channel 1 (300 Hz to 3.4 kHz): since this channel experiences no frequency translation in the multiplex process, maximum reliability is achieved.

TABLE 2: SUBTRAFFICBAND SUPERVISORY CHANNEL ALLOCATIONS



At a terminal, the output of the supervisory multiplex equipment is combined with the output of the 'wayside' channel multiplex equipment. The combined sub-trafficband output is then connected to the 70 MHz modulation equipment, where it is combined with the main traffic input, to modulate the main 70 MHz modulator. Similarly, at the demodulator, the sub-baseband traffic is filtered from the main traffic, and then fed to the sub-trafficband multiplex equipment, which translates the various channels to the audio frequency range.

The method by which this information is modulated on to and demodulated from the main bearer at a repeater may be understood by reference to Fig. 2.

Normally, all switches are positioned so that the sub-baseband information is transmitted to and received from the main telephony bearer. In the event of failure of the main telephony bearer, the IF protection switching equipment routes the IF signal over the standby bearer. At the same time it is necessary to switch the sub-baseband inputs at repeaters from the main bearer to the standby bearer. This is accomplished by a tone transmitted from the receive terminal, which when received at the repeater stations, results in changeover of the sub-baseband input switches from the main to the standby bearer modulated oscillator, which normally operates with its input muted. The IF input to the sub-baseband demodulator is similarly switched.

The changeover time of sub-baseband traffic from main to standby is about 250 ms, with a release time of 150 ms. These are controlled by the tone receiver time constants and are made sufficiently long to ensure that the main bearers have completed their changeover.

Modulated Oscillator. — The input signal in the frequency range 300 Hz — 54 kHz is first amplified (Fig. 33), then integrated by an RC circuit and further amplified before being used to phase modulate a carrier at about 10 MHz. At frequencies substantially above 2 kHz the 10 MHz carrier is therefore effectively frequency modulated by the sub-baseband input.

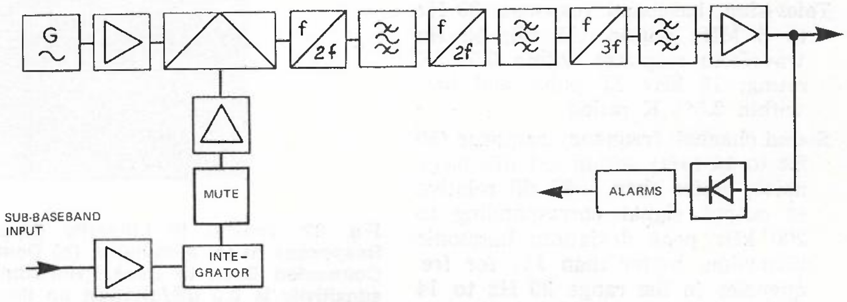


Fig. 33: Block Diagram of a Sub-Baseband Modulated Oscillator.

The frequency modulated 10 MHz signal is frequency multiplied by a succession of stages which multiply the frequency to about 120 MHz.

The input amplifier comprises two transistors in the common emitter configuration, and the RC integrating network is incorporated as the collector load of the first transistor. A muting circuit in the baseband amplifier removes any modulating voltage from the phase modulator and prevents interference with the transmission of television signals through the standby bearer. The 10 MHz carrier is generated by a quartz-crystal controlled oscillator, of the untuned type, fundamental-mode crystals being used. The absolute frequency accuracy is better than 30 ppm, including a temperature drift of about 10 ppm, over the temperature range 0 to 55deg. C. The oscillator output level is about 10 mW; to ensure a good signal-to-noise ratio reasonably high levels must be maintained throughout the unit. The phase modulation is carried out in a π circuit, as shown in Fig. 34. The capacitance C1 is provided by a hyper-abrupt varactor diode, whose capacitance is inversely proportional to the square of the input voltage. The phase of the voltage across RL is therefore a function of the input voltage as shown in Fig. 35. Good linearity is obtained over a range of ±30 deg.; this limitation of the maximum phase deviation determines the highest crystal frequency which can be used in order to achieve the output frequency deviation of 50 kHz r.m.s. at test-tone level.

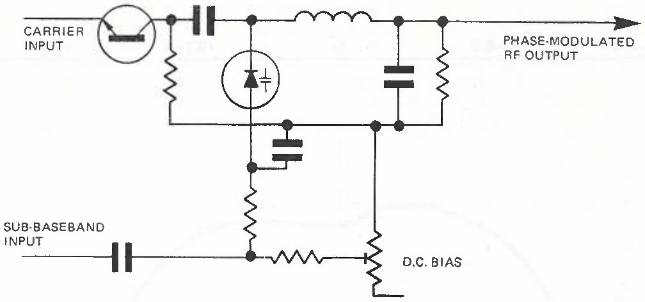


Fig. 34: Simplified Diagram of a Sub-Baseband Phase Modulator.

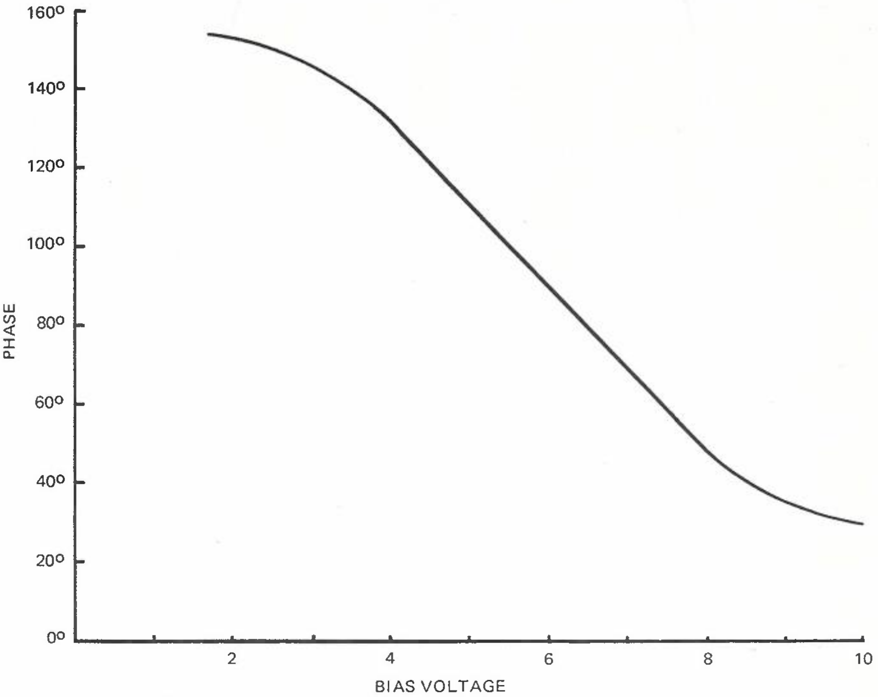


Fig. 35: Relationship Between Bias Voltage and Phase in the Phase Modulator of Fig. 34.

The output filter is of the helical-cavity type with an amplitude response as shown in Fig. 36 and reduces the noise contribution from the modulated oscillator at frequencies in the main trafficband.

IF Switch and Demodulator. — The switch that selects the appropriate IF input to the sub-baseband demodulator is similar to that used for main-channel switching. The demodulator used is identical with the main receive traffic demodulator (except that the phase equaliser is omitted) to ensure adequate linearity: the demodulator must be capable of handling the complete range of sub-baseband and traffic signals. A low-pass filter rejects the traffic modulation, and reduces the loading on the following baseband amplifier, which raises the level of the sub-baseband signal to —6 dBm into 600 ohms at the output.

Tone Receivers. — The modulated oscillators and demodulators in use in a given direction of transmission are determined by the presence or absence of a VF tone transmitted over the main bearer in the opposite direction. These tones are detected by receivers mounted together with the sub-baseband modem equipment.

Technical Summary.

Baseband Parameters.

Frequency Limits: 300 Hz to 54 kHz.

Transfer Levels: input at test-tone level, —12 dBm; output at test tone level, —9 dBm.

Impedance: 600 ohms.

Phase Modulated Oscillator.

Frequency limits: 88 to 132 MHz.

Frequency deviation at test-tone level: 2.8 kHz r.m.s.

Output level: 1 V r.m.s.

Output impedance: 75 ohms.

Return loss: 20 dB.

Frequency Demodulator.

Carrier frequency: 70 MHz.

IF input level: 15 dBm.

IF input impedance: 75 ohms.

IF input return loss: 26 dB.

IF deviation at test-tone level: 50 kHz r.m.s.

Changeover Time: 250 ms, including recognition time.

Control tones: 3060 or 3180 Hz.

Performance.

Distortion: not greater than 0.5 per cent. over the range 6 to 35 kHz.

Response: within 1 dB over the range 4 to 54 kHz.

Thermal noise injected into the main trafficband: not greater than 15 pWop at 250 kHz.

TDM REMOTE CONTROL AND SUPERVISORY EQUIPMENT.

A comprehensive remote control and supervisory system is provided in which supervisory information is continually updated by using a continuously scanning system in which a maximum of 1152 indications can be assembled in time-division multiplex (TDM) on to 24 FSK channels within a CCITT speech-band. Remote-control instructions are transmitted, when required, by a similar process.

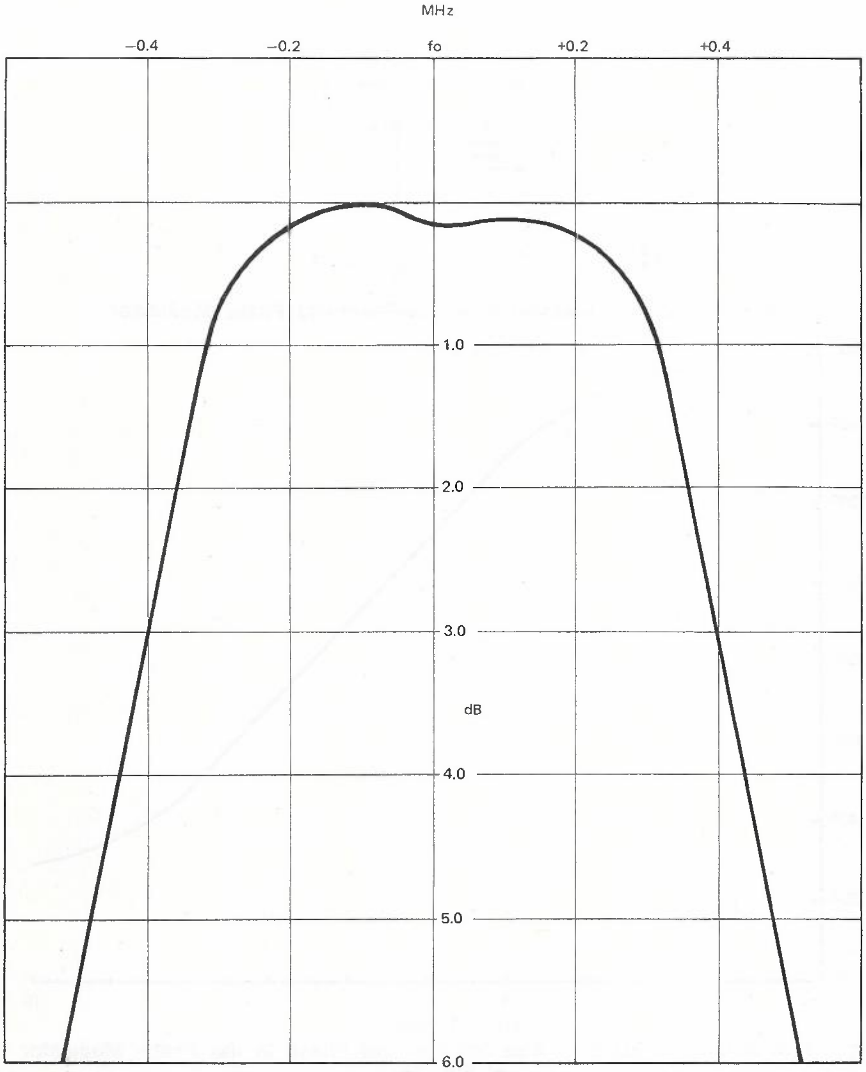


Fig. 36: Frequency Response of the Sub-Baseband Modulator.

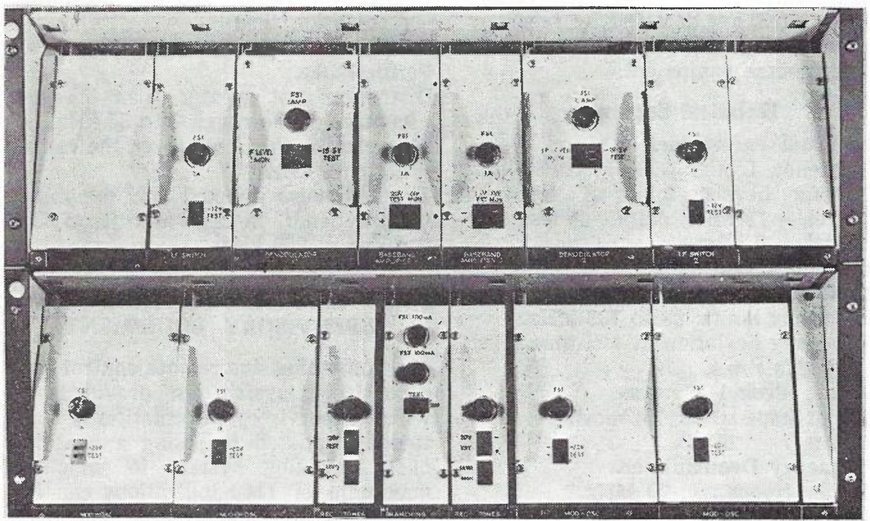


Fig. 37: Complete Duplicated Sub-Baseband Modem.

Whether used for the remote control of on/off functions or the remote supervision of alarm indications, the basic function of the supervisory equipment is the same: it is required to transmit the state of a number of binary conditions from one point to another over the standard CCITT 3.1 kHz speech channel.

The supervisory alarms and indications from, and the control functions to, remote stations are exclusively binary (on/off) and are typically indications of received signal failure, transmitter output failure, waveguide feeder low pressure, low diesel fuel, unauthorised entry to station site, etc. Typical control functions are 'start diesel generator,' 'stop and reset diesel generator,' 're-route traffic,' etc.

The principal advantages are:

- Low initial cost.
- Easy extension as required.
- High reliability.
- Low power consumption.
- Simple maintenance.
- The ability to utilise an easily available transmission medium.

Equipment Description.

Fig. 38 illustrates how the equipment can be applied to control a number of remote stations. The state of up to 48 inputs is sampled in time sequence at a nominal 27.5 inputs per second and the resultant sequential binary information is assembled to form a serial bit stream which modulates a frequency-shift-keyed oscillator operating at one of 24 centre frequencies spaced at 120 Hz intervals in the range 420 Hz to 3180 Hz.

Each FSK oscillator has a bandpass filter at its output which band limits the signal presented to line so that any number of oscillators up to the maximum of 24 may be multiplexed on to the same 300 to 3400 Hz transmission channel at a level of —23 dBm. At a receiving point the required signal is selected by means of another bandpass filter, demodulated, and the resultant serial bit stream converted back to parallel form.

Other forms of modulation could be used, but for this application, three-frequency FSK modulation in which the centre frequency is used for a pause period, both between pulses and at the end of a scan or frame period, provides better protection against transmission noise interference than 'tone on — tone off' modulation. In addition, bit synchronisation can be derived from the received-pulse transitions.

This method of tone transmission means that a single audio tone is capable of transmitting the status of a large number of inputs. The maximum number of inputs is limited to 48 to avoid excessive delays in updating the outputs from the decoding equipment.

When used for the remote supervision of alarms the encoding equipment cycles continuously so that if

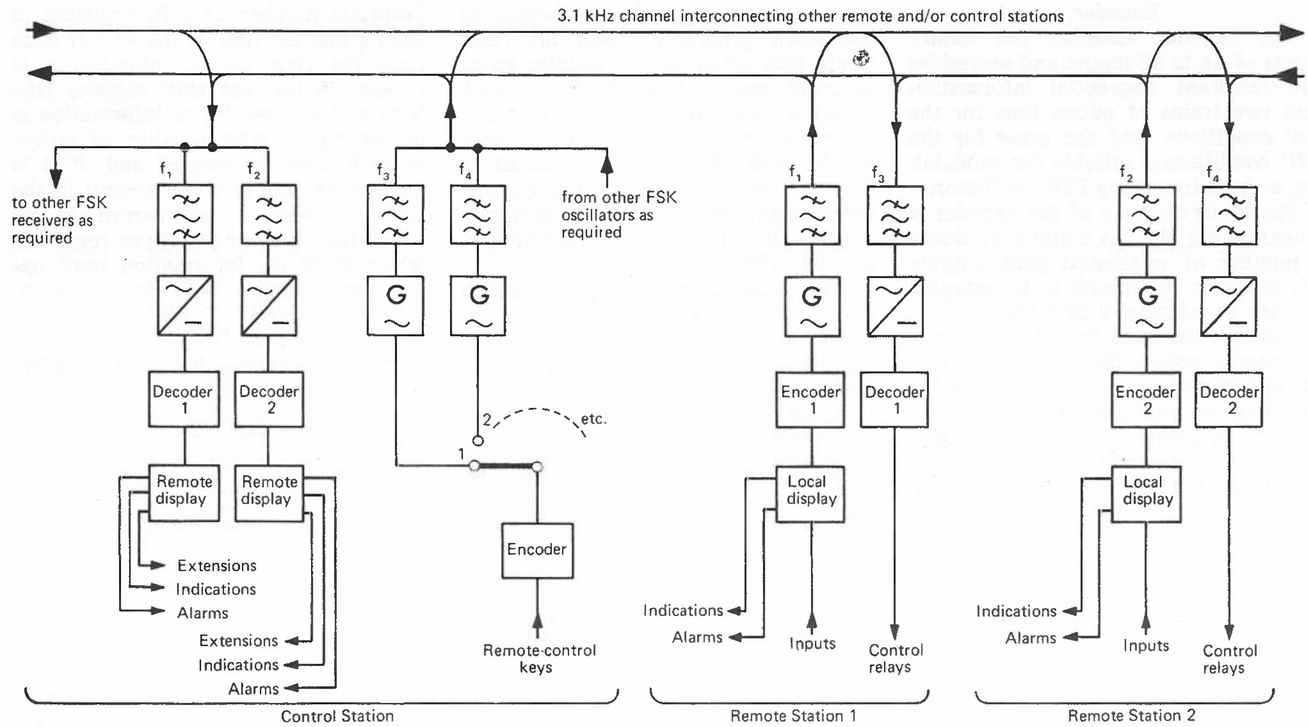


Fig. 38: Block Diagram of a Typical Supervisory System with One Control Station and Two Remote Stations.

multiple receiving points are required, it is only necessary to arrange for the appropriate signal to be routed to all of them. This is normally accomplished by interconnecting the transmission channel as required. When used for the remote control of on/off functions the FSK tones are only switched to the line when the control functions are to be changed.

These arrangements allow a number of control points (either control centres or intermediate control stations) to be easily connected to a single remote station. Should more than one control point attempt to control the remote station at the same time, an error detector built into the decoder comes into operation and false controls are prevented.

Various arrangements of peripheral equipment provide the display and control facilities needed to suit individual requirements. The encoding equipment at a remote station is preceded by its own centralised lamp display for use of visiting maintenance personnel; this is in addition to the lamp display and alarm equipment at the intermediate control stations and control centres. In the control mode of operation, the control-centre peripheral equipment consists of key switches (make, break or changeover), which precede the encoder: at the remote station, the decoder is used to operate the control relays, which can be either make or changeover, locking or non-locking.

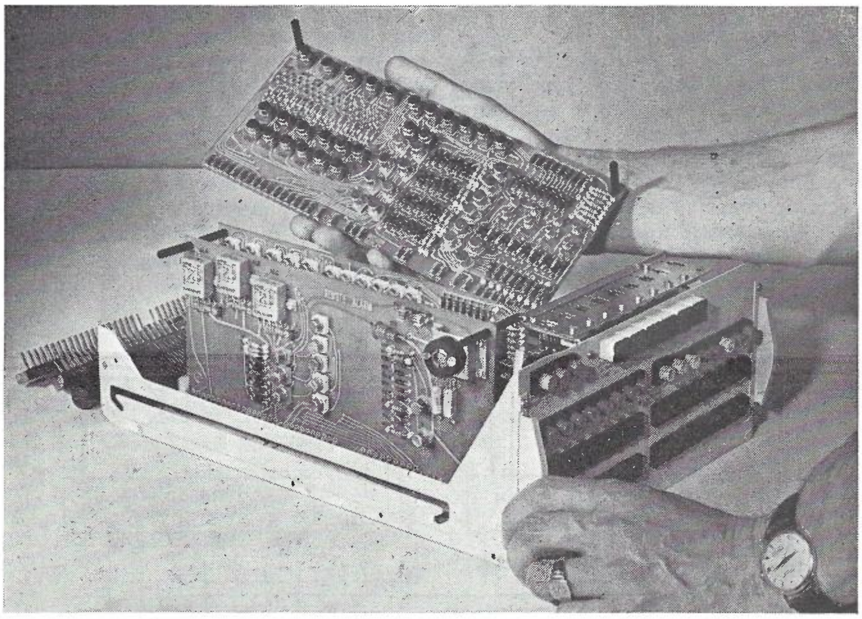


Fig. 39: Lamp-Display Unit Showing Plug-in Cards and Logic Elements.

The encoding and decoding equipments, together with the peripherals, are arranged in a modular form (Fig. 39) for assembly into standard 'CASE' equipment racks. Each unit or module is capable of processing 8 inputs and any quantity from 1 to 16 of each type of module may be fitted in the unit illustrated. The system capacity may be any multiple of 8 inputs, up to the maximum of 48, and may be increased at any time without difficulty.

The equipment is solid state and makes extensive use of integrated circuits — relays are only used where dictated by interface requirements. In these instances the relays selected are all either hermetically sealed reed relays or 'crystal can' relays. The use of these components has led to considerable savings in size and power consumption compared with other systems which do not use integrated circuits.

Encoder.

The encoder samples the binary states of up to 48 inputs and assembles the resultant sequential information into two trains of pulses (one for the 'on' conditions, and the other for the 'off' conditions), suitable for modulating a three-frequency FSK oscillator.

The block diagram of the encoder is shown in Fig. 40. A counter produces a number of sequential gate outputs which cause the inputs to be sampled in turn at nominally 27.5 Hz.

The sampling is a two-stage process in order to reduce the numbers of gating pulses necessary, thus reducing the numbers of interconnections and the amount of gating required. The gating signals are produced by selectively gating the outputs of a series of successive divide-by-two stages driven from a multivibrator which generates the nomial 27.5 Hz timing waveform.

The outputs from the first three divide-by-two stages are gated to produce the eight successive sampling pulses which control the first stage of the sampling process.

The outputs from the other three divide-by-two stages are gated to produce the six successive sampling pulses which control the second stage of the sampling process.

Five of these pulses, together with one additional pulse, are also made available at the scan-length strapping field so that the cycle time of the counter may be varied to suit the number of inputs to be monitored. The selected pulse sets the reset latch which resets the counter to count number 64 (all 1's in the truth table), the last count in a complete cycle of the counter. The next positive half-cycle of the clock generator resets the reset latch, thus allowing the counter to go to count number 1 (all 0's in the truth table) at its completion. By this means, each time the counter is reset at the end of its selected count, a delay of one cycle of the clock generator occurs before the next sampling period, thus forming the end-of-scan interval shown in Fig. 40.

The time-sequence signals which result from the gating process are combined and further gated by the 27.5 Hz clock generator. The output from the reset latch is also connected to the output gates to inhibit them during the end-of-scan interval.

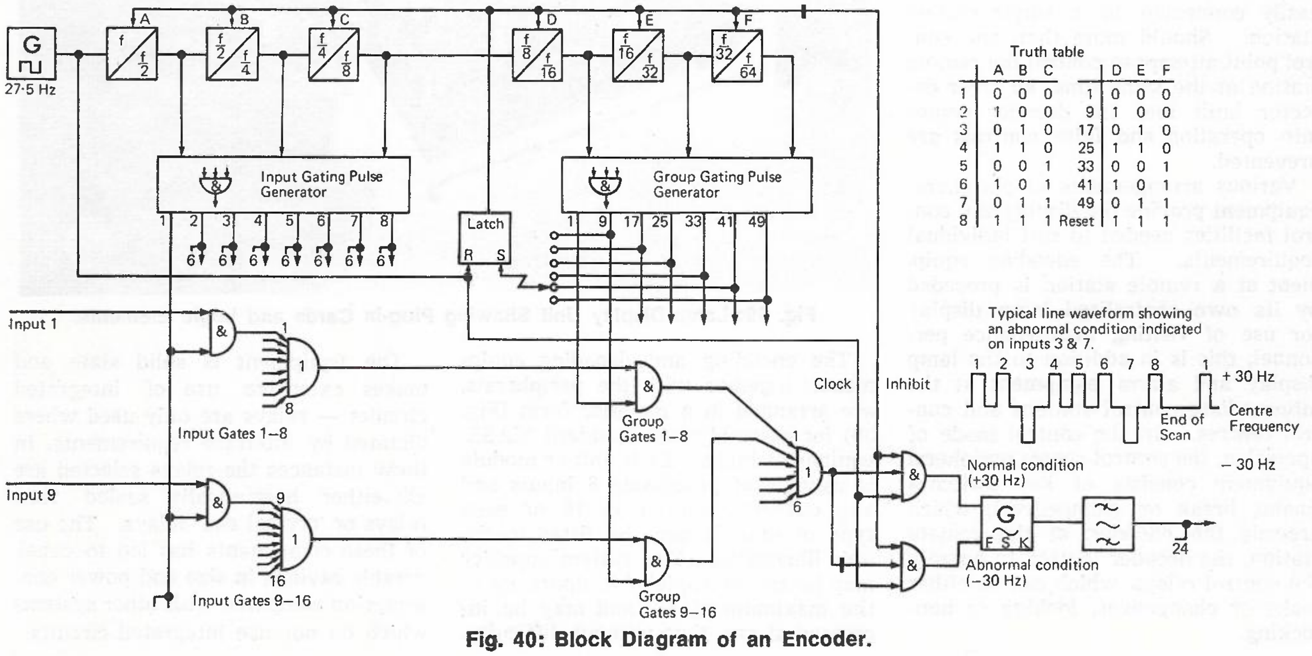
Decoder.

The block diagram of a 16-point system is shown in Fig. 41. At the receiving end of the transmission link a tone receiver demodulates the incoming waveform and reproduces identical pulse trains to those which modulated the FSK oscillator. In addition, the tone receiver is also equipped with a fast-acting carrier (tone) fail circuit, the output of which inhibits the acceptance of any scan during which the received tone level falls below the threshold of the tone receiver. This arrangement, together with the error detection circuit incorporated in the decoder, provides a high degree of protection against incorrect information being produced at the outputs of the decoder due to noise or spurious line signals.

The 27.5 Hz clock frequency is recovered from the incoming signals and used to shift the signals into the appropriate number of shift registers in such a manner that at the end of each scan the first bit of information is present in the last shift register (the Nth) and the last bit of information is in the first. The number of pulses in each scan is counted and, if it is correct, the information present in the shift registers is transferred to an equivalent number of output registers, which store the information until updated at the end of the next valid scan.

The 27.5 Hz clock frequency is recovered by combining the incoming signals, differentiating the leading edge of each pulse, and producing a narrow clock pulse coincident with each leading edge. The detection of the synchronisation interval at the end of each scan is accomplished by monitoring the spacing between successive pulses by means of a monostable circuit, the time constant of which is equal to 2/3 the synchronisation interval. At the end of each scan two successive pulses are produced, the first is the transfer pulse and this is followed by the reset pulse.

The number of clock pulses present in each scan is counted as follows: irrespective of the scan length two additional shift registers (the N + 1 and the N + 2 stages) are connected at the end of the appropriate number of signal shift registers. The reset pulse at the end of each scan resets all the shift registers except the first stage, which it sets to provide a validity pulse. At the end of the appropriate number of clock pulses, in this case 16, the signal shift registers contain the information present in the received scan, the N + 1 stage contains



Truth table

	A	B	C		D	E	F
1	0	0	0	1	0	0	0
2	1	0	0	9	1	0	0
3	0	1	0	17	0	1	0
4	1	1	0	25	1	1	0
5	0	0	1	33	0	0	1
6	1	0	1	41	1	0	1
7	0	1	1	49	0	1	1
8	1	1	1	Reset	1	1	1

Fig. 40: Block Diagram of an Encoder.

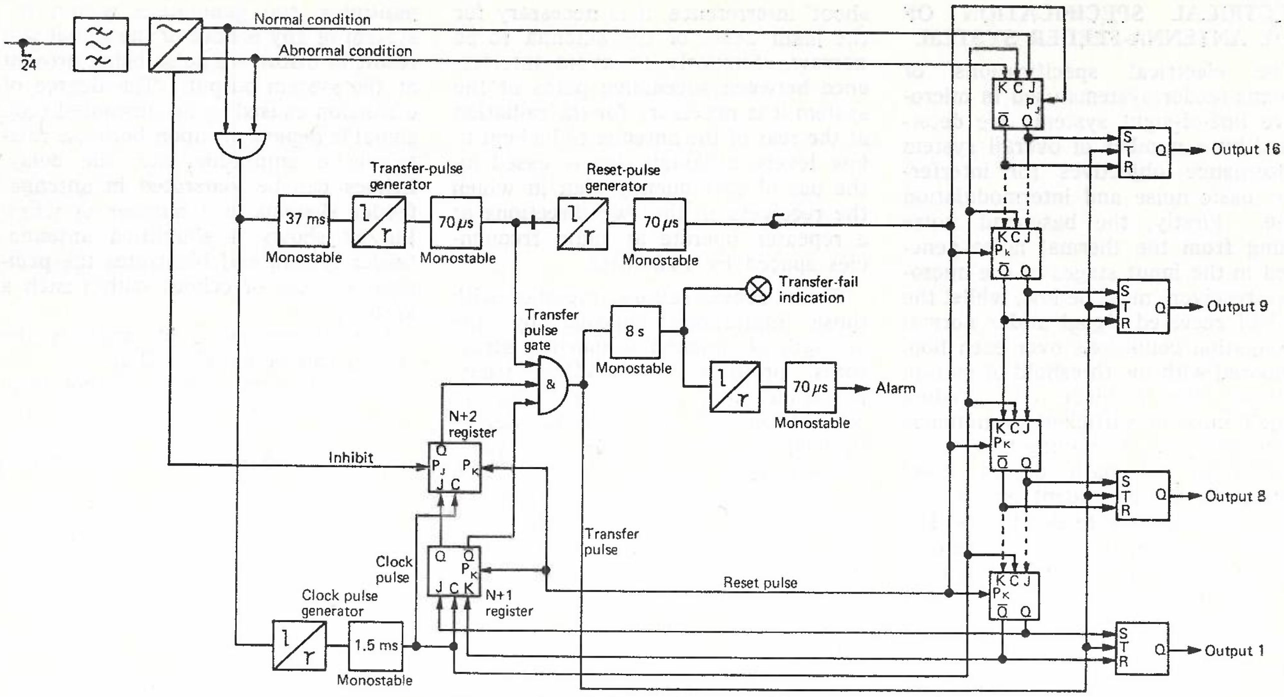


Fig. 41: Block Diagram of a Decoder.

the validity signal and the $N + 2$ stage is still reset. The outputs of the $N + 1$ and $N + 2$ shift registers are connected to the transfer pulse gate, so that the transfer pulse is only allowed through to update the output registers if the validity signal is present in the $N + 1$ stage and not the $N + 2$ stage. Should there be too few clock pulses before the synchronisation interval, the validity signal will not have reached the $N + 1$ stage. Should there be too many, the validity signal will have been shifted into the $N + 2$ stage. Either of these circumstances causes the transfer pulse gate to remain closed.

The $N + 2$ shift register stage is wired so that once a signal has entered it is stored until reset by the next reset pulse. Advantage is taken of this ability of the $N + 2$ stage to inhibit the transfer pulse by connecting the carrier-fail output (inhibit) of the tone receiver to the 'preset' input of the $N + 2$ shift register. Should a carrier fail occur at any time during a particular scan, that scan is therefore inhibited.

The intervals between successive valid scans are monitored by means of a monostable circuit with a time constant of nominally eight seconds, so that a transfer fail alarm is given when there is an interval of longer than eight seconds between valid scans. An alarm is not given for single non-valid scans as they may be caused by the momentary loss of, or transient noise interference with, the transmission channel. In that case the relevant indications should be shown elsewhere and would only be confused if alarms were to be given by the supervisory equipment as well.

In the remote control mode of operation where the carrier is not normally transmitted, the transfer fail alarm indication is inverted and retitled 'control-in-progress,' so that remote controls can only be effected subsequent to a valid scan.

Testing Facilities.

Intelligent use of the indications available allows rapid isolation of probable fault areas without having to resort to complicated fault-finding procedures. The encoder and decoder have also been arranged so that they may be d.c. interconnected either with each other, or with an encoder/decoder test set. This enables in-station tests and fault-finding procedures to be carried out without requiring a transmission facility.

Technical Summary.

General.

Power supplies: 21.5 to 32.0 V d.c.
Power consumption: encoder 1.2 A; decoder 0.8 A.
FSK tone frequencies: 24 frequencies spaced at 120 Hz intervals from 420 Hz to 3180 Hz.
Frequency shift: ±30 Hz.
Transmit level: –23 dBm/Tone in 600 ohms.
Receive level: –23 dBm/Tone ±10 dB in 600 ohms.
Carrier fail level: –38 dBm.

Local Display.

Inputs: 'normally open' or 'normally closed' in multiples of 8 to a maximum of 48 per unit.
Indications: 'non-locking' or 'locking' until locally reset.
Alarms: 2 separate alarm circuits which may be connected to operate as separate 'urgent' and 'non-urgent' alarms or alternatively separately on the occurrence and clearance of alarms.

Encoder.

Scanning rate: 27.5 Hz.
Inputs: multiples of 8 to a maximum of 48 per tone.

Decoder.

Outputs: multiples of 8 to a maximum of 48 per tone.
Indications: carrier fail; shift pulse; and transfer fail.
Alarm: transfer fail.

Decoder Display.

Inputs: multiples of 8 to a maximum of 48 per unit.
Indications: 'non-locking' or 'locking' until locally reset; alternatively indications which 'flash' on change until locally reset are available.
Alarms: 2 separate alarm circuits which may be connected to operate as separate 'urgent' and 'non-urgent' alarms, or alternatively, separately on the occurrence and clearance of alarms.
Extensions: d.c. extensions are available from the indication circuits for external displays, e.g., mimic diagrams.

ELECTRICAL SPECIFICATION OF THE ANTENNA-FEEDER SYSTEM.

The electrical specifications of antenna-feeder systems used in microwave line-of-sight systems are determined by a number of overall system performance objectives for interference, basic noise and intermodulation noise. Firstly, the baseband noise arising from the thermal noise generated in the input stages of the microwave receivers must be low, whilst the level of received signal under normal propagation conditions over each hop, compared with the threshold of muting level of the receiver (the 'fading range'), must be sufficient to minimise fading outages. Excluding factors dependent on the path design, these parameters are dependent on the antenna gains and the feeder losses. The radiation patterns of the antennae control the interference between the various radiated signals within the system, and from it to other systems, and this interference must be reduced to acceptable levels. Another parameter important to system performance is the intermodulation noise generated by the transmission of the modulated signals through the antenna feeders. This is controlled by the accuracy of impedance termination at the ends of the antenna feeder, and by the uniformity of the feeder. Lastly, for antenna-feeder systems in which both transmitters and receivers utilise the same antenna, amplitude non-linearity, which results in intermodulation of the transmitter output signals, must be minimised. This depends on the elimination of all significant function imperfections (i.e., 'rectifying' junctions) from the system.

The following comments discuss the particular features which influenced the electrical specification of the antenna-feeder systems used on the East-West system, the principles adopted in establishing this specification, and the test procedures for measuring the important electrical parameters in the field.

System Requirements.

Certain features of the system are of particular relevance in their influence on the antenna-feeder system specification. The use of the 2 GHz band which permits the use of all-semiconductored equipment with the resultant saving in power consumption and improved reliability, also necessitates the use of relatively large antennae in order to achieve adequate gain. For substantial portions of the route the paths follow the immediate vicinity of the relatively straight Eyre Highway to minimise access road construction. Therefore to avoid 'overshoot' interference, it is necessary for the main beam of the antenna to be narrow. Similarly to avoid interference between successive paths of the system it is necessary for the radiation at the rear of the antenna to be kept to low levels, although this is eased by the use of a frequency plan in which the receivers in the two directions at a repeater operate at radio frequencies spaced by 14.5 MHz.

These considerations, together with those limitations imposed by the strength of antenna supporting structures, problems of handling transportation and mounting, lead to the choice of an antenna design utilising a 3.7 m. (12 ft.) paraboloidal dish reflector. In addition to this standard design, certain special antenna with reduced rearward radiation and with modified radiation patterns were also required for a number of stations with particular interference problems.

Most of the route is substantially flat with relatively minor undulations, and in order to achieve the necessary clearance over the paths it is generally necessary for the antennae to be mounted on high supporting structures. Long feeders between the antennae and the radio equipment are therefore required: the average feeder length is near 84 m (275 ft), with some feeders as long as 107 m (350 ft.). In order to avoid excessive feeder losses, low attenuation elliptical waveguide feeders were chosen. To ensure that the intermodulation distortion was sufficiently low, special attention was paid to the quality and terminations of the feeders. The derivation of the feeder specification is described in the following paragraphs: the design of the feeder system is detailed elsewhere in this issue.

Distortion Noise Considerations.— In microwave systems employing frequency modulation and conveying telephony traffic in frequency division multiplex, the generation within the system of any echoes of the signal will result in distortion noise being present at the system output. The degree of distortion caused by an unwanted echo signal is dependent upon both the relative echo amplitude and the delay. Echoes can be generated in antenna-feeder systems in a number of ways; Fig 42 shows a simplified antenna-feeder system and illustrates the principal sources of echoes within such a system.

For the purposes of analysis the echoes can be considered as:

(a) end to-end echoes arising from successive reflections of the signal at the feeder-antenna junction and at the feeder/equipment junction;

(b) end-to-waveguide echoes arising from successive reflections at the feeder/antenna junction or the feeder/equipment junction and at small irregularities distributed along the waveguide; and

(c) internal waveguide echoes arising from multiple reflections between the small irregularities distributed along the waveguide.

The degree of frequency modulation distortion caused by echo signals has been studied in considerable detail and the single echo or end-to-end case can be evaluated (Ref. 1).

Considerable work was carried out at GEC on the special considerations associated with multiple echoes (end-to-waveguide plus internal waveguide) in flexible waveguide, that is, for very low attenuation, and the incidence of distributed discontinuities. From these studies the noise levels may be summarised as follows:—

End-to-end Echoes: The end-to-end echo distortion-to-signal noise-power-ratio (in dB) is the sum of the feeder/equipment junction composite return loss, the feeder antenna junction composite return loss, and the feeder loss plus a correction factor of 1 dB. The

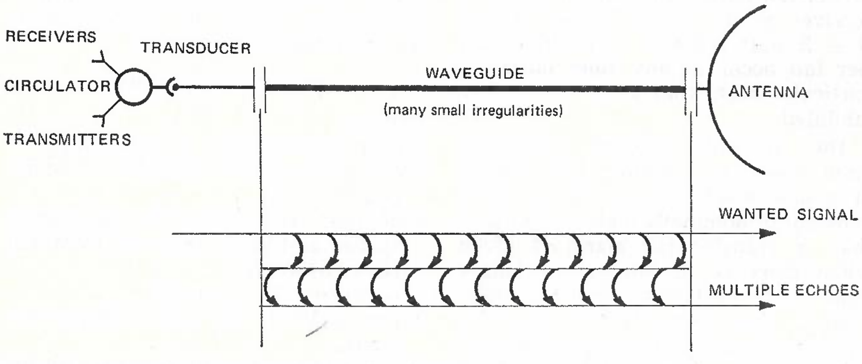


Fig. 42: Simplified Antenna-Feeder System, Illustrating the Principal Sources of Echo in a Feeder.

factor is derived from reference 1 and is determined by a study of the variation of noise with delay for small single echoes with the appropriate channel loading being taken into consideration. This variation is cyclic for delays of the order of those anticipated from antenna systems and has a mean value corresponding to a 'noise power ratio,' which is numerically 1dB greater than the relative echo amplitude.

Multiple Waveguide Echoes: For this analysis the feeder is divided up into a number of elemental lengths, N, over which the echo delays can be considered to be effectively the same. Then the multiple-echo distortion-to-signal noise-power ratio (in dB) can be expressed as:

$10 \log_{10} Z + 10 \log_{10} X^2.(r_1^2 + r_2^2) + Q$

where

Z varies with feeder length and has a probability distribution as defined in Fig. 43 for the modulation characteristics used for East-West system.

r_1 is feeder/equipment junction composite reflection coefficient.

r_2 is feeder/antenna junction composite reflection coefficient.

X is the r.m.s. reflection coefficient of the waveguide.

Q is a factor involving the length and attenuation of the feeder and can assume values between -10 and -15 dB.

Thus the mean value of intermodulation noise over the whole system can be estimated on the basis of the r.m.s. value of return loss of the various feeders and the mean values of return loss of the feeder equipment and feeder/antenna junctions. The summation of distortion noise for the numerous feeders has been taken as a power addition of the individual mean noise for each feeder.

Test Procedures.

The actual values of the component parameters must be checked individually and also as far as possible the interconnection between the various components should be further checked. To ensure that the distortion performance is achieved, tests are specified on each installed antenna system as follows:—

(a) the reflection coefficient of the antenna is checked over the operational frequency band with specified limits of maximum reflection looking directly into the waveguide input port. The mean value can be derived from this test.

(b) the reflection coefficient of the feeder alone is checked with a low reflection termination at the remote end of the feeder, looking into the waveguide at the equipment end. The reflection coefficient limits, as well as the peak values of reflection coefficient over the operational frequency band, are checked to ensure that feeder irregularities are in fact randomly distributed along the feeder.

(c) the reflection coefficient of the coaxial antenna circulator connected to the coaxial waveguide transition with the equipment ports of the circulator terminated is measured looking into the waveguide junction over the operational frequency band. A limit is set on the maximum reflection coefficient.

Further tests are conducted at various stages of the antenna-feeder system assembly to ensure that the various junctions have been made satisfactorily.

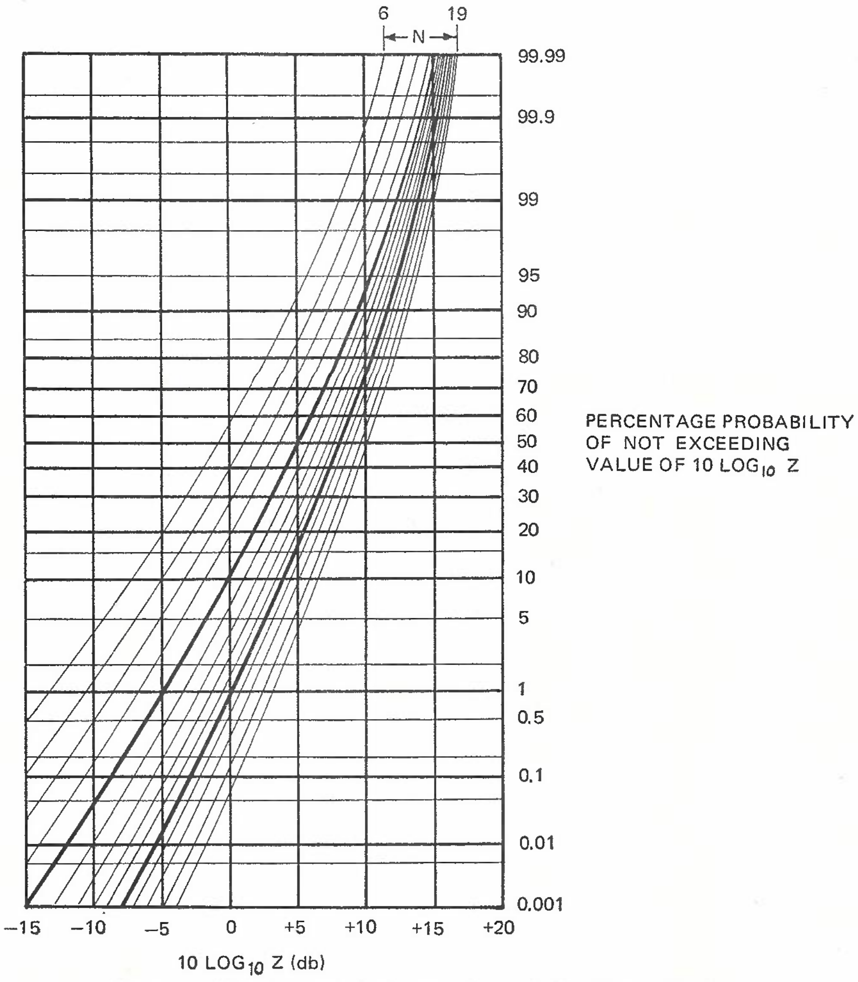


Fig. 43: Probability Distribution of Z for the Worst Channel.

Transmitter Intermodulation.

Imperfections in current-bearing junctions (for example loose tuning adjustments) or any form of amplitude non-linearity within an antenna system can produce multiple cross modulation between operating radio transmitters, which may cause unwanted products to fall in the vicinity of receive channel frequencies. This can result in excessive noise, or malfunctioning of the protection switching system. The inner connections of coaxial junctions are common sources of such non linearity, due to high current densities and relatively light contact forces, and, particular care was taken in the design of the connector between the antenna circulator and the coaxial-to-waveguide transition mounted at the end of the antenna feeder.

The antenna systems were carefully checked during commissioning to eliminate such interference, by correcting any faulty connections or components. Any interfering signals were located by deliberately fading the received signal level of each receiver to below the threshold level with all associated transmitters in operation.

CONCLUSION.

This article has outlined the problems presented by the stringent requirements of the Northam to Port Pirie micro-wave radio system, particularly with reference to the inherent difficulties of providing and operating long-haul transmission systems in remote and inhospitable regions. An important objective throughout the project has been to facilitate production, minimise on-site installation and commissioning, and reduce maintenance effort to a minimum.

Details have been given of the development of an all-semiconductored equipment which provides the reliability and low power consumption so essential in such a system. It will be appreciated that considerable development work was required, both on electrical and mechanical aspects, which has provided the Australian Post Office with one of the most advanced systems of its type in the world.

REFERENCE.

1. "Echo Distortion in Frequency Modulation", R. G. Medhurst: Electronic and Radio Engineer, July 1955, Vol. 33, pp253-259.

TECHNICAL NEWS ITEM

TIP WELDING TOOL

The Research Laboratories have developed a novel technique for tip welding stripped and twisted telephone cable conductors, and the A.P.O. has applied for a patent covering the technique. There is considerable interest in the technique for the following reasons:—

(i) extensive laboratory tests have indicated good and consistent electrical properties of the joint, even after long periods in an adverse environment;

(ii) the technique allows simple automatic control of the welding cycle;

(iii) it gives consistent results with little dependence on operator judgment;

(iv) it can weld copper/copper, copper/aluminium and aluminium/aluminium joints;

(v) the tip-welded joint may prove cheaper and more reliable than hand-soldered or crimp-connected joints.

Five hand-tools are being designed and produced with control units and power supplies. These will be used in Victoria shortly in a field evaluation of aluminium/aluminium and aluminium/copper joints associated with a field trial of 10 lb. aluminium conductor cable.

INSTALLATION AND COMMISSIONING REQUIREMENTS

*M. H. HUDSON**

INTRODUCTION.

The objective was to install and bring into service all the radio and associated equipment for the whole route between Northam and Port Pirie together with the supervisory equipment at Mt. Yokine and Mt. Bonython. The detailed planning commenced at the beginning of 1968; the project was completed by April, 1970. Both the planning and implementation were carried out by GEC-AEI Telecommunications Ltd. engineers and technicians. This paper describes the plan, its evolution and execution and deals in detail with aspects of the operation which were unique to this project.

SPECIAL FEATURES.

Compared to the more usual configuration of a microwave system, the distinguishing features of this project were its route length and the uniformness of its equipment content. In addition, the route traverses a virtual desert region with very high temperatures during the day, which can drop to near freezing at night. Rainfall is very low, and in certain regions virtually non-existent during the summer months. All these features combine to produce the need for a special approach to the planning of the installation and commissioning operation. The system comprises the 58 hop overland route from Northam to Whyalla, plus the single overwater hop from Whyalla to Port Pirie and a single-hop spur from Kongwirra to the satellite earth station at Ceduna. The road distance from Whyalla to Northam is nearly 2400 km (1500 miles), and at each end, sections run through relatively populated regions and extend 636 km (395 miles) from Northam to Norseman in the west, and 475 km (295 miles) from Kongwirra to Whyalla in the east. The centre section is virtually unpopulated, and covers a road distance of 1240 km (770 miles). Norseman and Ceduna (Kongwirra) also mark the last points on the route with a piped water supply and any substantial public telephone communications. These considerable distances and environmental conditions create special problems of communications, accommodation, general support and control. The radio stations are reached by access roads leading from the transcontinental highway, the average length of the roads being about 2 miles, the longest being 13 miles. The highway surface is sealed from Northam to Eucla and unsealed from Eucla to Kongwirra and from Kimba to Whyalla. Because of the low rainfall and the fact that very few areas of the route are hilly, dirt access roads were adequate. Road conditions were generally good, the principal hazards being the invisible dust-filled potholes encountered on the dirt road sections and the wild life encountered at night.

From the equipment content viewpoint, the installation and commissioning operation benefited in two ways. One was the relatively small number of equipment types needed to cover all the nominal radio frequencies used within the system. For example, only eight bearer frequencies were required to cover most of the route.

The other benefit was the repetitive nature of the commissioning work. In planning the installation of a more usual system consisting of stations which may vary considerably in equipment content one from another, it is difficult to make detailed advance plans wherein installation teams can be most efficiently employed. On the East-West system a work programme was devised which defined the sequence and inter-relation of the various activities in detail and ensured a continuous work load for all members of a given team. Time consuming and unpredictable repairs on site, and the consequent disruptive effect on a tightly scheduled programme, were eliminated by a replacement-unit philosophy made possible by the relatively small range of spare modules needed.

PROGRAMME.

In preparing the estimate of the work content, various choices had to be investigated in both installation and commissioning. Installation was, in effect, a continuation of the factory process and due consideration had to be given to deciding how much prefabrication could be done either in the factory or included in the shelter manufacture, and how much remained to be done on site.

The commissioning work programme was affected by the choice of intermediate objectives (and the need to keep a permanent record of unit test results for maintenance purposes), leading to the position where the whole system is functioning correctly.

A thorough series of in-station tests was specified, followed by inter-station adjustment and test, a four-hop subsection adjustment and test, leading to the final objective, which was the control-section or system test. Because of the environmental extremes and the considerable delivery distances involved, a relatively high unit-fault rate had to be allowed for during the settling in period.

The installation and commissioning work content was thus established. At the same time it was possible to foresee the time scale for the various phases of the installation and commissioning operations. This information significantly affected the general approach to the many problems of logistics, support and plant provision which had to be planned in detail before the start of work in the field.

The GEC field element of the project had to be considered in two parts, the first being the relatively long process of installation, which (because of the time available) could be carried out by a small team, and the second being the very critical and short period during which the active units had to be delivered to site and the system commissioned. Little flexibility could be built into the commissioning plan and there would be little opportunity to alter its basic shape once it was under way. It was therefore important to learn as much as possible at the installation stage about the special problems which might be encountered along the 2400 km route.

ORGANISATION.

The field programme called for very special planning to provide the necessary manpower and skills, together with supporting services, to have the maximum flexibility and ability to sustain operations. The outline organisation of the team undertaking the field operation was along well-tried lines used previously by GEC. The team was headed by a Field Contract Controller (FCC) directly responsible for all aspects of the field operation. These included the various administrative aspects, including the control of funds and expenditure, the control of staff (their discipline, working hours, and welfare), and the control of fixed and moveable plant embracing its purchase, allocation, maintenance and disposal. His technical responsibility was to ensure that the technical content of the installation and commissioning work was properly carried out. It was not, and could not be, the sole responsibility of the FCC to ensure that the specified system performance was met: this is a responsibility he shared with others, including those responsible for the design and manufacture of the equipment and its associated parts. The FCC reported to his U.K.-based principals and worked in close liaison with the GEC project management office set

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up in Melbourne. This close liaison is specially important on a project where large quantities of materials and large numbers of staff are applied to the project over a relatively short period of time.

The other personnel were organised with a senior engineer being given overall charge of system installation, a senior commissioning engineer appointed for each end of the route, and a leader appointed for each of the installation teams.

It was envisaged that the field programme would commence simultaneously at each end of the route, progressing towards Eucla at the centre. Had this occurred, two separate headquarters would have been necessary, one for each end of the route. In the event, the final stages of the programme allowed the operation to be controlled from a single administrative headquarters first at Adelaide and later moved to Perth. The Perth headquarters was the delivery point for the equipment arriving from the U.K. and a trucking service was established between Perth and the sites for the delivery of materials. In addition, a field office was established at Northam, later moved to Norseman. This office was the primary collection point for paper work and information emanating from field staff. The field office at Norseman was also the buying and distributing centre for food, water, etc., for the field staff working on the centre section of the route. A telecommunication link interconnecting the U.K., Perth, Melbourne, the field office, and the various installation and commissioning teams was provided by a combination of telex, public telephone network and privately owned HF-radio network.

Base Repair Centres were established as near to the field teams as practical; initially, a centre was established at Whyalla to serve the Port Pirie to Ceduna section and later moved to Kongwirra, near Ceduna, once the centre section was being commissioned. Similarly in the West, the centre was first set up at Northam and later moved to Norseman. In essence the centres were workshops equipped with tools, test gear, and spares to be able to replace and repair virtually any active unit of equipment.

PLANT.

The correct provision of plant, not only of installation tools, appliances and test equipment, together with vehicles of various kinds, but also mobile living accommodation, had a considerable influence on the success of the operation and involved considerable capital investment.

There is a close relationship between staff accommodation, the composition of the teams, and the way in which they move from one location to another. It was considered that the overall programme would be most effectively carried out by a number of five-man teams deployed along the route. This resulted in the choice of a small two-man self-contained caravan-based unit, the advantages of which outweighed the benefits that might be gained from the use of larger accommodation units. The caravan selected was a 4.3 m. (14 ft.) by 2.4 m. (8 ft.) caravan, aluminium clad on a steel chassis and body frame. In addition to the usual fittings, it included a refrigerator, deep freezer, air conditioning, and a 90 l (20 U.K. gal.) water tank. In a team leader's caravan the second bunk normally provided a necessary amount of office space, but could be used to accommodate a visitor.

Once the two man caravan had been established as the basic accommodation unit, the necessary supporting requirements could be specified, namely, supplying food and water and providing a communications link, both inter-team and back to the operating centres and headquarters.

Deep freeze units in the caravans were capable of storing perishable food for two men for three to four weeks and were replenished en route, where possible, or by a fortnightly supply truck. For water, the teams relied largely on rain water tanks installed at each station. These tanks, of approximately 900 l (200 U.K. gal.) capacity, were topped up from a water bowser which made a series of journeys along the route in the early stages of the operation and from trucks that delivered the equipment to site. The type of vehicle required for the teams was determined by the need to tow the caravans and the room needed to carry considerable amounts of test gear which, packed in bulky vibration-absorbing cases, needed a lot of room. A typical vehicle was the Dodge 1.27 tonne (1½ U.K. ton) van, powered by a 3687 cc (225 cu. in.) 6-cylinder petrol engine. The fibreglass body provided a load area of 2.4 m. by 1.8 m. (8 ft. by 5 ft. 10 in). In addition, a number of smaller vans were used by lightly loaded or more mobile teams. Some senior staff used station waggons.

The fleet was completed by flat-bed or tray trucks. These were used to deliver equipment to site and were equipped with a hydraulically operated 1.27 tonne (1½ UK ton) extendable-jib crane. (Fig. 1).

All installation teams had to carry their own electrical power generating plant, both for operating installation tools and to operate the deep freeze and air conditioning units in the caravans. A good deal of attention was paid to the specification of these sets to ensure that they gave the required service in the light of the generally conflicting requirements of lightness, reliability and simplicity of maintenance.

The total plant complement comprises 18 vans, 4 station waggons, 4 tray trucks, 12 caravans and 8 generator sets.

In selecting the test equipment (much of it highly sophisticated), attention was paid to its ability to work reliably in high ambient temperatures. The tightly scheduled nature of the commissioning programme made fault-free operation of the test gear essential, and special measures were taken to protect the equipment from the two main enemies, vibration and dust. For every item of test equipment a special transit case was made.

STAFF.

The staff requirement totalled 35 men (5 installation staff and 30 commissioning staff), consisting of two senior field controllers, one senior installation engineer, 4 installers, 2 senior commissioning engineers, and 26 commissioning engineers (7 team leaders and 19 team members). By late 1968 the FCC was appointed, together with some of his senior field staff. The staff chosen for these senior positions all had previous experience in microwave projects and had been involved in GEC commissioning work in many countries. These appointments constituted the first step in setting the field organisation and in the subsequent preparations these senior engineers were continuously involved in the selection and training of the main work force.

The installation staffing presented no special problems. The installations were of a fairly standard nature requiring no special on-site techniques, and, therefore, no special training was undertaken. However, the senior installation engineer spent a period of familiarisation with the equipment and the contract engineering before departing for Australia. His team of installers were selected from the pool of some 150 U.K.-based personnel, bearing in mind the skills and work rate required.

A much more involved selection and training process was necessary to form the commissioning work-force. The basic requirement was for 26 men and it was evident that a delayed start to the commissioning operation could result in a requirement for an even larger number, therefore it was decided to select and train a force large enough to allow the saturation point of the field programme to be reached if the time scales made this necessary. Thus the formation of a 36-man force was aimed at, to create a relatively high reserve element. Of the 130 candidates available for consideration, some 80 had previous experience in testing microwave equipment, whilst the remaining 50 were experienced in other types of telecommunication equipment; the majority had previous field experience, most of them being permanent members of the GEC installation staff. After a series of assessments based on their experience, technical competence, personalities, staff evaluation reports made from previous assignments, and interviews, 55 engineers were accepted for training. About half were microwave specialists.

The size of the project and the rapidity with which it was to be commissioned made it particularly important that each engineer was thoroughly familiar with all equipment involved; to retain flexibility, all staff sent to Australia were as far as possible trained to undertake almost any task. Training consisted of three stages, each with its own evaluation process: to assess the general progress of the candidate. The three stages were basic commissioning, equipment familiarisation, and equipment testing.

For technically competent engineers without on-site experience a short training course was arranged on basic commissioning techniques. A 3-week equipment familiarisation course dealt with equipment design and all phases of on-site step-by-step testing. The trainees were given the full benefit of the expertise of GEC laboratory, installation and training staff.

The familiarisation course was timed so that trainees could be introduced into the factory test departments to gain further experience on the equipment. This proved to be an ideal follow-up to the theoretical preparations. All staff spent several weeks actively involved in testing equipment before its despatch to Australia. It was necessary to phase the trainees into the test departments in small groups so that they could work with the permanent factory test engineers and become actively involved in the testing operations. This was an important move since otherwise the majority of the staff might have only received 'over the shoulder' experience which provides a learning opportunity much inferior to experience gained through active participation.

The Senior Commissioning engineers co-ordinated and generally supervised the commissioning engineers under training during this period. Their terms of reference were to ensure that each man made an adequate contribution to the factory testing effort whilst at the same time ensuring that they gained experience on all equipment types.

The thirty-six men finally selected for the project were handpicked from the company's staff of permanent employees. They were, as far as possible, strongly motivated persons, fully aware of their responsibilities and fired with determination to meet the stipulated time scales. These qualities are known to be vital, but they cannot be found in a field organisation composed of hastily recruited personnel who have not previously worked together and for whom the contractor is no more than a temporary employer.

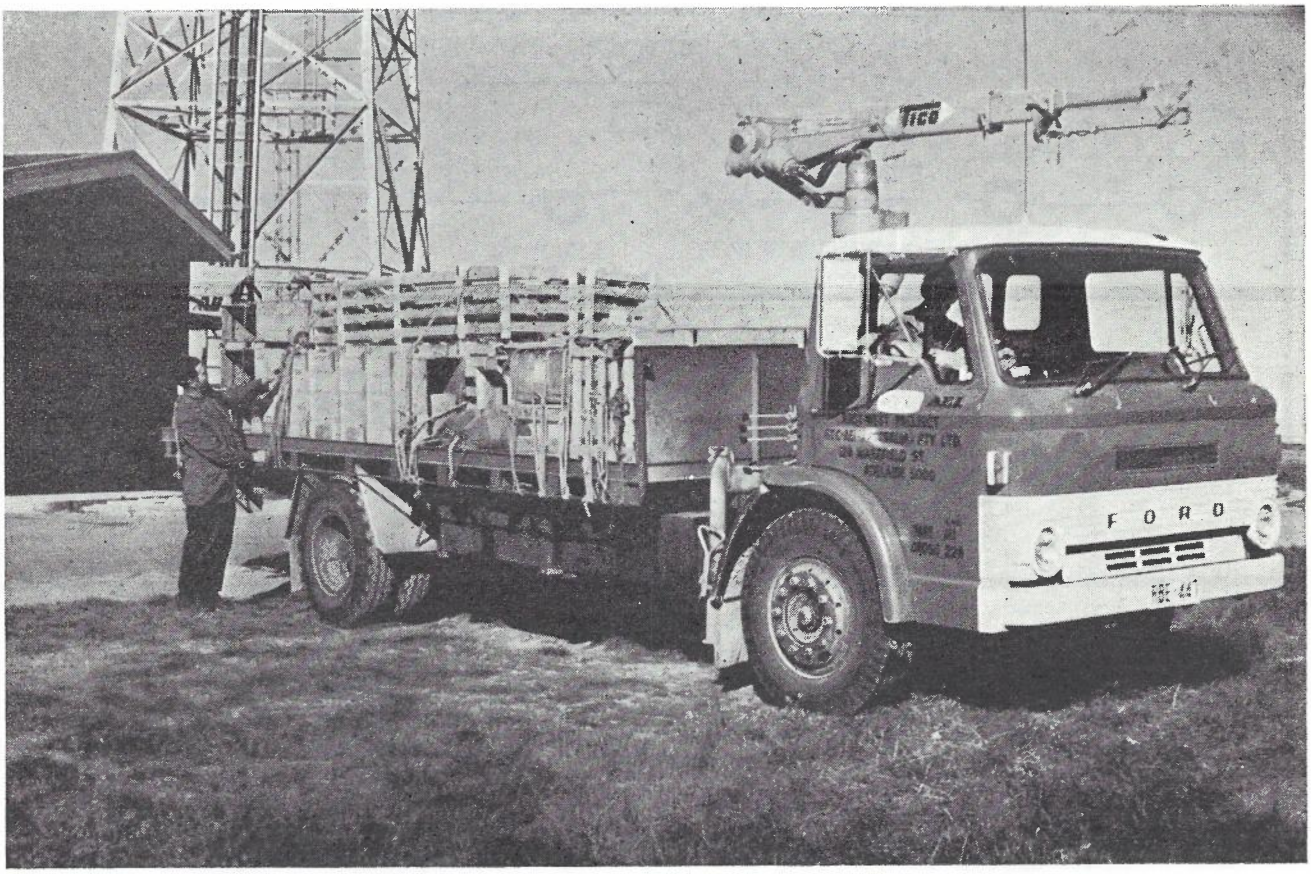

Fig. 1. — Flat-Bed Truck.

INSTALLATION AND COMMISSIONING

Installation.

As the shelter was to be prefabricated, it was decided to install the equipment support structure within the shelter during its manufacture, together with some of the inter-rack cabling. The installation effort thus comprised the relatively lengthy process of installing the rack frameworks and completing the inter-rack cabling. The rack framework complement usually comprised one rack for the supervisory and control equipment plus the order-wire and wayside channelling equipment and two racks for the radio equipment itself. Some repeaters were supplemented by additional radio racks where diversity operation was required.

Commissioning.

The commissioning phase was divided into four main stages, each involving route or route section tests.

During the first, or pre-commissioning stage, the active radio units were installed, the station switched on and any malfunctioning equipment replaced. The pre-commissioning team carried only the basic test equipment and tools necessary to detect faults of a "catastrophic" character, i.e., faults which prevented units from functioning at all or faults which had a radical effect on performance and could therefore be detected by abnormal meter readings. Any such units were either repaired on site or returned to the base repair centre after temporary replacement. The operation was a rapid one and was carried out by a two-man team which moved along the route spending little more than a day at each site.

At the second stage, the sub-traffic band modem and TDM supervisory and control equipment were installed and fully tested. A full test of the supervisory system was essential at this stage because the associated order-wire circuit was used as the communication medium during the inter-station test period.

The third stage consisted of fitting the radio modules and conducting a comprehensive series of in-station and inter-station tests. The composition and size of the commissioning

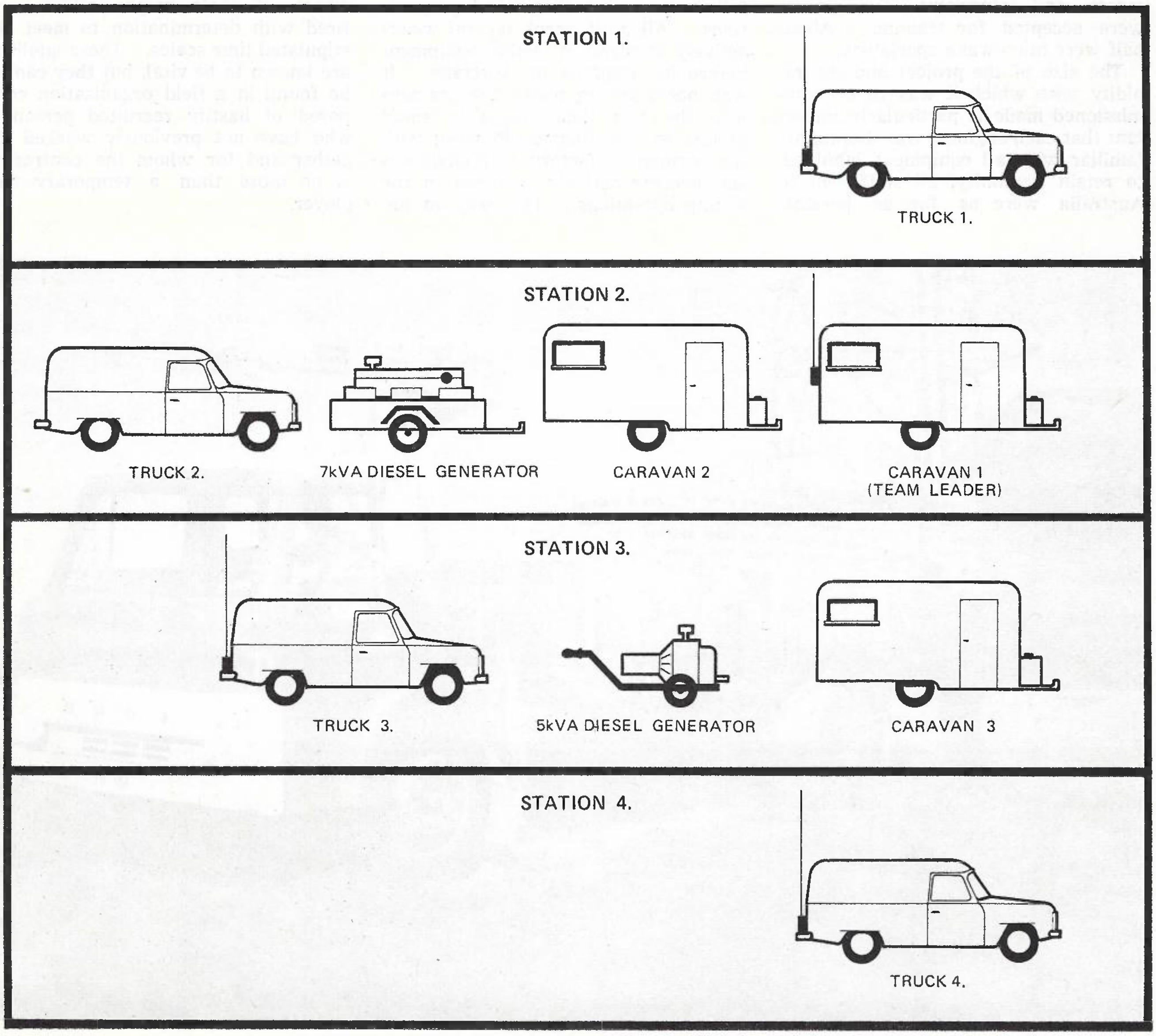

Fig. 2. — Disposition of Plant During In-Station Testing.

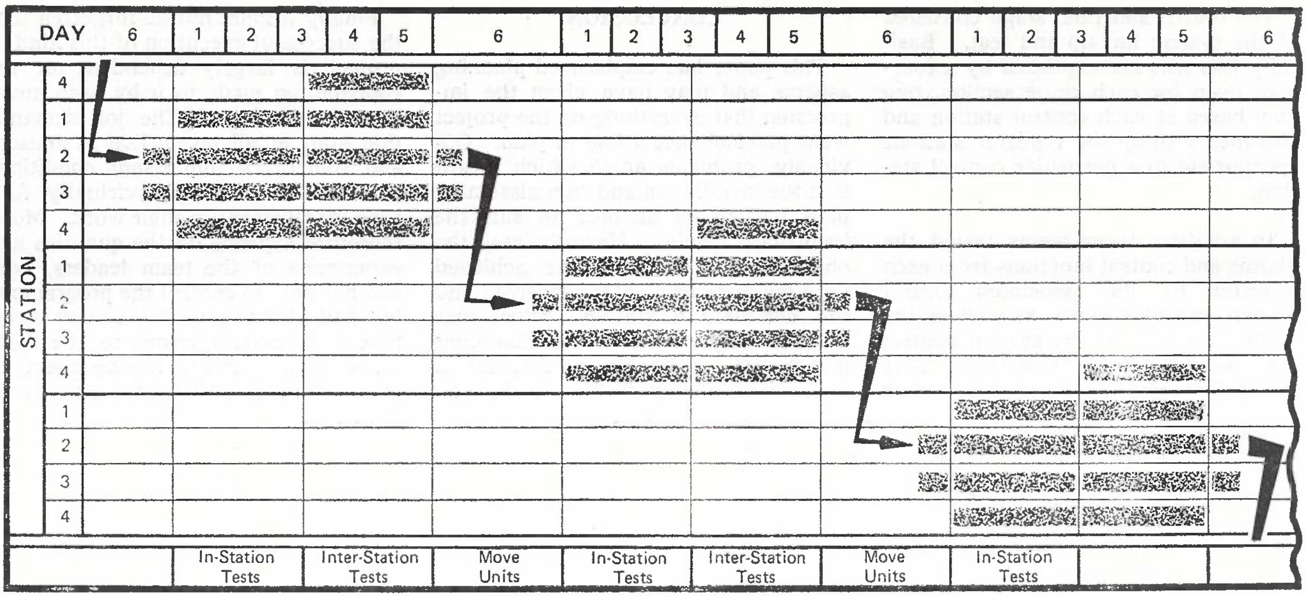

Fig. 3. — Movement of the Five-Man Commissioning Team.

team was closely related to the average length of a switching section, the time available for the overall commissioning operation, and a detailed analysis of the work content. This stage was completed in an average of four days per site by a 5-man team comprising one team leader and four team members, accommodated in three caravans (Fig. 2).

In-station testing was carried out simultaneously by the team members at four adjacent stations (Fig. 3). Inter-station tests were followed by a four-hop sub-section test which required that five adjacent stations were manned simultaneously. This was achieved by the team leader, with appropriate test equipment, returning to the last station of the previous four-station section to complete the final IF group delay, baseband response, and white-noise measurements. Moving camp was accomplished within a day.

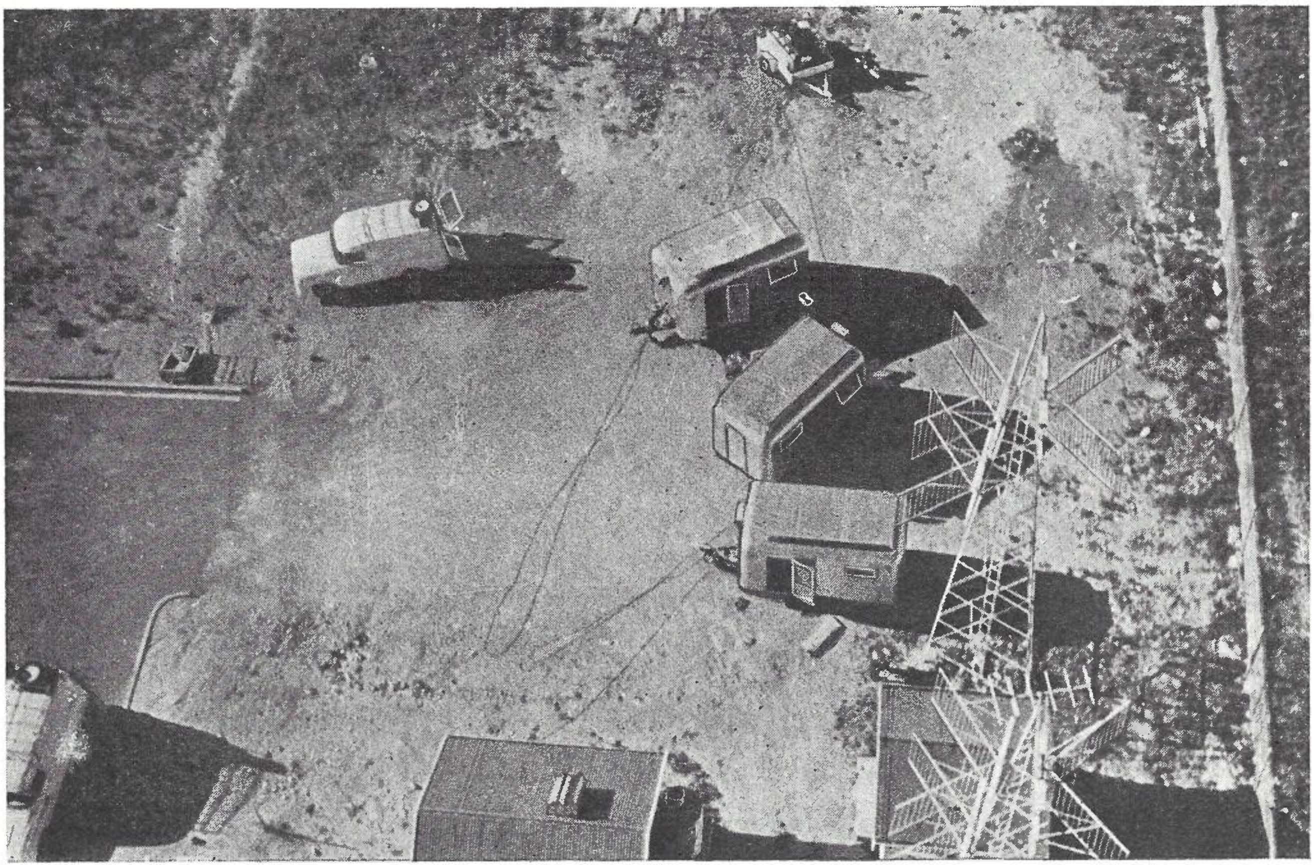

Fig. 4. — Vehicles on Site.

The fourth and final stage consisted of the system line-up and test. Basically this was accomplished by a four-man team for each route section, two men based at each control station and two men visiting the repeater stations appropriate to a particular control station.

In addition, these teams tested the alarms and control functions from each repeater to its associated control station and vice versa, as well as the alarms through to the system control stations at Mount Bonython, near Adelaide, and Mount Yokine, near Perth.

CONCLUSION.

This paper has emphasised planning aspects and may have given the impression that everything on the project went precisely according to plan. Obviously, problems arose which meant that the installation and commissioning plan had to be adapted to suit the immediate needs. Nevertheless, the objective of the plan was achieved very much as originally conceived and the complete 61-station system was handed over to the A.P.O. within eight months of commencing the installation and commissioning of the radio and associated equipment.

Finally it must not be forgotten that the successful execution of this kind of project is largely dependent on the contribution made to it by each member of the team. The job demands that staff at all levels live in unusual and sometimes unpleasant conditions and that they have a virtually full-time involvement in their work. Much therefore depends on the qualities and experience of the team leaders, who had not only to control the programme, but had also to give day to day direction and encouragement to the team members and create among them an atmosphere of enthusiasm and determination.

STRESSED ROCK-ANCHOR ANTENNA-SUPPORT TOWERS

R. N. KELMAN, B.E., F.I.E. Aust. and H. E. HOLMES, B.E. (Hons.), M.I.E. Aust.***

FOUNDATIONS

Of the total route length of 2250 km (1400 miles), the central section crossed 1100 km (750 miles) of barren, featureless plain, virtually devoid of any services, with summer temperatures reaching 50°C (120°F), and with no recognised sources of water. Supply of materials, maintenance of equipment and adequate accommodation for men over a period of a year presented formidable problems. The normal gravity type of foundation for a 75 m (250 ft) tower contained nearly 80 m^3 (100 yd^3) of concrete for each leg, and it was obvious that any design which could reduce excavation and concrete quantities was desirable. Furthermore, little knowledge of local geology existed and there were few known sources of supply of concrete materials. Such were the considerations that led to the development of stressed rock-anchor foundations.

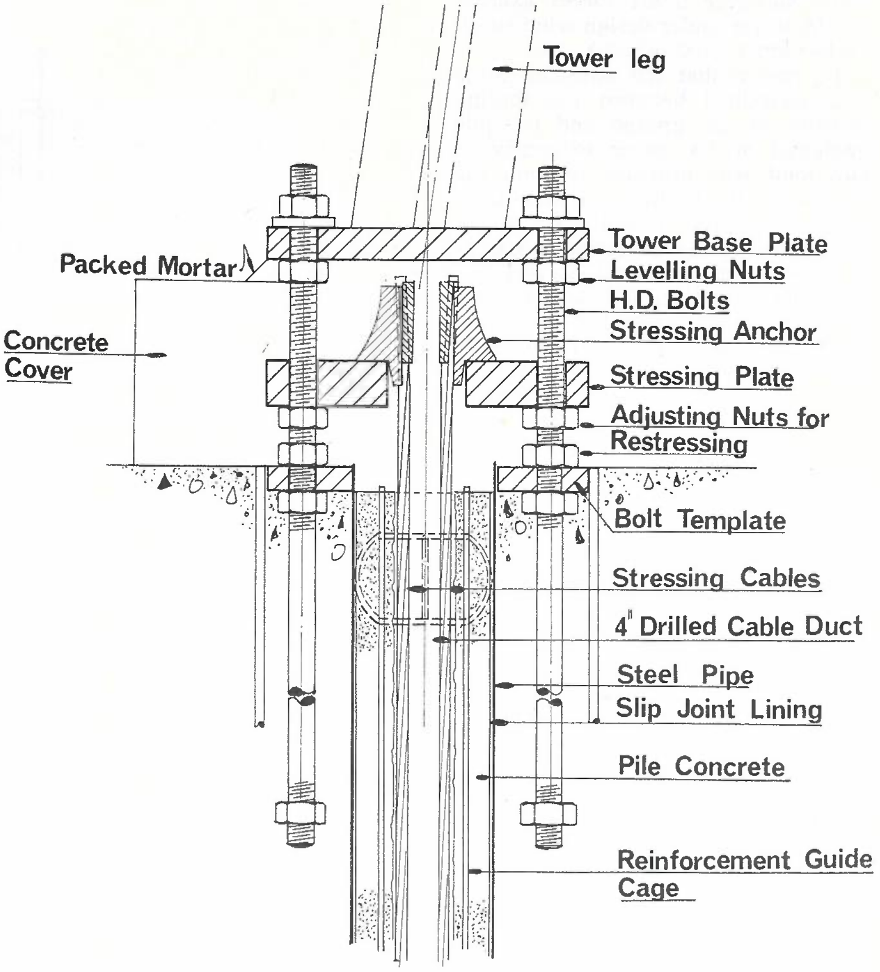

Fig. 1. — Connection to Tower Leg

Site Investigation

At the time of tendering, only the sites for the end sections of the route were firmly established. Provisional sites existed for the central section. A site investigation was carried out by George Wimpey and Company during which test bores for soil investigation were carried out at all accessible established sites, and the central section of the route sampled by drilling approximately every fifth provisional site. The results were encouraging and indicated three zones with transition areas in between.

a) Western Australia (Northam to Kalgoorlie) — generally a sandy soil over decomposed granite.
b) Central Nullarbor region — Nullarbor limestones porous and very variable and likely to contain cavities of considerable size.
c) South Australia (Ceduna to Whyalla) — hard igneous rock often close to, or at the surface.

Design

The design of rock-anchor foundation had to satisfy certain requirements. It must provide:

adequate anchorage against uplift forces;
adequate resistance to downward forces;
adequate stability against sliding or overturning under combinations of vertical and horizontal forces; and
adequate factor of safety against overload and long term corrosion.

In principle it is simple. The tower leg base plate (Fig. 1) is directly connected to the stressing anchorage plate through the holding down bolts. Uplift forces are conveyed to the anchorage zone at the lower end of the pile. Under no-load conditions, the stressing forces are restrained by the bearing of the footing on the soil or rock. Not until the tower uplift forces exceed the residual stress is there any tendency for the footing to lift.

The disadvantage is that the downward load on any footing is doubled, as it must resist the stressing force together with the maximum downward tower leg force. Thus a foundation bearing value of about 6.4 MN/m^2 (6 $tonf/ft^2$) was considered essential if the stressed footings were to be much smaller than gravity footings. On sound igneous rock, the stressed footing pad was just sufficient to accommodate base plate, anchorage and bolts. Towers varied in height from 23-76 m (75-250 ft). Uplift forces varied from 52,000 to 104,000 kg (115,000 to 326,000 lb). For the purpose of design two types of footing were developed, one for towers from 23 m (75 ft) to 46 m (150 ft) and the other for 53 m (175 ft) to 76 m (250 ft).

Various prestressing systems were examined and the 'Fressinet' System was chosen. It proved most easily adaptable to the design and offered cable capacities most suited to the range of forces required. Anchorage forces available from the ground were assumed to be the weight of a 60° inverted cone with its vertex at the anchorage depth (Fig. 2). No advantage was taken of soil cohesion, in-

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** Mr. Holmes is Technical Manager of Electric Power Transmissions, Pty. Ltd.

ternal friction or tensile strength in soil or rock. A factor of safety was taken at 1.6 for the weight of the soil cone over uplift forces exerted by the tower under design wind speed of 160 km/h (100 mile/h).

To ensure that the stressing force was restrained between the footing bearing on the ground and the pile anchored at its lower extremity, a slip joint was provided through the depth of the footing. If this were omitted, the risk would exist of the pile resisting the stressing force as a column in compression, and the stressing operation, designed to load test the pile anchorage for each foundation, would give no indication of pile slip.

Development

A test programme, prior to any field construction, was designed to perfect and prove each phase of the operation and to establish safe values for bond between cable and grout and between concrete and rock.

The basic problem to be overcome was the means of placing and anchoring cables 9 m (30 ft) down in the ground, with efficient protection from corrosion over a long period. It was suspected that ground water, if present, could be high in sulphates and chlorides, and the Nullarbor limestones were known to be porous. It was not considered that sufficient corrosion protection could be given to cables if these were simply grouted into a bored hole. It was therefore decided to cast a concrete pile in the ground, with a central 100 mm (4 in.) duct for the cables. Minimum pile diameter was considered to be 230 mm (9 in). Equipment selected for boring the 230 mm pile hole was the Ingersoll-Rand rotary percussion 'Down the Hole' hammer used in conjunction with a Pioneer rotary drill and compressors.

After several attempts at 'casting in' the 100 mm duct, it was successfully achieved by casting a solid pile with a concentric cage of reinforcement and then drilling a 100 mm duct down the centre. The reinforcement cage acted as a guide to the drill. Three full scale foundations were constructed and a routine established for setting out, drilling, concreting, grouting and stressing.

The experience gained during the test programme, itself the result of collaboration between the consultants, Ove Arup and Partners, and the contractors, Electric Power Transmission Pty Ltd. (EPT), was incorporated in the final design. EPT were able to go into the field with a new form of construction with which they were already experienced with the result that field procedure generally ran smoothly and efficiently.

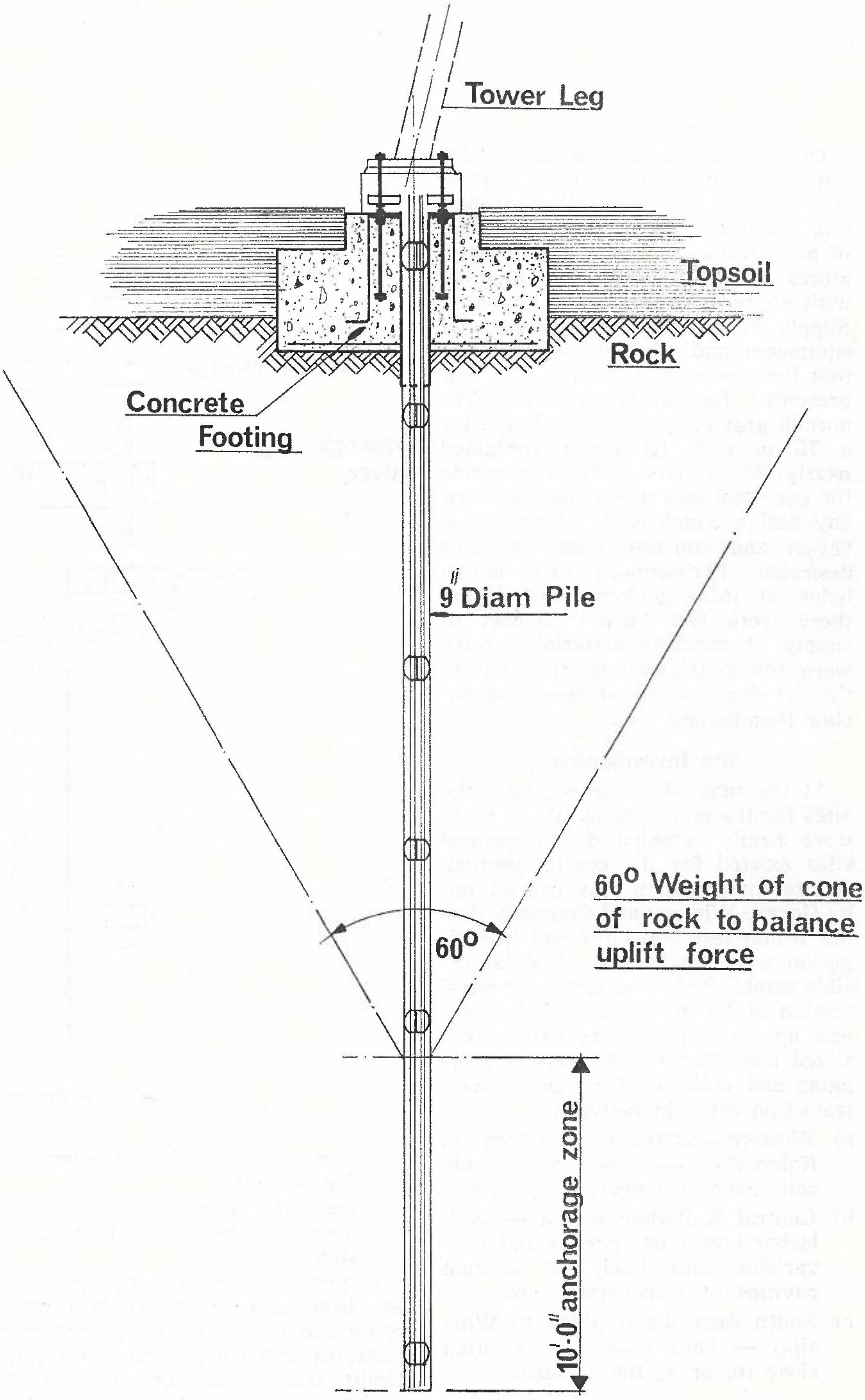

Fig. 2. — Anchor Footing, General Detail

Construction

Field work commenced at Whyalla in November 1967 and at the western end of the route in February 1968.

Each gang was fully equipped to construct both stressed and mass type of foundations, although only two mass types were constructed in the West. Each gang was accompanied by a Resident Engineer and Clerk of Works provided by Ove Arup and Partners.

Conditions along the route had improved considerably since the time of tendering. The road over the Nullarbor Plain was carrying much more traffic, and from the West Australian border to Perth was substantially sealed although the South Australian section had 650 km (400 miles) of deeply pot-holed roads. However, the logistics of construction remained formidable. Concrete aggregates were carried from Ceduna and Kalgoorlie with a maximum distance between source and site of 800 km (500 miles). Water has carried in 11,000 l (2500 UK gal) collapsible rubber tanks up to 650 km (400 miles) from Norseman and Ceduna. Cement was brought up to 1600km (1000 miles) by road from Adelaide and Perth.

It was necessary to maintain a stable and skilled labour force in this isolated area for more than a year when even daily variations in climate were from 50°C (120°F) with wind and dust, to cold, wet winds from the Antarctic Ocean. EPT decided to use completely mobile air-conditioned camps to be towed by construction vehicles from site to site. The standard complex consisted of a 13 m (40 ft.) messing and kitchen unit, a 6.7 m (22 ft) bathroom and toilet unit with pressurised hot water, a 6.7 m office and and foreman's accommodation and two 6.7 m sleeping units. Electric power was provided by a 75 kw generator. Such camps accommodated up to 17 men.

As far as was possible, construction followed an 8 day cycle, six or seven days work and a day moving camp to the next site. Stressing was carried out after one week and the restressing check and final grouting a week later again. Planning allowed for a second stressing operation should the restress check indicate a loss of prestress to below 60% of the cable capacity.

Once camp was established on site, work proceeded approximately to the following sequence:

Day 1 Survey, setting out, excavation.
Day 2 Position pipe sleeve, bolts and reinforcement.
Day 3 Place concrete.
Day 4 Drill pile hole through pipe sleeve, place reinforcement cage and concrete pile.
Day 5 Drill 100 mm (4 in) duct in pile, place tendons and grout the lowest 3 m (10 ft.) anchorage zone.

With four bases to each tower, these operations tended to overlap a couple of days. Concurrently, the foundations for equipment shelters, waveguide bases and wind-generator towers were constructed.

On sites incorporating mass concrete bases some 300 m^3 (400 yd^3) of excavation was required and the construction extended to 12 or 14 days.

Pile Failure

South Australian sites gave few problems. Conditions were either dense igneous rock or deep sand. The type of foundation was clearly indicated and construction was straightforward.

In the West, the weathered granite proved to be extremely variable, from almost sound rock to material from which most of the felspars had weathered away to a kaolinized grit.

At the foundation level of the footing pads this material was firm and noncompressible, but tended to abrade easily. The percussion drill penetrated it rapidly and the drillings were ejected as fine talc-like powder.

When the foundation first constructed at Bulgin Rock (Site number 2) was stressed, cable extensions apparently exceeded calculated elongations, and a careful check showed that the pile was in fact moving upwards through the slip joint in the footing. There was no alternative to extracting the piles and reconstructing the foundation to give more effective anchorage.

This was done with the prestressing jacks, but as these had a stroke of only about 500 mm (20 in), the pile had to be broken up with jack hammers each time the jacks reached their limit. The procedure was slow, laborious and risky, because a broken cable would have eliminated the means of removal and necessitated complete reconstruction of the site.

Means were then considered of ensuring against further pile slip. A bulb at the base of the pile seemed the obvious answer. Discussions with an explosives expert in the New South Wales Department of Mines raised hopes, and on his advice, a bundle of 21 sticks of gelignite was detonated at the base of a deepened hole. Apparatus was developed to plot the size of the cavity produced and this proved to be from 500 to 600 mm (20 to 24 in) diameter and from 1.2 to 1.5 m (4 to 5 ft) in height.

The foundation was reconstructed and restressed. On the first application and release of the load there was an upward yield of approximately 9.5 mm ($\frac{3}{8}$ in). This was not repeated on restressing and no creep or loss of stress was evident on restressing after seven days, even though the second and third holes had been detonated while the stress was held on the first.

It is interesting to record that this site was the most closely situated to the centre of the earthquake which demolished the village of Meckering in 1968. There was evidence that considerable ground movement had taken place at the tower, but no evidence of damage.

The lessons learnt at this site were put to good use later on. At all sites where rock appeared weathered, friable or soft, the hole depth was increased and a charge fired in the base to provide a bulb. Early difficulties in checking the size of the bulb were overcome by the simple expedient of lowering a light on a flex and swinging this across the hole. The period of darkness as the light went beyond the limits of the shaft gave a clear indication of the size of the bulb formed.

This experience all proved extremely valuable once construction had moved into the Nullarbor limestone and allowed the use of stressed foundations continuously from sites 3 to 33.

Cavities in Limestone

Initial geological advice had emphasised the presence of cavities in the Nullarbor limestone. These could be vast, extending many tens of metres horizontally and vertically. The existence of such large ones was generally known, but smaller ones, from 1.5 to 6 m (5 to 20 ft) deep constituted a real problem, and various techniques of sleeving the pile through these had been considered. In practice only one, at site 27, was encountered, about 2.5m (8 ft) deep and it rapidly filled when the pile was concreted.

No other serious problems were encountered, although the design of each foundation had to be confirmed, and often modified by the Resident Engineer on site, to accommodate the bearing capacity available and the depth of excavation necessary to achieve this, when these varied from the design assumptions shown on the drawings.

TOWER DESIGN

Full calculations of a basic tower structure to support four to six reflectors were required by the specification. The towers were to resist a wind velocity of 160 km/h (100 mile/h) at ground level, increasing with height, the design code being in accordance with a Post Office document, and which would result in a factor of safety on ultimate structure strength in the order of 1.5-1.7. The design used a common geometry for four- and six-reflector towers and is very similar to that commonly used by the Post Office throughout Australia. All of this resulted in structures with standardized members which could be mass produced in an economical manner.

Reflectors were considered to be at two or three levels at the top of the tower but route design required widely different levels, particularly for diversity reflectors. EPT proposed that reflector mounting positions should be established at twelve distinct heights. It was agreed that these levels would be adequate to achieve the route performance required and also facilitate any late changes in reflector levels indicated by propagation tests.

At each level, platform steelwork was designed to suit the face or faces on which reflectors were to be mounted. These platforms connected with the tower access ladder which had full rest platforms at a maximum spacing of 15 m (50 ft). All tower bracing was proportioned to resist shear forces which would result from reflectors at any level independently of the actual usage.

Waveguide Runs

The type of waveguide used on this system, 145 x 68 mm (6 x 3 in) elliptical, although flexible, placed considerable constraints on tower arrangements. On its H-plane axis the waveguide has a bending radius of 1.55 m (60 in) which is significant compared with the total tower width of 2.4 m (8 ft) at the top of the structure. Moreover, each antenna had a specified polarisation which determined which axis of the ellipse was horizontal.

The vertical waveguide runway was placed on the outside of the tower. This reduced difficulties in hauling the waveguide off the drums compared to that which would have been experienced with the normal waveguide run inside the structure. It also made the full tower width available for bends. Although the heights of many reflectors were known at the time of detailing steelwork, their polarisation was not and waveguide bends could not be predetermined to establish the position of a reflector on the pair of horizontal mounting bars used to support it. It was therefore decided that mounting bars should be provided with holes to permit reflectors to be mounted at positions variable in 50 mm (2 in) steps across the tower face.

Finally, it was necessary to design ancillary supporting steelwork for a horizontal waveguide gantry between the tower and the shelters and to support the final bends in the waveguide to the reflectors at 1 m (3 ft) maximum spacing. The former was standardised into a few simple component structures, but the latter had extensive provision for adjustment on site.

Erection

Two tower erection crews were employed each with mobile camping arrangements as for the foundation crews. Erection of steelwork to approximately 45 m (150 ft) height was done with a 27 ton mobile crane, having a total jib length of 49 m (160 ft). Above this height erection was done with an aluminium floating jib. The average erection time for a 76 m (250 ft.) tower was 6 days.

CONCLUSION

Notwithstanding the decision to adopt a completely new type of foundation requiring extensive preliminary development, all tower structures were finally erected within the intended time. By approaching the formidable problems of logistics and establishment in this difficult area in a proper manner, it was demonstrated that modern techniques could be employed on both foundations and tower structures with very favourable results.

On technical grounds, there is no doubt that the departure from the type of foundation traditionally accepted for towers has proved to be successful. It is effective, simple and quick to construct, adaptable to varied site conditions (subject only to certain overriding requirements) and lends itself to the efficient organisation of site labour, in that tower erection and foundation work can be done quite separately by specialist gangs.

The end result is that the rock-anchor form of construction can give a considerable saving in both money and time over the traditional mass-footing method. Geological survey information is essential to establish that sufficient number of the prestressed foundations can be constructed to justify the cost of mobilisation of the specialised equipment required. In this case, the original assessment was that 48 out of the 58 sites would be suitable. In fact only 40 proved to be so, although the experience subsequently gained indicates that at least some of the 8 might have been stressed foundations. It was particularly disadvantageous that the majority of these 8 sites were in the most remote areas where the saving of transport costs for the great quantities of material for the mass footings would have given the stressed footings their greatest savings.

As a result of the standardised tower design, erection costs, placing heavy emphasis on mechanical equipment, produced results which compared very favourably with those achieved in erecting similar structures in much more hospitable locations.

APPENDIX

Design Stresses

Concrete	211 kgf/cm^2 (3,000 lbf/in^2) in bases. 281 kgf/cm^2 (4,000 lbf/in^2) in piles.
Grout	176 kgf/cm^2 (2,500 lbf/in^2)
Cables	At design working loads equivalent to 160 km/h (100 mile/h) wind speed: 60% minimum guaranteed ultimate tensile strength.

Bond Stress — Design loads

Cables 9.84 kgf/cm^2 (140 lbf/in^2)

Concrete to rock 7.73 kgf/cm^2 (110 lbf/in^2)

Stressing Values

Initial Stress = 85% ultimate strength of cables.

Check Restress = 75% ultimate strength of cables.

Minimum Residual Stress = 60% ultimate strength of cables: and is the minimum permanent stress and thus equals the design wind load uplift for the tower, increased by a factor which depended on the overturning moment at the base. Due to the fact that cables were used in groups of 6, 8, 10 or 12, these increments did not exactly match the uplift forces for different tower heights and there was frequently an excess of cable capacity in the smaller towers.

Thus minimum ultimate load factor = 1.67.

THERMAL DESIGN OF NATURALLY COOLED REPEATER SHELTERS

J. TOMLINSON, B.Eng. and R. P. SLATTERY, Dip.M.E., Grad.I.E.(Aust.)***

INTRODUCTION.

When the Department decided to install a broadband radio relay system between Port Pirie and Northam to complete the Adelaide to Perth trunk route, one of the important provisioning matters concerned the type of equipment shelter to be provided at the 50 or more unattended repeater stations. The length of the route, about 1500 miles, and the low population density along most of this distance invited consideration of designs other than of normal brick construction. A further factor, also affecting building design, arose at this time. This was the fact that wholly solid state radio equipment suitable for broadband radio relay systems would be offered when tenders were called for the supply of the required plant. It was anticipated that the power consumption of the wholly solid state systems would be less than one-half that of the part valve/part solid state equipment types already in service, and this would ease the problems of cooling and therefore sheltering of the equipment.

Equipment types at present in use on this type of service have required the use of air-conditioned or forced air cooling plant, and have been housed in buildings of normal brick construction, in order to restrict the range of temperature of their environment. This type of construction would have been very costly for the East-West route, and as continuously running ventilation machinery would have required service attention at frequent intervals, it was decided to investigate other forms of construction requiring, if possible, no continuously running ventilation plant.

The most important characteristic of the shelter would be to surround the equipment with a temperature not exceeding that for which the equipment reliability and performance was guaranteed. The shelter would, therefore, have to be capable of dissipating the heat of the ultimate load of the equipment, but at the same time insulate against the effects of direct and indirect radiation from the sun and ground. These latter effects are potentially equivalent to several tens of kilo-watts under clear sky conditions at midday in mid-summer (see Fig. 1).

The equipments likely to be offered had similar temperature characteristics, i.e., full performance to 50 deg. C. and slightly degraded performance to 55 deg. C. As the maximum ambient temperature expected over a long period on the route was 50 deg. C. the shelter design would have to be based on an inside maximum temperature of 55 deg. C. when this ambient temperature was reached.

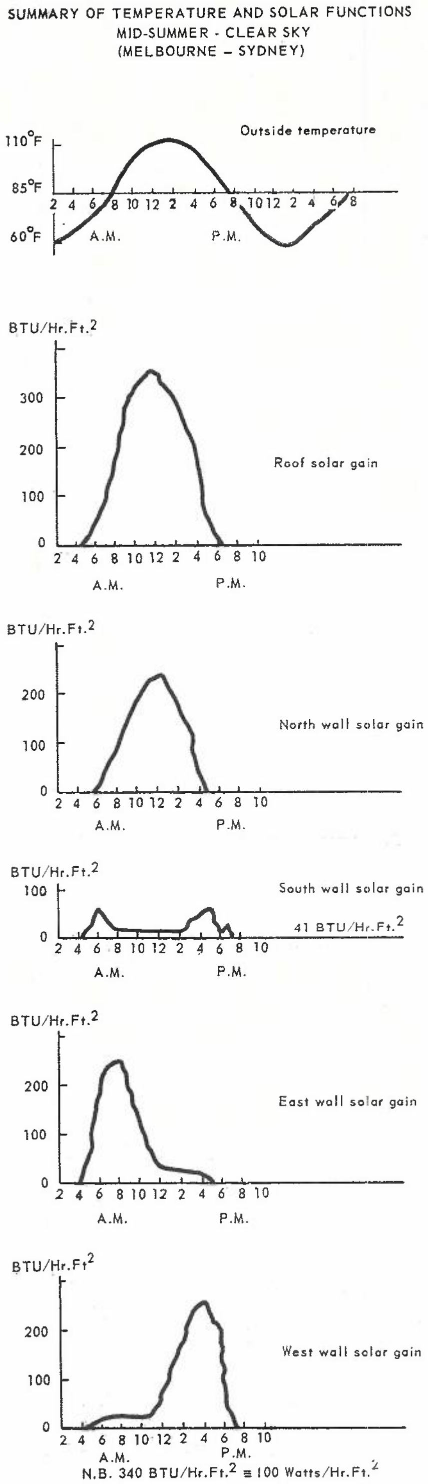

Fig. 1. — Summary of Temperature and Solar Functions, Mid-Summer, Clear Sky (Melbourne-Sydney).

CONCEPTION OF SHELTER DESIGN

A thin-skinned metal shelter with no internal insulation appeared to promise effective natural cooling by convection and radiation, conduction would be negligible because of the long path through the metal cross section. A sunshade appeared to be the inevitable answer to insulation of the shelter from external heat sources, i.e., sun and ground. In addition, because of the high temperature, about 180 deg. F., to be expected on the external surfaces of the sunshade and ground on a day of ambient temperature (120 deg. F. (50 deg. C.), the sunshade itself would have to be insulated on the underside of its roof and the inside of its walls, in order to ensure that these surfaces remained at a lower temperature than the shelter's external surfaces and thus absorb radiated energy from them. Calculations confirmed that this design philosophy was sound. Further, the shelter would be amenable to prefabrication techniques, preinstallation of equipment, and transport of the whole to a site in one operation. These latter features would be of considerable importance to provisioning of systems for routes like Adelaide-Perth or even for single installations in similar hot, remote areas.

As no other organisation in Australia seemed to have encountered this problem, and therefore, the necessity to solve it, it was decided to organise a trial of a full-scale model in the field. At this time the idea was also discussed with the Building Research Branch of C.S.I.R.O. and compared with other possible solutions through C.S.I.R.O. computer programme. One solution, involving a part mass construction (2 earth walls) and part thin metal, gave a slightly better result temperature-wise, but as the all-metal construction was also confirmed as suitable, and was more amenable to prefabrication, as discussed earlier, it was decided that the field trial should be of a shelter design of this form.

EXPERIMENTAL BUILDING

A simple full-scale experimental shelter suitable for dissipating 1kW

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of heat was designed. The dimensions, 12 ft. by 10 ft. floor area and 9 ft. high, were decided after taking into account model tests made in an environmental chamber supplemented by calculations of solar and ground radiation effects. The unit was constructed in the Postal Workshops in Perth and installed in the grounds of the National Broadcasting Service station at Kalgoorlie, this site being on the East-West route and having staff available to supervise the experiment. The shelter was instrumented with calibrated thermo-couples and 12-point pen recorder for continuous measurement of temperature at all important points, including a Stevenson screen for shade temperature measurements. An anemometer was also provided for measurement of wind velocity. The measurements were made in January and February, 1966, and continued in February and March, 1967. The experimental shelter was fully sealed against entry of dust and included a gabled shelter roof and gabled sunshade. The gabled sunshade was vented along the ridge, the vent being covered to keep the direct rays of the sun away from the shelter. The gable construction was provided to increase convection heat transfer by creating a chimney effect between the sunshade and shelter and to guard against condensation falling on equipment, which could have been a problem with a flat roof. The gabled construction also increased the surface area available for convection heat transfer, and created a reservoir at the top of the shelter, above rack height, for the hot air rising from the racks.

TEMPERATURE OBJECTIVE

The objective was for the shelter to suit the temperature characteristics of radio equipment likely to be used on the East-West route, i.e., equipment to perform to full specification in a surround of 50 deg. C. (122 deg. F.), and to slight degradation of performance to 55 deg. C. (131 deg. F.). Thus on a day of ambient temperature 50 deg. C., encountered in the long term along the East-West route, the shelter internal temperature in the vicinity of the radio racks would not have to rise above 55 deg. C.

RESULTS OF EXPERIMENT

The experimental results, shown in Fig. 2, confirmed the success of the design. Fig. 3 shows the basic design idea, which has been accepted for East-West route building design, and is now being translated into a practical and economic building consistent with location.

It should be noted that the sunshade must insulate against the sun and ground radiation to such a degree that the air temperature between the sunshade and the inner equipment shelter is as close as possible to the outside ambient temperature. The temperature rise above ambient within the shelter is then due only to the heat dissipation of the equipment inside and is kept within the required limits by the natural convection and radiation from all external surfaces of the shelter. The greatest heat transfer is, of course, from the roof and the top of the walls since the temperature here is highest compared to the surrounding air and screen inside surface temperatures.

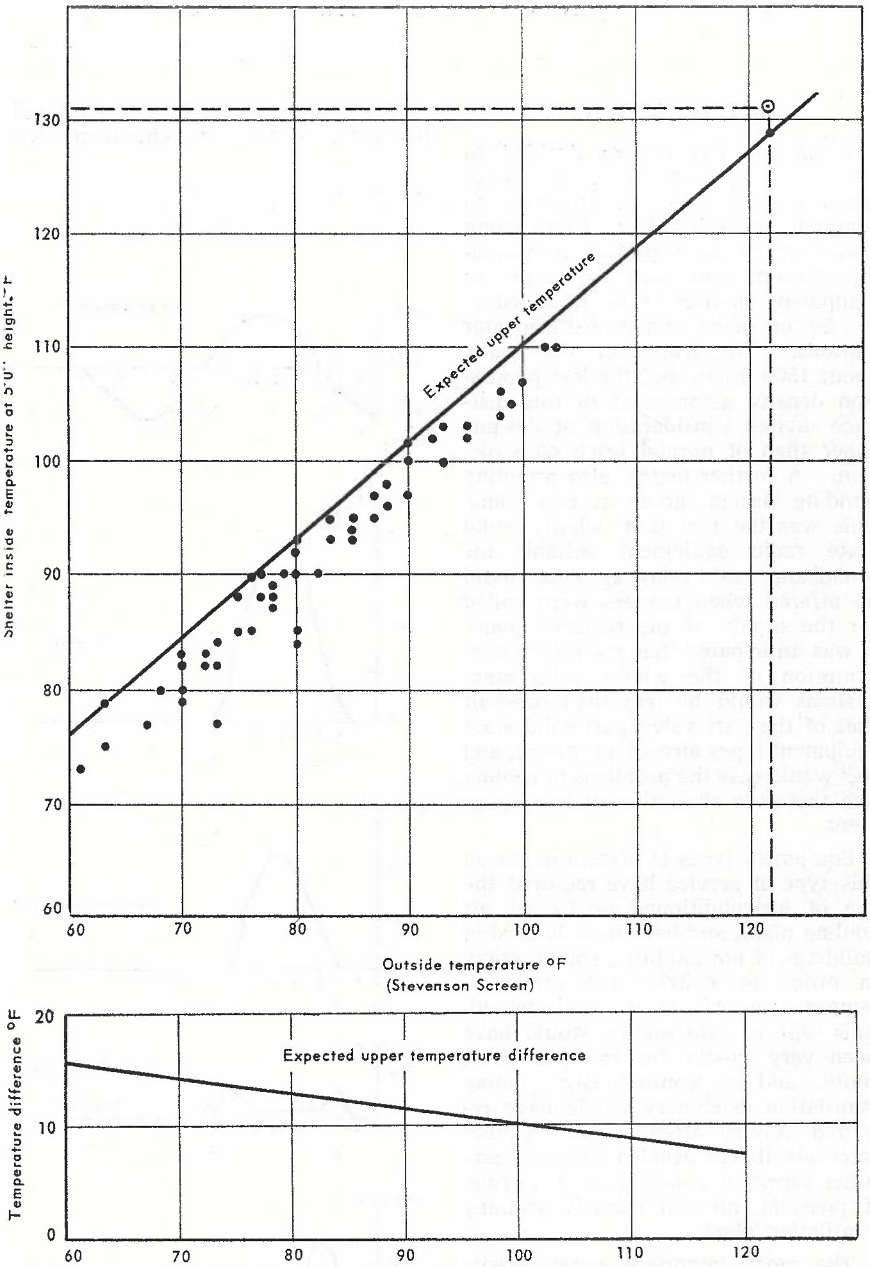

Fig. 2. — Results for Experimental Design.

The shelter can easily be translated to suit other power and ambient temperature conditions by adjustment, up or down, of its surface area dimensions (a law well proven by model measurement) or by leaving off one or more vertical shade walls, etc.

In the practical case of East-West project and many similar uses, fan filter units would be provided for use on the occasion of staff maintenance visits or under thermostatic control, to reduce abnormal temperature conditions which could occur for a very small percentage of time.

It will be realised that the inside temperature conditions in the shelter

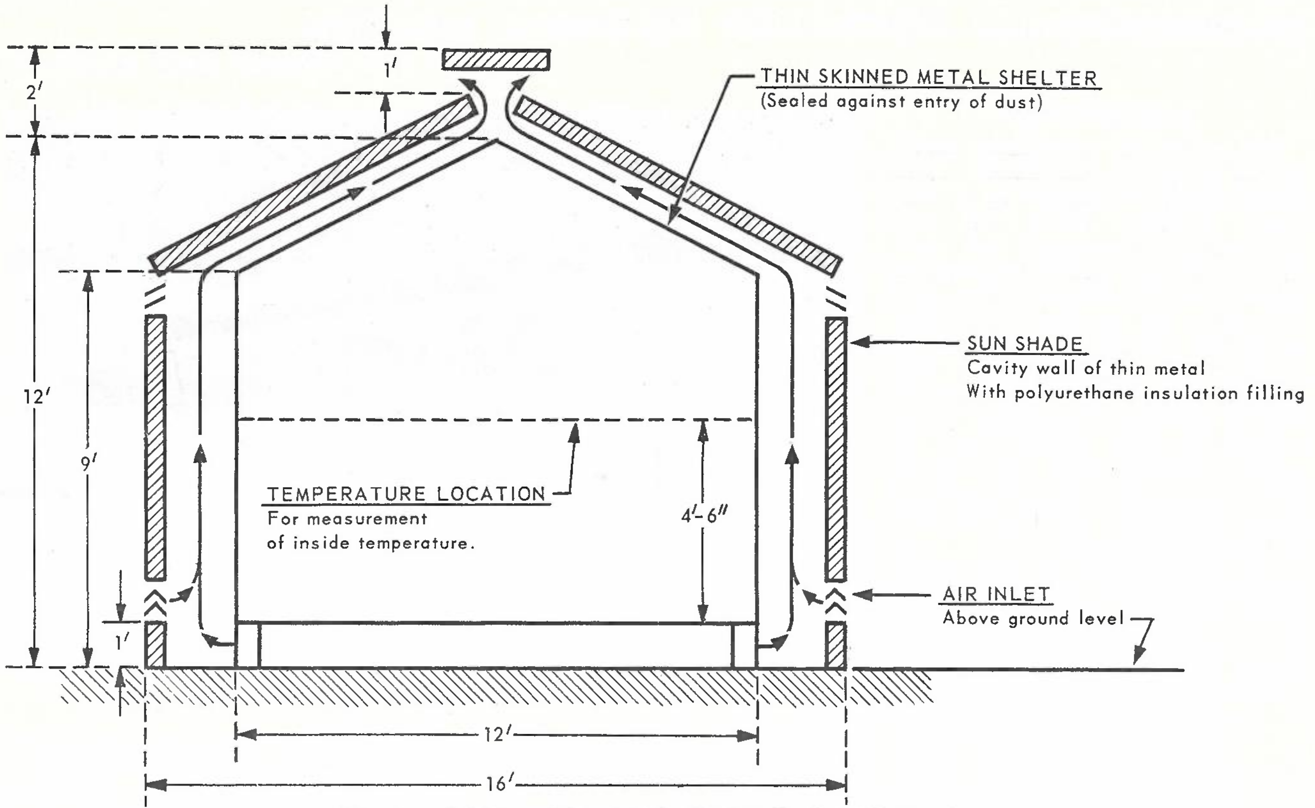

Fig. 3. — Experimental Naturally Cooled Equipment Shelter.

will follow closely the movement of external ambient temperature, but being always higher than ambient by 5 to 15 deg. F. The effects of this daily temperature cycling on components in the equipment cannot be fully assessed; however, the decision has been made that these effects will not have any significant effect on component life, and no attempt will be made by introducing additional heat treatment, to limit the range of temperature cycling beyond the limit imposed by the shelter as designed.

INTERPRETATION OF TEMPERATURE CHARACTERISTICS OF SHELTER

It will be noted more clearly from Fig. 2b that, if the temperature characteristic is drawn in the form inside-outside temperature difference versus outside temperature, the temperature difference is greater at low ambient temperature than at high, indicating that heat flow from the shelter is becoming more effective as the ambient temperature rises, i.e., is proportional to absolute temperature, e.g., at 62 deg. F. ambient the inside building temperature is 16 deg. F. higher (78 deg. F.), but at 122 deg. F. it is only 7 deg. F. higher (129 deg. F.). Thus for each rise of 1 deg. F. in ambient temperature the inside shelter temperature rises by 5/6 deg. approximately.

This result can be explained as follows:

As mentioned previously, heat transfer from the shelter can be assumed to be almost wholly as result of convection and radiation, conduction being negligible.

The basic heat flow equations are as follows:—

Convection flow $= F_c \propto (T_1 - T_2)$
where F_c = convection-surface area
$\propto$ = convection coeff.
$= A + B\,(T_1 - T_2)$
where A & B are constants
$\infty\ C\,[A + B(T_1 - T_2)]T_1 - T_2 \qquad (1)$
where C is a constant.
Radiation flow $= E\,\sigma\,F_r(T_1^4 - T_2^4)$
where E = radiation coefficient of radiating surface.
σ = Stefan/Boltzman constant
F_r = radiating surface area
$\infty\ K\,(T_1^4 - T_1^4) \qquad (2)$
where K is a constant.

Also T_1 = Temperature in °K inside shelter at mid-height.

T_2 = Ambient shade temperature in °K and also approximate air temperature between sunshade and shelter, and on inside surfaces of sun-screen.

0°C = 273°K.

In equation (1), $B(T_1 - T_2)$ is small compared to A for the metal surfaces used in the shelter and it can be seen therefore that convection heat flow is proportional to $T_1 - T_2$ only, i.e., temperature difference between the convecting surfaces which is less than 5°K.

However, from equation (2), it is seen that radiation flow is proportional to absolute temperature, more clearly shown as follows:—

Let $T_1 = T_2 + \Delta T$

ΔT being small, <5°K compared to T_1 or T_2 (in the region of 300°K) then substituting in equation (2), expanding and neglecting powers of ΔT of the order of 2 or more, it can be shown that radiation flow is proportional to $\Delta\ T.T_2^3$.

Now if we take any 2 values for T_2 (ambient temperature) within the operating range of the shelter, say 27°C (300°K) and 47°C (320°K), we find that relative radiation flow at these points is in the ratio $300^3/320^3 = 5/6$.

This ratio agrees closely with that obtained in the practical field test already mentioned above. Thus, as the ambient temperature rises radiation heat flow becomes more effective and therefore more important, convection heat flow remains reasonably constant.

CONCLUSION.

Experience with installed shelters has shown that their temperature performance is well within the Departmental objective, i.e., internal temperature not to rise more than 5°C above shade temperature.

ENVIRONMENTALLY CONTROLLED EQUIPMENT SHELTERS

D. S. THOMAS[*] *and B. M. SIGAL*[**]

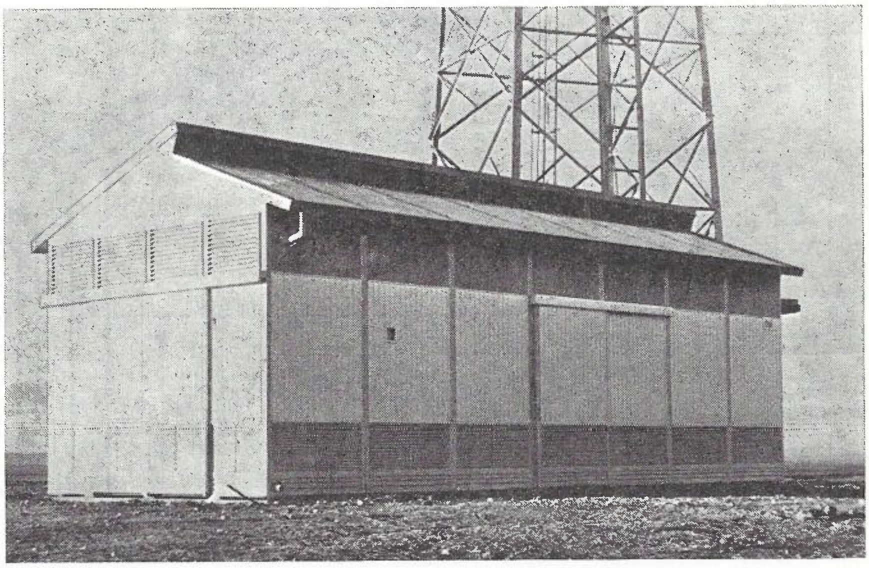

Fig. 1 — A Completed Shelter.

INTRODUCTION

The use of an un-insulated metal-walled equipment and battery room (inner shell), surrounded by a ventilated radiation screen and surmounted by a sun-shield roof (heat shield assembly), was the outcome of research and development work carried out by the Australian Post Office during the investigation stage of the project. The requirement for this type of shelter arose because of the lack of commercial electrical power supplies at most repeater sites. It would, therefore, have been uneconomic to use powered temperature-control equipment. A completed shelter is shown in Fig. 1.

The development of the A.P.O. design concept to the stage of production line manufacture involved further design studies and materials testing with particular reference to:

(a) the control of equipment room environmental temperature to within acceptable upper limits under extreme outdoor conditions subjected to the heat dissipation of a fully equipped system (12 racks of equipment);

(b) the use of materials and finishes having a high durability and requiring the minimum of maintenance attention for an estimated 20 years life;

(c) the use of materials and techniques suitable for production line manufacture and subsequent long distance transport over rough terrain and frequent handling without deterioration.

DESIGN CRITERIA

Climatic Conditions

The route within the southern margins of the Nullarbor Plain is characterised by very high summer temperatures, low overnight and winter temperatures, large diurnal variations, low rainfall, high dust incidence and high solar radiation intensity. A particular feature is the high incidence of winds, which vitally affects the thermal performance of the shelters.

Outdoor reference conditions used for thermal design calculations were:

Outdoor ambient shade (summer), 50°C (122°F);
Outdoor ambient shade (winter) — 1°C (30°F)
Diurnal temperature range, 22°C (40°F);
Number of consecutive days over 38°C (100°F) assumed to be 12;
Relative humidity, 15 to 65%;
Wind velocity, 160 km/h (100 mile/h).

The temperature records taken at stations along the route (see Fig. 2) indicate that the design reference conditions could be expected to occur at any station in the system.

Continuous Heat Dissipation

Radio equipment room 1600 W maximum
Battery room (trickle charge) 400 W

Environmental Temperature Limits

The design was required to ensure that the ambient temperature in the equipment room did not exceed 55°C (131°F) when the outdoor shade temperature was 50°C (122°F), with a fully equipped system dissipating 1600 W, and measured 1.5 m (5 ft) above floor level. The ambient temperature in the battery room was not to exceed 50°C and the temperature rise in the diesel enclosure was not to exceed 50°C above ambient shade.

Equipment Weight

Batteries: 2900 kg (6400 lb)
Control cubicle: 272 kg (600 lb)
Radio equipment and installation materials: 1360 kg (3000 lb)

General

In addition to the quantitative criteria summarised above, other conditions which were required to be satisfied were:

(a) dust infiltration to the equipment room must be prevented

(b) the shelter must be proof against the entry of birds, snakes and other animals

(c) materials of construction must be non-flammable throughout, and timber was not permitted due to fire risk, termite attack and deterioration under the severe climatic conditions.

Station	Merredin	Kalgoorlie	Eyre	Eucla	Fowlers Bay	Ceduna	Kyancutta	Whyalla
Maximum Temperature	45.0°C (113°F)	46.1°C (115°F)	47.1°C (116.8°F)	50.8°C (123.2°F)	48.3°C (119°F)	47.2°C (117°F)	49.3°C (120.7°F)	49.4°C (121°F)
Minimum Temperature	—3.9°C (25°F)	—1.1°C (30°F)	—3.9°C (25°F)	—2.2°C (28°F)	—2.5°C (27.6°F)	—2.8°C (27°F)	—5.6°C (22°F)	—2.8°C (27°F)

Fig. 2 — Maximum and Minimum Temperatures at Typical Stations.

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[*] Mr. Thomas is Senior Partner of D. S. Thomas and Partners.

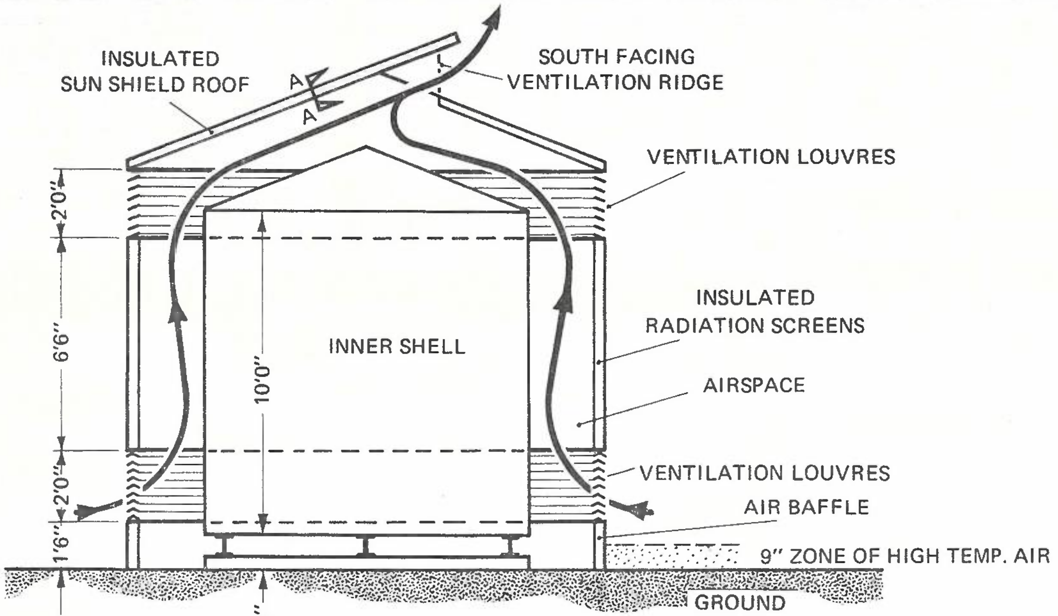
[**] Mr. Sigal is Chairman and Managing Director of the Sigal group of manufacturing, companies.

THERMAL DESIGN

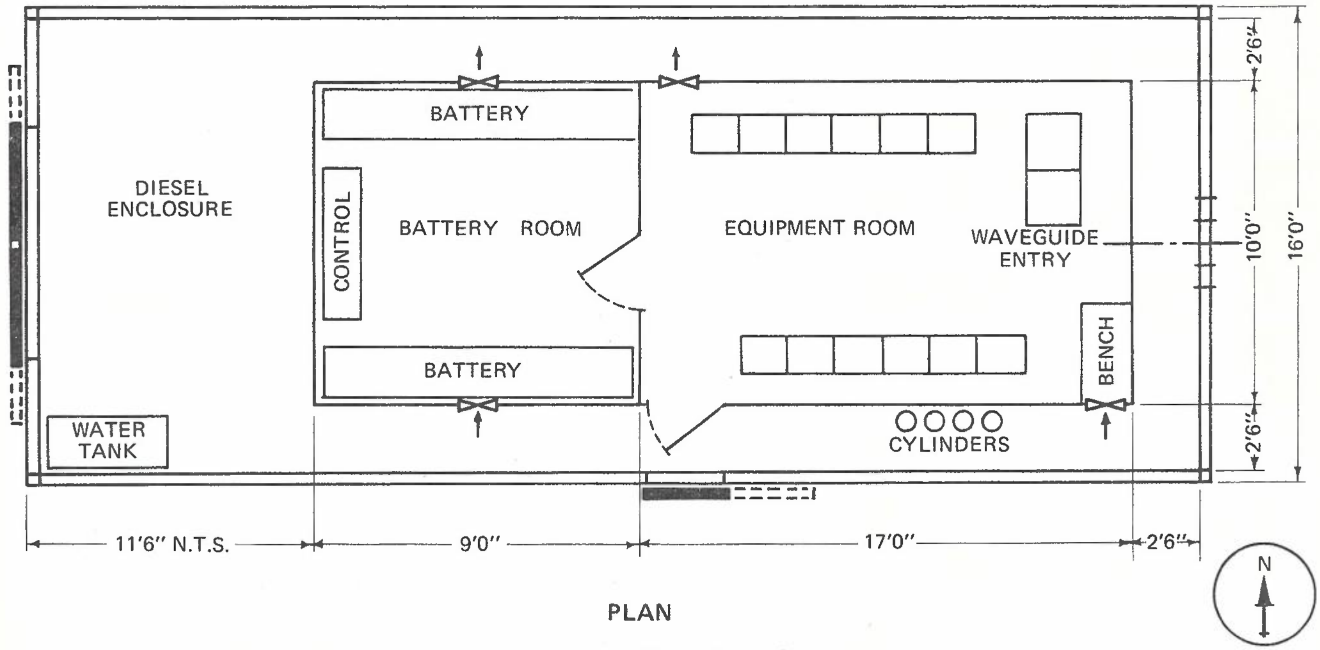
The most critical criterion that had to be satisfied was the temperature rise limitation within the equipment room. Although the permissible temperature difference from indoor to outdoors at design reference maximum conditions was specified at 5°C at 50°C shade temperature, it did not necessarily follow that this would ensure adequate heat transfer from the equipment room. The amount of heat flow into the shelter due to direct and indirect solar radiation and ground reflection could be many times greater than the expected heat dissipation rate and could cause a net heat gain and corresponding rise in shelter temperature. Without specific attention to this aspect, the space temperature rise could greatly exceed the maximum permissible.

As the thermal performance of the surfaces could be expected to deteriorate in service, the design reference used in the final thermal calculations was for a space temperature of 2°C above an outdoor shade temperature of 50°C.

Heat transfer from the inner shell to its surroundings occurs by convective dissipation of heat from its surfaces. This transfer is increased or decreased depending whether the radiant heat transfer component is inwards or outwards between the opposing surfaces of the space between the inner shell and the screens. It follows that if it were economically practical to envelop the inner shell in a blanket of air at ambient



SECTION



PLAN

Fig. 3 — Shelter Layout.

shade temperature and to maintain the inner faces of the screens at or close to this temperature, then under peak outdoor ambient temperature conditions, the radiant heat transfer would be outwards from the inner shell. Under night-sky irradiation conditions it could also be expected that the screens would impede radiation losses from the inner shell and tend to minimise the diurnal variation of the inner-shell temperature.

Studies were made of several approaches to the basic shelter design concept with the view to determining the most economic form of construction, consistent with the design criteria. Calculations showed that the optimum solution of the thermal design requirements would be met by a design incorporating the following features:

(a) orientation of the shelter with the long axis in an E-W direction.

(b) total screening of the inner shell with thermally insulated sun-shield roof radiation screens and panel incorporating low and high level ventilation louvres

(c) location of low level air inlet louvres above the high temperature ground air layer to prevent entry of ground reflected solar radiation

(d) continuous open-ridge ventilation orientated to the south to promote wind movement over the inner-shell surfaces

(e) Profiling of the inner-shell surfaces to increase the convective heat dissipation component.

(f) use of white painted external surfaces to radiation screens and sun shields to minimise surface temperatures

(g) use of thermal insulation in radiation screens and sun shields to reduce surface temperatures of their inward-facing surfaces to minimum economic limits under full sun load

(h) use of high emissivity surfaces on inner-shell surfaces and inside surfaces of radiation screens and sun shields.

The calculated thermal performance of the final shelter design indicated a peak space temperature of 52°C with an outdoor ambient of 50°C and an internal heat dissipation of 1600 W. Calculations further indicated that the temperature in the battery room would not exceed peak ambient and generally should be some 2°C below shade temperature and be subject to a substantially reduced diurnal variation due to the thermal storage effects of the batteries.

Subsequent thermal performance tests on the prototype shelter proved that the design calculations were conservative and allowed a substantial margin for deterioration of surface characteristics.

CONSTRUCTION

The general layout is shown in Fig. 3. The inner shell, comprising the equipment and power rooms, is of all-welded construction using cold formed galvanised structural sections and profiled galvanised sheet steel cladding with all joins lapped, sealed and double riveted. The framing is welded to a heavy duty rolled steel chassis carrying a steel sub floor assembly. The complete unit is painted internally and externally and the steel floor is finished in vinyl tiles.

During manufacture, each shell was equipped with a.c. and d.c. electrical installation, cable trays and cable forms, power ducting, battery stands, pressurisation system fittings, rack ironworks, bench and cupboard units, ventilation fan/filter units, lighting fittings, and waveguide entry glands. Doors are steel clad and fitted with air and dust seals.

The radiation screens and sun shields are constructed of galvanised steel structural sections jig-formed into readily transportable modules, insulated and sheeted on both sides (Fig. 4) with galvanised sheet steel paint finished. The sun shields are supported by a system of portal frames bolted to the radiation screens. Access to the diesel areas is by means of sliding doors in one of the radiation end screens (Fig. 5) Access to the equipment room door is via a sliding door in one of the screens. An air space of approximately 0.45m (2 ft. 6 in) is provided between the shell and the screens.

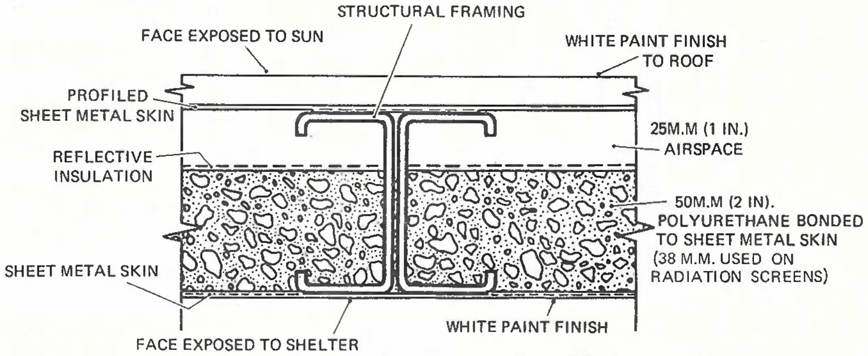


Fig. 4 — Cross-Section through Sun-shield panel.

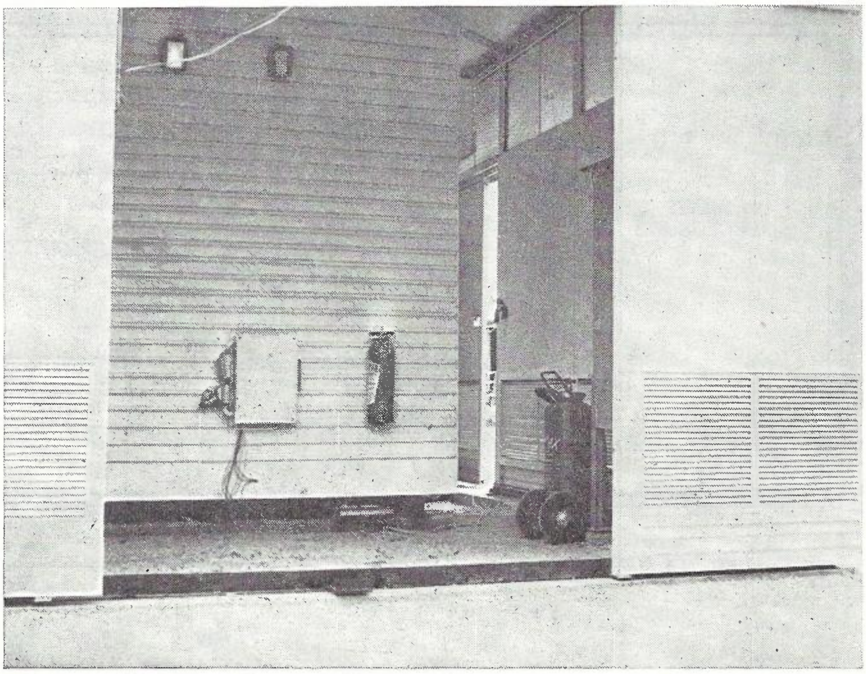


Fig. 5 — End View, Doors Open, Showing Diesel Enclosure and Inner Shell.

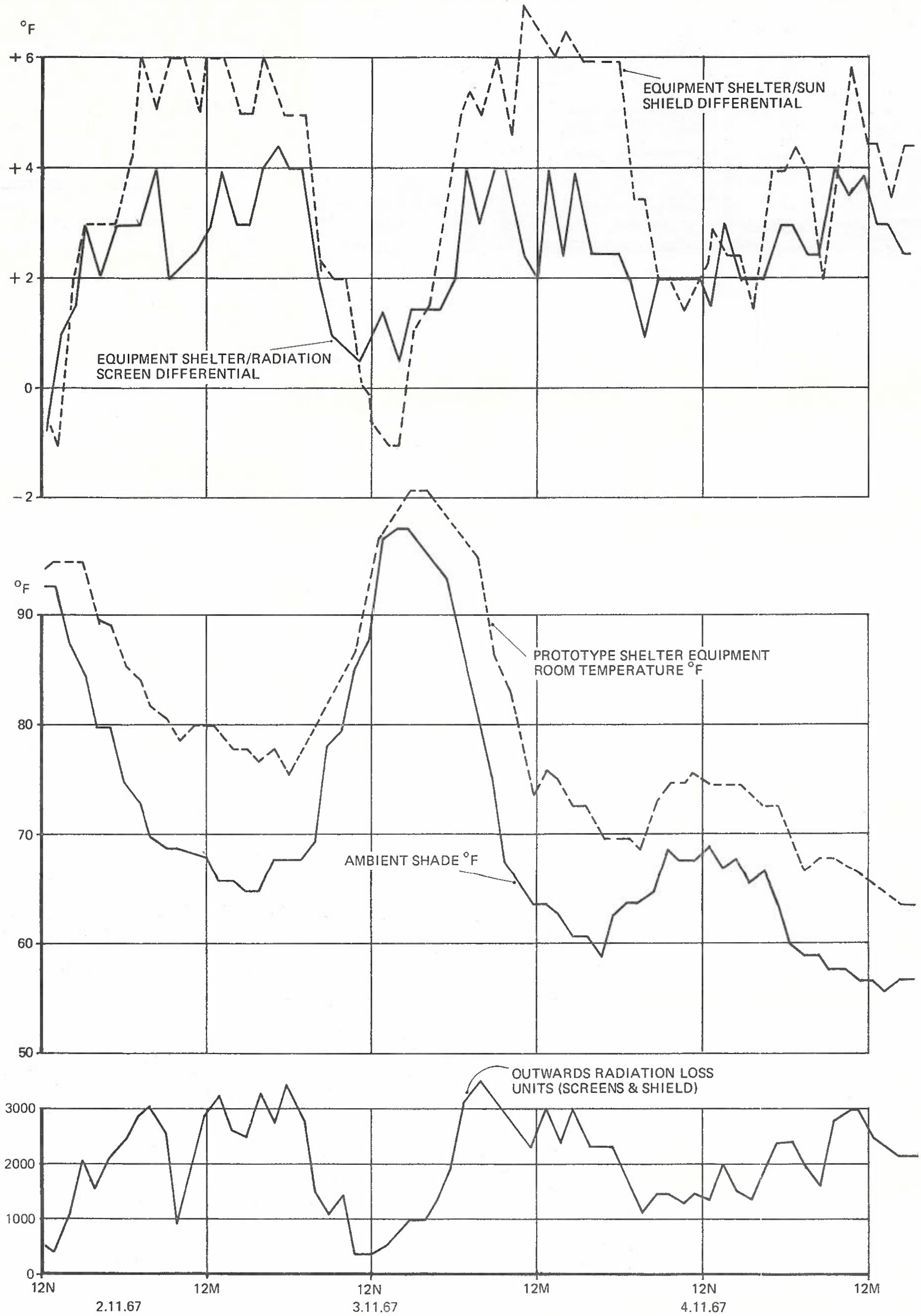


Fig. 6 — Thermal Performance Characteristics.

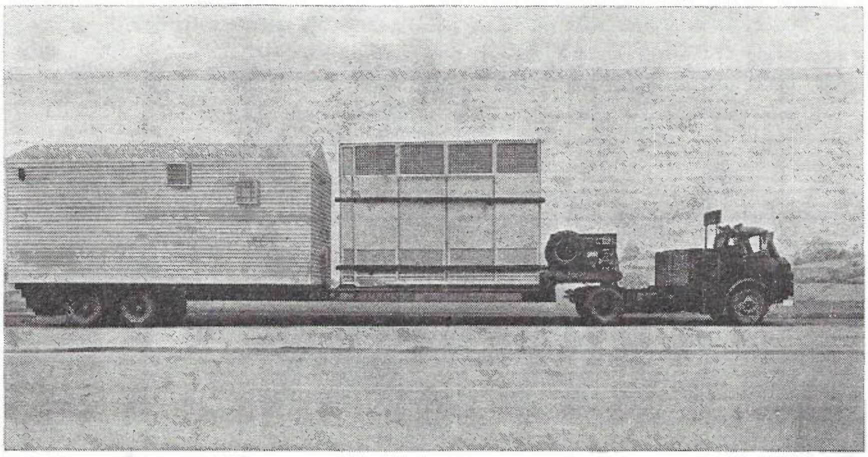


Fig. 7 — Loaded Transporter with One Inner Shell and Two Sets of Sun-shield and Radiation-screen Structures.

Thermal Performance Tests

A prototype shelter, complete with sun shields, radiation screens and all ancillary fittings, was constructed and erected at Sigal Industries works in Adelaide.

Fig. 6 shows the typical thermal performance characteristics of the shelter and comparative surface temperatures with a test load of 1600 W installed in the inner-shell. Tests were carried out over periods totalling approximately 3 months and included heat wave temperature conditions up to 45°C (113°F). Analysis of the test data indicated that the peak temperature in the equipment room at the upper limit design ambient condition of 50°C (122°F) was unlikely to exceed 51°C (124°F).

MANUFACTURE

Minor modifications were made to the prototype to suit manufacturing facilities and production line techniques and a programme was set up for manufacture to suit the field programme. During the peak manufacturing period the shelters were being completed at a rate of more than two per week.

All shelters were inspected regularly during the construction sequence by reference to a master checking list which required the inspection of several hundred items. Prior to despatch from works all shelters were also inspected and passed by the APO Departmental Inspecting Officer.

TRANSPORT

The transport to site was carried out by Sigal Industries using specially designed transporters with heavy-duty prime movers equipped for extended periods of operation in the remote regions (Fig. 7).

For sites between Whyalla and Eucla, shelters were transported from Adelaide. Three transporters were used to ship four shelters. The first vehicle transported two inner shells, whilst the other two vehicles each transported one inner shell and two sets of screens.

The inner shells were transported fully assembled, whilst the sunshield and radiation-screen structures were transported in a knocked down module form in a special jig assembly. Water tanks, nitrogen cylinders, fire extinguishers and miscellaneous items were carried in the shells. The loaded vehicles had an all up weight of approximately 35 tons and measured some 21 m (68 ft.) in length by 3.4 m (11 ft.) in width with an overall height of 5 m (16 ft. 6 in.).

Because of Western Australian road transport regulations, shelters for sites in Western Australia were road transported to the Commonwealth Railways terminal at Port Augusta, some 320 km (200 miles) north of Adelaide, railed to Parkeston (Kalgoorlie) and then transported by road to the various sites accompanied by an escort vehicle because of the over-width and over-height of the loads.

Having regard to the extreme duty under which the transport operation was carried out, damage during transport was minor and no other major problems were encountered, with the exception of delays which were caused by impassable road conditions due to freak wet weather along parts of the route, which reached a near record in this normally dry region.

SITE ERECTION

The site layout and design of the pre-constructed foundations enabled the transport vehicles to be driven over the foundations and to position the inner shell immediately above its final location. The inner shell was then raised from the transporter by means of special heavy-duty mechanical jacks, the transport vehicle moved away, and the shell then lowered (Fig. 8) onto levelling shims placed on the foundations. They

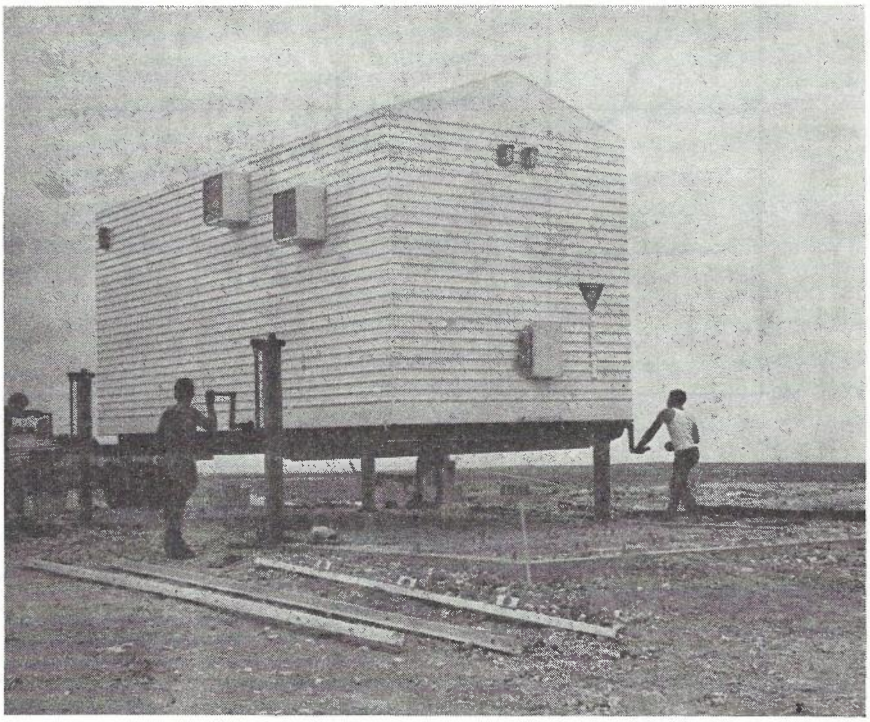


Fig. 8 — Lowering the Shelter on to its Foundations by Means of Mechanical Jacks.

were levelled to within ± 1/16 inch by using hose levels and finally straight edge levels. After levelling the inner shells were secured by means of adjustable toe clamps bolted to the foundations and fitted over the RSJ flanges of the shell chassis. The base angle supporting the radiation screens and sun shields was then positioned, levelled and bolted to the foundations taking the waveguide entry level as datum. The screen and shield modules were then erected (Fig. 9) with the aid of a mobile crane. The fitting of internal wind braces, sliding doors, vermin screens, gutters, downpipes, water tank, earth lugs and nitrogen bottle stands completed the site works except for final cleaning down and checking of door seals and microswitch operation and paint touch-up.

The time required for site erection works was less than two days per shelter for normal site conditions, given favourable weather, although during one period of exceptionally wet weather, the delivery and erection of four shelters kept the erection crew in the field for six weeks.

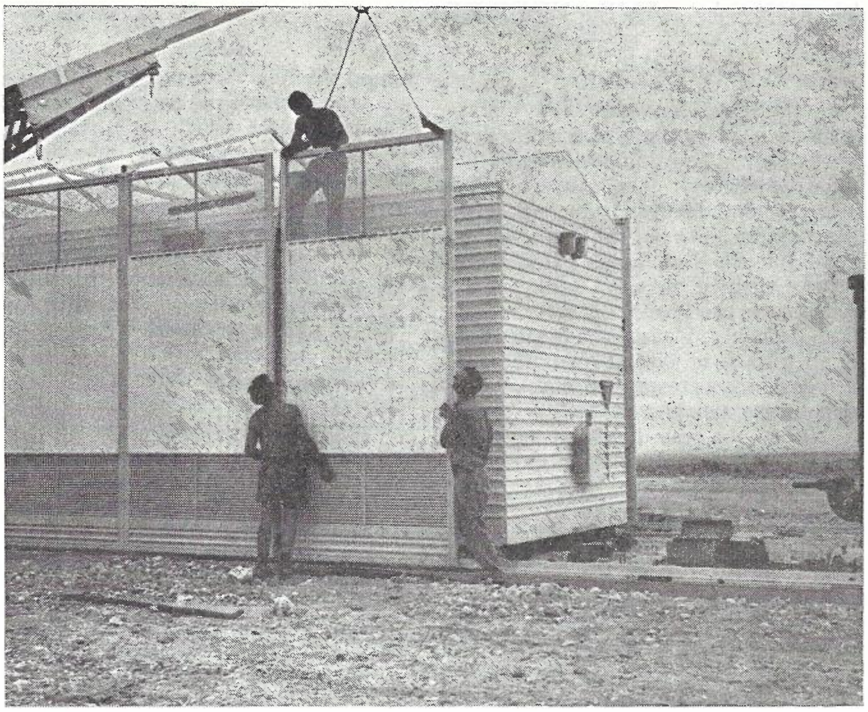


Fig. 9 Erecting the Radiation Screens.

CONCLUSION

The successful completion of the project has proved that the use of industrialised transportable lightweight equipment shelters offers a practical solution to the problem of equipment accommodation and environmental temperature control in remote areas. Experience on the project and particularly in the field, suggests that the design concept could be developed to avoid the need for orientating the shelters and to eliminate the separate sun-shield and radiation-screen structure, thus reducing manufacturing and transport costs and minimising site works.

ANTENNAS AND FEEDERS

E. L. BROOKER B.Sc., F.I.E.(Aust.), F.I.R.E.E.(Aust.)*

INTRODUCTION.

In the final analysis, the distinguishing characteristic of a radio system is that it transmits its signals by radiation through free space. The antennas and feeders, which provide the coupling between the radio equipment and the free space path, are a critical element in any radio relay system. In the East-West system they have been given exceptional attention in all phases of design, manufacture, installation and testing to ensure that each antenna feeder system performs in exactly the way that had been assumed in the overall system design.

Although there are several other factors, the main indicators of the quality of an antenna are its gain, polar pattern and return loss. Similarly, the feeder quality is indicated mainly by its attenuation and return loss. The East-West system uses high gain antennas and low loss feeders so as to utilise the maximum radio frequency power available from radio equipment. The antenna polar pattern has been controlled to give adequate front-to-back ratio in all cases and, at certain special sites, to give additional control of the pattern at other angles. The return loss of the elliptical waveguide feeder itself, and also of the antenna and circulator terminations, has been kept as high as the state of the art will permit so as to limit intermodulation noise arising from feeder reflections.

ANTENNAS.

All of the antennas are 12 ft. in diameter, and, except for three special antennas, employ a Hansen-Yang high efficiency feed horn as a primary illuminator giving a gain of 35.1 dB. The horn feed arm is of corrugated elliptical waveguide to give a direct interface with the main elliptical waveguide feeder. The Hansen-Yang horn design controls the illumination pattern of the primary radiator to give a more uniform amplitude distribution across the aperture of the antenna than can be obtained with the conventional sectoral horn. The illumination drops off steeply at the edge of the reflector. This broader illumination distribution increases the gain efficiency of the antenna, while the steep drop-off at the periphery reduces the edge illumination and so improves the front-to-back ratio.

The basic repeater antenna (Fig. 1) is an unshrouded focal plane reflector fitted with spaced half-wavelength tabs around the rim. The function of these tabs is to disperse the otherwise prominent back lobe, which is intrinsic to all symmetrical antennas on axis at 180 degrees. This lobe arises from the in-phase axial summation of diffraction components from the edge of the reflector. An improvement in peak front-to-back ratio of the order of 4dB can be obtained from this device, giving a guaranteed figure of 52 dB peak envelope.

Antennas of this basic type have been provided at most stations, but at certain locations special polar pattern requirements were to be met and this has been done with two variations to the basic antenna. Shrouded antennas have been used where increased directivity was needed. A deep cylindrical shroud extends forward of the paraboloid and is lined with absorbing material. The absorber avoids degradation of the antenna return loss and also improves further the polar pattern in the 90 degree region. The front-to-back ratio is 58 dB guaranteed. A low-loss hypalon radome is stretched taut across the shroud aperture to reduce wind loading and to protect the absorber from the weather. At a few sites a third type of antenna was required to provide additional directivity at angles between 10 and 15 deg. in the forward direction so as to reduce over-shoot interference on problem paths. These antennas use long focal length reflectors with modified illumination and small superimposed secondary reflectors dimensioned to reduce the low order side lobe levels.

Most of the antennas are monopolar, but diversity antennas, where needed, are dual polarised. The primary horn design is such that a second horn can be added in tandem, at the rear, to provide a dual polarised feed. All antennas terminate in an elliptical waveguide aperture behind the reflector and this interface is tuned to the reference elliptical standard impedance so that there is no interface mismatch introduced at the junction of the antenna and the waveguide feeder.

The antennas are of all-aluminium construction, comprising a one-piece flanged spinning for the reflector with welded and riveted back-up structure. The feed horn is a precision machined aluminium casting matched directly to the corrugated aluminium waveguide feed arm and supported by two or three adjustable fibreglass struts. All hardware is stainless steel.

ELLIPTICAL WAVEGUIDE

All feeders are of premium quality Heliax elliptical waveguide, type EWP 17. Notwithstanding its large size, this corrugated copper waveguide is

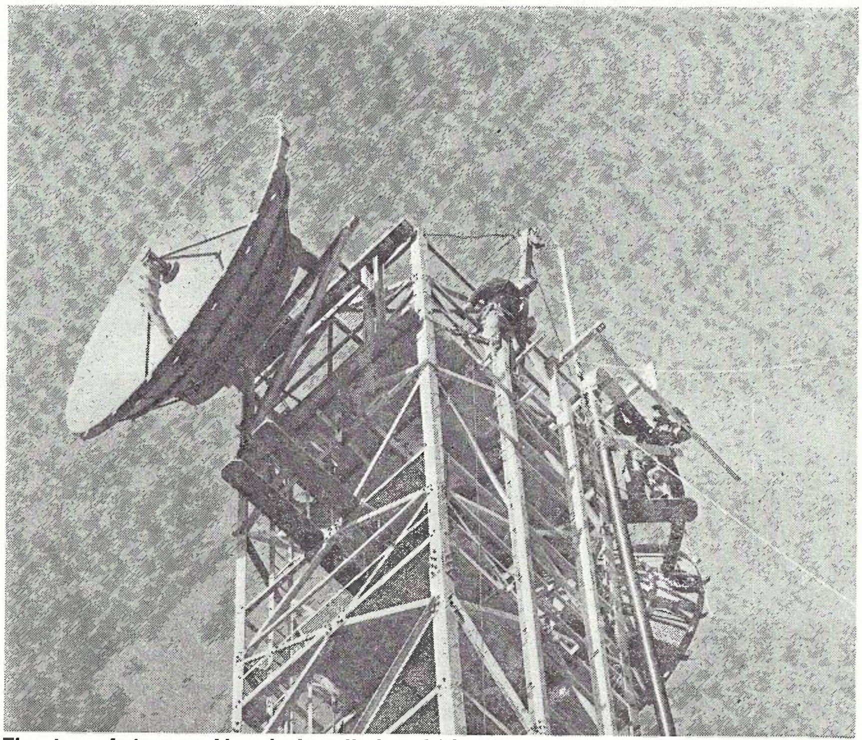


Fig. 1. — Antennas Already Installed and First Pre-Formed Waveguide Moving into Final Position.

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*Mr. Brooker is Managing Director, Andrew Antennas, Division of Andrew Corporation, Melbourne.

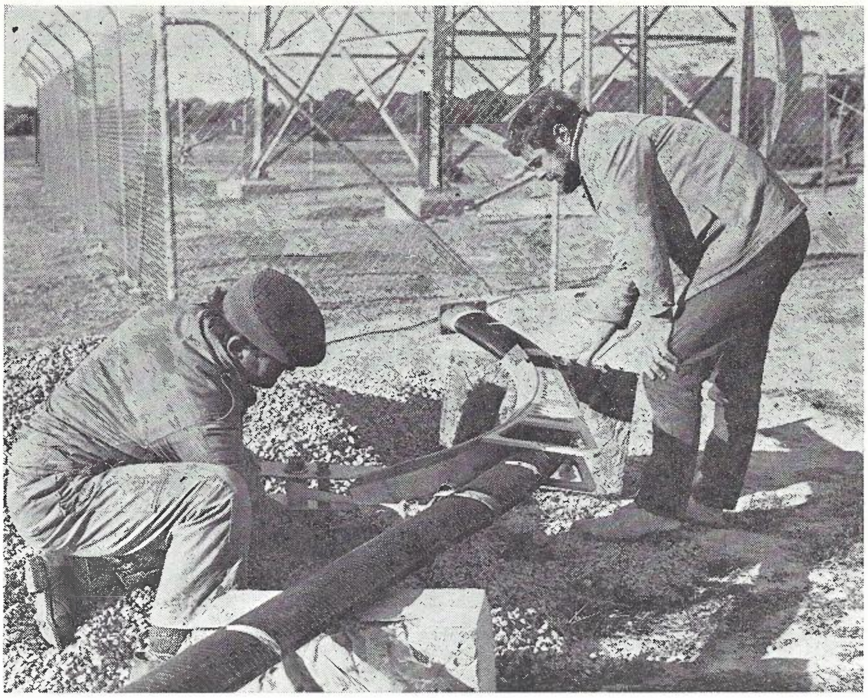

Fig. 2. — Preparation of H-Plane Bend Using Special Bending Tool.

sufficiently flexible to be formed to the required shape on site (Fig. 2), so that it may be installed in an unbroken length from the radio equipment to the antenna. The attenuation of this waveguide is very low, being only about one-third that of $1\frac{5}{8}$ in copper coaxial cable, which is its nearest alternative. Whilst having the obvious advantage of conserving transmitter power, the low loss increases the need for good matching at the antenna and circulator terminations to avoid excessive feeder echo distortion.

The feeder terminates in half-splice flanges, giving an elliptical interface. The half-splice is fitted with external and internal silicone rubber gaskets to give reliable gas sealing. The sleeve of the half-splice encloses the end of the waveguide and the space between the two is filled with an epoxy casting resin. This provides a complete mechanical termination to the waveguide and relieves the electrical interface of any static or dynamic mechanical forces generated along the length of the waveguide. The waveguide is cut into tabs and flared out against the flange to provide electrical contact at the waveguide aperture (Fig. 3). The multiplicity of individual tabs provides a cushioning action as the flange is drawn up and ensures a sharing of the available contact pressure around the circumference, a necessary condition to obtain a good return loss and low non-linearity. A return loss of better than 40 dB can always be met with this termination and no case of non-linearity at this face has occurred in any installed feeder.

The waveguide is attached to the tower runway by stainless steel hangers. These hangers are constructed from a broad thin strip of stainless steel, designed to wrap around the waveguide and hold it securely without applying compressive forces to the broad face of the waveguide. Any deformation of this face, repeated cyclicly with uniformly spaced hangers, would cause high amplitude spikes in the return loss sweep pattern. An on-site test of a 300 ft. feeder, measured on the tower before and after fastening the clamps, showed no variation to the peak return loss within the measuring accuracy of the test (0.1 dB). On the same feeder, the addition of an E-plane and H-plane bend at the bottom contributed only 0.004 to the peak VSWR (representing 0.2 dB variation in return loss at the 23 dB level).

At the point where the waveguide enters the shelters, an anti-twist device is fitted to enable the axis of the waveguide to be aligned and maintained within 5 deg. of vertical. This device is in the form of a split aluminium casting enclosing the waveguide, with the annular space between filled with epoxy resin. The anti-twist devices were provided also as a precaution against the transmission of torque along the waveguide to the terminations over the radio equipment. It was at one time considered possible that the elliptical waveguide may twist to some degree with age or temperature after initial installation. Towards

Fig. 3. — Preparation of Waveguide Termination to Produce Tabbed Contact Face.

the end of the installation programme a series of controlled tests was made in an attempt to establish the existence and magnitude of this phenomenon. In all cases it was found that no detectable change (less than ¼ deg.) occurred within the first five days immediately after installation. It seems questionable therefore whether these devices are strictly necessary for this purpose, although they may be useful in limiting movement of other kinds, including vibration, from being passed through to the equipment.

Equipment Circulator Termination.

Each waveguide passes through the wall of the building to terminate at a point immediately above the rack with which it was associated. The termination is in the form of a waveguide-to-coaxial transition, directly coupled to a coaxial circulator. The circulator is connected to the radio equipment by means of a small diameter coaxial line to provide some mechanical flexibility between the rack and the feeder. This arrangement of feeder termination allows the feeder echo distortion to be kept to the smallest possible value by providing the best available termination to echoes in the feeder. The transition and circulator combination was considered electrically as a single unit whose impedance was measured at the elliptical waveguide interface. Tuning of the transition and circulator as part of the antenna feeder installation programme ensured a consistently high performance at this point and must be regarded as a major contributor to the final achievement of good feeder intermodulation performance on the overall system.

TESTING.

Most of the electrical properties of the antennas and feeders can be reliably guaranteed from control during manufacture. Prototype testing and adequate mechanical quality control is sufficient to ensure that antenna gain, polar patterns and cross polar rejection, will be met in all cases. Similarly feeder attenuation is not subject to variation during manufacture. The return loss of all components, however, falls into a different category. When working to the highest performance specification that the state of the art permits, it is always possible that an individual antenna, feeder or circulator termination will be found to have a return loss peak outside the specification. The installation of these components on the East-West system was therefore based on the premise that every component would be measured in the field during installation to ensure 100 per cent. compliance with specification. Each antenna was measured on the ground before lifting and each waveguide was measured on the tower after installation. The combination of antenna and waveguide, connected together at the top, was then measured. Each circulator termination was measured and tuned before final attachment to the waveguide. The primary measurement in all cases was to a 'worst peak' specification, but r.m.s. measurements were also taken on the waveguides. Sweep frequency methods were used.

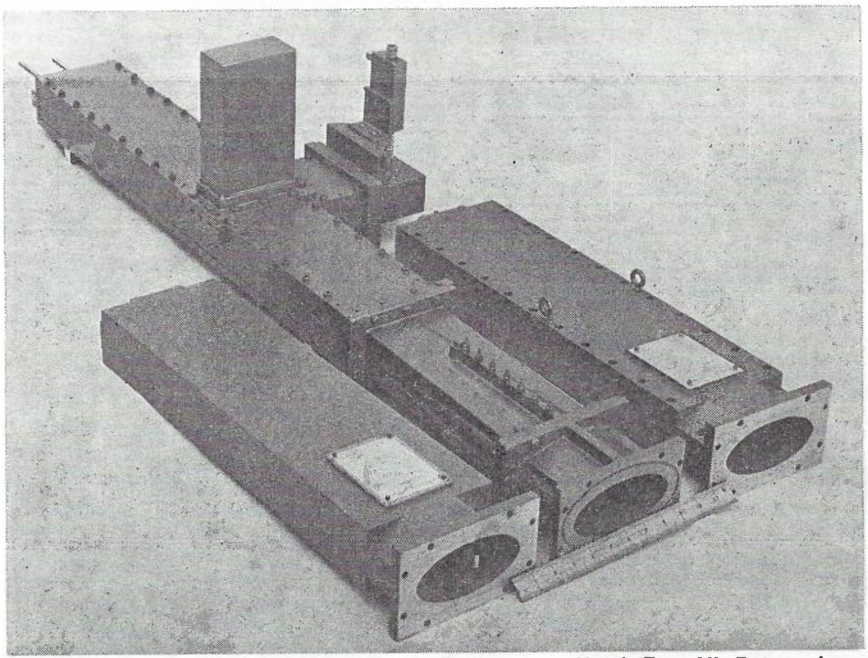

Fig. 4. — Basic 2 GHz Hybrid Tee Reflectormeter Used For All Return Loss Measurements.

In order to measure return loss figures accurately at the levels required, it is essential to have available a reflectometer of sufficiently high directivity to avoid excessive measurement error. An Andrew hybrid tee was used for this purpose (Fig. 4). This is necessarily a physically large unit because of the waveguide dimensions involved. The rectangular waveguide hybrid itself has a directivity of better than 58 dB, which falls to 50 - 54 dB at the elliptical interface of the rectangular to elliptical transition. All measurements were made with reference to this ellipse, which is a match to the elliptical waveguide termination. Because the directivity of the hybrid is so critical to the measurement accuracy, it was re-checked daily in the field before each series of measurements, using the sliding mismatched load technique.

Associated with the hybrid were sweep generators and display units, ratiometers, cavity frequency meters, r.m.s. integrators and chart recorders. The resolution of the return loss readings on the test equipment was 0.1 dB and overall accuracy of any return loss reading was generally appreciably better than 0.5 dB.

Return Loss Measurements.

An analysis has been made of the measured peak return loss values for the entire route. This covers 142 antennas with associated waveguides and terminations. The results of this analysis are given in Figs. 5 to 8. These cover respectively measurements on the antennas and waveguides separately, on the waveguide/antenna systems, and on the circulator terminations. In each case the results have been expressed as a percentage of the total number of measurements better than the specification by the margin indicated. It was a requirement that 100 per cent. of the components must meet the specification and in most cases the curve touches the zero margin line at 100 per cent. representing usually a single component somewhere in the system measured at the specification level. It is useful to review the median (50 per cent.) condition in each case, since this could be said to represent an 'average' component of its type. Thus the median antenna has a small margin of 0.6 dB and more than this could not be expected because the specification is on the borderline of currently achievable figures. The specification for waveguides varied with the length in four categories, as shown in Table 1, and the margins for these have been shown separately in

TABLE 1: SPECIFICATIONS FOR WAVEGUIDES AND WAVEGUIDE/ ANTENNA SYSTEMS.

	Length	VSWR		Spike Patterns
		Peak	r.m.s.	
Waveguides Only.	0 - 149 ft.	1.13	1.06	4 over 1.12, 11 over 1.11
	150 - 199 ft.	1.15	1.065	5 over 1.14, 15 over 1.12
	200 - 249 ft.	1.17	1.07	6 over 1.16, 18 over 1.13
	250 - 299 ft.	1.19	1.075	11 over 1.16, 30 over 1.14
Waveguide Antenna Systems	0 - 149 ft.	1.17	1.075	4 over 1.16, 11 over 1.15
	150 - 199 ft.	1.19	1.075	5 over 1.18, 15 over 1.16
	200 - 249 ft.	1.21	1.085	6 over 1.20, 18 over 1.17
	250 - 299 ft.	1.225	1.085	11 over 1.20 30 over 1.175

Fig. 6. The margin for the median waveguide below 200 ft. is about 1.6 dB and is almost 3 dB for waveguides above 200 ft. This should be compared with the analysis of complete waveguide/antenna systems (Fig. 7). The margins for complete systems are generally appreciably better than for waveguides alone and it should be recorded that this was achieved without interface adjustment or correction having been necessary in any case. A great deal of effort was expended in the early stages of this project to ensure that the measuring interface standards were accurate and constant, so that the connecting together of two components did not cause a return loss situation worse that the summation of their individual values. Given that this has been done adequately, the present analysis implies that the measurement of waveguide antenna systems is of little practical value, being less rigorous than the measurement of the antenna and waveguides separately.

The circulators, measured at the waveguide interface on the transition, showed the largest range of return loss values (Fig. 8). The median figure for these terminations is 5 dB better than the specification.

The existence of these margins, relative to the nominal specifications, represents a very considerable reduction in the actual feeder intermodulation noise compared with a calculated design value based on the assumption that each antenna feeder system would perform to the specified figure. For example, noise due to the end-to-end reflections on the East-West system should be 5.7 dB lower for the median case that would have been calculated from the design peaks specification. Similarly the waveguide-to antenna and waveguide-to-termination noise levels would be approximately 2.5 dB and 7 dB respectively better than calculated values based on peak specification. The significance of these margins would have been easier to assess if r.m.s. readings had been available from all components, but there are practical problems in making r.m.s. measurements accurately. During the installation testing, r.m.s. checks were taken on all waveguides and antenna/waveguide systems and all fell comfortably below the r.m.s. specifications, even for those waveguides whose peak return loss was close to the limit values. It must be concluded therefore that, in cases where all waveguides, antennas and circulator terminations are proved to be within peak specification, a design based on the specification figures will lead to a pessimistic result for the feeder intermodulation noise.

GAS LEAKAGE.

Since the pressurisation of the feeders on this system is from high pressure storage cylinders, it was necessary that great attention be paid to minimising the gas leakage rate on

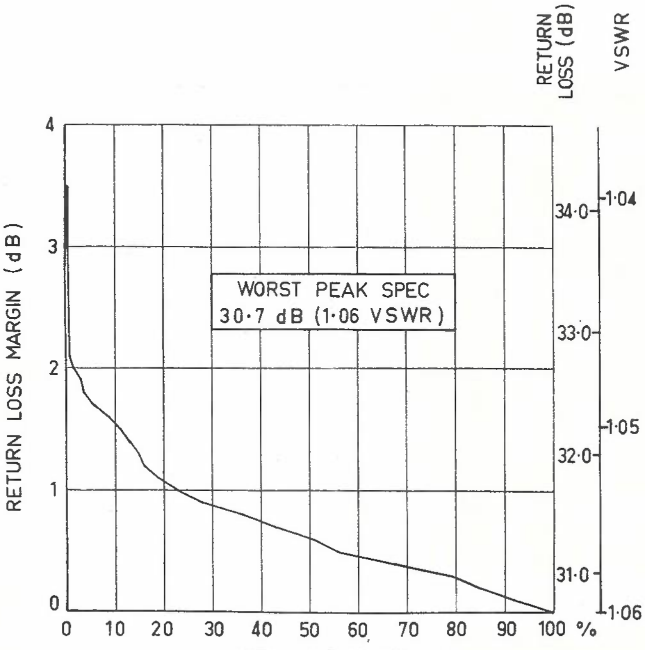

Fig. 5. — Analysis of Measurements on Antennas.

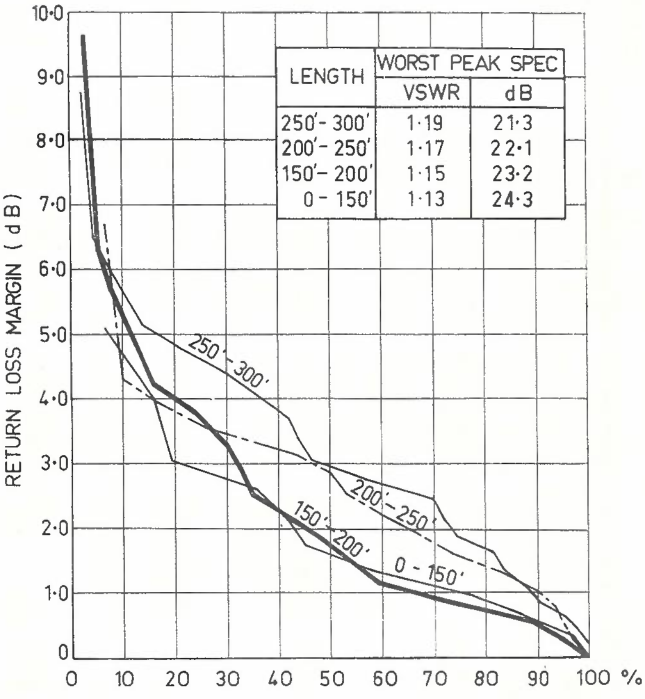

Fig. 6. — Analysis of Measurements on Waveguides.

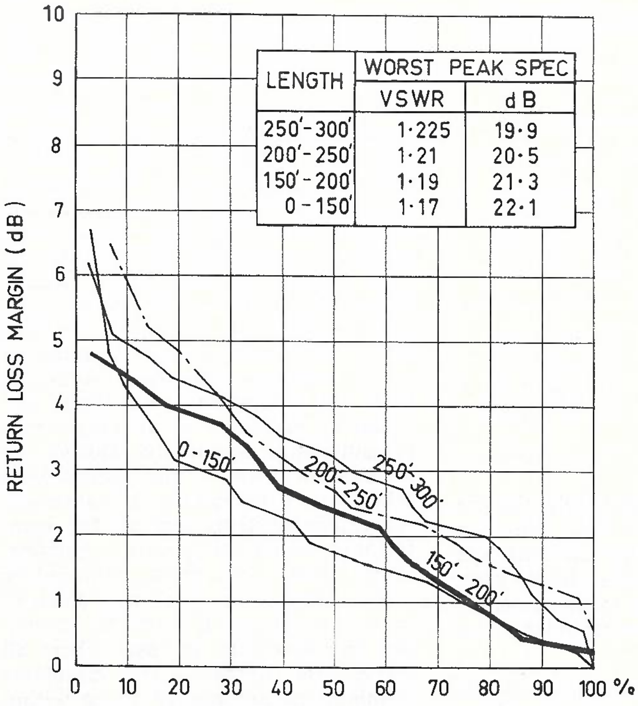

Fig. 7. — Analysis of Measurements on Waveguide/antenna Systems.

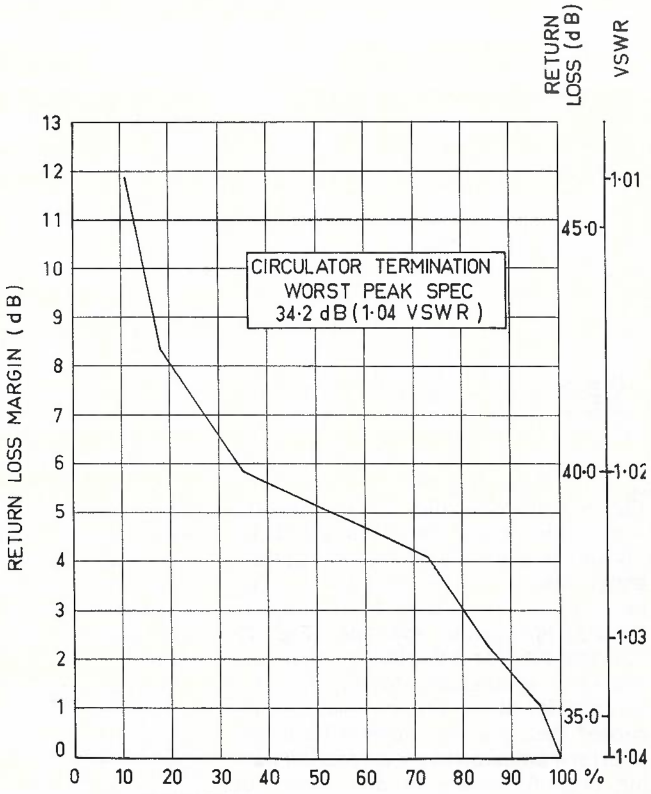

Fig 8. — Analysis of Measurements on Circulator Terminations.

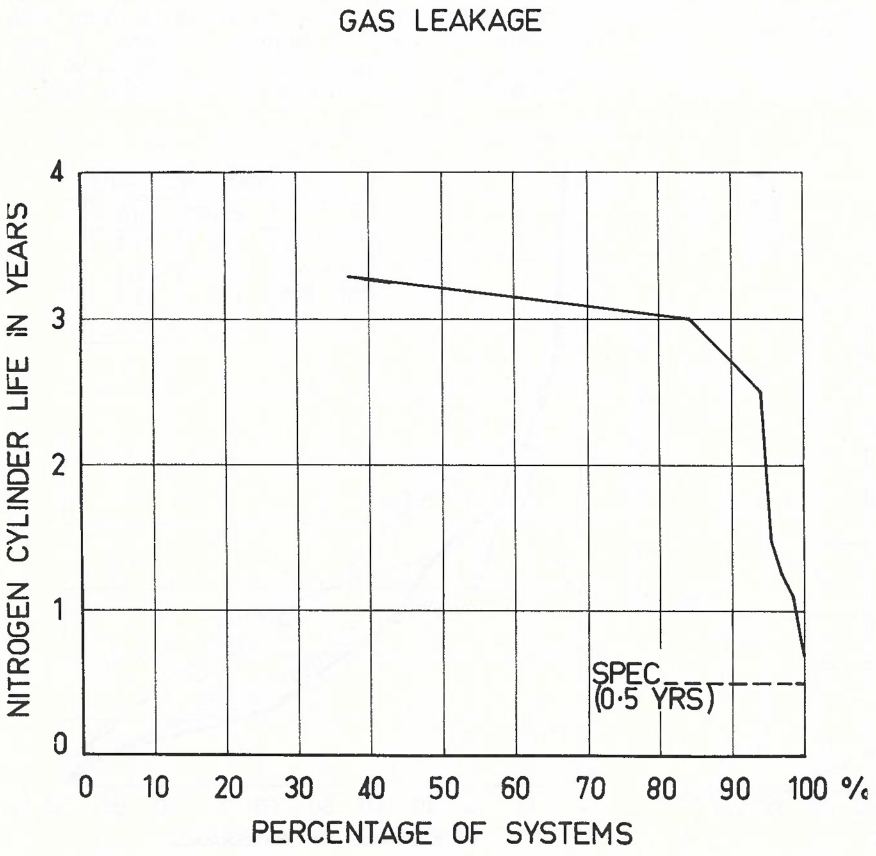

Fig. 9. — Gas Leakage Rates Expressed as Expected Life of Nitrogen Cylinders.

each overall system. The waveguide itself is manufactured by a process requiring a continuous seam-weld in the waveguide wall, but this is not a practical source of leakage. The sources of gas leakage are to be found in gaskets and tuning screws, and also in pressure windows both top and bottom. Careful attention is needed in the construction of waveguide fittings and gaskets for corrugated waveguide to ensure that an adequate seal can be established and maintained. The half-splice flanges used on this system, and their gaskets, were designed with this in mind. No difficulty was found in the field in achieving a gas seal at these points, while the casting in epoxy of the rear of the flange shell ensures that no mechanical forces will be passed through to disturb the seal during the life of the installation.

In the final stage of acceptance testing on each feeder system, the gas leakage rate was calculated from pressure drop readings taken at 24-hour intervals and corrected for temperature. A statistical analysis of these measurements, converted into the equivalent life of each nitrogen cylinder, is given in Fig. 9. The specified cylinder life was six months minimum, but it will be seen that a life of better than three years might be expected for 80 per cent. of the cylinders. It must be pointed out here that the sealing of 2 GHz elliptical waveguide is inherently more difficult than for waveguide of smaller dimensions because of the increased length and larger tolerances of gaskets. It should be noted that the successful use of gas cylinders requiring low leakage rates depends upon adequate care being taken in the design and setting up of pressurisation levels and pressure relief valves. Temperature cycling of the waveguide over a range of 55 deg. C, which can occur in summer, causes a pressure rise at the peak of 2.7 p.s.i. above the regulated setting. Any pressure relief valve, which may be placed in the circuit as a general safety precaution, must be so adjusted as to permit such a rise in pressure without release of gas. Pressure relief valves commonly begin to release gas progressively during the onset of their operation so that this component must be set well above the maximum pressure to be expected for any variation of the pressurisation level supplemented by the thermal rise. The nominal regulated pressure in the East-West waveguides is 2.5 p.s.i.g. with the pressure relief valve set to 10 p.s.i.g.

ANTENNA INSTALLATION.

The antennas were delivered overland direct from factory to site, mounted on a specially equipped semi trailer to avoid unnecessary crating and cartage costs.

Although some preliminary work had been carried out earlier on the route, the main installation programme commenced in the field in July, 1969, and was completed in December, 1969. The installation personnel were divided into three specialist teams, each trained and equipped primarily for one self-contained phase of the work. This arrangement conferred a high degree of flexibility on the field effort and prevented delays in one phase of the work from holding up progress on the entire project.

The antenna team was the first to site with the responsibility for assembling, testing and erecting the antennas. This team comprised a superviser, two technicians, six riggers, a mechanic, cook, and provision driver. The team was well equipped with instrumentation to ensure that antenna return loss performance was correct, and was also well equipped with rigging gear to permit the antennas to be installed safely under all conditions, including times of moderate wind. After erection on the tower, the antennas were optically aligned in azimuth by means of a jig-mounted telescope referencing to the plane of the aperture. The elevation adjustment was set to vertical against a spirit level.

The antenna team was followed by a small panning team comprising a superviser, two technicians and a rigger and was equipped with transmitters and receivers to set up a radio path between adjacent antennas. The antennas were then electrically panned to verify or correct the earlier physical and optical alignment. The task of electrical panning is always complicated when fading conditions exist, and this occurred frequently on the route. The uncertainty introduced by fading can be reduced markedly if the panning transition between 3 dB points can be made very quickly. The team used a pneumatic power ram for this purpose, an arrangement which was particularly valuable in panning vertically where the weight of the antenna makes movement difficult, and for azimuth panning under windy conditions.

Although electrical panning is the established practice to ensure the correct alignment of microwave antennas, it is of interest to note that this work proved to be entirely redundant in the case of the East-West system. Mechanical tolerances on the antennas were held close enough to ensure that the azimuthal and elevation squint would be less than 0.5 deg. In no case, following the initial mechanical setting up with telescope and spirit level, was it necessary to make any correction as a result of the electrical panning. It was found that the inaccuracy of the mechanical alignment was no greater than the inaccuracies of electrical panning.

WAVEGUIDE INSTALLATION.

The waveguide team was the last to site. Its responsibility was to install the waveguides and pressurising equipment and to test the waveguide and the waveguide/antenna systems. This team included a superviser, two technicians, five riggers, a mechanic and a cook. The cutting, bending and lifting of the waveguides required several special techniques to ensure that the completed installation was electrically and mechanically correct. The waveguide was brought to site in 12 ft. diameter reels carrying a bulk supply. They were transported on a specially designed trailer incorporating electrically powered rolls to drive the reel. The waveguide was first terminated on the ground and the major bends then formed to suit the antenna location and feeder run at that site. The bends were formed always to be standard minimum radii applying to this waveguide (60 inches for H-plane, 28 inches for the E-plane). The special bending tool shown in Fig. 2 incorporates guides to ensure that no twisting of the plane of the waveguide occurs during bending. It is important that this condition be met because, at the final presentation of the connector to the antenna, it is necessary that the flange be of the correct orientation to avoid the need for twisting forces in the waveguide at this point. In order to obtain control of this parameter, all bends were simple H-plane or E-plane configurations and no compound bend was permitted.

The pre-formed bends are vulnerable to damage during the lifting operation unless they are properly supported. Each bend was supported by a U-section plywood splint. A diagonal brace was lashed to the feeder beyond the ends of the splint to avoid kinking. Multiple ropes were used to distribute the weight in the vicinity of the bends. This technique is illustrated in Figs. 1 and 10. Fig. 10 shows a pre-formed waveguide, complete with E-plane splint and brace, commencing the lift under the control of the winch truck operator. The reel is power-driven on its trailer to maintain the correct catenary. Two tag lines are used to control the waveguide laterally against the wind. The lower bends are formed in the waveguide after the top section had been placed finally in position to the antenna and in the waveguide runway.

This installation technique proved to be entirely satisfactory, its only limitation being at times of high wind, when it was sometimes necessary to wait for one or two hours for a drop in wind intensity. In several cases the wind thrust on the waveguide during the course of erection needed the strength of more than three men to stabilise the lower end. At the completion of the project, it was recorded that no waveguide had been damaged during erection following the introduction of this technique, and no waveguide failed to meet its electrical specification when first installed.

FIELD EQUIPMENT.

In order that the field teams be free to move as the programme demanded, it was necessary then to make them completely self-contained in vehicles, equipment and sleeping accommodation. Eighteen vehicles, including 5-ton trucks, winch trucks, test vans and station waggons, were used. These

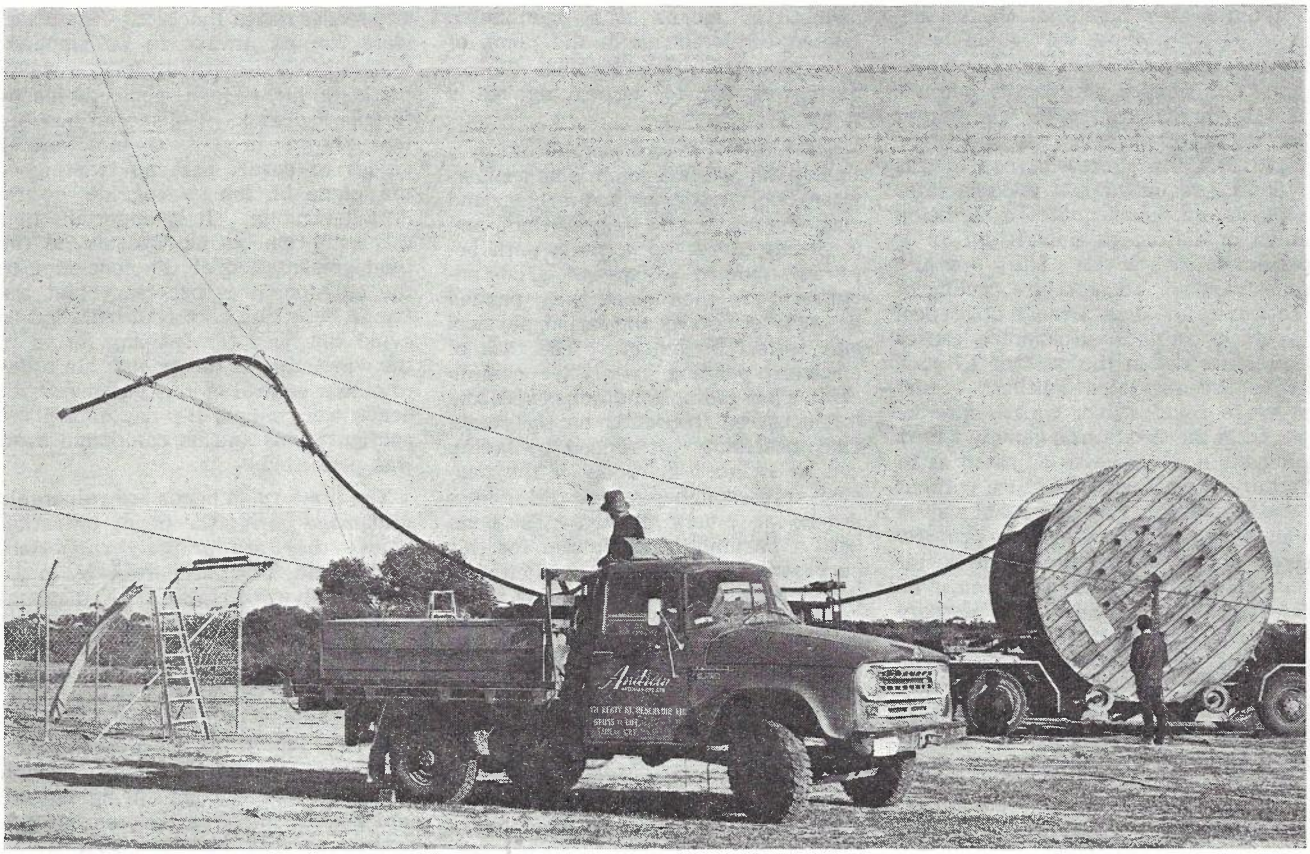

Fig. 10 — Commencement of Waveguide Lift, Showing Reel Trailer, Winch Truck and Waveguide Splints.

were supplemented by four general purpose trailers, together with four reel trailers needed for the transport of the waveguides.

All power necessary for installation work and for staff accommodation was provided by mobile alternators, completely independent of the station power supplies. In all, eleven mobile power plants were in use by the three teams.

Adequate staff accommodation is essential on a project of this magnitude because great demands are made upon the field staff, and it is essential that they be provided with comfortable accommodation and adequate meals. Six large caravans were used, mostly of a basic eight-berth capacity. Two were modified to provide office working area to ensure that the management of the programme and of materials could be handled adequately. Two caravans were fitted out as complete self-contained kitchen / dining units. Large-scale cooking facilities, together with refrigerator and deep freeze units, were necessary in each of these caravans to allow for the storage of sufficient food to cover the period between provisioning runs, and to ensure that each whole team could be fed simultaneously and comfortably, since to do otherwise would have interfered with the available working hours and efficiency of the teams.

COMMUNICATIONS.

Although the East-West project was conceived primarily to augment communications between Adelaide and Perth, the additional provision of reliable telephone channels along the Eyre Highway will surely be appreciated by all travellers along this road. It must be said that the antenna and waveguide teams were made very aware of the importance of the project in this respect. Communication between teams, and from the teams back to the base or the factory was difficult. Because of the large distances, it was frequently necessary to depend upon HF communications and, as was to be expected, this proved to be unreliable. Failure to establish communications between parties often led to many hundreds of miles of extra travelling.

SPECIAL ENVIRONMENTAL PROBLEMS.

Although it might have been expected that the Nullarbor Plain area could have presented a harsh installation environment in terms of heat in summer and muddy roads in winter, these did not prove to be troublesome. The teams were equipped with an aggregate water tank capacity of 4000 gallons divided amongst several separate tanks and there was no serious difficulty in maintaining an adequate water supply for all parties.

The main environmental problems derived from the great distances and the isolation. Distance in particular presented supervisory and communication problems. At one stage the antenna and waveguide teams were over 1000 miles apart. For the same reason the supply of food and other general provisions to keep all teams functioning required very long delivery runs. The aggregate vehicle mileage accumulated by all vehicles during the installation period was 300,000 miles. A motor mechanic in a self-contained repair van with spare parts moved along with one or other of the major teams to undertake repairs on demand.

Driving was not confined to the daylight hours and it was often necessary to drive long distances at dawn or dusk. At this time of day the mild and harmless kangaroo excels in pedestrian foolhardiness. Several vehicles were damaged and one overturned as a result of a kangaroo jumping unexpectedly into the roadway.

CONCLUSION.

The design, manufacture and installation of the antennas and waveguides for the East-West Project all contained a number of uncommon elements. These were the first microwave radio relay antennas manufactured in this country and were transported directly from factory to site. The project also introduced the use of 2 GHz corrugated elliptical waveguide on a large scale. The thorough measurement of every antenna, feeder and system along the route has given valuable statistical evidence on the margins available in actual system performance, compared with limit specifications, in cases where all components are installed to meet the specification.

The mounting of an installation project of this magnitude has shown that the highest standards of installation, both electrical and mechanical, can be met in remote areas, provided that the team is fully equipped and trained to be self-supporting in the environment.

ACKNOWLEDGMENTS.

The author acknowledges with gratitude the contributions of the design staff of Andrews Corporation, U.S.A., and the installation staff in Australia.

POWER PLANT

A. L. HOLDERNESS, M.I.E. (Aust.)[*]

INTRODUCTION.

This article describes the power supply systems and equipment developed to supply the d.c. power to repeater and terminal stations on the East-West broadband radio relay system.

Much of the route traverses the desert of the Nullarbor Plains and sparsely populated areas where commercial mains supply is not available. Forty-three of the 60 radio stations have no commercial mains supply and are unlikely to get supply in the foreseeable future. Fortunately, the radio equipment is of solid state design and requires comparatively small amounts of 'no break' d.c. power. A small requirement exists to supply a.c. power, which mainly occurs when personnel are in attendance on maintenance visits. Airconditioning is not provided at repeater stations because of the advanced thermal design of the shelter and the wide temperature range over which the radio equipment will operate.

Of the sixty stations requiring –24 volt d.c. power:

(i) Forty-three are repeaters with no mains supply ;
(ii) Nine are repeaters with mains supply available;
(iii) Six are back to back terminals or control stations with three-phase commercial supply;
(iv) Two are terminal control stations with a.c. supply from a 'no break' supply source.

A brief summary of the station loads and the rating and type of equipment installed at these stations is as shown in Table 1.

The microwave radio stations will be operated on an unattended basis with maintenance staff located at several maintenance centres along the route. The supervisory system detects any power plant faults and a 24-hour battery reserve is available to allow for fault clearance.

The design of the power plants has been directed to the problem of providing a highly reliable source of d.c. power with other important objectives being the flexibility for growth, ease of maintenance and repair, and minimum cost.

To meet this need on such a long system under such harsh environmental conditions is probably the most rigorous requirement for any telecommunication power plant system yet designed, manufactured and installed in Australia.

Three basic types of plant are supplied to meet the requirements:—

(i) At non mains supplied repeaters the basic supply is provided by diesel generators backed by wind generators.
(ii) At mains supplied repeaters and back to back terminals duplicate rectifiers with diesel alternator standby are provided.
(iii) At terminal stations, where a.c. no-break supply was available, battery eliminator rectifiers are fitted.

As the equipment for (ii) and (iii) above had already been designed and proven on other systems, the engineering development has been directed in particular to power plant for the non mains powered repeater.

This design and development brought to light many engineering problems which have been satisfactorily solved. It is significant that the power plant has been designed and manufactured in Australia.

SELECTION OF POWER SYSTEM.

During investigations into the suitability of various power sources for non mains supplied repeaters on this project, the A.P.O. discarded thermo generators, fuel cells and solar cells because these sources had insufficient capacity and were considered unsatisfactory for maintenance reasons or uneconomical to operate.

At an early stage of the project the 3M Company allowed the A.P.O. first evaluation of their prototype 250 watt thermo generator unit. Although attractive from a maintenance point of view, the problem of propane

TABLE 1

Station	Radio Load in Amps		Power Plant.	Battery Capacity	
	Initial	Ultimate		Initial	Ultimate
Repeater (Non Mains)	25	64	Diesel Generator {4kW, 24V d.c. 2kVA, 240V a.c.} Single Wind-driven Generator. Control Cubicle 2kW, 24V d.c.	2 x 500 Ah	4 x 500 Ah
Repeater (Mains)	25	64	Duplicate Rectifiers 24V, 100A d.c. D.C. Distribution Cubicle 24V, 200A d.c. Standby Diesel Alternator 10kVA, 240V, single phase. Diesel Control Cubicle 10kVA.	2 x 200 Ah	2 x 200 Ah
Back to Back Terminal (Mains)	67	145	Duplicate Rectifiers 24V, 200A, d.c. D.C. Distribution Cubicle 24V, 400A, d.c. Standby Diesel Alternator 35kVA, 415V, Three Phase Diesel Control Cubicle 35 kVA.	2 x 500 Ah	2 x 500 Ah
Terminal (No Break Supply)	44	73	Battery Eliminators 24V, 15A. (Up to five in parallel)	—	—

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fuel cost and transportation to site, coupled with the prohibitive factors in providing for ultimate loads of 1500 watts, made this form of power plant unacceptable.

Fuel cells were then, as now, still at the development stage and at the present moment the best energy converter known to us for this application is the diesel engine.

The exotic types of power supply were discarded for the proven diesel engine driven generator, which forms the basic supply for all the non mains supplied stations. The reduced power requirement of the fully transistored radio equipment meant that wind-driven generators could provide satisfactory amounts of power provided that the wind characteristics of the site were suitable.

Later in this article the use of wind driven generators will be fully discussed. Suffice now to say that many of the non mains supplied stations on the route, particularly in South Australia, are considered to be favourably located with regard to wind power.

Continuously running diesel plant was not used mainly because of the increased maintenance required in running diesel engines under very light load condition and the need to utilise wind power when available.

RADIO EQUIPMENT REQUIREMENTS

The G.E.C. radio transmission equipment on the East-West system requires d.c. power at between 21.8 and 31.0 volts and will operate without degradation between these limits. The initial and ultimate load requirement for the repeater and terminal stations is given in Table 1. The performance requirement with regard to electrical noise or ripple on the d.c. supply is:

(i) At frequencies between 45 - 125 Hz, less than 50 mV r.m.s.

(ii) At frequencies between 300 - 3000 Hz, less than 2 mV (psophometric telephony weighted).

(iii) At frequencies above 3000 Hz. less than 5 mV (unweighted).

The radio equipment power units utilise converters operating at a frequency of 20,000 Hz to provide the various regulated voltages and respond quickly to input voltage changes.

For reasons of reliability, cost, maintenance and circuit simplicity it was preferred that the diesel engine at repeaters with no mains should be started from the 1000 ampere hour station battery, rather than a separate starter battery.

As the radio equipment power units were designed to cater for input voltage changes which can occur during battery and rectifier switching sequences on a normal floating battery system, then changes which occur when a small diesel is started from the station battery would present no problems. Tests showed that provided a 'Bendix' and not an 'axial' type starter was used, a half discharged station battery (500 Ah) would not drop its voltage below about 23.2 volts—a figure well above the minimum operating voltage (21.8V) of the radio equipment. Electrical noise generated by the starter motor is suppressed by the filter network provided in the output circuit of the brushless d.c. generator and wind generator.

Stepped voltage changes of up to 8 volts can occur when coupling a boost charged battery to the load battery. Tests were carried out over the Syd-

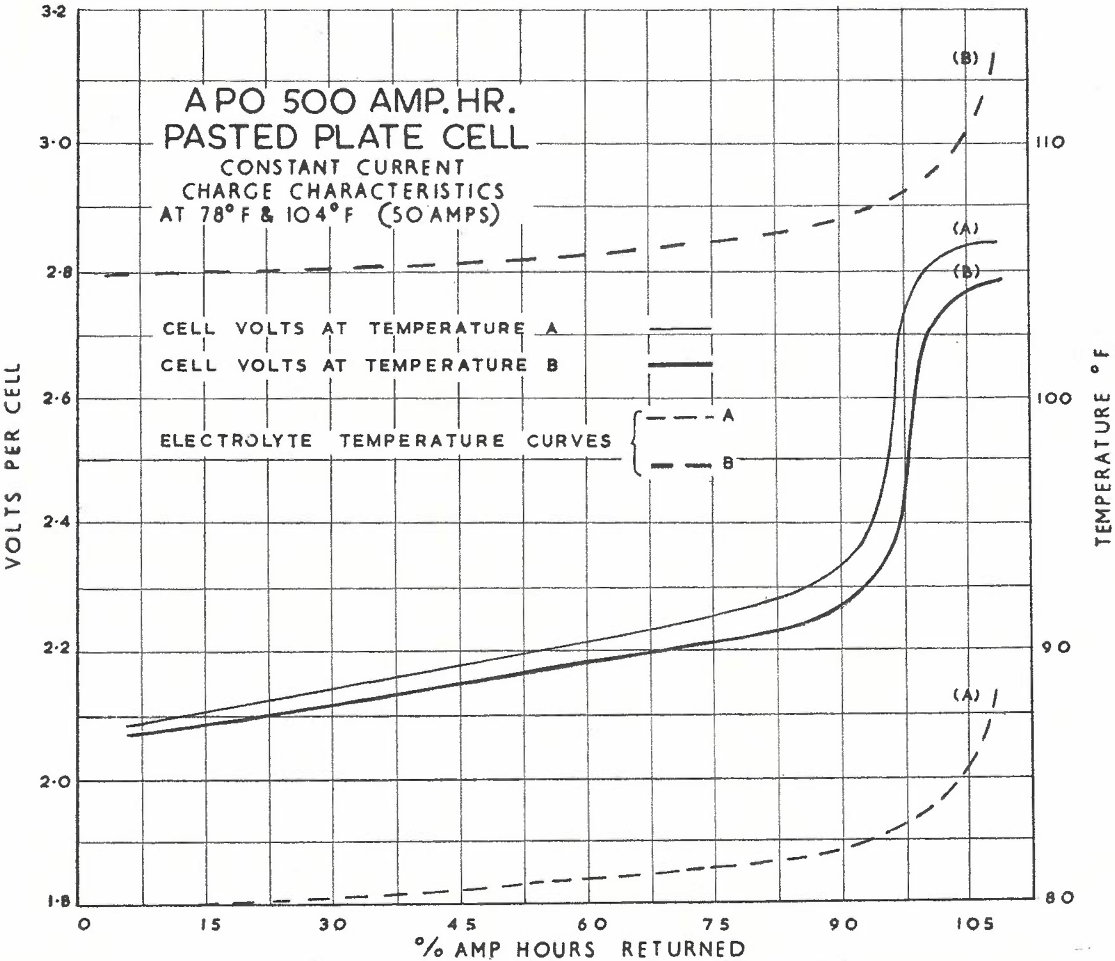


Fig. 1. — Battery Constant Current Charge Characteristic.

ney-Tamworth route to determine if service interruptions would occur when the battery supply voltage at a terminal or repeater was suddenly changed by connecting a boost charged battery in parallel with a discharging battery, whilst the busbar was supplying power to the broadband radio system. The system used for test was a Marelli CTR119 operating at 2 GHz.

It was found that the system is not likely to cause service outages or 20 millisecond signal element errors when the 48V battery supply is step changed by up to 5.0V at terminals and 8.5V at a repeater. It was, however, decided to limit the voltage differential between batteries to be coupled to 2 volts, giving a step voltage change of 1 volt, and boost charge operating procedures were drawn up accordingly.

BATTERY CHARACTERISTICS.

Lead Acid Station Battery Operation.

Where d.c. 'no-break' supplies are a requirement the lead acid storage battery is usually used in conjunction with battery charging equipment.

All power plant systems, except the terminal equipment supplied by battery eliminators, for the system rely on storage battery operation. In the case of mains supplied stations, the principle of operation is to float charge the batteries, whilst at non main supplied stations a charge-discharge mode of operation is used.

If at all possible, it was decided to use the standard A.P.O. long life pure lead positive grid stationary cell, which had been used on float applications for many years, at stations which operated on either the float or charge-discharge system.

Although plante' type cells and special antimonial positive grid cells were considered, it was finally decided to use the pure lead positive grid type cells on the charge-discharge system after consultation with the battery manufacturers.

Since the performance and operation of lead acid batteries is basic in the design of the power supplies, it may be advisable to look at the characteristics of the lead acid battery more closely.

Charge Characteristic.

A battery on charge is not a fixed or static load. Its low ohmic resistance and the difference between the charger voltage and the back emf of the cell determine the flow of charging current. In addition the battery voltage rises with increase in state of charge. Temperature also has an effect on the characteristic, high electrolyte temperature reducing the charger voltage necessary to pass a given current.

The percent ampere hours returned to a battery versus battery voltage when charged at a constant current of 50 amperes at a temperature of 80 deg. F. is shown in Fig. 1.

It shows that the battery voltage rises slowly until it reaches the 90-95 per cent. capacity returned point, then rises steeply between about 2.3 and 2.7 volts per cell (gassing point) and then flattens out at about 2.8 volts when the battery is fully charged.

This sharp rise in voltage during which only a small part of the charge is returned, is a characteristic of the lead acid cell and does create some design and operational problems:

(i) To return the last 15 per cent. of charge in a reasonable time the charger voltage must increase by about 20 per cent.

(ii) The high charge voltage required to complete the charge may be unacceptable in so far as the equipment operating voltage is concerned.

(iii) The current charge rate should be reduced at the gassing point to above the 20 hour rate.

The charge characteristic of any battery may be determined by test, by taking a series of battery voltage readings taken at different current values at different states of charge of the battery. Such a composite charge characteristic for the A.P.O. long life pure lead positive grid 500 Ah cell is given in Fig. 2 — and is necessary in choosing a satisfactory charging method.

Fig. 2 shows also how the voltage/current characteristic or load line of

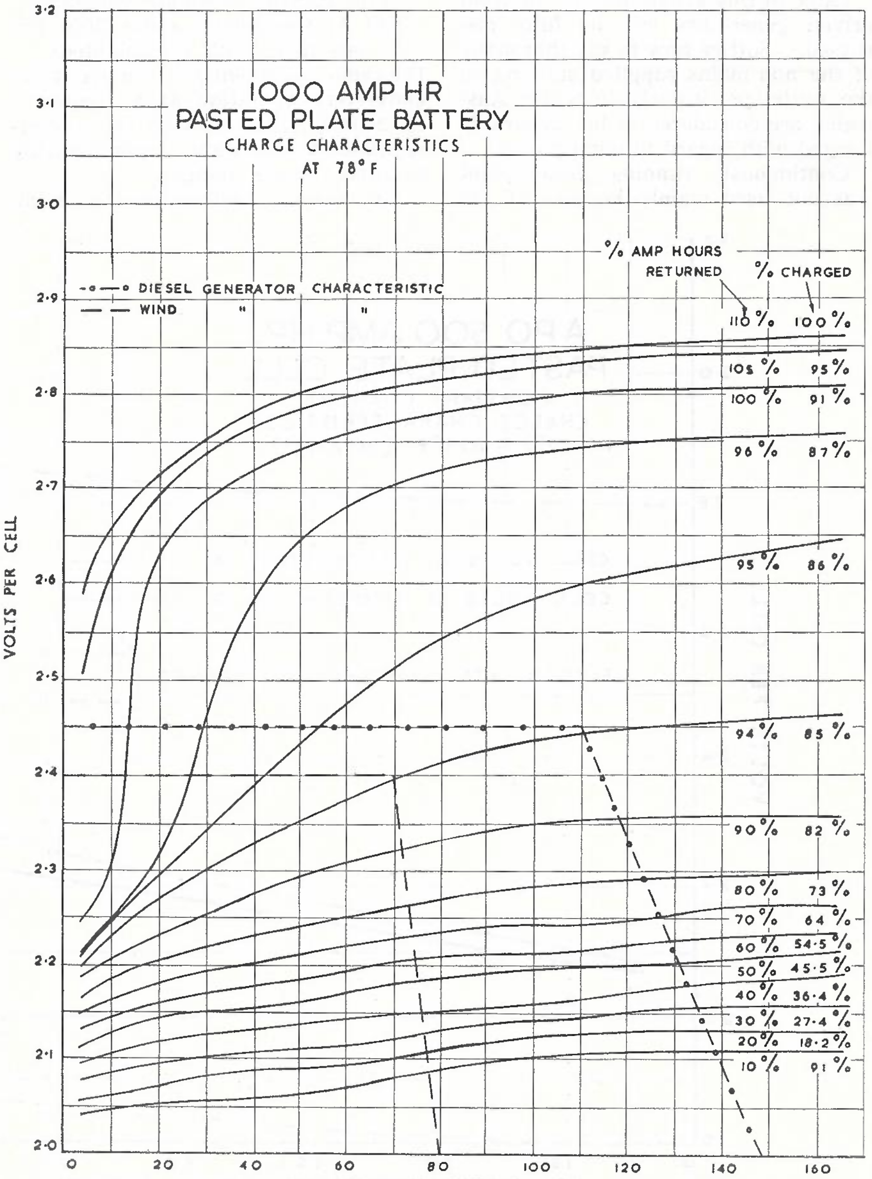


Fig. 2. — Battery Charge Characteristics.

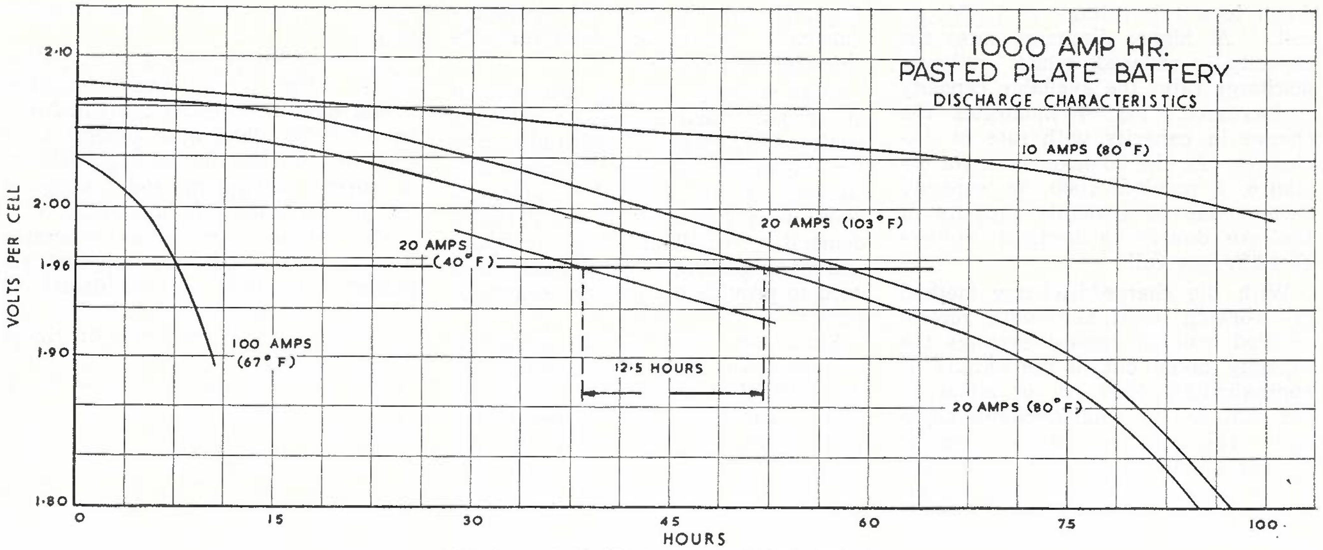


Fig. 3. — Battery Discharge Characteristic.

the charging equipment can be superimposed on the battery charge characteristic. This enables one to understand the charge cycle of both the wind generator and diesel generator while still operating the charging plant within the radio equipment voltage limits.

This generator characteristic is discussed later in this article.

Discharge Characteristics.

The discharge characteristics (Fig. 3) show the change in battery voltage against time in hours on discharge at various current discharge rates. The marked change in voltage at the high rates of discharge is in contrast to the flat characteristic when discharging at 50 or 100 hour rates.

At non mains powered repeaters where the charge/discharge system of working has been employed, it has been necessary to employ large battery reserve capacities to obtain long periods between diesel runs and to ensure maximum usage of the wind generator. For these reasons the batteries installed for the initial loads of about 24 amperes at 24 volts have capacities totalling 1000 ampere hours.

The very flat nature of the discharge curve and the change in position of the curve with electrolyte temperature changes raises problems when voltage sensing methods are used to control the recharge cycle.

From recordings of electrolyte temperature and ambient temperature it has been found that a variation in electrolyte temperature for the 500 Ah Battery from summer to winter would be between about 45 deg. F and 85 deg. F.

Battery Capacity.

The nominal rated capacity of the A.P.O. lead acid battery is always taken at the 10 hour discharge rate

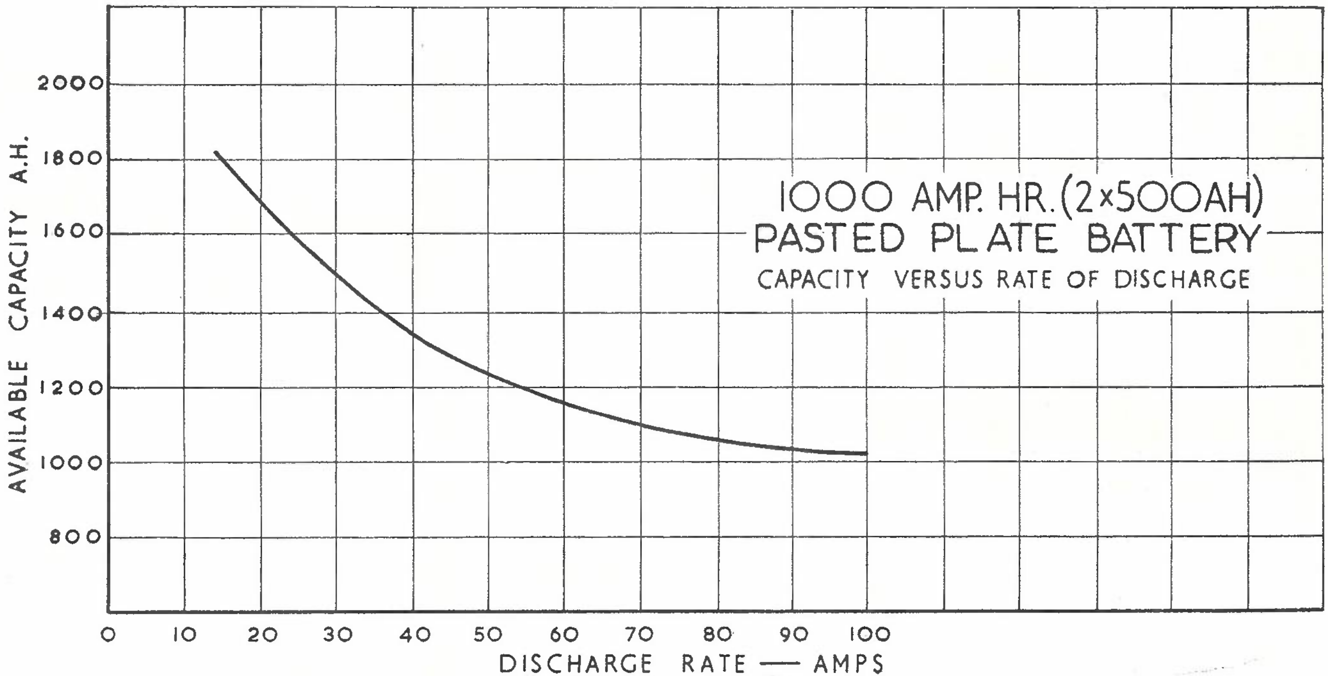


Fig. 4. — Battery Capacity.

down to a cell voltage of 1.85V per cell. At higher discharge rates the capacity is reduced, whilst at lower discharge rates the available capacity is increased. Fig. 4 illustrates the change in capacity with rate of discharge. At the 50 hour rate, for instance, a nominal 1000 Ah capacity battery has an available capacity of 1640 Ah, down to a discharge voltage of 1.85V per cell.

With the charge/discharge method of working used and with recommended voltage control settings the capacity taken out of the battery is approximately 1040 Ah or about 63 per cent. of the total available capacity. This limitation on the extent of discharge is to ensure that the battery is not worked excessively and to provide a reserve capacity of at least 24 hours in the event of diesel/generator failure.

Assuming that the diesel start control voltage sensor is set at 23.5 volts and the discharging current 25 amps, Fig. 3 shows the discharge curve for the 40 hour rate. It can be seen that the discharge time can vary by up to 14 hours from electrolyte temperature effects alone. The tolerance of the sensing devices (± 0.2 volt) could possibly add to this variation by up to another 4 hours.

Although temperature effects could have been nullified by temperature compensation on this voltage sensing device, it was decided not to do this because:

(i) A variation in the discharge time from summer to winter was acceptable provided that if the diesel failed to start there was still sufficient battery reserve (at least 24 hours).
(ii) The diesel charge/discharge cycle period was still of acceptable duration.
(iii) Complications would arise in the calibration of the four identically designed voltage alarm and control sensing devices.
(iv) For most of the year the electrolyte temperature would tend towards the higher mean and the cycle time would be of normal duration.

WIND-DRIVEN GENERATOR.

The first wind-driven generators used by the Post Office were installed in 1936 for battery charging at small rural telephone exchanges and repeater stations where wind conditions were favourable. Although up to 150 units were in operation in the post World War II period, this number declined to about 60 units in 1960 due to the extension of commercial mains throughout many rural areas.

More recently, with the introduction of transistorised equipment into repeaters for long-line and radio, and the expansion of long distance telecommunications, particularly into outback areas, there has been a renewed demand for small d.c. power supplies and wind generators have again been used to provide the primary source of power.

Since the direct current power requirement for the radio equipment on the East-West microwave system repeater was initially to be comparatively small (less than 500 watts) and was expected to stay near this level for at least five years, wind generation was considered to be a proposition. Some of the factors influencing this decision were:

(i) Previous experience with wind generators;
(ii) The availability of a low cost, locally manufactured wind generator;
(iii) Availability of comprehensive wind survey information for part of the route;
(iv) Desirability to restrict diesel engine running hours and thus reduce maintenance;
(v) Saving in fuel costs.

A wind survey conducted by the Electric Trust of South Australia (Ref. 1) had shown that winds of satisfactory velocity and duration existed in the southern regions of Australia. The winds over most of the route are predominantly south-westerly, interspersed with high velocity winds from the both western quarters. As many of the repeater stations in South Australia and a lesser number in Western Australia are close to the coast they should be favourably located in regard to this wind pattern.

Because of the ultimate load requirements (1500 watts) and the need for an uninterrupted and reliable supply on this important route, it was necessary to install a diesel generator to provide the base power load requirement for the station with the wind generator reducing the number of starts and running time of the diesel.

This would reduce maintenance, save fuel, reduce battery cycling and at times bring the battery to its fully charged condition. Because of the large number of stations and their remoteness these factors become increasingly important.

One diesel generator is provided initially, although facilities exist for the fitting of a second diesel generator and extending the battery installed capacity from 1000 to 2000 ampere hours.

Although a wind survey for each site giving mean annual wind velocities would have determined the suitability or not of installing wind generators at a particular site, the cost, availability of survey equipment and timing of the project made this impossible.

The Dunlite wind-driven generator used at the non mains supplied repeaters consists of a three-bladed, 13 ft. diameter wind mill, coupled, via a gearbox, to a 24 volt, 2kW brushless d.c. generator.

The generator and gearbox (ratio 5 : 1) are mounted as one unit on a steel tower 40 ft. high. The wind-driven generator is illustrated in Fig. 5.

Over-speeding of the windmill in high wind speeds is controlled by a centrifugal governor, which changes the blade pitch angle, thus reducing the propellor rotational speed.

A magnetic latching device prevents the action of the centrifugal governor changing the propeller pitch up to wind speeds of 30 m.p.h.

The 2kW brushless generator is basically an eight-pole three-phase alternator of the rotating field type with full wave silicon diodes in the output of stator winding to provide the required 24 volt supply. The d.c. supply for the rotating field is provided by a small a.c. exciter armature mounted on the same shaft, the output of the latter being rectified by small silicon diodes mounted on a disc which is located between the exciter armature and the rotating field. The exciter field is fed via a transistored regulator or single phase a.c. winding with full wave rectifiers providing a 48V d.c. supply.

It is important to note, however, that the regulator sensing circuit monitors the battery voltage and not the output of the wind generator. Fig. 6 shows the circuit schematic.

Wind Generator Characteristic.

As the wind generator may be required to run from no load to full load in high winds, the generator output voltage must be clamped to ensure that excessive voltages are not applied to the radio load. A voltage regulator clamps the output voltage under all conditions of load and windmill speed at 28.8 volts, being slightly lower than the setting for the diesel generator regulator (29.5V).

It has been arranged that the wind generator output will be inhibited during the diesel running period so that the stop set voltage control function would not be operated by the output

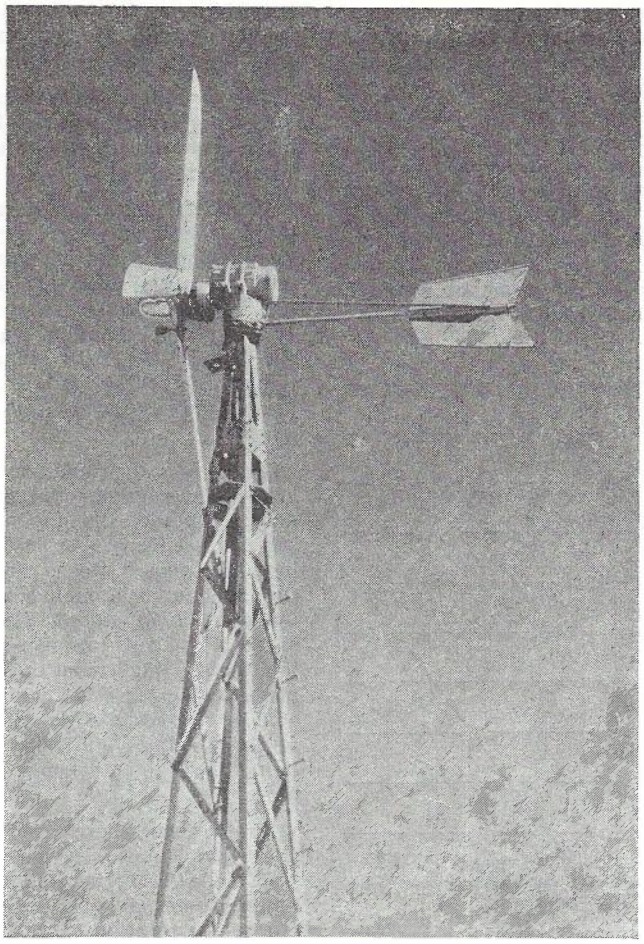


Fig. 5. — Wind Driven Generator.

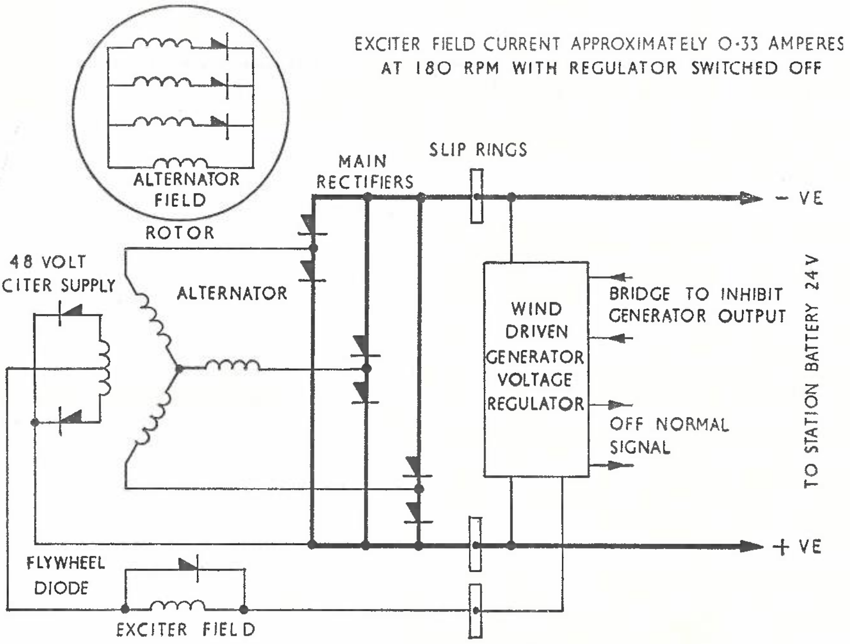


Fig. 6. — Circuit of 2kW Wind Generator.

from the wind generator, causing premature shut down of the diesel. Although the wind driven generator and diesel generator will operate satisfactorily in parallel, it was decided not to operate in this mode for the above reason and the fact that the circuitry for shut down of either generator on over-voltage would be more complicated.

Like the generator on the diesel generator, the wind generator has a substantially constant current characteristic until it reaches the set clamped voltage at which stage it has a constant voltage characteristic (Fig. 2).

The 28.8V (or 2.4V/cell) setting of the voltage regulator ensures that the battery will accept reasonable amounts of power even if the battery is near to full charge with minimal gassing and consumption of water from the electrolyte. In any event, the continuous load provided by the radio equipment will ensure that any available wind power is utilised.

Design.

Prior to 1967 the Department used standard brush type d.c. generators of 750, 1000 or 1500 watt rating. With the advent of the brushless alternator design it was decided that development of a 2kW brushless d.c. generator to extend the range of wind-driven plant and reduce maintenance was warranted.

Following limited field trials, evaluation of the performance of a 2kW wind-driven brushless generator unit was made in the main wind tunnel at the Aeronautical Research Laboratories in Melbourne by Dr. W. H. Melbourne.

The A.R.L. investigation (Ref. 2) was mainly concerned with the windmill performance. The windmill and generator units were tested in wind velocities up to 30 m.p.h. (44 ft./sec.) in the 18 ft. x 14 ft. section of the tunnel. The results of these tests showed:

(i) The windmill propeller blade system and generator torque/speed characteristics were not matched to give optimum performance.

(ii) The propeller blade design could be improved.

(iii) Feathering of the blades was occurring in the operating range.

Rather than change the gearbox ratio to match the generator torque to the optimum windmill rotational speed, the exciter field current was reduced. The overall effect was for the windmill or propeller speed to increase at all wind speeds, improving the windmill efficiency, with a corresponding inincrease in power.

The wind-driven generator is designed to operate at a cut in speed of 120 r.p.m. and to give the rated output of 2kW at 180 r.p.m.

A new blade section was designed by Dr. Melbourne and limited field trials on the new blade section showed some improvement in performance, although not marked, over the original blade section.

However, the new complex section was difficult and expensive to manufacture, compared with the existing blade, as fibreglass or cast aluminium construction was necessary to produce the complex section. In addition, the increased weight and size of the blades raised serious doubts as to the mechanical strength of the existing propeller hub assembly as well as creating problems on the centrifugal speed governing system. As only small gains in performance would be obtained and because there was little available time for further development it was decided to use the existing blade design with only minor changes.

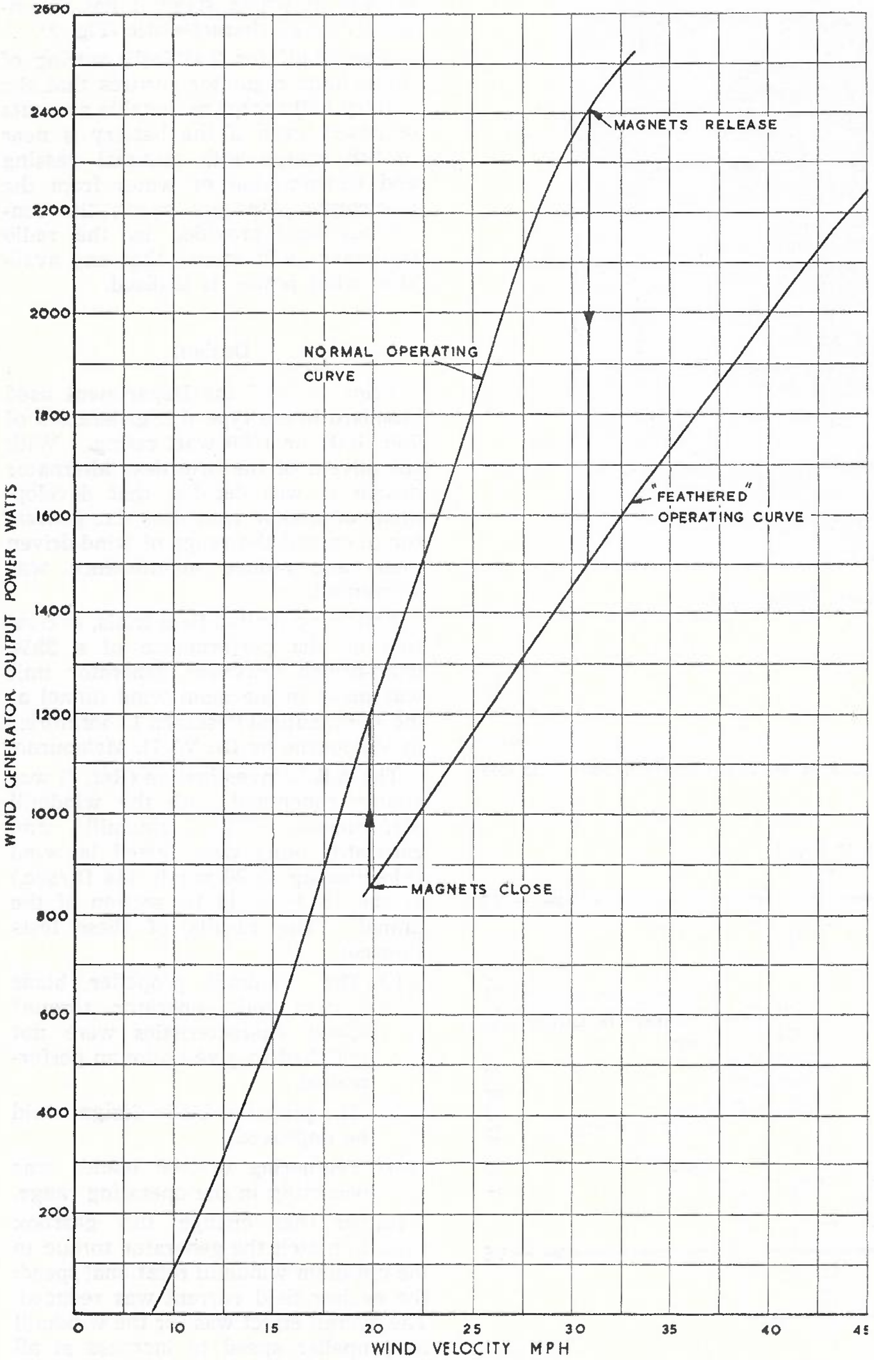


Fig. 7. — Wind Generator Characteristics.

The power output versus wind velocity performance of the 2kW wind-driven generator used on the system is illustrated in Fig. 7.

Field trials had shown that, although the propeller centrifugal speed governing system was not supposed to come into operation until full load speeds had been reached, it was found that propeller blades did feather over the whole operating range. This change in propeller blade angle dropped the available power from the wind generator.

Tightening the main spring in the centrifugal governor and changing the bob weights of the governor did not offer a satisfactory solution. While by adjustment it was possible to limit the change in propeller blade pitch, by so doing it raised the rotational speed of the mill to unacceptably high limits under high wind conditions. The blade feathering system must be capable of regulating the rotational speed of the windmill under no load conditions, as well as normal load conditions.

To overcome these problems a magnetic latching device was designed to stop blade feathering and at the same time by using a lower spring tension, reduce the rotation speeds of the mill to acceptable limits.

Fig. 8 indicates the speed governing achieved, whilst Fig. 7 shows the effect governing has on the power output curve.

DIESEL GENERATOR CHARACTERISTIC.

Any generator or charging equipment has a definite relationship between its output voltage and output current. This volt-amp or voltage characteristic (Fig. 9) chosen for the diesel generator used on non mains supplied repeaters combines an approximate constant current characteristic for the first part of the charge cycle with a constant voltage characteristic for the latter part of the cycle.

Use was made of the inherent constant current characteristic of the machine to ensure that the battery was recharged in the shortest possible time, at the same time ensuring that the diesel engine, for the greater part of the charge cycle, was running at a reasonably heavy load. Diesel engines running lightly loaded for long periods of time coke up and require more frequent maintenance.

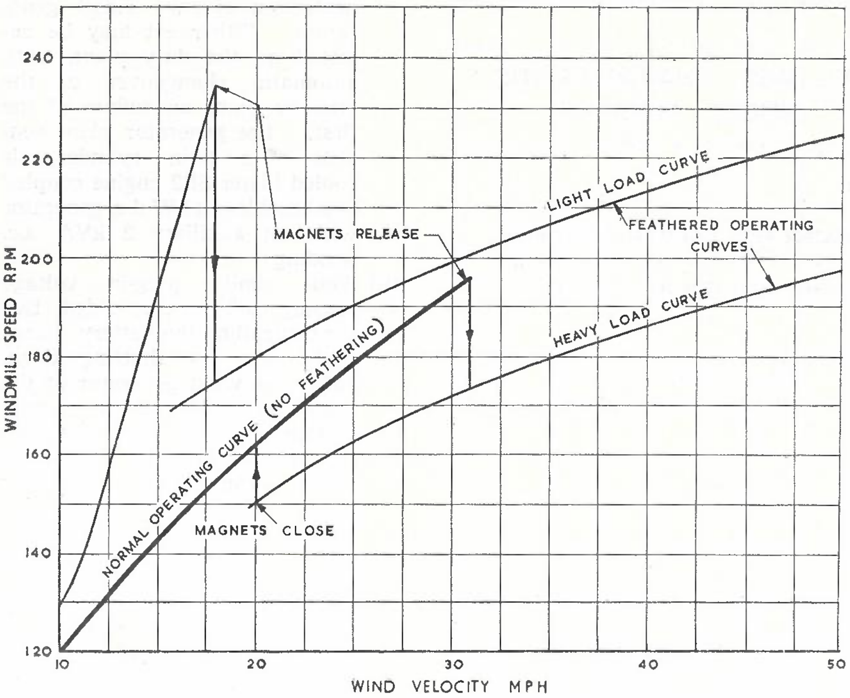


Fig. 8. — Wind Mill Speed Governing.

The changeover to the constant voltage characteristic on the latter part of the recharge cycle has the desirable effect of reducing the charging rate once the battery has reached its gassing point. At the same time it ensures, together with the high voltage diesel stop alarm, that the equipment operating voltage is not exceeded. Reduction of engine temperature prior to close down is also accomplished in the process.

It is important to note that the voltage regulator only clamps the generator voltage, only coming into play when the battery and generator voltage reach the set clamp voltage.

As the auxiliary a.c. 240V winding is wound in the same slots as the brushless d.c. generator output windings, the same field acts on both windings. The overall effect on the a.c. winding of the d.c. voltage regulator clamp is to also clamp the a.c. voltage —a very desirable feature. The a.c. output winding voltage characteristic is shown in Fig. 10.

The output current on the d.c. generator may be varied from full load (154 amps) to about 20 per cent. full load current by a rheostat (current control) in the field circuit.

A boost charge facility is incorporated which raises the clamp voltage of the voltage regulator from 29.5 to 34.2V. In this role the clamp feature has the added advantage that the 'set' boost voltage cannot be exceeded and it is possible for maintenance personnel to leave one battery on boost charge without supervision.

To ensure that the a.c. voltage would not also increase proportionately when the generator is switched to the boost position, the a.c. winding is tapped and switched to a lower voltage.

Although the full 4kW d.c. and 2 kVA a.c. may be taken simultaneously from both windings, there can be interaction between the windings. If for instance the 'current control' is set for 154 amps on the d.c. output with no a.c. load and then a.c. load is applied, there will be an equivalent power drop off on the d.c. winding.

This has no disadvantage from an operational point of view. Normally the 'current control' is set for the required d.c. current output with the normal unattended a.c. station load (fans), which is usually about 60 watts.

NON MAINS POWERED REPEATER

Some of the factors which influenced the design of the power plant for repeaters with no mains supply are:—

(i) The radio equipment would operate without degradation in performance on a direct current supply voltage of between 21.8 and 31.0 volts.

(ii) An initial load requirement of approximately 500 watts would rise to an ultimate load of 1500 watts.

(iii) The initial load would persist for approximately five years and then increase in steps of several hundred watts depending on radio bearer requirements.

(iv) All repeater stations would be unattended but could be reached on recall within 24 hours.

(v) Several maintenance centres would be established along the route and all diesel maintenance on repeater power plant, other than routine maintenance, would be carried out at these centres. Diesel generators should therefore be provided on a plug-in, plug-out basis and be easily handled by two men.

(vi) Wind survey data for a portion of the South Australian route was readily available.

(vii) A small amount of a.c. power (2kW) was required for lighting and test equipment when the station was attended. There was no requirement to meet an air conditioning load.

Fig. 11 shows the single-line schematic circuit diagram of the power plant. The initial installation consists of one diesel generator, one wind generator and two batteries each of 500 Ah capacity. Although initially only one diesel generator is installed, provision has been made for a second diesel generator and an increase of battery capacity to 2000 Ah by the addition of two extra battery banks.

Operation.

(i) In normal circumstances the two batteries, which are switchable, operate in parallel to supply the load with assistance from the wind generator.

(ii) Under favourable wind conditions the wind generator will supply the load and charge the batteries. Its transistorised regulator ensures that the generator output will not go above 28.8 volts by clamping it at this voltage.

(iii) When the wind fails, the battery will supply the load until the battery is approximately 50 per cent. discharged, at which stage the battery voltage will have dropped to 23.5 volts (initial load).

(iv) The diesel generator is automatically started by the 'engine start' voltage sensing unit. The voltage at which it is set is dependent on the station load, battery capacity, the reserve capacity

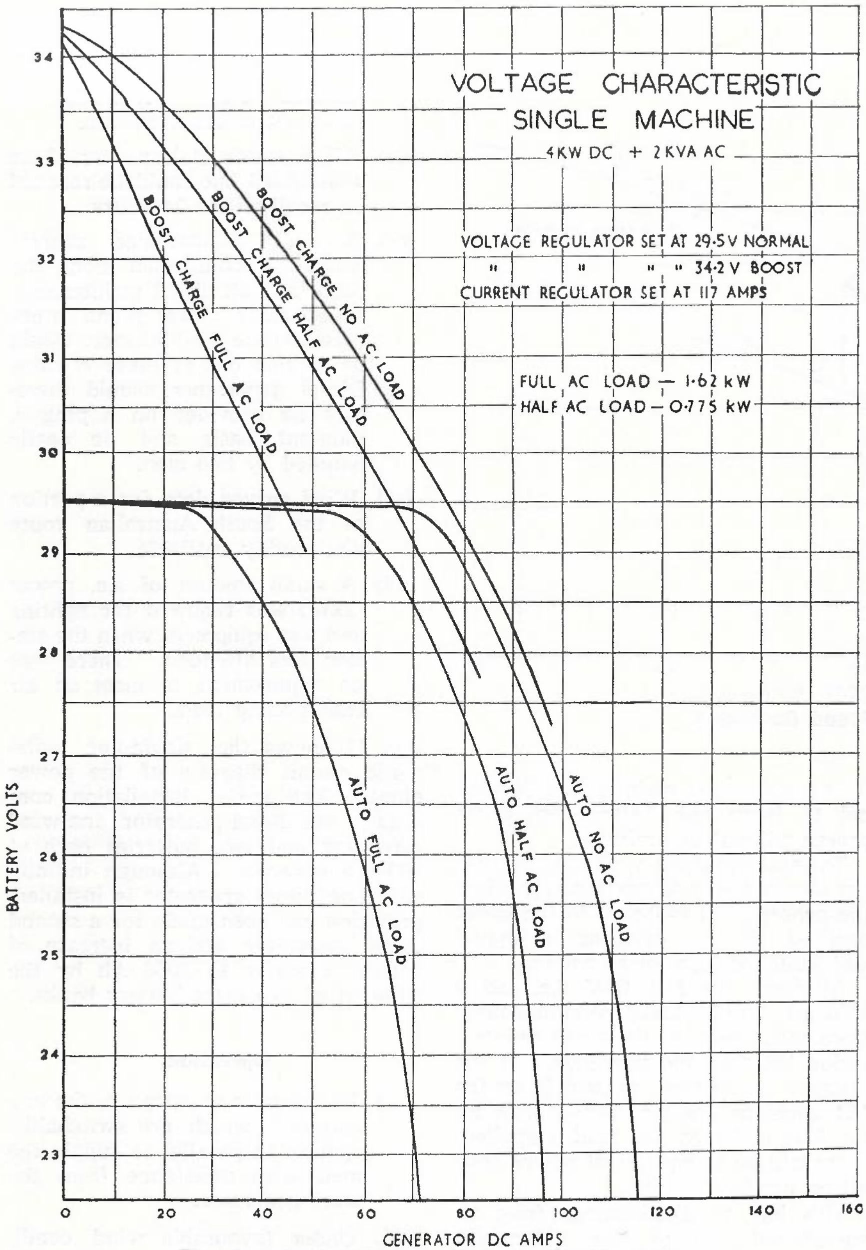


Fig. 9. — Generator D.C. Voltage Characteristic.

required in event of the diesel failing to start, and the depth beyond which the battery should not be discharged if reasonable battery life is to be expected.

(v) On the recharge cycle (see Fig. 2), the generator gives a substantially constant current output and when the battery is approximately 83 per cent. charged the stopping of the diesel generator is initiated by the 'diesel stop' voltage sensing unit which is set at 28.2 volts. This leaves capacity for some charge to be added by the wind generator. At this point a run on timer (adjustable 0-6 hours, and normally set at 2 hours) controls the final shut down of the diesel generator. During this period the charging current is limited and the charge proceeds under constant voltage control.

Using this control method, the diesel generator does not fully charge the battery, and for this reason regular boost charging will be necessary, dependent on how frequently the wind generator may fully charge the battery.

Facilities.

(i) Although initially only one diesel generator is installed, facilities are provided for the control and protection of two diesel generators. Either set may be selected as the duty plant, with automatic changeover to the standby plant on failure of the first. The generator plant consists of a twin cylinder, air cooled Lister SR2 engine coupled to a brushless 4 kW d.c. generator with an auxiliary 2 kVA a.c. winding.

(ii) Four similar plug-in voltage sensing units are provided, two for controlling the battery charge cycle, one for shutting down either the wind generator or the diesel generator if the supply voltage exceeds 30.6 volts, and the other for raising a low battery alarm. The voltage of the 'low alarm' unit is set so as to give 15 hours' reserve battery capacity. These highly accurate voltage sensing units will maintain an accuracy of ± 0.2 volts in ambients between 0 deg. C and 60 deg. C. The units are precisely calibrated in the factory, the vernier dial setting corresponding to each control and alarm setting being marked on the unit. Alternative voltage settings may be interpolated.

(iii) An important maintenance feature is that the setting knobs for the voltage regulators, current control and voltage sensing units are fitted with vernier type knobs, the accurately calibrated setting of which is marked on the unit during factory or commissioning tests. If the settings are changed for any reason they may be reset accurately to their control settings. This means that there is no need for field testing with sub-standard instruments and units may be interchanged with confidence.

(iv) A number of protective signal and alarm features are provided: Diesel plant shut down and lamp indication will occur on diesel fail to start, failure of generator, generator over-voltage, engine overheat, low oil pressure and fuel extremely low. On high voltage output from the wind generator its output is inhibited by inserting resistance in its field circuit. Failure of either battery fuse, diesel generator output fuse, filter fuse or load fuses will give an alarm. An 'off normal' alarm is given if any of the selector or control switches are not left in their normal position.

(v) Battery volts high, battery volts low, urgent power alarm, fuel low, generator on and off normal alarm conditions can be extended over the radio supervisory system.

(vi) Provision has been made for remote starting and stopping of the diesel generator from control stations and remote resetting of alarms. The main function for the remote start facility is to allow pre-charging of station batteries prior to a maintenance visit for battery boost charging purposes. This will save many hours at the station.

(vii) Selector switches in the diesel generator, wind generator output and battery circuits provide for connection to the normal load busbar or to a boost busbar. Generator testing and boost charging may be carried out on one battery, while the other is connected to the radio load.

(viii) An emergency supply selector switch allows for bypassing of cubicle components and connection of the load to an emergency d.c. socket which is mounted on the outside of the shelter.

(ix) Metering facilities are provided

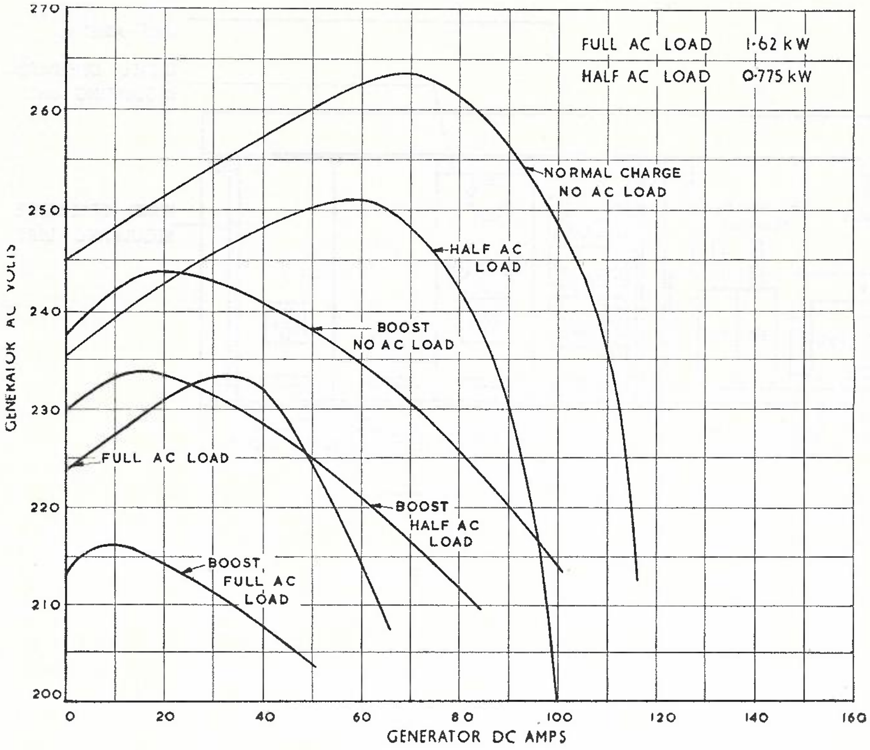


Fig. 10. — Generator A.C. Voltage Characteristic.

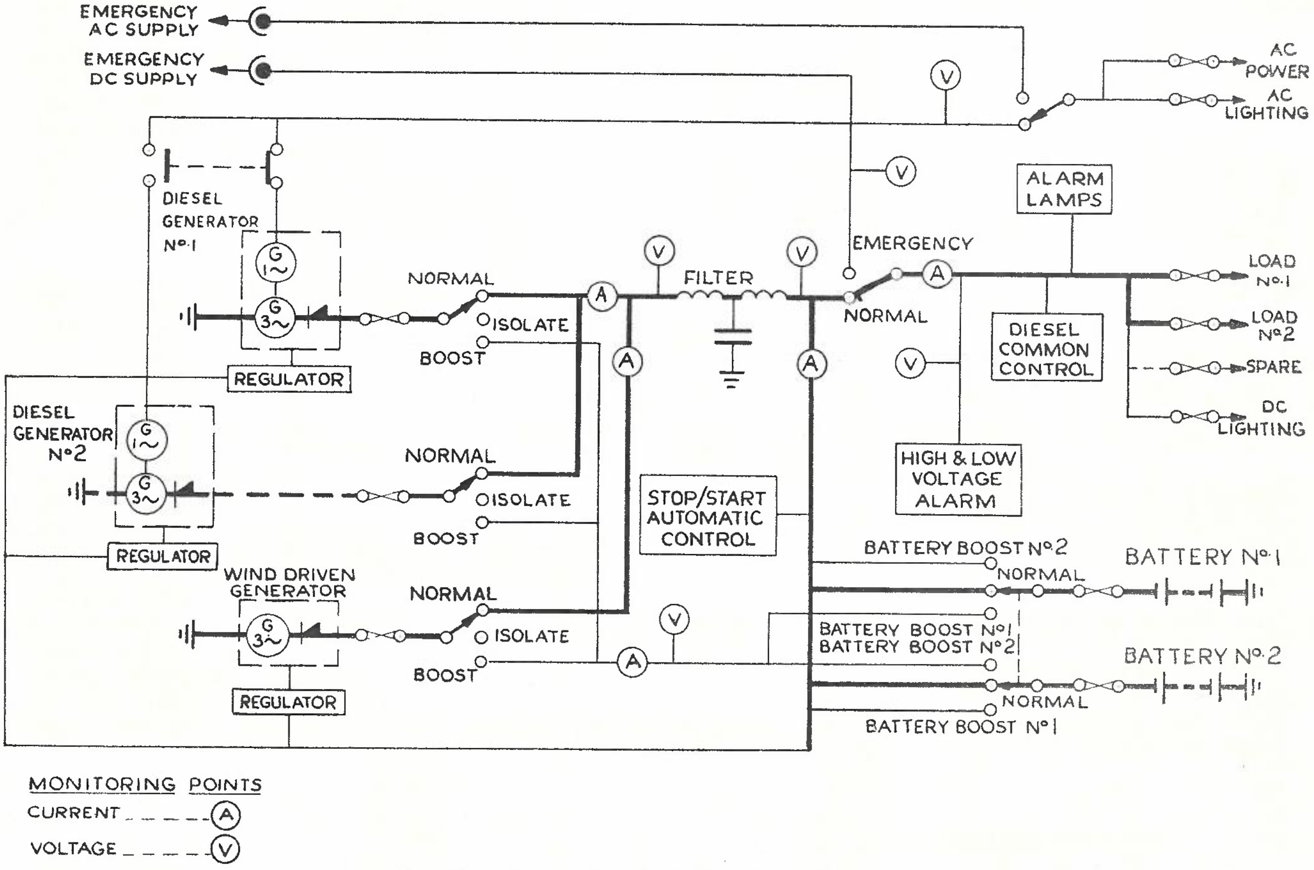
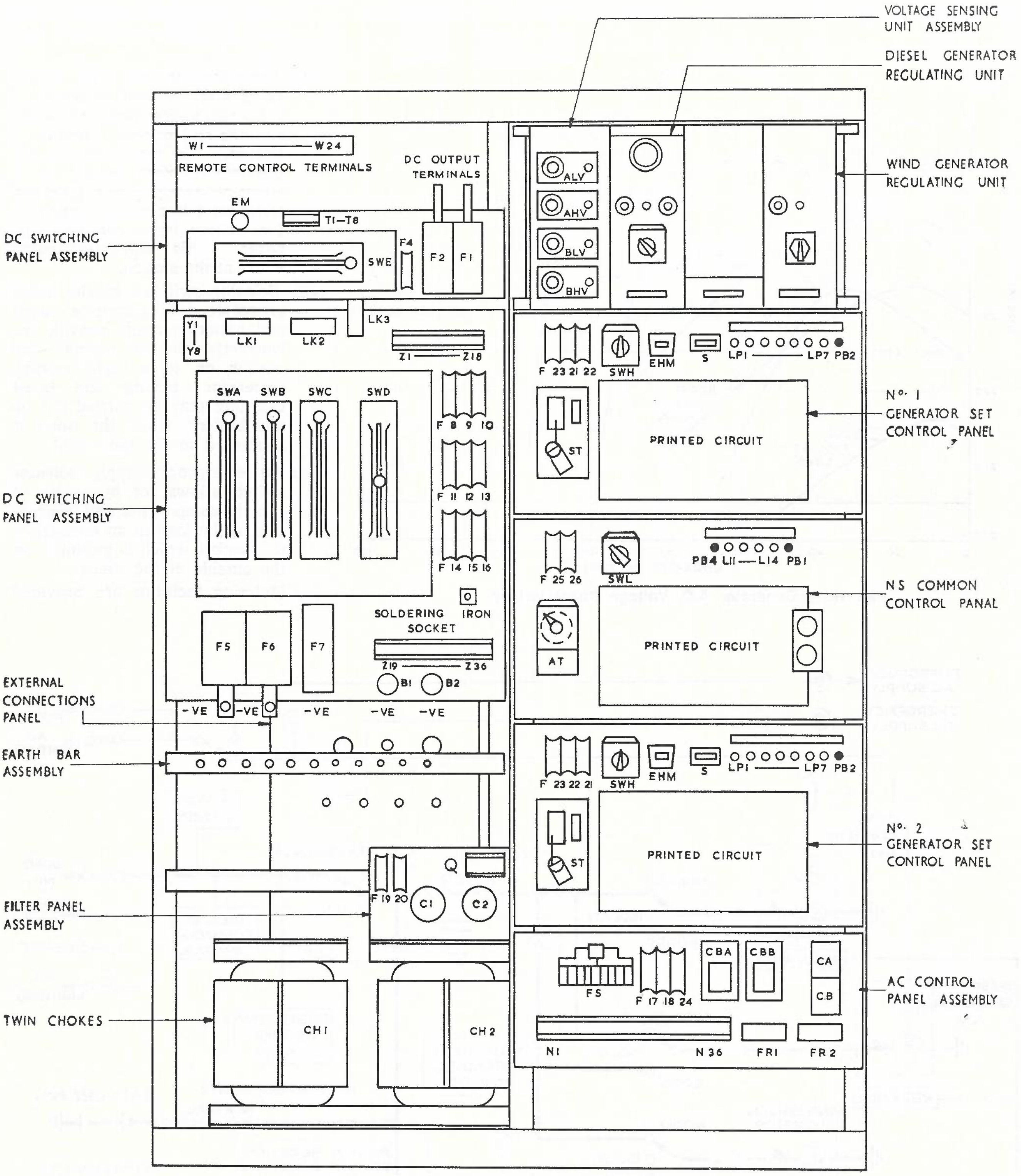


Fig. 11. — Power Circuit of Non Mains Repeater.



INTERIOR CUBICLE ASSEMBLY AS VIEWED 6'-0" HIGH 4'-0" WIDE

Fig. 12. — Power Cubicle for Non Mains Repeater.

for monitoring the output voltage and current of generators, batteries and the load and boost busbar.

(x) A 2 kVA 240V a.c. auxiliary winding on the brushless d.c. generator provides a.c. power for shelter lighting, power and radio test equipment as required. The diesel generator may be switched on at any time without affecting the automatic charging arrangement because the voltage regulator on the d.c. generator ensures that both the d.c. and a.c. voltage is within limits under any load conditions.

A diagram of the cubicle interior

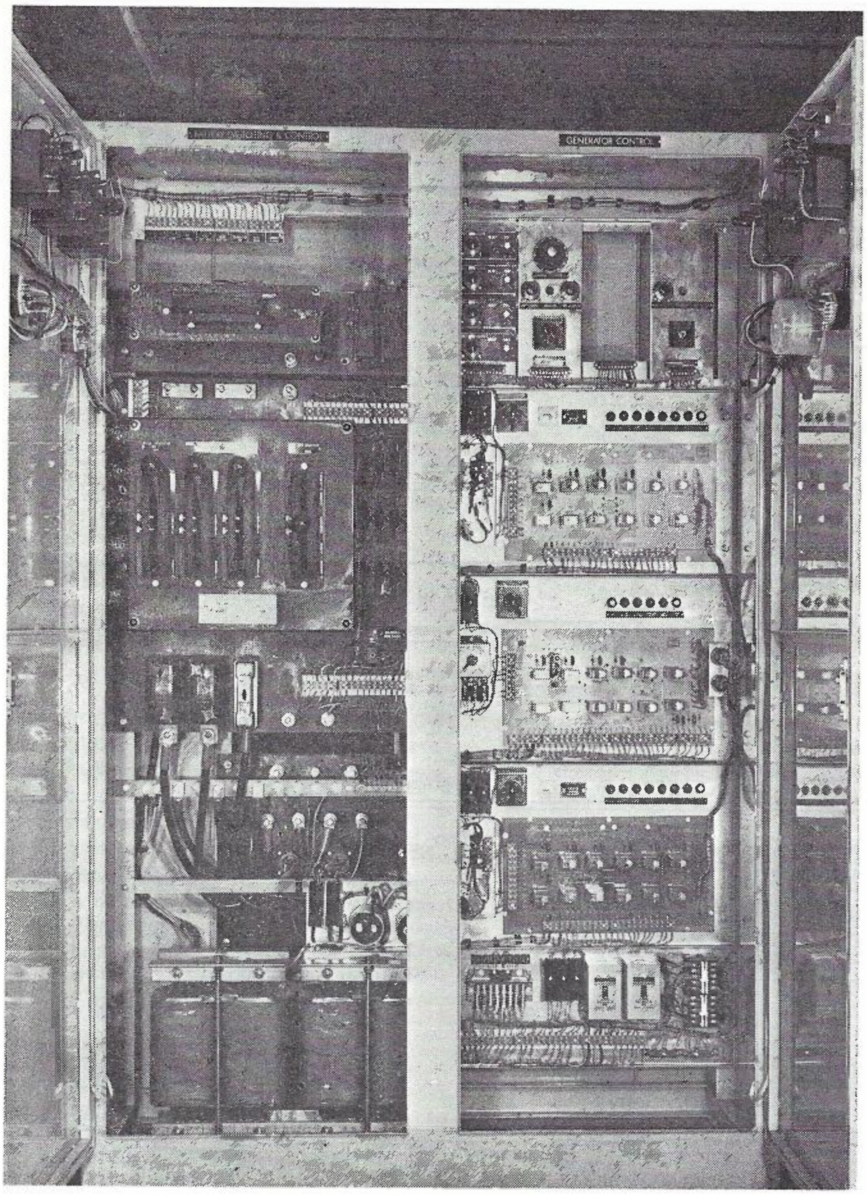


Fig. 13. — Interior View of Control Cubicle for Non Mains Repeater.

showing the assembly of the control gear is shown in Fig. 12, while Fig. 13 illustrates the cubicle by a photo.

Construction and Layout of Plant.

The equipment shelters on the above route provide a small 8 ft. x 10 ft. power room for housing the batteries and control cubicle, while the diesel generator plant is installed under the shade screen. Fig. 14 shows a plan of the installation.

The skid-mounted diesel generator set (Fig. 15) is supported on a steel stand, which also houses the 165-gallon bulk fuel tank. Provision has been made for winching the diesel generator set to and from the stand via a transfer bridge on to a specially constructed transporting trailer. This is to enable quick replacement of faulty sets and for other than routine diesel maintenance to be carried out at the maintenance centres.

All the control gear, including the large filter chokes which are necessary to reduce the ripple in the output from both the brushless wind generator and the diesel generator, is housed in a folded sheet metal cubicle 6 ft. high and 4 ft. wide. The batteries are mounted on two tier wooden stands. When the diesel generator is operating, a.c. operated fans ventilate the power room.

COMMERCIAL MAINS SUPPLIED STATIONS.

For these stations the power plant provided is similar to existing designs for radio telephone stations requiring d.c. power. The plant consists of:

(i) A d.c. no-break suite consisting of two closely regulated rectifiers and a d.c. distribution and battery switching cubicle.

(ii) An automatically controlled diesel/alternator set.

A typical suite of cubicles is shown in Fig. 16. Two batteries of 12 cells each are provided, floating at 2.17 volts per cell during the normal operating condition, with dividing facilities for boost charging. Either rectifier may be selected as the duty plant with the other as the standby. If the duty rectifier fails due to high or low output, overload, diode or fuse failure it is automatically disconnected and the standby unit switched on.

The rectifiers will maintain their set output voltage of 26.0 volts to within ± 0.5 volt for all loads from 10 per cent. up to full rated load for supply voltages between +10 per cent. and -17 per cent. of nominal. If required both rectifiers may be switched to operate in parallel and will share the load within ± 5 per cent. On failure of one unit the other continues to supply the load.

WIND SURVEY AND COMPUTER PROGRAMME.

Two wind survey stations were set up along the East/West route, one at Emu Hill near Kalgoorlie and one at Nullarbor, to obtain mean hourly wind velocities. The information from these stations, although as yet incomplete, has been used with data from the survey made by the Electric Trust of South Australia in a computer programme to ascertain the probable performance of the wind-driven generators.

The computer programme was designed to give information on the state of charge of the station battery over the period, the number of times the battery would discharge to a point where the diesel was required to start and how often the battery would reach the fully charged condition.

Because of the empirical nature of the data (wind velocities, wind generator output characteristic, battery charge and discharge characteristics, for which there is no simple mathematical expression), the Research Sec-

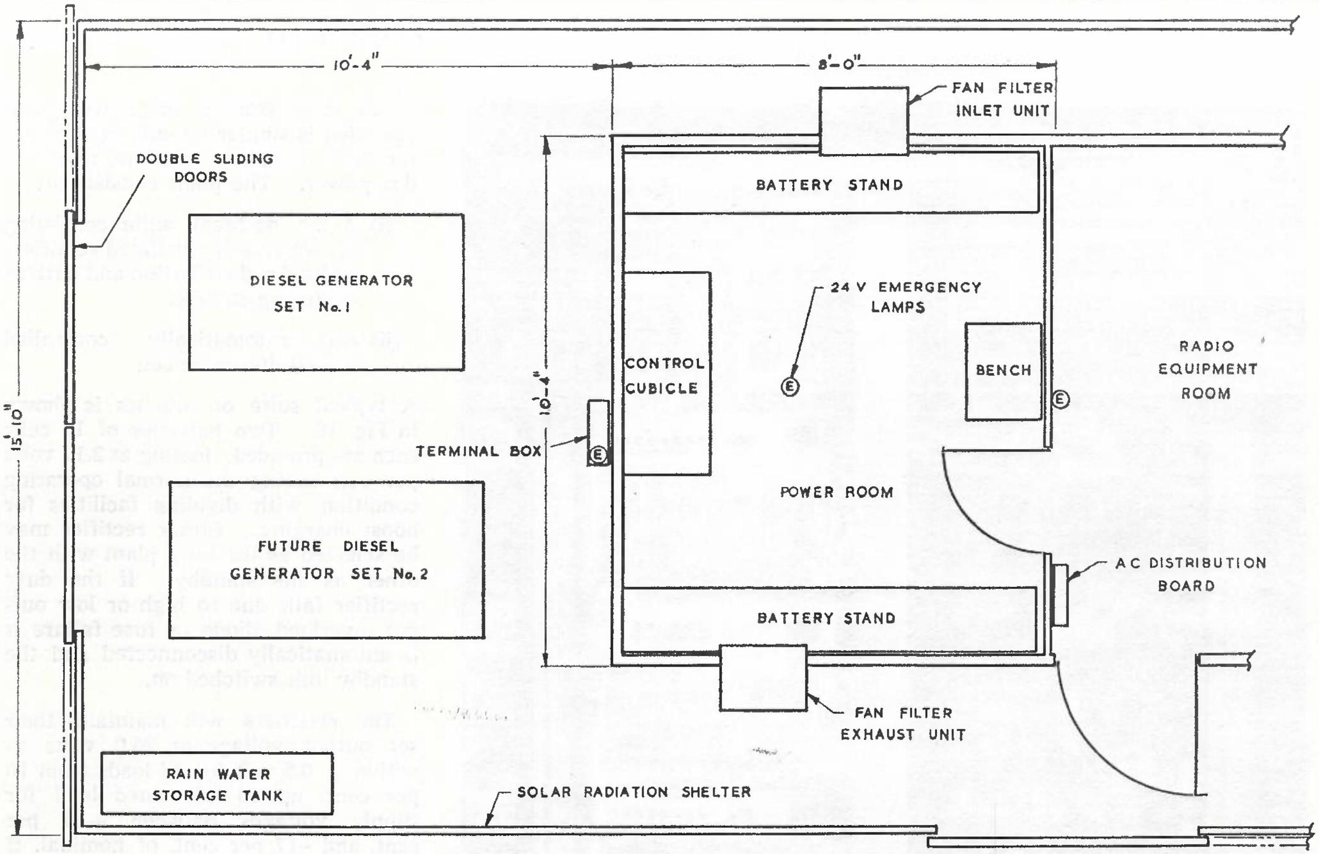


Fig. 14. — Plan of Power Installation at Non Mains Repeater.

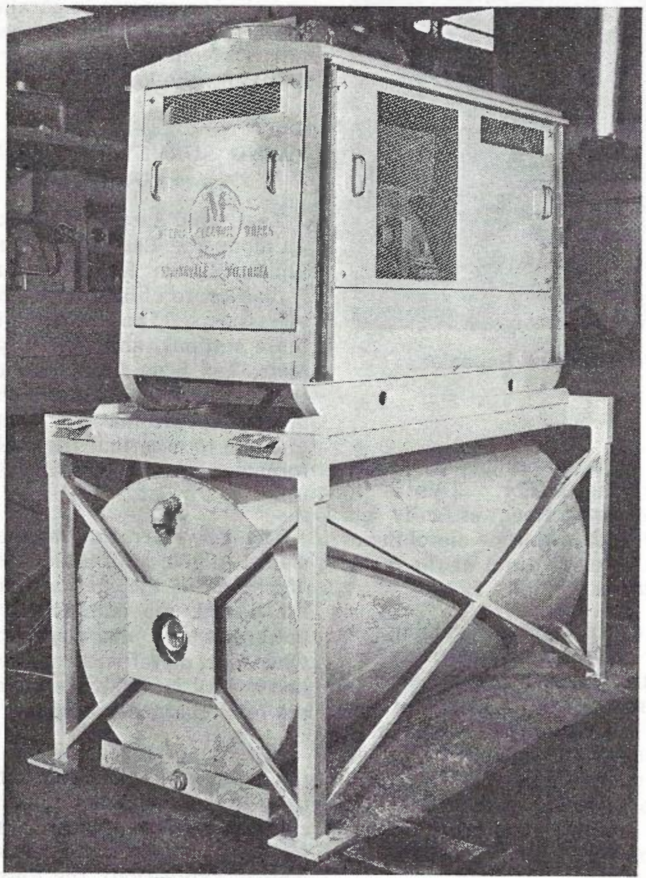


Fig. 15 — Diesel Generator Set.

tion decided to use an incremental technique in the solution where the various quantities are updated at hourly intervals. The required information can be obtained by continuously monitoring the solution.

The charge increment for the battery was computed as follows:—

Charge increment $= \Delta C = W - L + D$

Where $W =$ Charge supplied by the wind generator

$L =$ Charge lost due to loading

$D =$ Charge supplied by the diesel generator.

The time increment was taken as one hour since the data for mean wind velocity was based on hourly intervals. As the available output of the wind generator could not necessarily be absorbed by the battery above about 82 per cent. charge, a correction factor was used.

For a load of 500 watts the computer results showed that for a site with mean annual wind speeds of 11.21 m.p.h., the diesel would start 38 times in one year, and recharge the battery to a full charge condition six times. This compares with actual field results for the same period of 24 starts. The

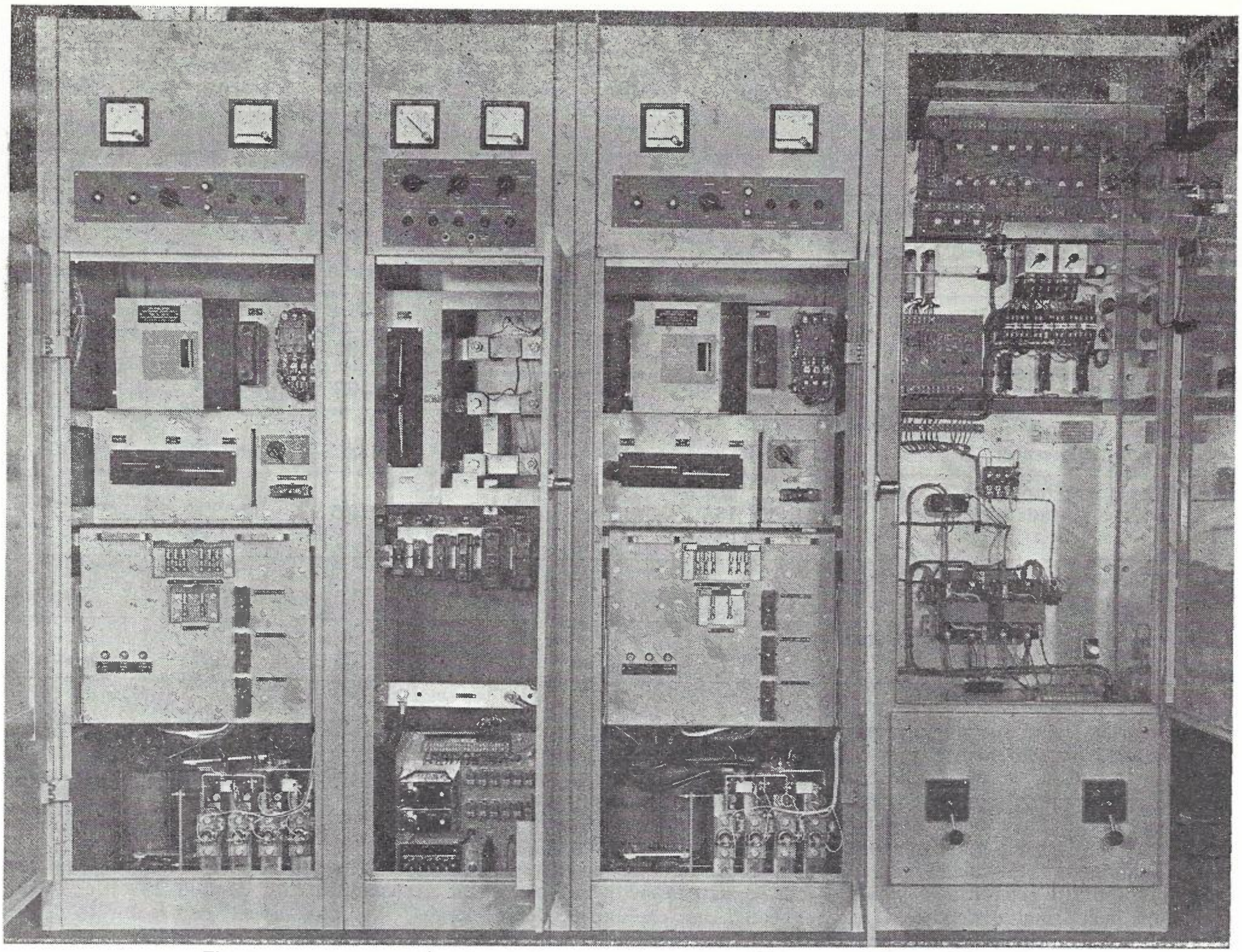


Fig. 16. — Rectifier Suite and Diesel Control Cubicle for Mains Supplied Repeater.

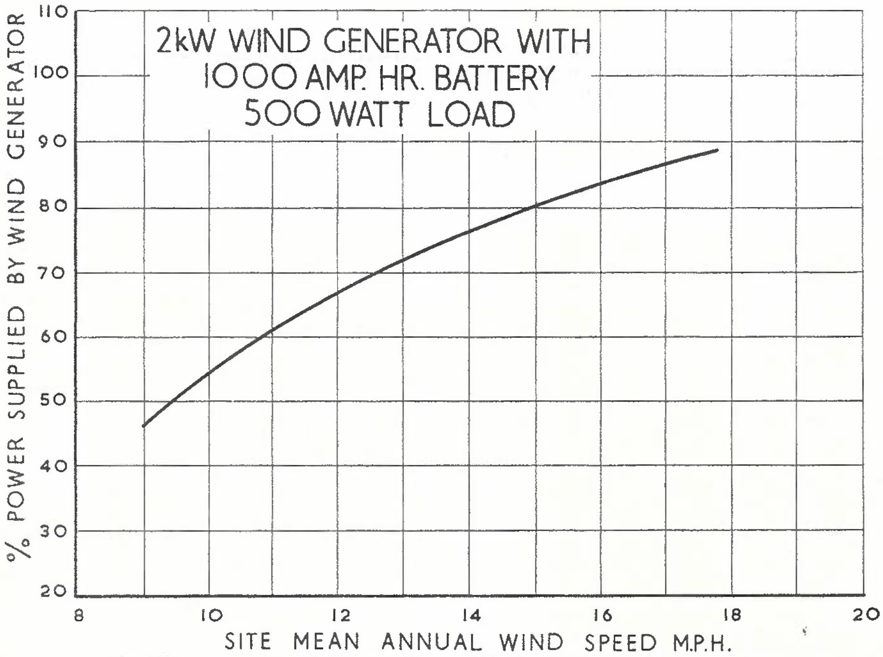


Fig. 17. — Predicted Power From Single 2kW Wind Generator.

discrepancy is probably due to an error in the estimate for the actual battery capacity available during the discharge cycle.

The predicted power available from a single wind generator at various site mean annual wind speeds is shown in Fig. 17.

TEST RESULTS.

Records for the Broadbent Hill repeater, located near Whyalla, in South Australia, where special recording equipment has been installed, shows that about 66 per cent. of the power requirement is being met by the wind-driven generator.

Performance data for the repeater at Broadbent Hill is summarised in Table 2. The figures were obtained on the working radio system, where the radio load is approximately 500 watts, the wind generator capacity 2kW and the installed battery capacity 1000 ampere hours.

TABLE 2 — BROADBENT HILL, SOUTH AUSTRALIA — POWER PLANT PERFORMANCE SUMMARY

Observation.	November 1969	December 1969	January, 1970	February 1970	March 1970	Totals
Total number of days in period	30	33	31	28	31	153
Number of starts by diesel	9	9	7	8	8	41
Kilowatt hours delivered by diesel	118	145	127.5	122	122	634.5
Kilowatt hours delivered by wind generator.	243.0	249.5	244.5	214.0	250.0	1201
Hours run by diesel	49	52	47.2	45.4	45.3	238.9
Kilowatt hours consumed in load	359.5	394.5	372	336	372	1834
Average wind speed (m.p.h.)	—	11.3	12.2	10.1	10.9	11.1
Percentage of total power delivered by wind generator	67.6%	64%	65.7%	63.6%	67.2%	65.6%
Wind generator ran voltage regulated for these periods in hours	4, 17, 18, 5, 11	17	5, 38, 10, 12.5	10.5	2.5, 10, 4, 2	166.5
Average time between diesel starts (days)	2.5	3.66	4.4	3.5	2.4	3.3
Longest time between diesel starts (days)	6.5	7.3	7.3	7.8	6.7	—

From earlier wind survey information obtained from the Electricity Trust of South Australia it was expected that the annual mean wind speed for this area would have been slightly higher than the 11.1 m.p.h. mean speed so far obtained. However, annual variations and site conditions would explain the fairly small difference. Considering the mean annual wind speed recorded the power output from the wind generator is very satisfactory.

The charge/discharge mode of operation of the non mains powered repeaters is proving satisfactory and performance of the plant is in accordance with the design concept.

CONCLUSION.

An overall survey has been given of the design features of the power plant for the various types of radio station with specific attention being paid to the non mains powered repeater stations where primary power is generated by diesel generators and wind-driven generators. The performance of the wind-driven generators will be watched with interest, but it is expected that the unprecedented large growth on this route will require a sudden increase in the power requirements, thus reducing the effectiveness of the wind generator.

The power equipment has been designed and manufactured in Australia, the equipment and installation being of high standard in all respects.

Although the plant has been designed to keep maintenance and maintenance visits to a minimum, it must be recognised that power plant, performing a primary generating function, demands conscientious and skilled maintenance.

ACKNOWLEDGMENTS.

The power plant was supplied and installed by McColl Electric Works Pty. Ltd., as sub-contractor to G.E.C. A.E.I. (Aust.) Pty. Ltd.

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SERVICE ASPECTS OF THE RADIO SYSTEM

*A. G. ELLIS B.Sc., A.R.M.I.T., M.I.R.E.E.(Aust.)**

INTRODUCTION

Within the Australian Post Office, the service responsibility with respect to radiocommunication systems includes operations, performance, reliability and availability, and a number of aspects of staffing and administration.

This paper attempts to link some of these responsibilities with the actual decisions and actions taken for the first completely solid state microwave system installed by the Department.

GENERAL PHILOSOPHY

Systems previously installed by the Department have had the benefit of the ready availability of staff and transport and, for the most part, a proven method of maintenance oriented towards the valved systems. With this project, these factors were either not present or did not apply, so that a review of the basic service needs of the later generation solid state systems was needed.

The most impelling feature offered by the proposed equipment was its ability to separate into maintenance units (a transmitter, a receiver and a power supply unit) which presented standardized interface conditions to neighbouring units. This standardization meant that a direct interchange of units would be possible without causing any measurable effect in the associated bearer.

The resulting philosophy adopted for this system had three major concepts:—

(i) Replacement of positively identified units in the field without further adjustment.
(ii) Unit repair at specially equipped and staffed field repair centres.
(iii) Control by specialist personnel.

The application of these concepts was developed as follows:—

Field Unit Replacement of Positively Identified Units: Action here requires a determination with a high level of confidence of the type and location of the unit requiring replacement, followed by a direct, simple plug-in replacement of the faulty unit. This predetermined knowledge of the plug-in required was planned to be available from an extensive supervisory readout located at each of the control centres.

Once the type and location of the faulty unit was known, successful fault clearance became then dependent only upon the availability of spares. Because the cost of these spares represented a significant portion of the cost of the installed equipment, the provision was minimised to that required to ensure that the replacement time was, for all practical purposes, never increased due to a unit shortage. It then followed that such a minimum provision could only be effective if the spares were held in closely co-ordinated centres which were specially equipped and staffed to finalise all types of repairs.

Unit Repair at Specially Equipped and Staffed Repair Centres: The entire route reliability and performance, and the ability of the proposed service organisation to meet the continued demands of the system was seen as being vitally dependent upon the quality of the output from the repair centres. It was regarded as essential that each faulty unit be brought back as closely as practicable to 'line-up' characteristics over the entire operational temperature range before it was returned into the working system.

In order to achieve this, test equipment and spare units were provided for each repair centre at a direct cost of approximately one quarter of one million dollars. Appropriate staffing positions were raised for the repair centres and special training courses arranged.

Maintenance Control: The Maintenance Control function includes responsibility over a section of the route for the day to day co-ordination of fault clearance, operational switching and the regular bearer performance checks. In order to ensure the long term existence of these special abilities, the staff needed were to be permanently based at the Maintenance Control sites, although it was expected that additional country staff would assist with end to end bearer measurements.

Because of this continuing concentration of skill, the possible need (as seen later) to relate spares usage to repair effort, and the availability at first hand of detailed fault effects, Maintenance Control was planned to encompass the repair function, both centres being located at the same site.

Radio Line Section Control: Apart from the day to day activities within the Maintenance Control Sections, there was a need for the control of route performance (Northam to Port Pirie), and in particular for the overall control of the 'annual' line-up, a technique used to re-establish overall system performance margins which existed at the time of commissioning. In order to allow this control to be effectively established, the system supervisory was extended to the two capital city terminals, Mt. Yokine and Mt. Bonython, each of which, being line section control for a number of routes, was to be staffed on a 24 hour a day basis.

The need for overall control during system performance measurements had long been recognized. The annual 'line-up' also required this overall specialist control for the following reasons:

(i) Although the Maintenance Control staff would become skilled in the repair of faulty units, they were not expected to have the opportunity to apply the integrating techniques of system line-up until this infrequent period arrived. Depending upon the long term stability and reliability of the system, the period could extend to two or three years so that a new learning-period would be necessary on each occasion for staff not immersed in this type of work.

(ii) The deterioration of margin within the maintenance units was a long term effect which could not be easily seen on a day to day or even a month to month basis within a single bearer.

It came about because the specication for day to day maintenance reached the limits set by today's 'state of the art'. Accordingly the effects would be best detected and analysed from a long term comparison of bearer performance from all the Maintenance Sections.

(iii) The techniques required during an annual inspection included the use of test equipment which had only been provided on a 'state' basis rather than on a system basis, and in some cases, e.g. waveguide sweep measurement, a great deal of experience was needed before aberrations which masked the result could be recognized and eliminated.

Additional test racks and test equipment were therefore provided for the two line section control stations (Yokine and Bonython) so that they could extend their expertise and so effectively control the 'annual' line-up program.

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* Mr. Ellis is Engineer, Class 3, Radio Section, Headquarters.

PROVISION OF SPARE MAINTENANCE UNITS

General

The spares provision calculated below refers only to quantities required to meet the day to day operational needs of the system. Because it was essential that the 'operational' spares were not used for other than the clearance of actual faults in the field, additional spares were provided for other purposes, i.e. one bay of each type located at both Perth and Adelaide to be used for special investigations and training, and an additional RF bay and baseband bay for each Maintenance Control station so that replacement units could be checked prior to being despatched to the field.

Bearer Availability

In calculating the guaranteed bearer availability, the manufacturer used as a basic reference the average availability published by the B.P.O. for English valved systems and then assumed that their solid state equipment would have an availability at least one order greater. That is the contractor assumed that the number of outages causing a complete bearer failure would be one order smaller than the figure of 0.7 per annum per bearer per site quoted by the B.P.O., i.e. 0.07, a figure which was then doubled to give the guaranteed index of 0.14.

In developing the number of spare units required, an allowance was needed to cover those bearer faults which did not cause outages but which required maintenance attention to rectify a degraded performance. An analysis of the SEACOM system between Brisbane and Cairns in Queensland, suggested that the ratio of degradation faults to outage faults was not more than 3:1. Thus the total number of visits per site per annum for a 1 + 1 two-way system was estimated at 0.14 x 4 x 4 = 2.2. As far as the radio equipment was concerned then, and taking into account the fact that the above figures represented upper limits, a value of 2 was assumed.

Unit Failure Rates

Dealing with the bearer-repeater (see Fig. 1), the main units were a receiver, transmitter and a power supply unit. Because the transmitter and receiver units were frequency dependent, a set of spares required eight units, one for each of the eight frequencies involved. Further, as they contained the greatest complexity, the receivers and transmitters were allowed the highest fault liability, so that in a bearer-repeater the overall failure rate was apportioned giving 40% of the failures to each of the transmitter and receiver units, and 20% to the power units.

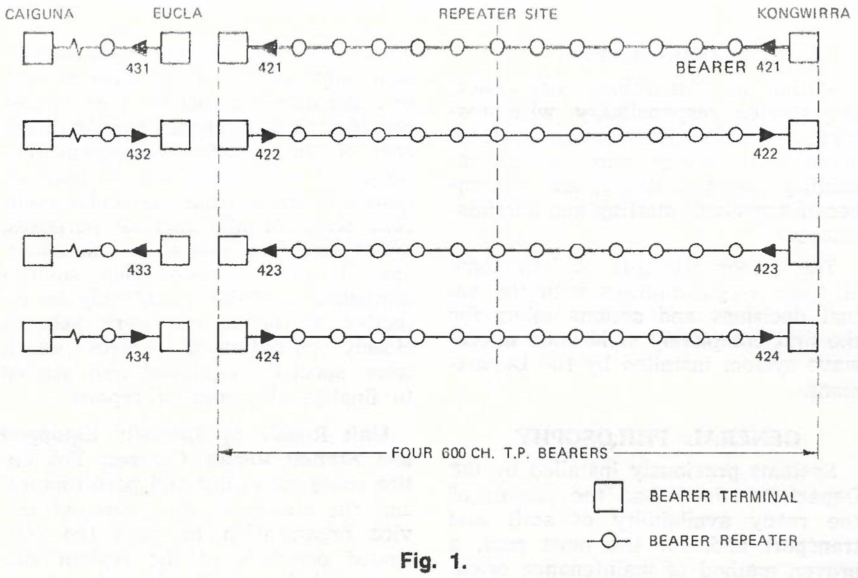

Fig. 1.

As installed, the equipment at each site consisted of four of each transmitter, receiver and power units, which as seen previously were assumed to have a total failure-rate of 2 units per annum per site. Now, with the above weighting, the failure rates will be: transmitter or receiver unit failure rate

$$= 0.4 \text{ of } \frac{2}{4}$$

$$= 0.2 \text{ failures p.a. per unit.}$$

and the power supply unit will have a failure rate

$$= 0.2 \text{ of } \frac{2}{4}$$

$$= 0.1 \text{ units p.a.}$$

Unit Quantities

Assuming that the maintenance units fail at random, e.g. there is no correlation between environmental effects and failure rates and that the design has no basic weakness, the probability of having exactly n simultaneous failures (Pn), is given by the Binominal distribution:

$$P_n = F^n (1-F)^{q-n} \frac{q!}{n!\,(q-n)!}$$

where q is the population and F is the probability of 1 failure in a population of 1. Since the total of all the probabilities must be equal to 1, then the probability of having more than n failures is given by

$$1 - \sum_{0}^{n} P_n$$

Using the values of failure rate given above, i.e. Tx or Rx, 0.2 failures per unit p.a. and PSU 0.1 failures per unit p.a., then for a repair time of 1 week, the probability of a fault occurring in any week is given by:—

$$F_{RX} = F_{TX} = 0.2 \times \frac{1}{52} = 0.004$$

$$F_{psu} = 0.1 \times \frac{1}{52} = 0\ 002$$

Assuming that the criterion for the quantities of spares required is that the probability of failing to meet a demand (i.e. $1 - \Sigma$ Pn) should be insignificantly small, then the spares required for each State as developed using the Binominal distribution were found to be as in Table 1. (The Pois-

TABLE 1 TELEPHONY

Number of Sets of spares (8 per set)				No. of Spare P.S.U.	
Tx		Rx			
W.A.	S.A.	W.A.	S.A.	W.A.	S.A.
2	2	2	2	3	3

son distribution also applies here — see Appendix 1.)

In the case of P.S.U., since the units are relatively inexpensive, 6 spares were provided for each State to give increased flexibility at very little cost.

TRAINING

With such an extensive provision of new techniques and responsibilities, a new concept of field training was developed in conjunction with the Contractor. Two radio training courses were held during and after the installation period, with the classes being located at appropriate sites along the route.

The aims of the first course were:

(i) to prepare Departmental staff training with the contractor installation team so that they could immediately carry out duties assigned to them, and

(ii) to train Departmental inspection staff in the techniques of section and in-station measurements.

The second course had three aims:

(i) to train the staff of the maintenance control centres in the specialist diagnostic techniques available for the different unit types,

(ii) to teach the Radio Line Section and Radio Maintenance Control staff the system design concepts with emphasis on system switching, system supervisory, the control of baseband sections, and the control and testing of the system as a whole, and

(iii) to train staff for replacement of people then unavailable from Course 1.

Each course was planned to run for four weeks and to train some fifteen technical officers at each.

TRANSIT CASES

The unit replacement philosophy placed a new emphasis on the need for safe transport between repair centres and the distance sites. Although the units themselves had been developed to eliminate resonances and to some extent to withstand shock, there was still a need to minimise both vibration and shock to ensure that the overall system performance was maintainable throughout the 20 or 30 years of its life.

Since road transport would be involved in almost all unit movements, early design efforts were directed towards developing a transit case which could be rigidly mounted on the floor of the usual station wagon. The forces acting upon the transit case then fall into three main groups, one being generated by the relatively rapid vibration of the wheels and undercarriage (unsprung resonance about 5-8 Hz), another from the chassis as a whole (the sprung resonance of 1-2 Hz) and a group of body cavity resonances of about 100 Hz.

The prototype transit case shown in Fig. 2 consisted of an isolating platform which could carry an assortment of units by means of an in-built ladder and strapping arrangement. Isolation depended upon a six inch thickness of soft polyurethane foam, a material which has a long flat plateau relationship between stress and strain (Ref. 1) and so effectively provided a spring having a long period. Forces due to the free motion of the transit case were to be eliminated by the rigid mounting.

In any spring system, the degree of isolation obtained is vitally dependent upon the relationship between the driving force frequency and the natural frequency of the system. The analogy of a series electrical circuit holds were the output effect is Q times greater than the input at resonance. In order to avoid this multiplication between cause and effect, the prototype design aimed at a resonance in the gap 2-5Hz, but secondary air damping of the platform increased the frequency into the range 16-20 Hz. Development of this model is not complete.

Measurement of acceleration acting on a Falcon station wagon showed that pot holes and speeds of 40 mph yielded chassis accelerations which were in the range 1G-3G. If the units could tolerate accelerations in this range, then a practical solution of the problem could be to avoid critical isolator tuning by using a simple case with a relatively hard plastic inner foam to effectively raise the isolating resonance into the broad gap between 10 and 100 Hz. Under these conditions, the very high frequency vibrations would be effectively eliminated, whilst the lower frequency shocks could be restricted to the chassis accelerations by providing a hard outer shell so that the completed case could be tied to the chassis. Possibly such a case would also meet the requirements of air transport, where the major hazard appears to come from a drop of some feet as the package is manually unloaded from the plane.

It seems certain that the use of any of the soft springy foams requires very careful investigation and design before they can be successfully used as isolators for use with road vehicles.

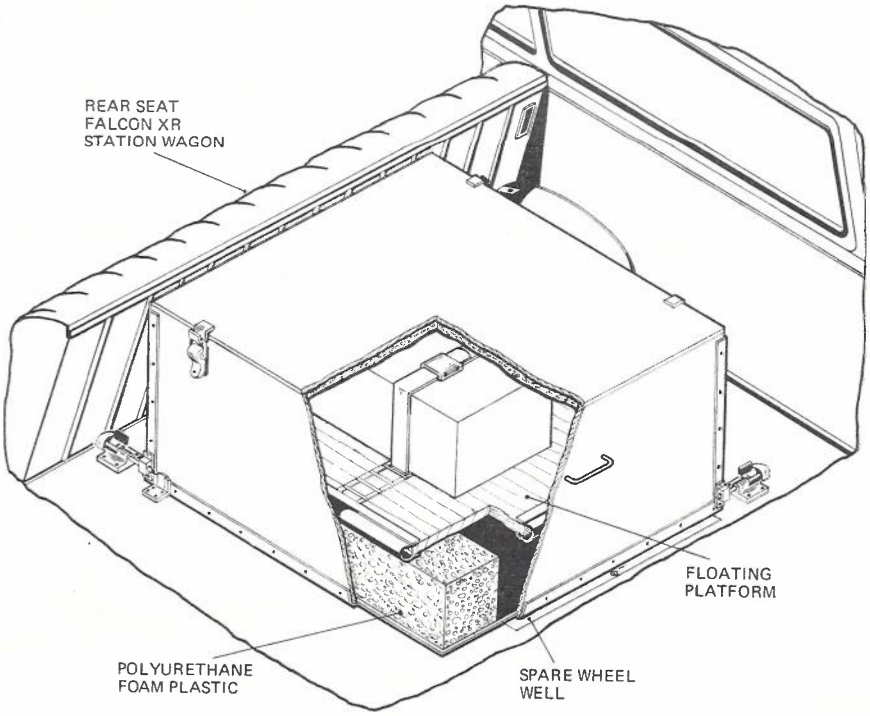

Fig. 2. — Prototype Transit Case.

AVAILABILITY AND RELIABILITY*

The yearly availability target set for the Northam-Port Pirie System was 99.9%. Of the 0.1% outage permitted, 0.07% was allocated to the radio equipment including power, with the remaining 0.03% of a year covering propagation requirements.

Although the 0.07% represented an outage of only about 8 hours each year, the target could be easily met because of the redundancy provided by the protection bearers in each switching section. Considering one of the seven switching sections between Northam and Port Pirie, and assigning them equal outage limits, then the allowable probability of failure reduces from 0.0007 for the overall system down to a minimum of 0.0001 for one section. Since failures were expected to be uncorrelated, i.e. no basic equipment design error existed, then the corresponding probability for the bearers of this 1+1 system became 0.01. This meant that provided the outages occurred at random, each bearer could in fact fail for a total of 90 hours each year without affecting the system performance target.

As seen previously, each bearer-site (bearer-terminal or bearer-repeater) was expected to fail only once in each two years, so that a bearer having 12 sites and an average travelling and preparation time of 5 hours per fault, would be expected to have an outage of 12 x 0.5 x 5 hours each year, i.e. 30 hours. Hence each bearer would have some 60 hours outage beyond fault periods when it could fail without affecting the system availability target. (Since a battery supply was to be provided with a reserve of some days, power faults were not expected to cause bearer outages.)

One obvious result from this spare outage capacity is the ability to extend the replacement unit travelling time to such an extent that maintenance could almost always be planned to take place in daylight hours.

It follows also that as far as equipment outages are concerned, the reliability (See Appendix II.) of the system on a short term basis will be very high even without an available protection bearer. Hence, even on such a long system as this, occasional short term national TV relays of the high reliability should be practicable using the protection bearers.

CONCLUSION

The service philosophy outlined for this solid state radio system is critically dependent upon the concept of random faults, the replacement without adjustment of maintenance units and their precise repair in a controlled total environment.

Provided the equipment meets its design fault rate, there is no doubt that the skill of the service staff will ensure that the other requirements are met. The resulting radio system is then expected to operate at levels of reliability and availability which could not be achieved by any other practicable means.

REFERENCE

1. Harris and Crede, Shock and Vibration Handbook', Vol. 3, Fig. 41.10.

APPENDIX I — PROVISION OF SPARE UNITS

Transmitter or Receiver Units

Northam-Eucla 1+1, 2-way Telephony

$F = 0.004$ is probability of a single unit failing in any one week

$Q = 34 \text{ x } \frac{4}{8}$ i.e. 17 sets of spares (34 sites, 4 bearers, 8 frequencies).

where each set contains a single unit for each of the 8 frequencies.

	Binominal	Poisson (QF = 0.068)
$P_0 = (1\text{-}0.004)^{17}$	= 0.93413	0.93426
$P_1 = (0.004).(1\text{-}0.004)^{16}$ .17	= 0.06378	0.06353
$P_2 =$	= 0.00205	0.00216
$P_3 =$	= 0.00004	0.00004

i.e. from the Binominal terms, the probability of having more than one failure in any one week is (1-.99791) = 0.002. The Poisson terms give a similar answer.

Hence with only one spare, bearer outages will be extended once in 10 years for a delay varying from zero up to the repair time of one week. The provision of a second spare should increase this 10 year period far beyond the possible life of the system. In actual practice, any delay even if it were imminent, could be considerably reduced by careful control of the available spares and the application of overtime measures at appropriate points in time.

Power Supply Units

Northam-Eucla

$Q = 152$ units, $F = 0.002$.

	Binominal	Poisson (QF = 0.3)
$P_0 =$	0.73761	0.74082
$P_1 =$	0.22468	0.22225
$P_2 =$	0.03400	0.03334
$P_3 =$	0.00341	0.00333
$P_4 =$	0.00025	0.00025
$P_5 =$	0.00002	0.00002

i.e. the probability of having more than 3 failures in any one week is less than 0.001.

APPENDIX II — DEFINITIONS APPLICABLE TO RADIO RELAY SYSTEMS

Availability and Reliability

Radio Relay System Availability. Radio relay system availability is the probability of finding that the baseband is providing a performance which is satisfactory for service when tested. The point at which the performance becomes unsatisfactory marks the beginning of an outage.

This radio relay system availability is dependent upon system outages from all causes including outages due to noise and outages caused by service activity.

Radio Relay System Reliability: The reliability of a radio system (R′ to R of C.C.I.R. Recommendation 380-1 Fig.1), is the probability that the system will carry traffic for a period with a performance which is satisfactory for service. The point at which the performance becomes unsatisfactory marks the beginning of an outage. The reliability of the system is not affected by noise provided the noise statistics conform to the requirements of the relevant C.C.I.R. Recommendations.

Note 1: The period applicable needs to be chosen so as to reflect the needs of the user. Accordingly the reliability of a radio relay system will have several values even for the one system, i.e. the system may have a telephony reliability, a special project television reliability and a data reliability. The actual period durations should be studied further.

Note 2: The reliability of this radio relay system is generally a complex function of the reliability of the individual bearers which comprise the system. However, the reliability of the bearers is directly dependent upon the reliability of the major items which comprise the bearer. It is this latter reliability which provides the information upon which necessary spares holding can be based.

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* The definitions used here are those which were studied at the meeting of C.C.I.T.T. Study Group Special C, Geneva 1969. They have now been adopted by the A.P.O. and are given in Appendix II.

OPERATION AND MAINTENANCE

*A. H. FAULKNER, C.E., M.A., (Cantab.), M.I.E.E.**

INTRODUCTION

This article deals briefly with the maintenance organisation of the East-West Microwave Radio system, and the results of field experience in the first few months of operation in Western Australia.

At an early stage in the design of the East-West system, the decision was made that maintenance should be carried out, as far as possible, by the replacement of complete faulty units by spare units. These faulty units would then be returned to a repair centre for overhaul. This method is the complete reverse of that employed in the maintenance of older valve-type microwave equipment, where faults are repaired on site, a stock of spare components being held at each site for the purpose. Under the new maintenance system no spare components would be available to the field staff, but they would hold instead, at their headquarters, a complete set of spare units, or modules, the appropriate unit being taken out to site by the technician attending the fault.

In order to enable this to be done, it is thus necessary for the technician to be able to identify the faulty unit before leaving his headquarters, and this information is provided by a remote supervisory system. The state of the equipment in a remote repeater is displayed by this system at the terminals of the route section, which are in most cases attended. Information for the W.A. section of the system out to Eucla is also displayed at the control terminal in Perth, Mt. Yokine, which is continuously staffed.

A second requirement is that the equipment should be designed and constructed in a modular form which permits the exchange of faulty units as a whole. For some of the equipment, such as modems, switching and supervisory units, this is straight-forward. However, in the case of the transmitter and receiver a more severe problem is presented. A microwave transmitter is a fairly bulky and complex unit, containing a considerable proportion of mechanical components, such as waveguide filters and circulators. Because of the problem posed by interface reactions between different sections of the transmitter, it was decided that the only satisfactory solution was to make the entire transmitter a single replaceable unit. This necessarily makes for a bulky and heavy unit, 29 x 10½ x 8 ins. and weighing almost 40lb. The receiver is constructed as a similar, slightly smaller, unit. Power supplies form separate units, as do some smaller items such as phase modulators, carrier reinsert units, and active equalisers.

ROUTE SECTIONALISATION AND SUPERVISORY DISPLAYS

The East-West system is divided into a number of sections, the end of each section being a terminal and also a protection switching point. At the terminals demodulation to baseband is carried out, thus permitting the insertion and extraction of supergroups. In the event of the failure of a working bearer at any point, traffic is switched automatically to the protection bearer over the section between the two adjacent switching points. The terminals on the East-West system are at Northam, Merredin, Kalgoorlie, Norseman, Caiguna, and Eucla in Western Australia, and Ceduna (Kongwirra) and Port Pirie in South Australia.

The supervisory indications of equipment performance from each repeater which are displayed at adjacent terminals and at Mt. Yokine, are as follows:

- (i) For each bearer (i.e. transmitter-receiver combination)
  - (a) 'Receiver Fail'. This indicates a drop of 6 dB in I.F. output (70 MHz) from the limiter.
  - (b) 'Transmitter Output'. This indicates a drop of 3 dB in the transmitter output power.
  - (c) 'Phase Modulator Fail'. This indicates a 3 dB drop in output of the phase modulator, which provides the basic 100 MHz (nominal) drive to the transmitter and also permits insertion of supervisory information into the sub-baseband of the telephony bearer.
- (ii) The following indications are common — that is only one is provided for all bearers, and they must in consequence be interpreted in conjunction with the individual bearer indications in (i) above.
  - (a) 'Transmitter Power Supply'.
  - (b) 'Transmitter Input'. This indicates a drop of 3 dB in the 70 MHz input to the transmitter.
- (iii) The following indications are provided for power plant:
  - (a) 'Battery Volts Low'. This operates at 23.2 volts at wind-generator powered (E Type) repeater and 24.5 volts at main-powered (B and D Type) repeaters. At E type repeaters it is thus an indication that the diesel has failed to start, since this should occur at a higher voltage (23.5V).
  - (b) 'Battery Volts High'. Battery voltage 30.6V (E type) or 27.5V (B & D Type). This will shut down the diesel immediately it occurs. At wind-generator stations, it will disconnect the battery from all sources of power, and must be reset either locally or remotely before the battery is reconnected.
  - (c) 'Fuel Low'. 30 gallons in tank.
  - (d) 'Urgent Power'. This indicates that the diesel has tried to start and failed, or has shut down due to a fault. At mains-operated repeaters, it indicates also a changeover to the standby rectifier.
  - (e) 'Generator On', indicates that the diesel generator is running on load.
- (iv) In addition, the following miscellaneous indications are provided:
  - (a) 'Off Normal'. This indicates that any one of certain control switches is not in its normal position.
  - (b) 'Pressure Fail' indicates that the gas pressure in the waveguides has fallen below about 1½lb per square inch, (normally it is 2½lb per square inch) and usually means that the nitrogen cylinder is exhausted.
  - (c) 'Doors'. Alarms are fitted to both outer and inner doors of the shelters.
- (v) Additional indications are provided from terminals, to cover modem and switching conditions.

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* Mr. Faulkner is Engineer Class 2, Microwave Maintenance, Western Australia.

It will be seen that the supervisory display is not always self-evident and requires interpretation by staff having a good knowledge of the equipment. For this reason, training has been given by G.E.C. personnel to staff concerned with the system, particularly those at the Mt. Yokine control station.

In addition to supervisory indications from repeaters to terminals, a limited number of controls can be transmitted from terminals to repeaters.

These are:—

(i) From a terminal to the repeaters in its adjacent sections:
  (a) Start Generator
  (b) Stop Generator
  (c) Reset Power. This restores all in-station automatic controls to normal. For example at a mains-operated repeater, a tripped-out rectifier can be restored to load.
(ii) From a terminal to its adjacent terminals.
  (a) (b) (c) as above.
  (d) Lockout Protection Bearer. This prevents a working bearer from switching to the protection bearer if it fails.
(iii) From Mt. Yokine control terminal to all terminals only.
  (a) (b) (c) (d) as above.

REPLACEMENT AND REPAIR OF UNITS

The three most numerous and most important units in the system are the transmitters, receivers, and phase modulators, which together form the actual bearers. These are capable of operation at one fixed frequency only, and consequently spare units must be provided for every frequency of operation. A total of ten different frequencies are used in the system, since the transmitters in alternate repeaters use the same frequencies for any one bearer. The maximum number of bearers in service at present is five (telephony go and return, protection go and return and TV one-way), on the Northam-Kalgoorlie section. Two complete sets of spare units have been provided in Western Australia and one set is held at each of the country maintenance centres, which are located at Kalgoorlie and Norseman. Kalgoorlie staff are responsible for the route from Northam to one repeater past Kalgoorlie (Alan Hill) and Norseman staff are responsible for the remainder of the route to Eucla.

The present staff provision is, at Kalgoorlie, one Assistant Supervising Technician, Grade 1 and one Senior Technician, and at Norseman, one Supervising Technician, Grade 2 and two Senior Technicians. Although the establishment makes allowance for additional staff these positions are at present unfilled. In addition, a Senior Technician is available at Merredin for assistance in emergencies.

The Base Repair Centre is located at the Mt. Yokine terminal, and is staffed by a Supervising Technician Grade 1 and a Senior Technician. All units returned from the field are repaired and tested here before being returned to the country maintenance centres. A wide range of test equipment is provided, including facilities for temperature-cycling units from freezing-point to 50°C (122°F). This latter is essential for transmitters and receivers, which may perform satisfactorily at room temperature but are prone to generate spurious oscillations at higher or lower temperatures. Before these units can be considered repaired, therefore, they must be tested over the above range to ensure that transmitter power and freedom from spurious oscillations are maintained over the above range. This range represents that actually encountered in service, since the repeater buildings are of the so-called 'thin-skinned' type, which maintain an internal temperature a few degrees above the outside shade temperature.

Units are conveyed to and from the Repair Centre by public transport — by air if possible, otherwise by road bus or rail. Transport cases are of plywood, lined with three inches of polyurethane foam to provide adequate insulation against shock and vibration. It had at one time been considered that it would be necessary to transport units by Departmental vehicles in order to ensure sufficiently careful treatment, but the method of transport adopted has proved entirely satisfactory. However, complaints have been received from field staff that the major-unit cases are difficult to handle, due to their size and weight. The transmitter case weighs 40lb and when loaded with a transmitter, has an all-up weight of 80lb. Consequently, a smaller and lighter unit is being investigated, probably constructed of fibreglass with a two-inch foam lining. Smaller cases, of the same construction, have also been provided for the minor units, such as phase modulators.

POWER EQUIPMENT

Power supplies at repeaters are of two different types, mains-operated and wind-generator operated. At mains-operated stations the plant consists of a standard d.c. No-break set comprising duplicate rectifiers with automatic changeover, and duplicate 200 Ah 24V batteries, normally paralleled. A normally - stationary automatic-start 10kVA diesel alternator is provided as mains back-up.

At wind-generator stations, the normal source of power is a 2kW wind generator which charges duplicate 500 Ah batteries, normally paralleled. A normally-stationary automatic start 4 kW diesel d.c. generator is provided as back-up. A 2kVA alternator on the same shaft provides a.c. power when required for test equipment, etc.

Maintenance of power plant is normally carried out by component replacement although four complete spare diesel generator units are provided. These units are skid-mounted and carried on special trailers having winching and other facilities, which enable changeover to be effected by two men (one in emergency) without other equipment.

At present, maintenance is carried out by local technician staff, but it is proposed to provide a Senior Motor Mechanic, stationed at Norseman, when facilities can be made available.

OPERATIONAL EXPERIENCE — EQUIPMENT

It could reasonably be anticipated that the major source of faults on the equipment would be the bearer components — that is, transmitters, receivers, and phase modulators, since they are by far the most numerous of all the units — in the W.A. section there are 155 operational transmitters. Also these units are more complex, and contain more exotic components than the remainder of the units.

At the planning stage, a failure rate of 0.56 faults per bearer per repeater year was postulated. This figure was based on extrapolation from the information available at the time and includes degradations as well as total failures. For the Northam-Eucla section, this gives a total figure for equipment faults requiring a visit by staff of 80 per year.

An analysis of faults which occurred during the three-month period May-July 1970 is given in Table 1. From this it can be seen that the failure rate over this period was four times that predicted.

TABLE 1 — SUMMARY OF RADIO EQUIPMENT FAULTS, ON NORTHAM-EUCLA SECTION, MAY-JULY 1970

	May	June	July	Total
Transmitters	7	11	21	39
Receivers	—	1	4	5
Phase Modulators	2	9	1	12
Power Units	3	—	2	5
TV Sound demod.	1	—	—	1
Carrier reinsert unit	—	1	—	1
Supervisory system	2	1	1	4
BNC Connectors				9
TOTAL				76

It will be seen from this, that over half the total number of faults occurred in the transmitters, and represented failure of 25% of the total of working transmitters during this 3 month period, The majority of the failures (24) were due to a drop in output sufficient to bring up a 'Transmitter fail' alarm (i.e., 3 dB drop). In 5 cases rejection was due to the production of high-level spurious oscillations. In the main, both these types of faults were caused by misalignment of the tuning adjustments.

The tuning of these units is a complex and time-consuming operation, due to the number of interdependent adjustments available, the average time required being two to three days, including temperature cycling. Past experience has shown that temperature cycling is essential if reliable operation of varactor-multiplier oscillators is to be achieved and this has been fully confirmed by experience with the present equipment. There had been some doubt about the necessity for having a cold-cycle as well as a heat-cycle, but it has been found that, where failure occurs due to ambient-temperature changes, the occurrence of failure corresponds to the low-temperature part of the daily cycle in many cases.

Evidence to date, although inadequate from a statistical point of view, indicates that once the transmitter units have been processed as described, they are not subsequently prone to this type of fault. Only a few processed units have been subsequently returned, and these were returned on account of component failures. Consequently, it is hoped that once all the transmitters have been through the Base Repair Centre, fault incidence will drop to a substantially lower level than at present.

The maintenance concept was based on the assumption that the supervisory system would indicate which particular unit had failed so that only one need be taken to the site. This is true for such faults as transmitter or receiver failure. In the case of spurious generation, however, this is not so, since the supervisory system does not indicate such a fault. Consequently, the fault could be anywhere in one bearer in one switching section. It is thus necessary for the attending staff to take with them, four major units, namely the appropriate two transmitters and two receivers, together with several minor items. It is then necessary to proceed down the route, operating the carrier reinsert unit at each repeater, until the faulty unit is located. Since the co-operation of staff at the far-end terminal is also required, this is considerably more demanding in terms of manhours than a clear-cut fault.

OPERATIONAL EXPERIENCE — POWER EQUIPMENT

Generally, the power equipment has performed satisfactorily. The wind generators have been found to make a useful contribution, amounting to over half of the total power requirements. However, several of them have suffered major mechanical damage in service, and this is being investigated.

A certain amount of trouble has also been experienced with the diesels. In the early days of commissioning, faulty non-return valves in the oil make-up tank caused flooding of the sump, and cracked fuel-pump diaphragms permitted fuel to escape into the sump. Both these problems now appear to have been cured by modification to the components involved. More recently, however, trouble has been experienced with starter motors and starter solenoids. These failures are particularly serious at wind-generator repeaters, since nothing is known of them until the battery is discharged to a point at which the diesel should start, and fails to do so. An 'urgent power' alarm is then extended. If the battery continues to discharge a 'battery volts low' alarm is extended. At this point the remaining battery capacity is in practice only about 8 hours if there is no wind-generator input. Since Eucla, the furthest station, is eight hours driving from Norseman, immediate attention is required if the system is not to fail completely. This attention usually involves towing a spare diesel set from the nearest point at which one is stationed (Kalgoorlie, Norseman or Caiguna).

Table 2 gives power faults recorded during the three-month period May-July, 1970.

TABLE 2 — SUMMARY OF POWER EQUIPMENT ON THE NORTHAM-EUCLA SECTION, MAY-JULY 1970

Equipment	Faults
Starter Motor or Solenoid	9
Power Control Cubicle, various	6
Diesel Engine, various	4
Wind Generator	1

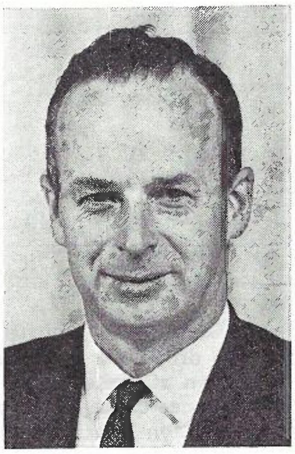
CONCLUSION

Apart from the two trouble areas described, the performance of the system has been generally good. It must be emphasised that the failures detailed above have not caused any loss of traffic. The effect of a 'transmitter fail' (3 dB drop in power) on the system is negligible — in fact, under non-fading conditions, a 30 dB drop would be undetectable by the user. However, it has serious implications in the case of the transmitter itself, since it indicates that the transmitter is probably close to complete failure. Even in the case of a complete failure, however, the automatic protection switching would ensure that traffic continued without perceptible interruption.

However, this high fault incidence has the effect of placing a very severe strain on the staff responsible for maintaining the system both in the field and in the base repair centre. A high rate of overtime working, and a great deal of long distance driving, have been involved, and because of the critical staff shortages through the Radio area, it has not been possible to provide additional staff to any great extent. Currently, an effort is being made to reduce out-of-hours working by restricting the categories of faults which are regarded as requiring immediate attention, and by the use of charter light aircraft in some cases.

OUR CONTRIBUTORS

A. G. ELLIS



R. P. SLATTERY

D. S. ROBERTS

A. G. ELLIS, author of 'Service aspects of the Radio System', graduated from Melbourne University in 1952. In 1966 he gained the Associate Diploma of Management from R.M.I.T.

For a number of years he was associated with the design and production of radio systems including portable, mobile and multi-channel trunk equipment. In 1962 he was appointed Class 3 Engineer, Headquarters, with responsibility for coordination and service aspects of all Departmental radio systems.

During the last year, he has specialized in the design of tropospheric scatter and automatic mobile and public paging systems.

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R. P. SLATTERY, co-author of the article 'Thermal Design of Naturally Cooled Repeater Shelters,' is an Engineer Class 2 in the Buildings Engineering Services Sub-Section, Mechanical and Electrical Section, Headquarters. He was employed by the Victorian Railways from 1939 to 1953 with the exception of 3½ years' war service in the R.A.A.F. During this period he gained a Diploma of Mechanical Engineering and is a Graduate Member of the Institute of Engineers Australia.

In 1953 he joined General Motors Holden's Ltd. at Fishermen's Bend where he was employed as a Project Engineer on plant and equipment installations associated with the Holden car.

He then joined the Postmaster-General's Department in 1960 where he has been engaged mainly on work associated with air treatment to provide the desired environmental conditions for equipment and staff in Departmental buildings.

He has also been involved in studies in the field and under simulated conditions to determine building constructions suitable for unattended telecommunication buildings.

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D. S. ROBERTS, co-author of the article 'A.P.O. Project Management', transferred to the A.P.O. from the Victorian State Electricity Commission where he was, during 1954-56, engaged as an Engineer Class 1 on the design and provision of the Commission's V.H.F. radio network. He took up the duties of an Engineer Class 2 in the A.P.O. Headquarters Radio Section in 1957 and was associated with the provision of the first broadband (600 channel 4 GHz) microwave systems in Australia. He has been engaged over the past thirteen years in the provision, installation and performance of broadband microwave relay systems and ancillary plant for the A.P.O. trunk network. In 1967 he was awarded an Overseas Fellowship for three months to study the advancements being made in Europe on microwave relay equipment. He was the Headquarters Project Engineer for the East-West radio relay system and is at present the Divisional Engineer (Class 3) Trunk Radio Systems for South Australia and Western Australia, which includes the expansion of the East-West system. In 1954 he completed an Associateship Diploma of Radio Engineering at the Royal Melbourne Institute of Technology and is a Member of the Institution of Engineers, Australia.

R. N. KELMAN, co-author of the article on 'Stressed Rock-Anchor Antenna-Support Towers', is an Associate Partner of Ove Arup and Partners, Sydney.

After four years of war service, he graduated from University of Sydney in 1948 and then spent some years in the United Kingdom, firstly with the London Metropolitan Water Board and then Sir Alexander Gibb and Partners, before returning to Australia to join MacDonald, Wagner and Priddle in 1951.

He returned to England in 1957 and joined Ove Arup and Partners in London. He became involved in the Sydney Opera House project, which brought him back to Sydney for a year in 1963-64. He returned in 1966 to become Associate Partner in the Sydney Branch.

Apart from the Opera House, he has had a varied experience in building structures in concrete and steel.

R. N. KELMAN

A. Z. BYCZYNSKI

J. TOMLINSON

A. H. FAULKNER

A. Z. BYCZYNSKI. author of the article 'Testing of the Prototype Equipment', studied science at the University of Warsaw. Shortly before the Second World War, he graduated from the Military College (Poland). In 1945 he commenced an engineering course at the Royal Polytechnic of Turin (Italy) and graduated from the Polish University College (P.U.C.), London, in 1950. In the following year he received his final degree from the P.U.C. and the R.A.S.T., London and subsequently joined the E. K. Cole Co. Ltd.. as a Senior Staff Engineer. There he worked on various problems in the field of radiocommunications and from 1953 until his departure from the United Kingdom he was responsible for the design and development of television translators. In 1955 he joined the A.P.O. Headquarters Radio Section, where, since 1961, he had been Divisional Engineer, Circuitry, Testing and Laboratory Division, Design Sub-section. Between September 1967 and February 1970, Mr. Byczynski was the A.P.O. Liaison Engineer at the G.E.C. Works, Coventry where he was engaged on work associated with the design and testing of the East-West prototype equipment. Later he acted as the A.P.O. Inspector, overseeing production and testing of the East-West equipment. At present. he is an Engineer Class 3, Division No. 4, Service and Trunk Radio No. 1 Sub-section. Mr. Byczynski is a Member of the Institution of Electrical Engineers and a Fellow of the Institution of Nuclear Engineers.

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J. TOMLINSON, co-author of the article 'Thermal Design of Naturally Cooled Repeater Shelters,' graduated Bachelor of Engineering, from the University of Liverpool, U.K. in 1933. He was employed until 1950 with the British Broadcasting Corporation being occupied with broadcasting studio equipment design until 1938, and then with the design, procurement, and testing of all types of vacuum devices, representing the B.B.C. on the Inter Services Valve Production and Allocations Committee throughout the war period. He joined the A.P.O. in February 1950 and after a short induction period in the Radio Section Services Sub-Section he was promoted to Class 2 and then Class 3 engineer in charge of the Head Office aspects of the technical facilities of the studios of the National Broadcasting Service. When responsibility for these facilities was transferred to the Australian Broadcasting Commission in December 1964, he was transferred to Class 3 engineer in charge of the Radio-communications Equipment Division, Design Sub-Section, Radio Section at Headquarters and is responsible for the design and specification of radio communications equipment throughout the H.F. to S.H.F. frequency ranges, and including as necessary ancillary equipment, antenna towers, equipment shelters etc.

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A. H. FAULKNER, author of the article 'Operation and Maintenance', is Class 2 Engineer, Radio Communication Service Division, Perth. He graduated in Engineering at Cambridge University, England, in 1941, and was granted a Master of Arts degree in 1945. He saw five years sea service with the R.N.V.R. as Escort Group Radar Officer, after which he joined the British Post Office Research Station, Dollis Hill, as Engineer, and was engaged in the design and construction of experimental microwave television relay systems. He was the Post Office representative on the Standardisation Sub-committee on waveguides, and the Research and Development sub-committee on microwave test equipment. In 1952 he came to Australia and joined the A.P.O. Headquarters Radio Section, leaving in 1955 for private employment. In 1961 he re-joined the Department in Western Australia, and was concerned with the planning of microwave systems in that State, including the East-West system from 1963 to 1966. Since then he has been concerned with the operation and maintenance of microwave systems in W.A. He is a member of the Institution of Electrical Engineers.

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A. L. HOLDERNESS, author of the article 'Power Plant', completed his Diploma of Electrical Engineering following four years war service. He then joined the State Electricity Commission and later the Department of Supply.

In 1958 he joined the Postmaster-General's Department, entering the Telephone Equipment Section, where he carried out development on power equipment. Since that time he has been concerned in the design and development of power plant for all broadband radio and coaxial cable

A. L. HOLDERNESS

H. E. HOLMES

S. M. PUGH

systems and more recently no-break power supplies for the computers in the Common User Data Network.

Mr. Holderness is an Engineer Class 3 with the Headquarters power group in the L.L.E. and Telepower Section and is a member of the Institute of Engineers.

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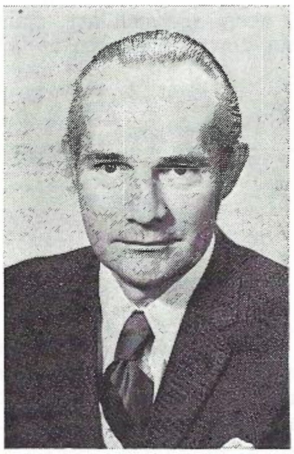
H. E. HOLMES, co-author of the article 'Stressed Rock-Anchor Antenna-Support Towers', graduated with an Honours Degree in Mechanical Engineering from the University of Queensland in 1949. He was also awarded a two year Graduate Scholarship by the British Thompson Houston Company (now GEC-AEI Group) in the United Kingdom. This period, and a further six months with Maschinenfabrik Oerlikon in Zurich, was occupied in the design and testing of heavy electrical machines, steam and gas turbines and power system equipment. He returned to Australia in 1953 and after nearly two years with a Power Supply Authority in North Queensland joined Electric Power Transmission in 1954. During the major portion of fifteen years with E.P.T. he has occupied the position of Technical Manager and has been engaged in the establishment of the company's specialized activity in the design, fabrication testing and erection of all types of tower structures and masts for electrical power and radio communication systems.

★

E. L. BROOKER, author of the paper 'Antennas and Waveguides' joined the APO in 1941 passing through technician and cadetship training with a Bachelor of Science degree from the University of Western Australia. After two years as a design engineer in the Headquarters Radio Section, he joined the first group of Australian engineers awarded CBI post graduate scholarships in the United Kingdom in 1953. Specializing in radio relay system design, he returned to Headquarters Radio Section in 1955, finally taking up the position of Sectional Engineer (Design) in 1961. In this capacity, he directed the specification and system design of the rapidly expanding radio relay network. Of particular significance was his direct involvement in the preparation of the tender schedule for the East-West Project, including the conception and feasibility study of the sunshaded shelter technique. Mr. Brooker was Deputy Leader of the Australian delegation to CCIR meetings from 1963 to 1968 and has visited the factories and laboratories of the major radio equipment manufacturers throughout the world. In 1969 he took up a position in Melbourne as Managing Director of Andrew Antennas Division of Andrew Corporation, in which capacity he is encouraging the development of a local industry in high quality antennas and feeders to support the technical needs of the APO. Mr. Brooker is a Fellow of the Institution of Engineers Australia and a Fellow of the Institution of Radio and Electronics Engineers Australia.



E. L. BROOKER

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S. M. PUGH, co-author of the article 'A.P.O. Project Management', joined the British Post Office as a Youth-in-Training in 1936 at the Dollis Hill Research Station. After demobilisation, three years were spent in the Lines Branch of the Engineer-in-Chief's Office, when he left the B.P.O. to take up a position of Communication Engineer in the Eastern Division of the Central Electricity Authority. He joined the A.P.O. as a Group Engineer in Western Australia in 1955 and after two years in Internal Plant Planning and Exchange Installation, he left to join the Hydro Electric Commission in Tasmania as a Communication Engineer.

With the advent of the American Man-in-Space Programme, Mr. Pugh returned to Western Australia as a senior engineer at the Muchea tracking station and after a period in Canberra at the Tidbinbilla Deep Space Instrumentation Facility he returned to the A.P.O. as Engineer Class 2, Microwave Installation and Maintenance, in Perth. In 1967 he became Western Australian Project Engineer for the East-West Project and is currently Divisional Engineer, Radio Communication Installation in Perth. He is a member of the I.E.E., I.E. Aust., and Institute of Nuclear Engineers.

ANSWERS TO EXAMINATION QUESTIONS

Examinations No. 6071 to 6075, 18th July, 1970, and subsequent dates, for promotion or transfer as Technician (Telecommunications), Postmaster-General's Department.

TELECOMMUNICATION PRINCIPLES

(Continued from Vol. 20, No. 3, P. 288)

QUESTION 12 (b):

A transformer supplies power to an electron tube amplifier from the 240 volt 50 cycle mains supply. The secondary windings supply 6 volts at 3 amps for tube filaments and 100 volts at 300 mA to a voltage doubler supply. Calculate:

(*i*) *The number of turns on the filament winding, if the primary has 1,000 turns.*

(*ii*) *The no-load output voltage of the voltage doubler.*

(*iii*) *The total power taken from the supply, if the transformer is 96 per cent. efficient and the secondary currents have a power factor of unity (1).*

ANSWER 12 (b):

(i)

$$\begin{aligned} Ns &= Np \times \frac{Es}{Ep} \\ &= 1{,}000 \times \frac{6}{240} \\ &= 25 \text{ Turns} \end{aligned}$$

(ii) The output is twice the peak value of the secondary voltage

$$\begin{aligned} E &= 2 \times Es \times 1.4 \\ &= 2 \times 100 \times 1.4 \\ &= 280 \text{ Volts (approximately)} \end{aligned}$$

(iii)

$$\begin{aligned} \text{Secondary Power} &= (6 \times 3) + (100 \times 0.3) \\ &= 18 + 30 \\ &= 48 \text{ Watts} \\ \text{Primary Power} &= 48 \times \frac{100}{96} \\ &= 50 \text{ Watts} \end{aligned}$$

QUESTION 13 (a):

On the characteristics shown, draw a D.C. loadline for a load resistor of 1250 ohms and a supply of 10 volts.

ANSWER 13 (a):

See Fig. 19.

The current at zero collector volts is 8 mA $\left(\frac{10 \text{ volts}}{1250 \text{ ohms}}\right)$ and the current at 10 volts is OmA. These points are joined for the loadline.

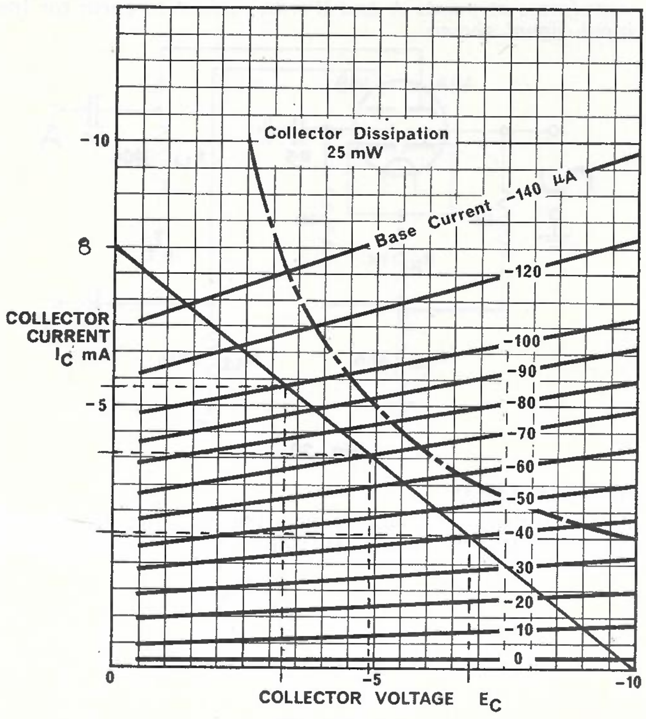


Fig. 19.

QUESTION 13 (b):

Determine the p.d. across the load resistor when the base current is 70 uA.

ANSWER 13 (b):

From graph, Ec at 70uA is 4.9 volts.
Erl is 10 — 4.9 = 5.1 volts.

QUESTION 13 (c):

What is the signal power developed in the load resistor when a 60uA peak to peak sine wave signal is applied in series with the 70uA base bias current?

ANSWER 13 (c):

This signal current will vary the base current from 40uA to 100uA. From the graph, this varies Ec from about 3.25 to 6.75 volts, or 3.5 volts peak to peak. Ic will be varied from about 2.6 to 5.4 volts, or 2.8 volts peak to peak. The r.m.s. values are found by dividing the peak to peak values by 2.8.

$$\begin{aligned} \text{Signal Power} &= \frac{Epp}{2.8} \times \frac{Ipp}{2.8} \\ &= \frac{3.5}{2.8} \times \frac{2.8}{2.8} \times 10^{-3} \\ &= 1.25 \text{ mW.} \end{aligned}$$

QUESTION 14:

Fig. 20 shows a phase inverter stage using a twin triode electron tube. It is operated from a 200 volt H.T. supply and the anode current in each tube is 0.8mA.

QUESTION 14 (a):

State a typical use for this type of circuit and show the waveforms at points A and B with respect to earth for the input signal shown.

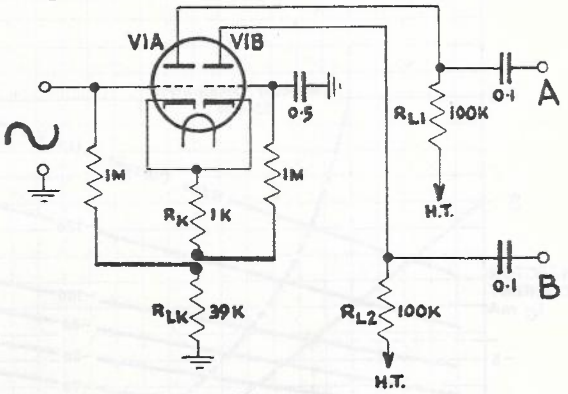


Fig. 20.

ANSWER 14 (a):

A typical use would be to supply the inputs to a push-pull stage. The waveshapes at points A and B are shown in Fig. 21.

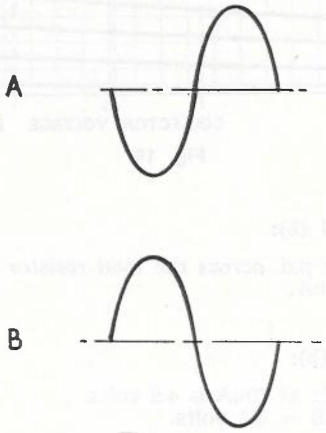


Fig. 21.

QUESTION 14 (b):

Calculate the anode voltage of V1B with respect to cathode.

ANSWER 14 (b):

$$E \text{ anode} = E - Erl - (Erk + Erlk)$$

$$Erl = 0.8 \times 10^{-3} \times 10^{5}$$

$$= 80 \text{ Volts}$$

$$Erk + Erlk = 1.6 \times 10^{-3} \times (39 + 1) \times 10^{3}$$

$$= 1.6 \times 40$$

$$= 64 \text{ Volts}$$

$$E \text{ anode} = 200 - (80 + 64)$$

$$= 56 \text{ Volts}$$

QUESTION 14 (c):

Explain how bias is applied to V1A and determine its value.

ANSWER 14 (c):

The bias voltage is developed by the cathode current of both sections of the tube passing through the 1kΩ cathode resistor. The top end (positive) is connected to V1A cathode and the lower end (negative) is connected via the 1MΩ resistor to the grid.

As the grid is negative there is no current flow and therefore no p.d. across this resistor and the full value of the voltage across the cathode resistor is connected to the grid.

The value is 1.6 volts, calculated below.

$$E = 1.6 \times 10^{-3} \times 1000$$

$$= 1.6 \text{ Volts.}$$

TECHNICAL NEWS ITEMS

RADIO PROPAGATION MEASUREMENTS THROUGH BUSHFIRES

Following the Lara bushfires in Victoria early in 1969, when a number of people lost their lives, there were suggestions that there had been a breakdown in the radiocommunications used by the firefighters, due to the severe disturbance to the radio paths caused by the fire. Subsequently, the A.P.O. Research Laboratories were asked to investigate any adverse propagation phenomena which might occur in a bushfire. By the courtesy of the Defence Standards Laboratories of the Department of Supply, a team of six from the A.P.O. Research Laboratories was able to join a controlled fire experiment being conducted by the Defence Standards Laboratories and make propagation measurements through that fire.

This experiment, known as Project Euroka, was conducted at Langley, Queensland, about 25 miles inland from the highway, midway between Rockhampton and Mackay. Some 6,000 tons of Brigalow, cleared from 300 acres and piled on to 50 acres, was fired simultaneously at 1,000 points on 23 October, 1969. The main purpose was to study the airflow patterns, temperature gradients, etc., which develop in a large fire and extensive electrical instrumentation was installed on towers within and around the fire.

The major A.P.O. installations were a transmitting station on the south-west side of the fire, transmitting normally across the fire to a 'near' receiving station on the north-east fire face, and also to a 'distant' receiving station 15 miles away.

Collaborating with the A.P.O. group, a team of three from the University of New South Wales, under Professor P. Angus-Leppan, made precision measurements of optical refraction and of range (with a radio instrument, the Tellurometer), across the fire.

Test transmissions across the fire were made at 2, 5 and 160 MHz, as well as the trunk-system frequencies of 450 and 4000 MHz.

The results show no substantial propagation effects on either the long (15 miles) or the short paths. The short path, of about 800 yards, had 495 yards through the fire. Signals varied both above and below "pre-burn" levels, minima being rarely more than 5 dB below the "normal" value. There was an overall tendency for signal levels to increase slightly during the fire.

Both the Tellurometer ranges and angle of arrival measurements of the 4 GHz signal, showed that the apparent positions of the transmitting sources were lowered and "subrefractive" propagation conditions occurred. This effect did not produce any substantial reduction of the received signal levels here, although there is a possibility that such subrefraction might become sufficiently marked in other fires to reduce "long-path" signals significantly.

DAMAGE TO BURNIE-LAUNCESTON COAXIAL CABLE

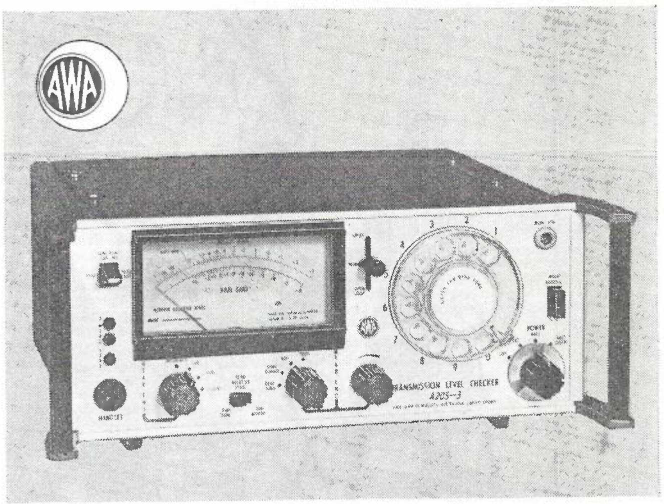
On 3 June, 1970, trunk circuits carried by the tubes of the Burnie-Launceston coaxial cable, failed by direct shorting between the central conductors and the outer tubes. Other circuits carried on wire pairs were unaffected and the cable had not lost gas pressure. Investigation by the line staff revealed that a number of manholes contained large quantities of sulphuric acid.

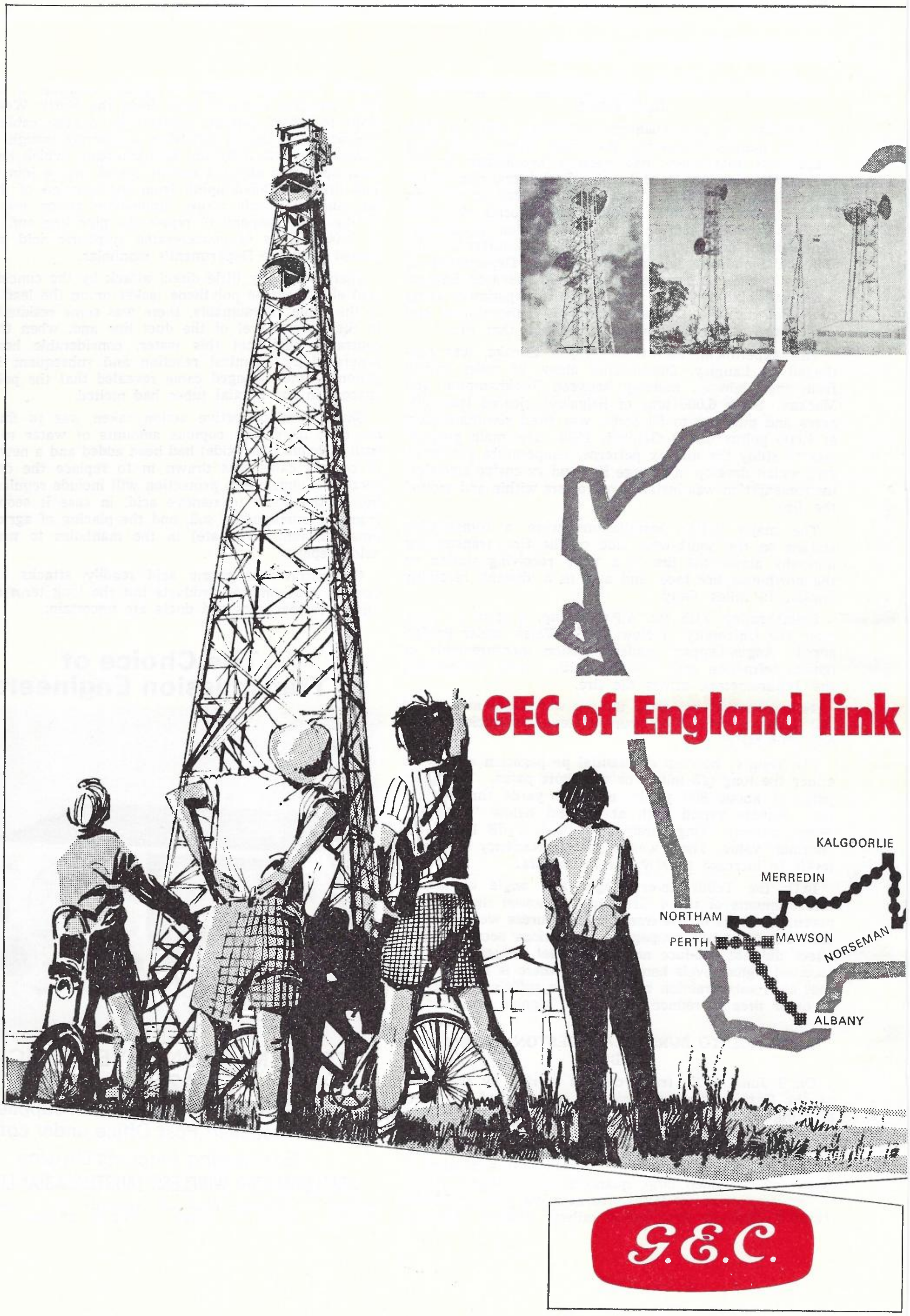
The location of the faults was at a low point in Marine Terrace, opposite the Burnie railway station. Approximately 150 yards from the failure location, a 4" pipe line, carrying sulphuric acid from the North West Acid plant to wharf storage, crosses the coaxial cable route. The acid pipe line is carried in a concrete trough. Investigation conducted by the acid company, which had only been operating about a month, found that a joint in the acid line had failed uphill from the junction of the acid line and the cable route. Immediate action was taken by the acid company to repair the pipe line and a total of 2000 gallons of concentrated sulphuric acid was removed from the Department's manholes.

There was very little direct attack by the concentrated acid either on the polythene jacket or on the lead sheath of the cable. Presumably, there was some residual water in the lowest level of the duct line and, when the concentrated acid met this water, considerable heat was generated by chemical reaction and subsequent investigation of the damaged cable revealed that the polythene spacers in the coaxial tubes had melted.

Short term corrective action taken was to flush out the duct lines with copious amounts of water to which limil (calcium hydroxide) had been added and a new length of coaxial cable was drawn in to replace the damaged section. Longer term protection will include regular flushing of the ducts to remove acid, in case it seeps back from the surrounding soil, and the placing of agricultural lime (calcium carbonate) in the manholes to neutralise acid seepage.

Concentrated sulphuric acid readily attacks asbestos cement and concrete products but the long term damage effects to manholes and ducts are uncertain.

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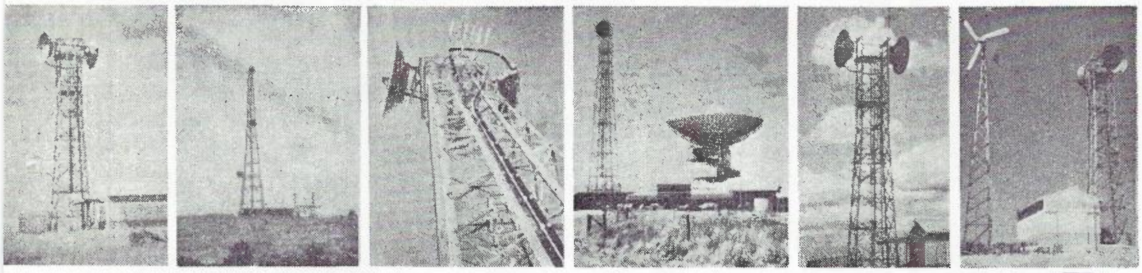

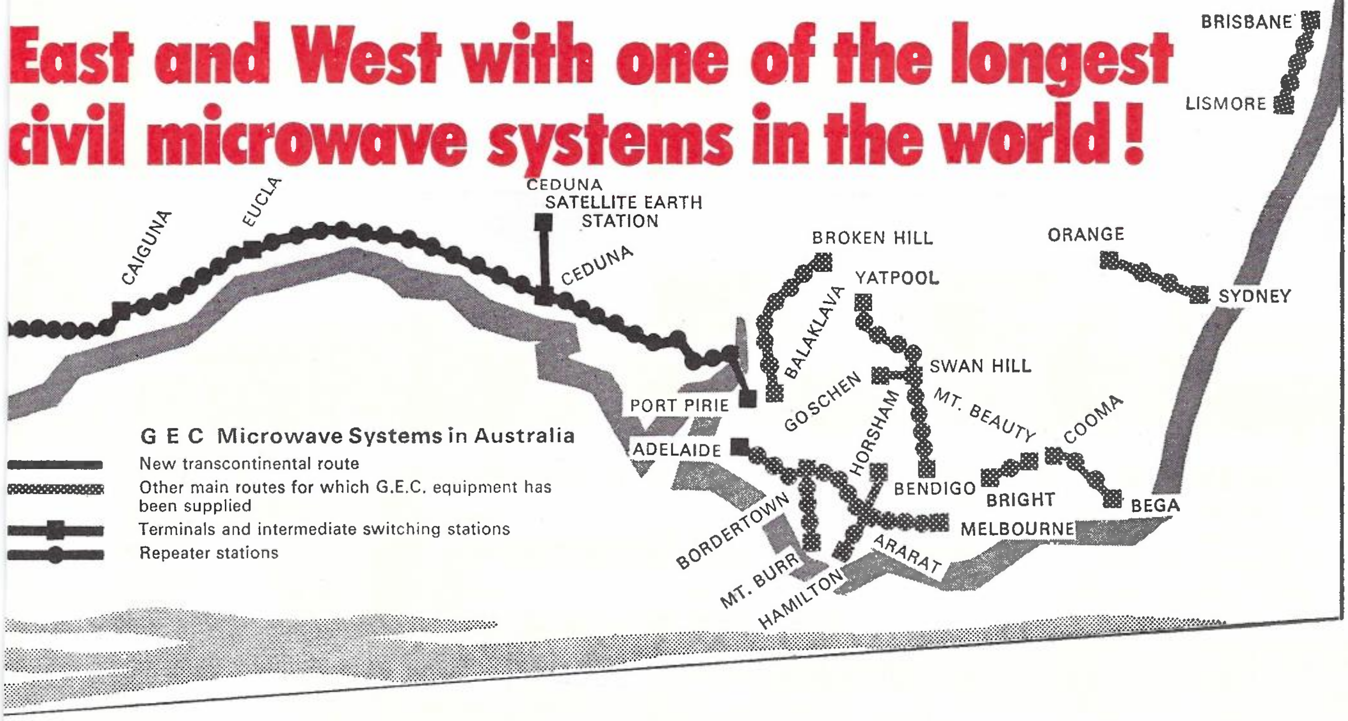
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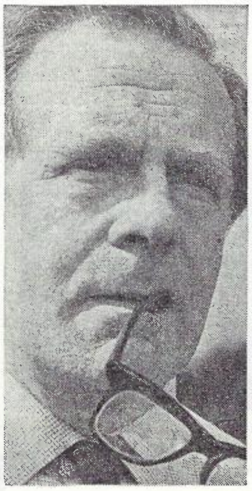

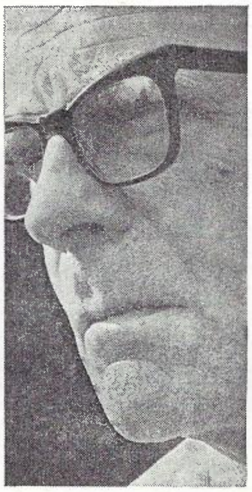

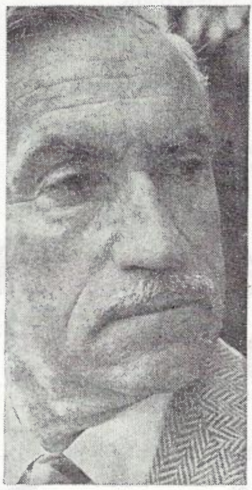

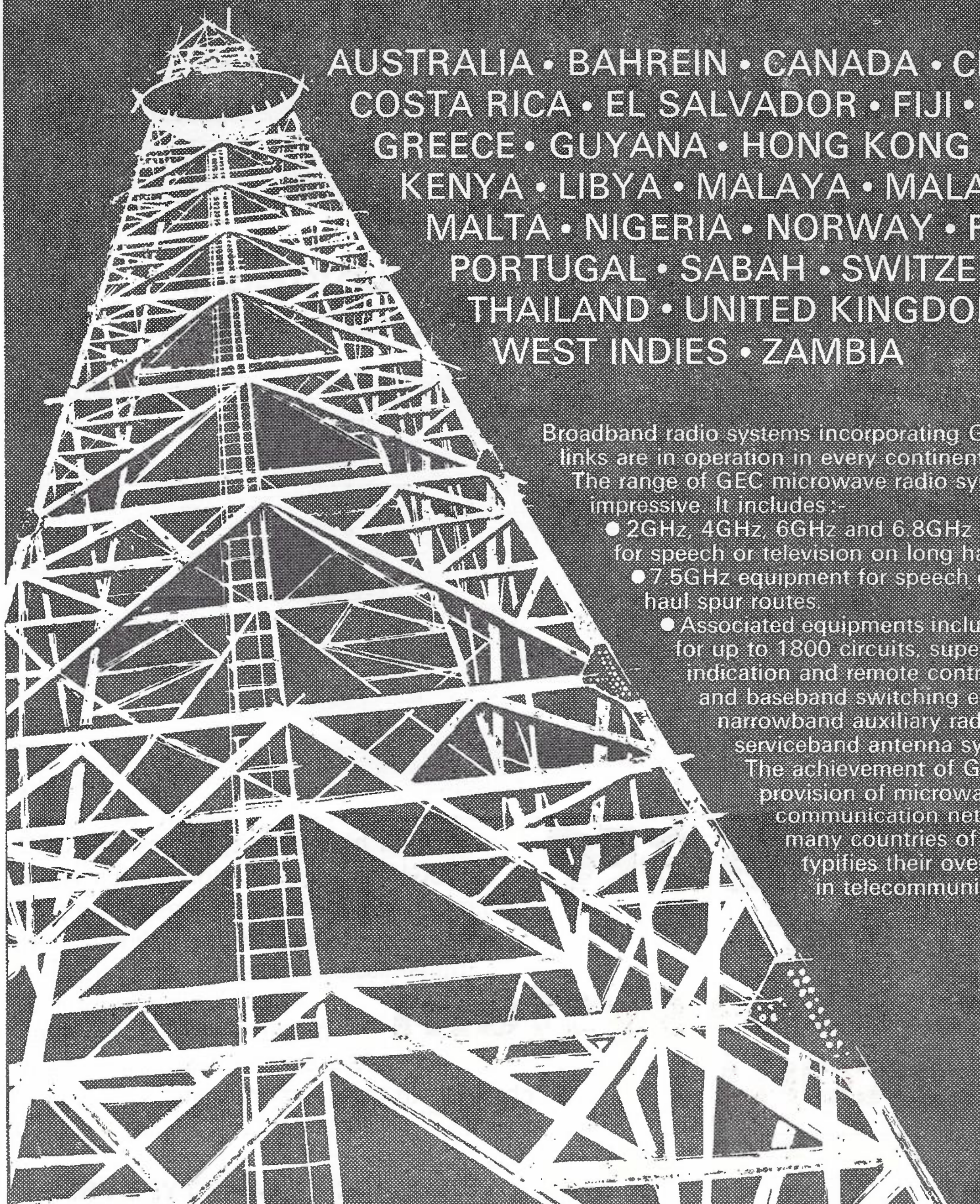

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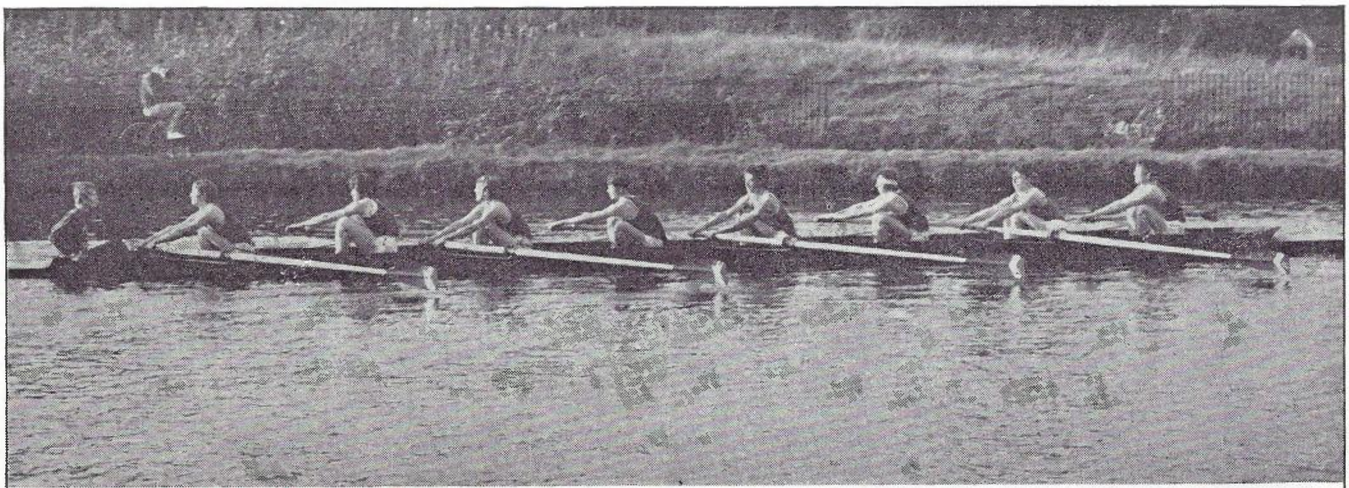

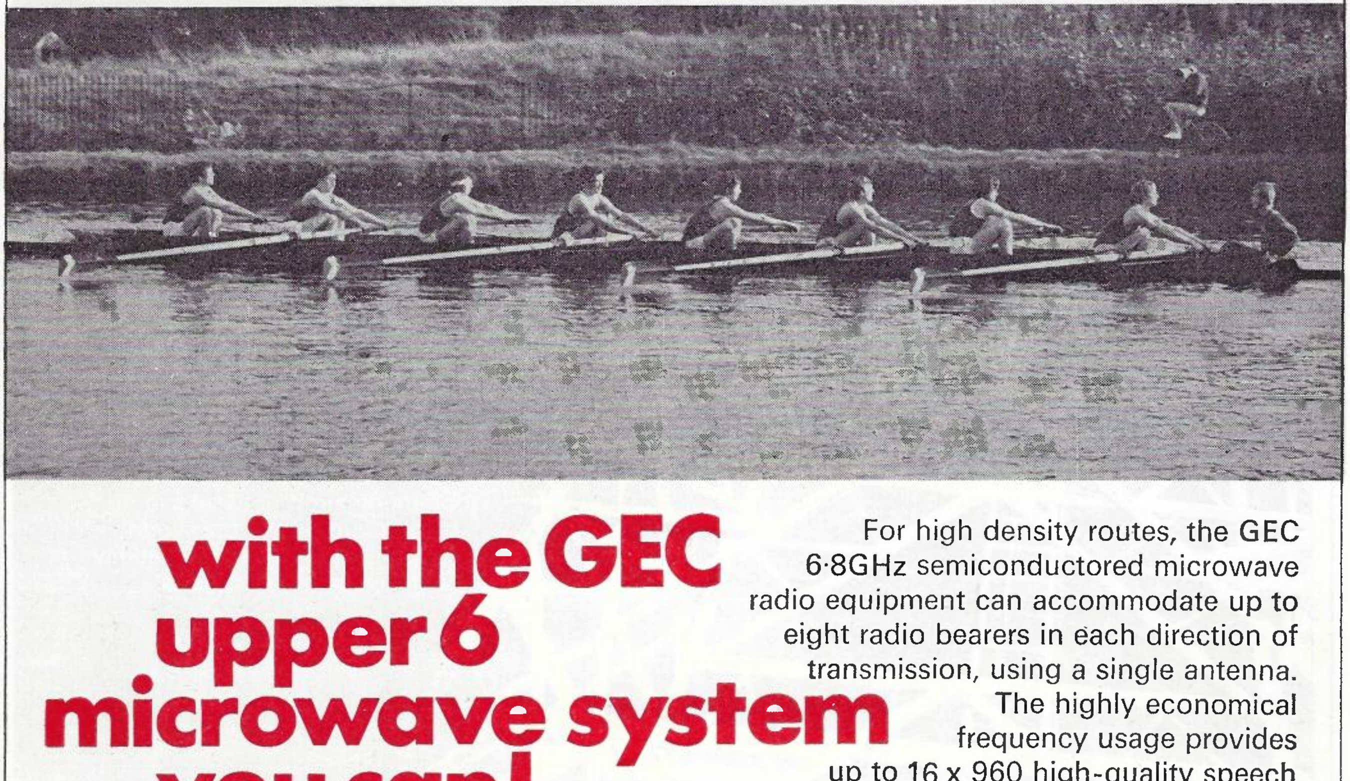

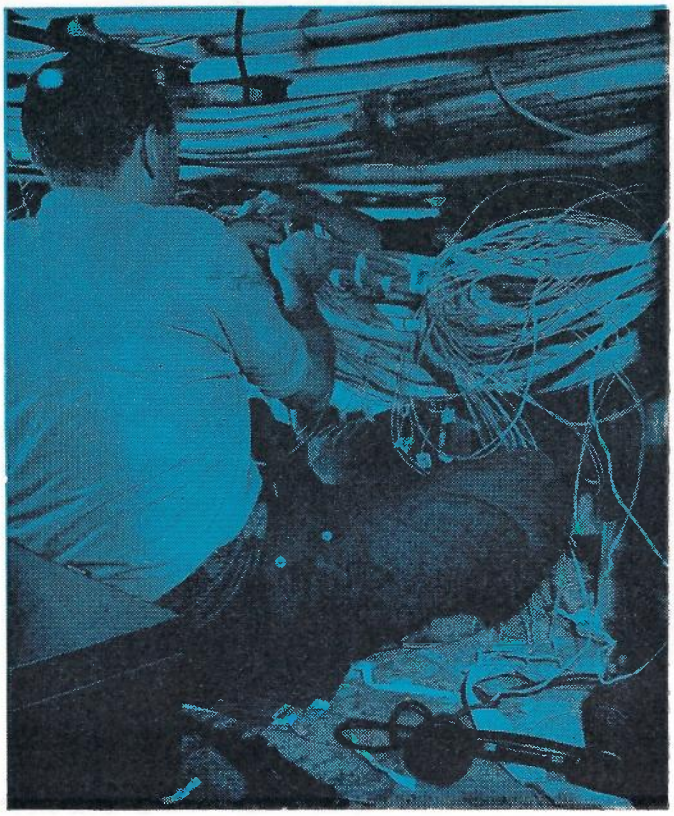

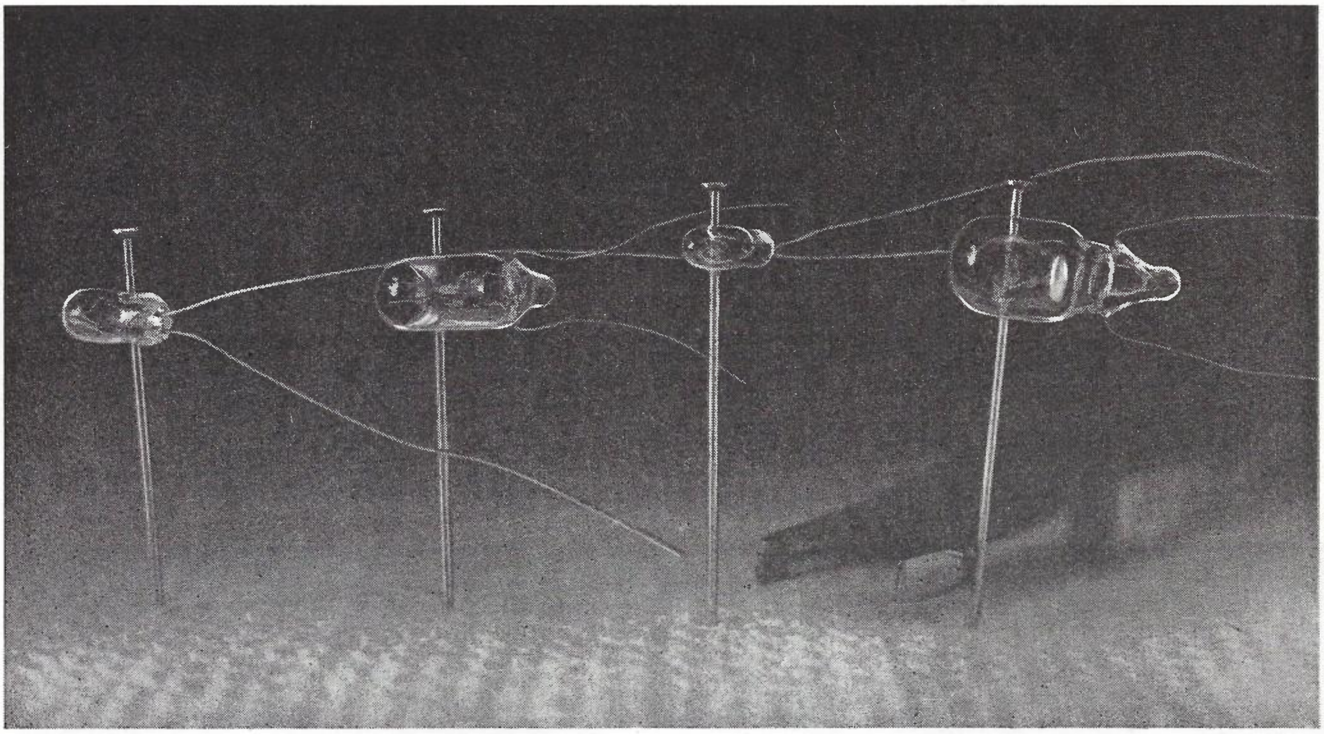

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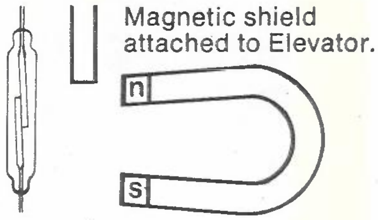
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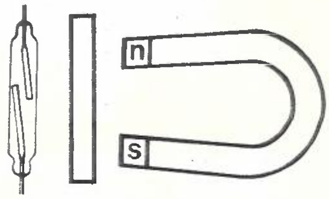
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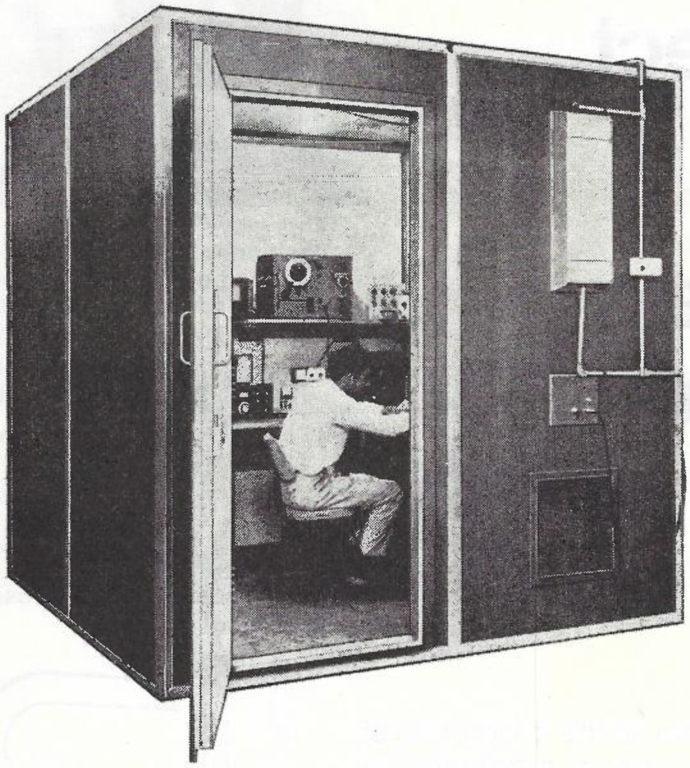

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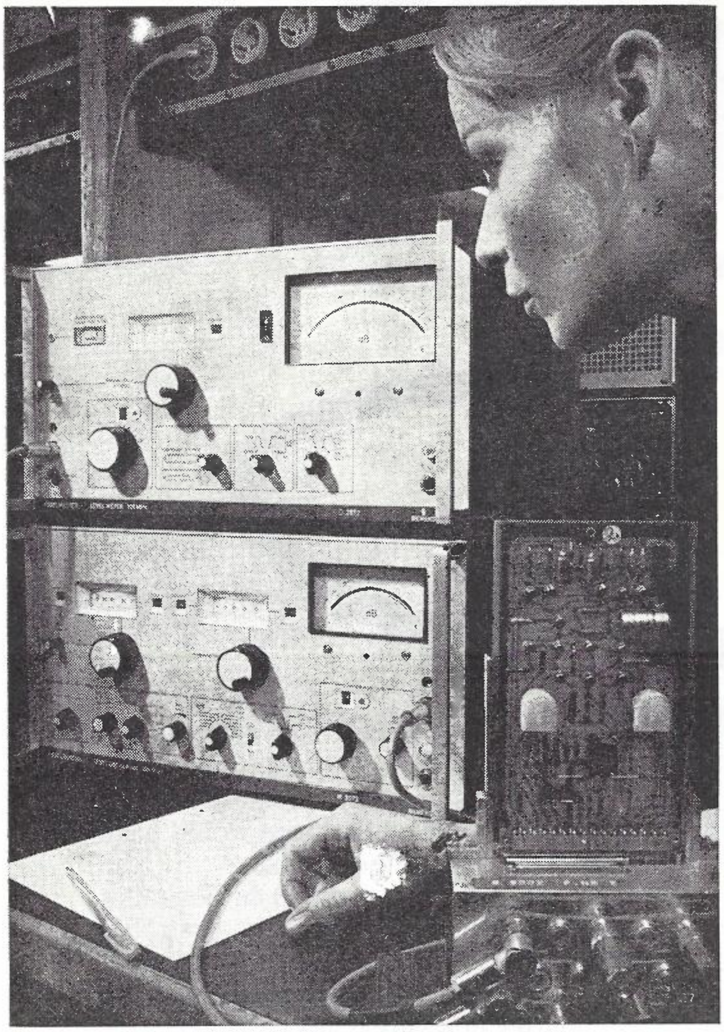

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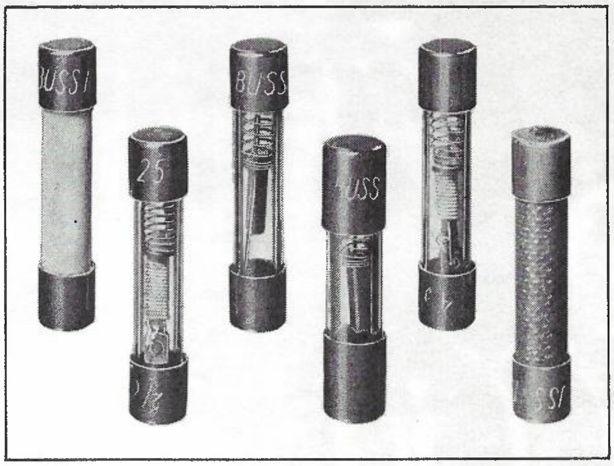

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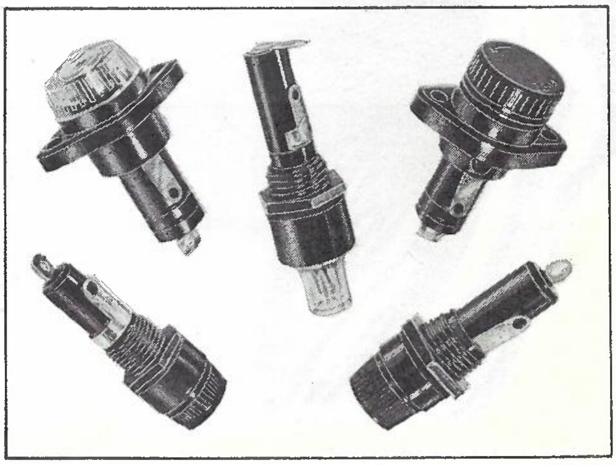

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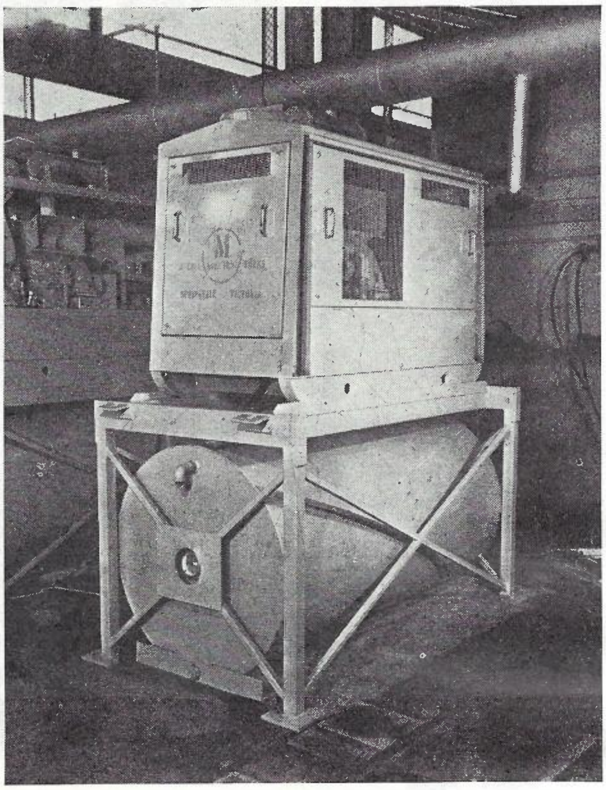

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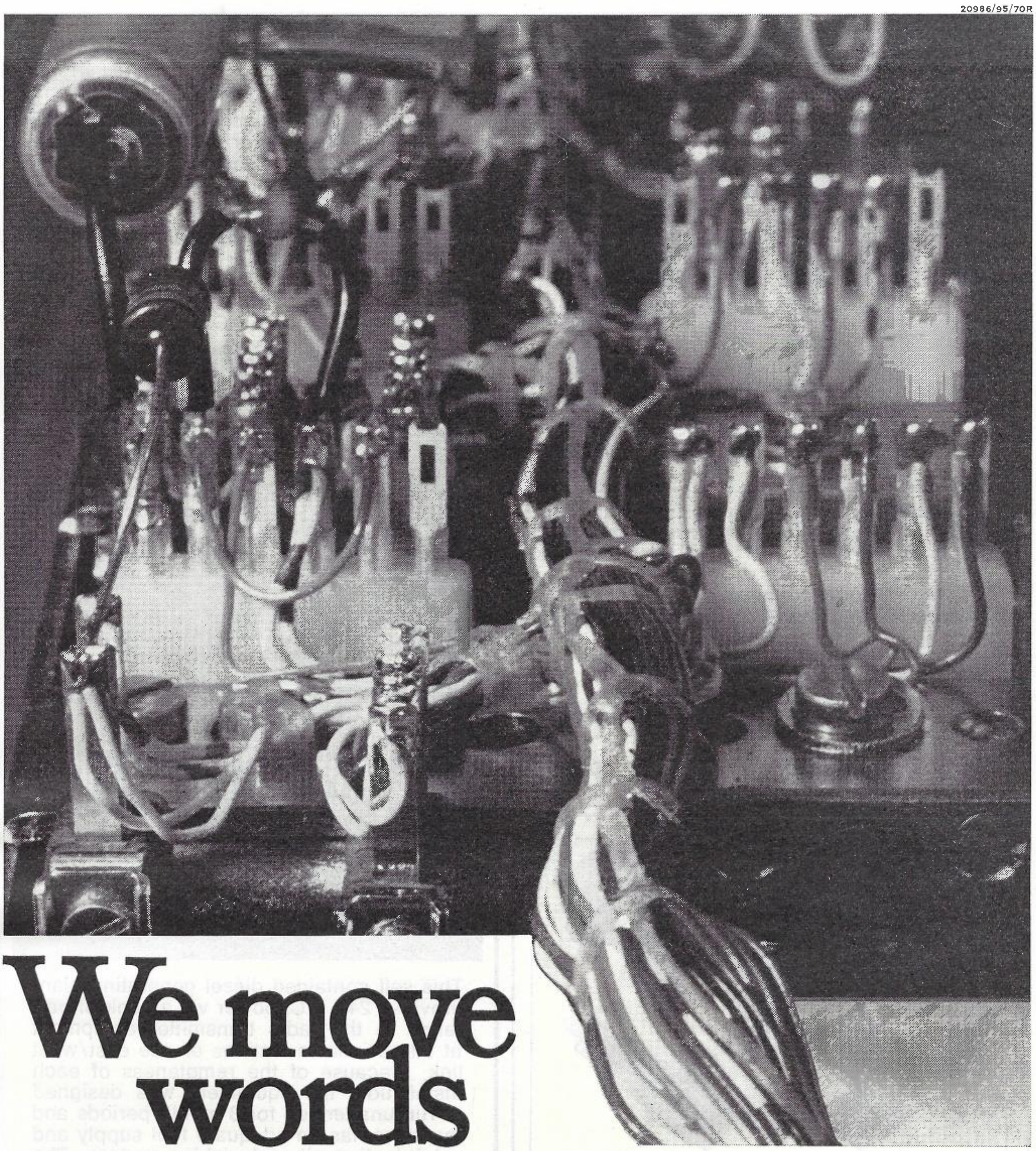

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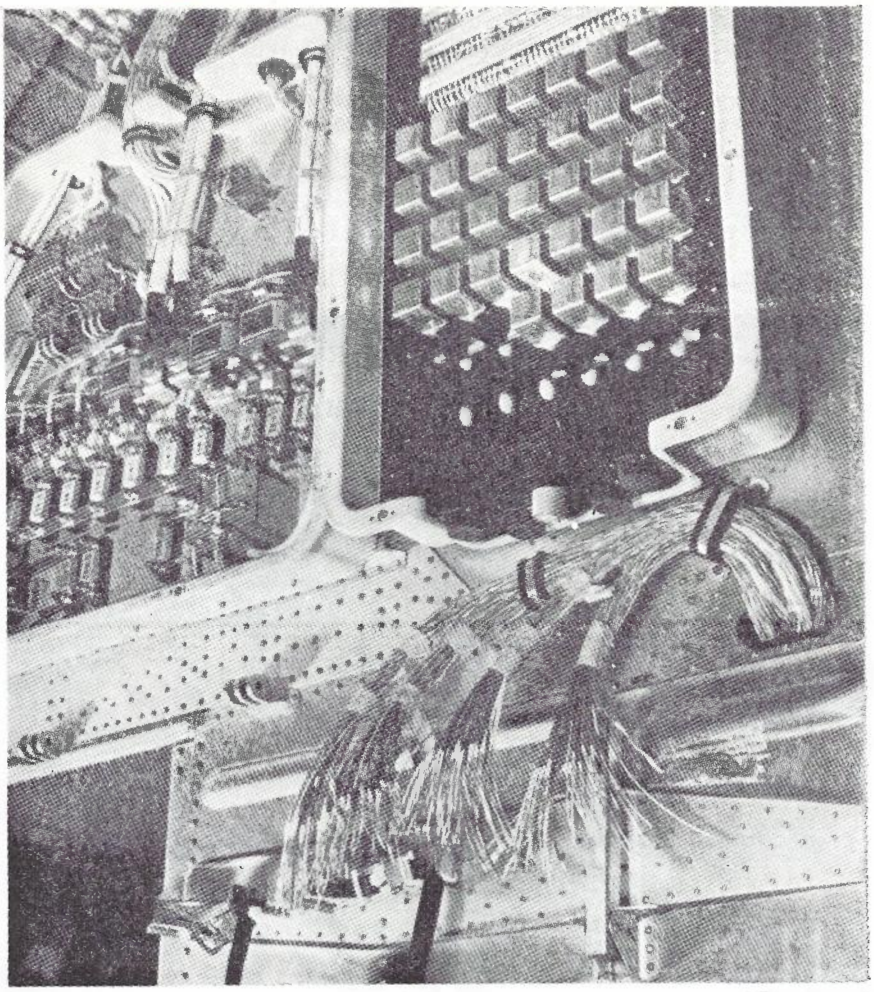

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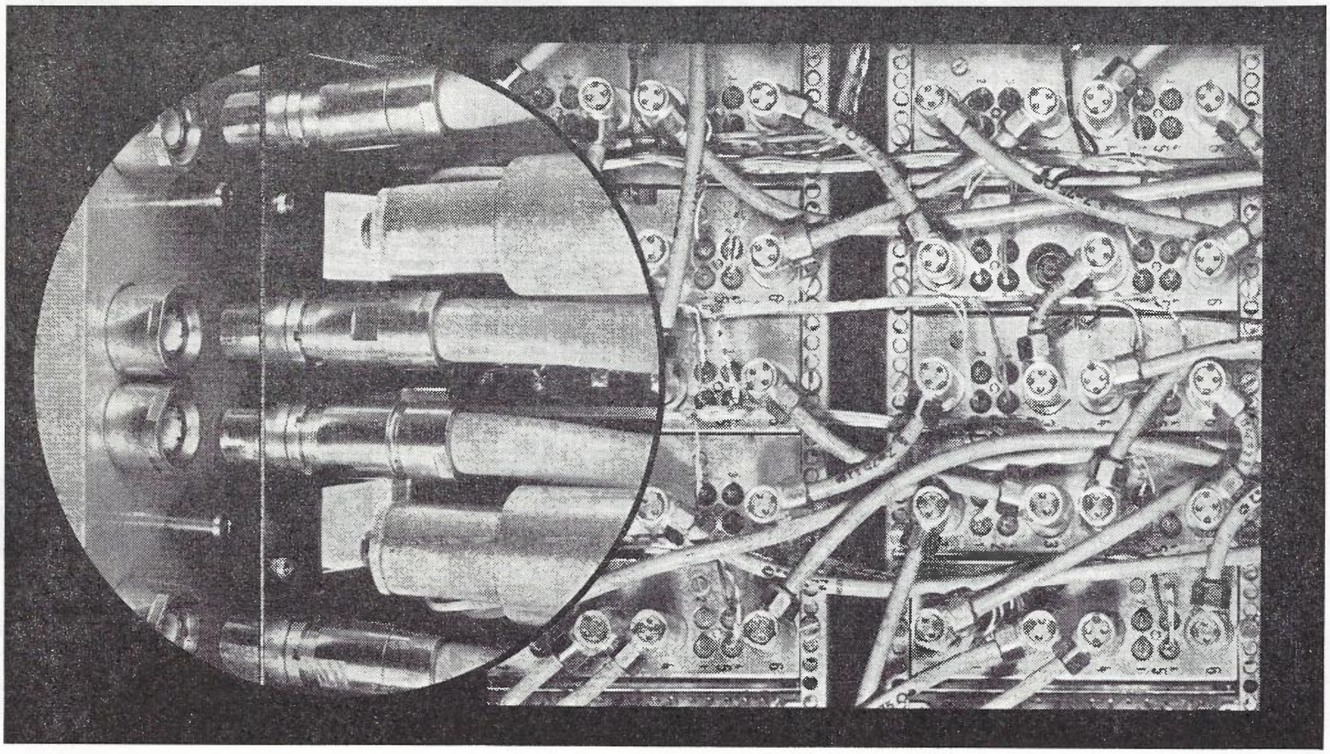

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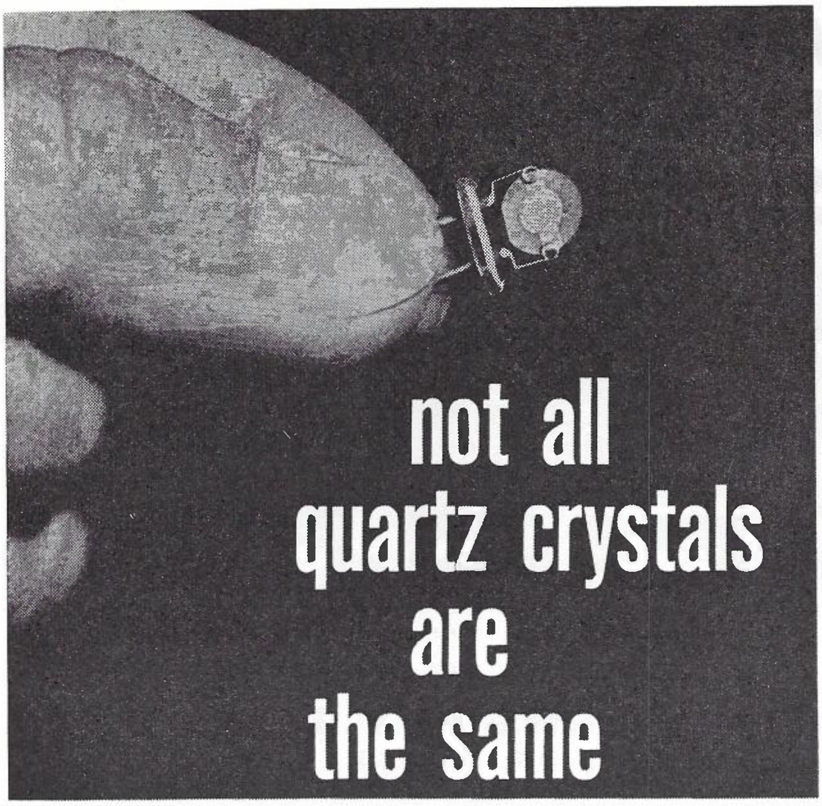

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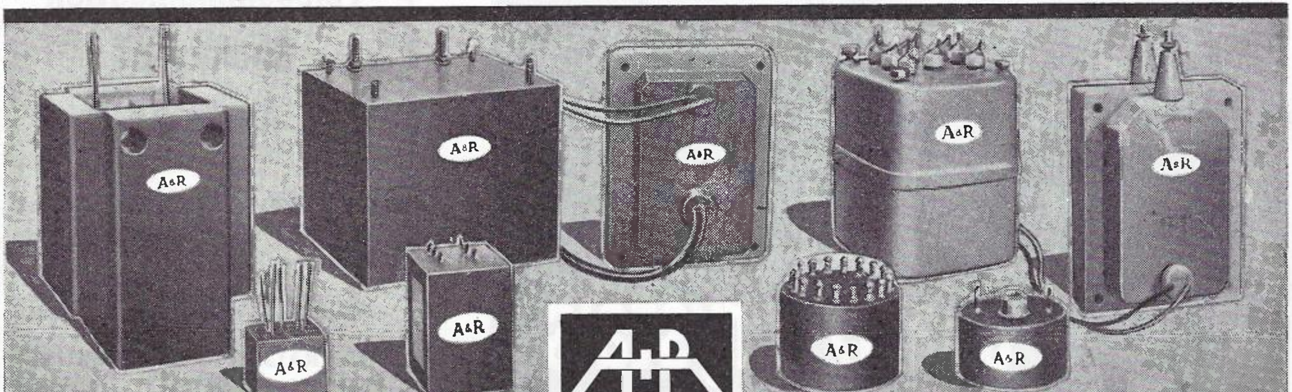
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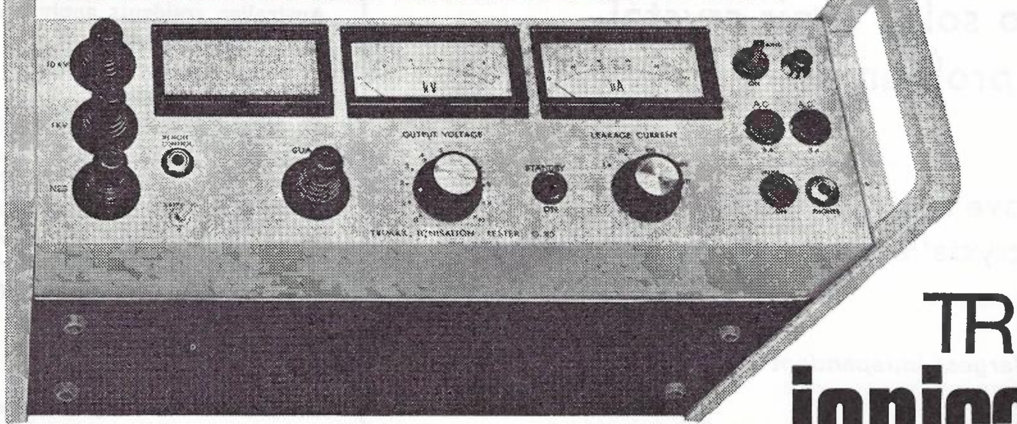
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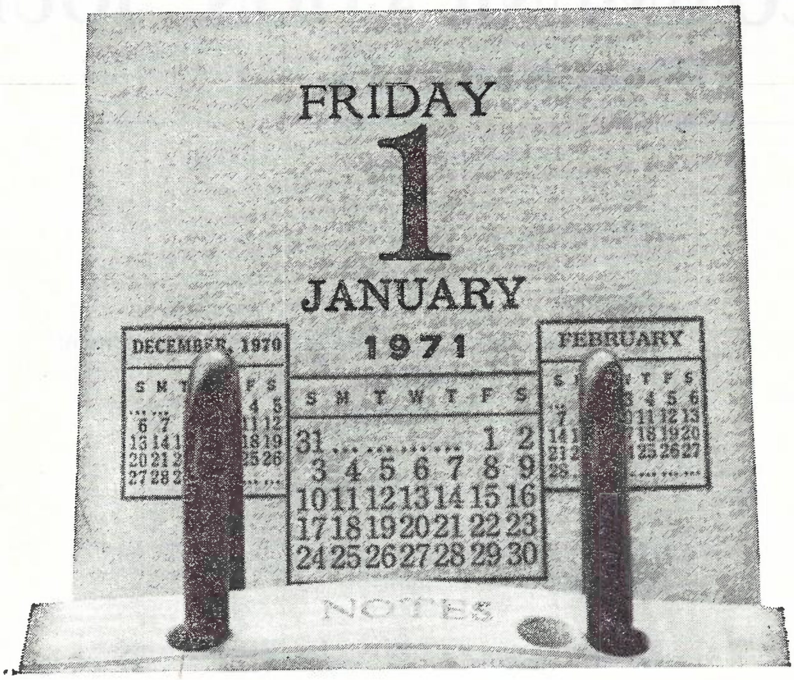

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The TELECOMMUNICATION JOURNAL of Australia

ABSTRACTS: Vol. 21, No. 3

BROOKER, E. L.: 'Antennas and Feeders'; Telecom. Journal of Aust., February 1971, page 72.

The paper outlines the electrical and mechanical design of the antennas and waveguide and of the incidental hardware. The performance and configuration of the test equipment is discussed in some detail. The specification for antenna and feeder VSWR and that of the combination is given, together with an analysis of the performance actually achieved on all 142 cases. Figures are also given for the gas leakage rate and the effect of waveguide hangers.

An outline is given of the installation programme including staffing and equipment complements, environment problems and special installation techniques. Particular mention is made of the procedures for bending and lifting the 2 GHz elliptical waveguide to avoid degradation of VSWR.

BYCZYNSKI, A. Z.: 'Testing the Prototype Equipment'; Telecom. Journal of Aust., February 1971, page 16.

Purpose of test of tenderer's production model and the final East-West prototype developed from it is briefly outlined. Special facilities for testing both models in the Radio Section Laboratory and programme of tests are described. Tests results, together with recommendation regarding required modifications to the equipment, are briefly discussed. Finally, joint A.P.O.-B.P.O. inspection and test of the East-West production equipment in the manufacturer's factory at Coventry is briefly discussed.

ELLIS, A. G.: 'Service Aspects'; Telecom. Journal of Aust., February 1971, page 95.

This paper discusses the basic maintenance philosophy of unit replacement in the field and equipment repair at special centres. Some detail is given on estimating spares quantities, the transportation of these spares and bearer reliability.

FAULKNER, A. H.: 'Operation and Maintenance'; Telecom. Journal of Aust., February 1971, page 99.

The paper gives a description of the facilities provided for the maintenance of the East-West microwave system, with a summary of maintenance experience during the first months after commissioning.

HOLDERNESS, A. L.: 'Power Plant'; Telecom. Journal of Aust., February 1971, page 80.

This article describes the power supply systems and equipment developed to supply d.c. power for the East-West broadband radio relay system. It covers the design of power equipment for remote areas where commercial mains are not available, and in particular it outlines the design and development principles used in incorporating diesel generators, wind driven generators and lead acid batteries into an integrated power system.

HUDSON, M. H.: 'Installation and Commissioning Requirements'; Telecom. Journal of Aust., February 1971, page 53.

This article describes the plan, its evolution, and execution, and deals with aspects of the operation which were unique to the East-West project. The plant and organisation associated with field activities are also emphasised.

HYAMSON, H. D., et al.: 'The Design and Development of the Radio and Associated Equuipment'; Telecom. Journal of Aust., February 1971, page 24.

Described in this article are the design and development details for the all-semiconductored equipment which provided the reliability and low power consumption so essential in the 2 GHz 600 channel East-West radio relay system.

KELMAN, R. N. and HOLMES, H. E.: 'Stressed Rock Anchor Antenna-Support Towers'; Telecom. Journal of Aust., February 1971, page 59.

A completely new type of tower foundation requiring extensive preliminary development was used at 40 of 60 sites on the East-West route. The design, development and construction of a stressed rock-anchor type foundation is detailed in the article. Brief mention is also given to the tower and waveguide runway design.

RICHARDS, R. W., and DONOVAN, J.: 'The Prime Contractors Role'; Telecom. Journal of Aust., February 1971, page 4.

The article includes a schematic of the system and illustrates one means of contract co-ordination employed by a company that has experience in overseas 'turnkey' contracts. An outline is given of the company's efforts relating to pre-tendering investigations and post-contract organisation associated with the East-West project.

ROBERTS, D. S. and PUGH, S. M.: 'A.P.O. Project Management'; Telecom. Journal of Aust., February 1971, page 8.

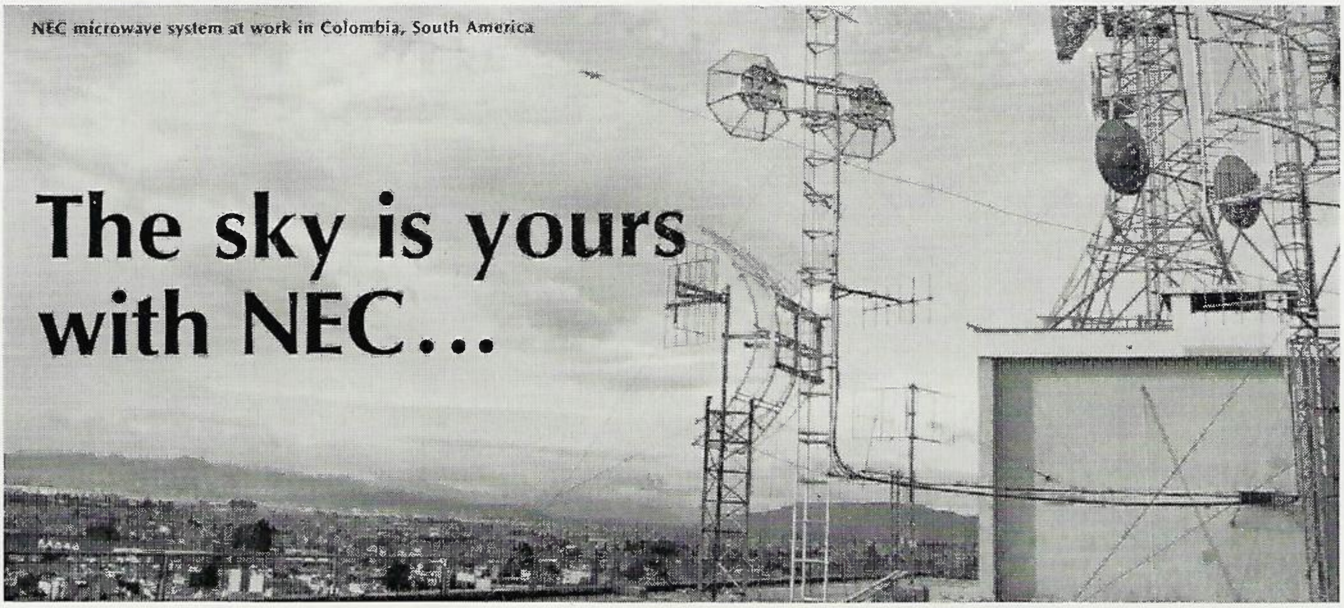
This article lilustrates the A.P.O. Headquarters and field aspects associated with the provision of sites, roads, commercial a.c. power, buildings, contract supervision and field inspection. The overall programme, cost estimates, staffing and proposals for in-traffic measurements are also detailed.

THOMAS, D. S., and SIGAL, B. M.: 'Environmentally Controlled Equipment Shelters'; Telecom. Journal of Aust., February 1971, page 66.

The successful completion of the East-West project has proved that the use of industralised transportable lightweight equipment shelters offers a practical solution to the problem of equipment accommodation and environmental temperature control in remote areas. This article describes the design, manufacture, transport and creation of the sun-shaded thin walled metal radio equipment shelter.

TOMLINSON, J. and SLATTERY, R. D.: 'Thermal Design of Naturally Cooled Shelters'; Telecom. Journal of Aust., February 1971, page 63.

The need for a specially designed equipment shelter because of long stretches of uninhabited country and wide range of climatic conditions, is described. The philosophy of the sun-shaded thin walled metal shelter evolved by the A.P.O. is outlined and the prototype test objectives and results to prove the basic design idea, are given. The shelter, as finally manufactured, was based on the thermal design described in the article.



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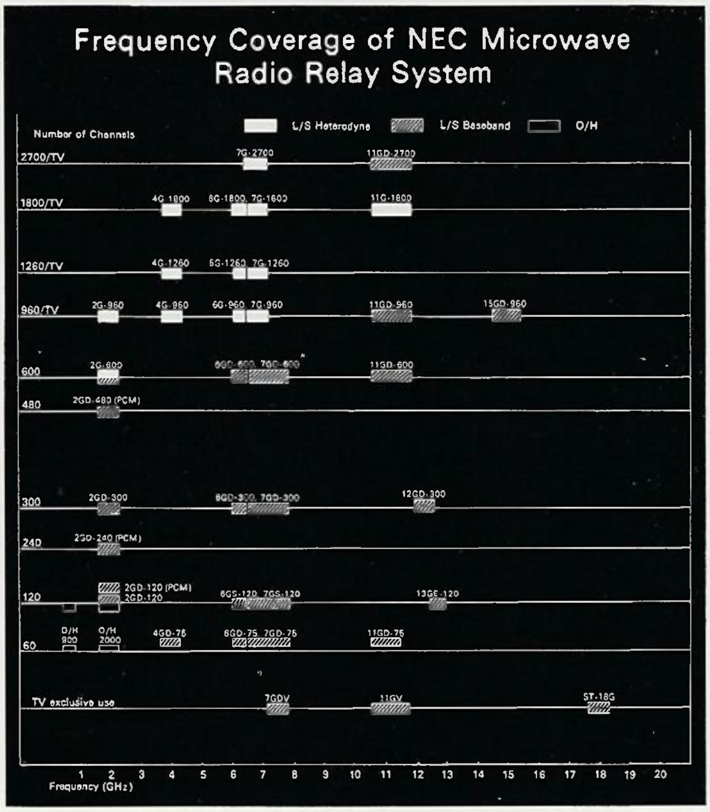

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