THE DARWIN-NHULUNBUY TROPOSPHERIC SCATTER SYSTEM — PART 2

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INTRODUCTION

Part 1 of this article in the previous issue of the Journal described the basic design considerations of the Darwin-Nhulunbuy system. This second part describes the equipment, power plant, accommodation, installation and maintenance aspects.

EQUIPMENT

The radio equipment for this system was manufactured by NEC in Japan and during its production it was examined and tested by an engineer from the APO.

The equipment types and their specifications are defined in Table 3 (see Part 1) and block diagrams of the system are shown in Figs. 7, 8 and 9. The basic equipment units which go to make up the system are as follows:

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(a) *Modulator (type MO-120-3B)*
120 frequency multiplexed circuits in the band 60 - 552 kHz and various sub-baseband circuits for supervisory and order wire purposes in the band 0 - 44 kHz, are fed into this unit which frequency modulates them on to a 70 MHz carrier. The modulator also incorporates pre-emphasis in accordance with CCIR recommendations.

(b) *Exciter (type TO-2G120-4A)*
The 70 MHz signal from the modulator is mixed in the exciter with a local oscillator signal in the band 2.4 to 2.7 GHz. The 2 GHz signal is generated by successive multiplications from a basic crystal frequency.

(c) *Power Amplifier (type PO-2G1K-5A)*
The power amplifier is the only unit in the system which uses a vacuum tube. The tube used in this particular instance is a four cavity klystron type LD4036. The klystron is fed with approximately 50 mW of RF power from the exciter and produces an output of 1 kW. The output of the klystron passes to the antenna via a band pass filter.

Since the klystron is a relatively narrow band device, tuning of each cavity is necessary when a new klystron is commissioned. Tuning requires the application of swept frequency techniques to optimise the amplitude characteristics of the tube. The replacement of a klystron therefore requires a considerable amount of test equipment — and is quite time consuming and consequently represents the most difficult aspect of maintenance operations in the field. The life of the klystron is guaranteed to be 8,000 hours and the cost of each tube is approximately $5000, so therefore it can be seen that

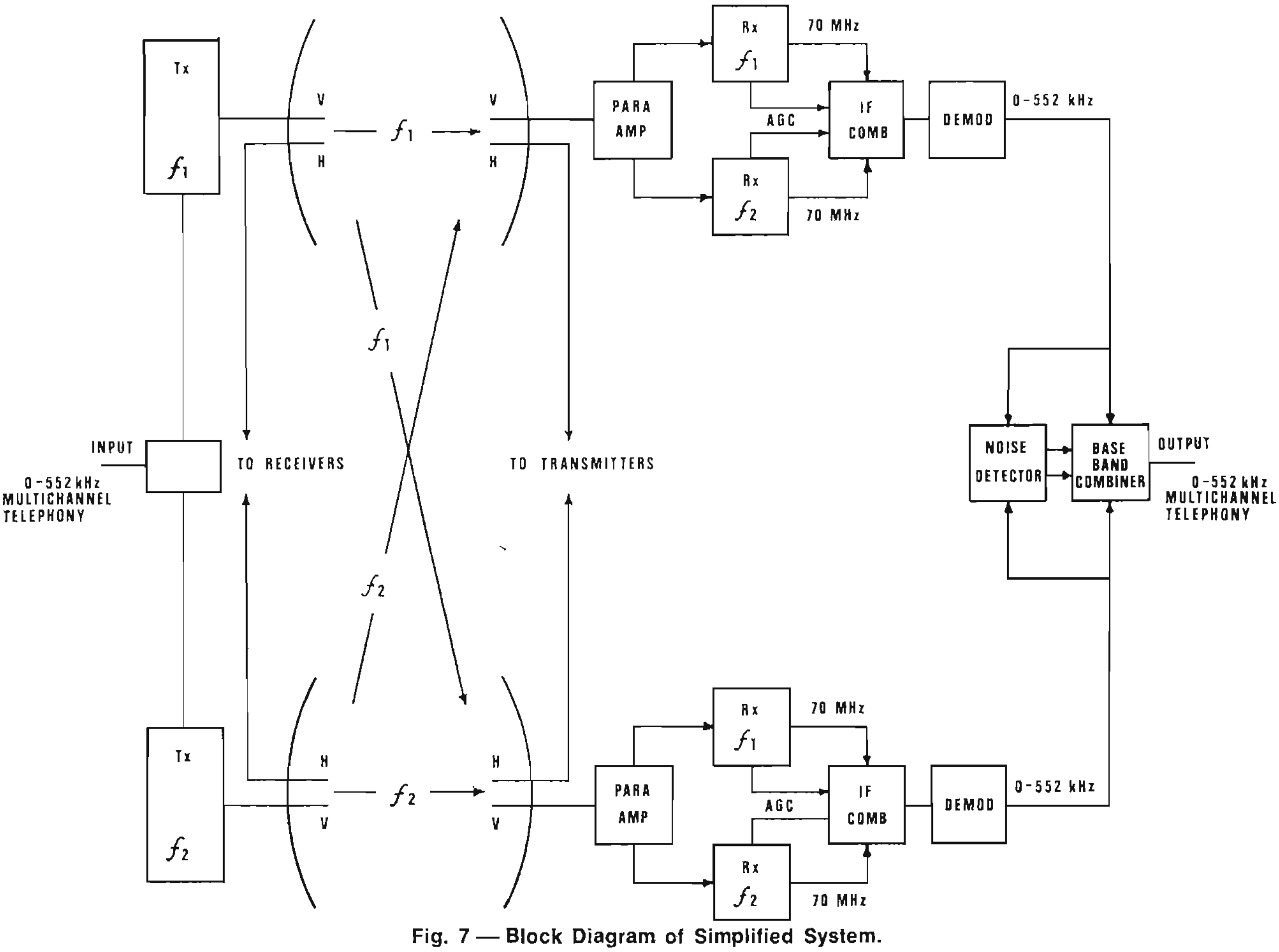

Fig. 7 — Block Diagram of Simplified System.

klystron replacements represent a significant portion of the operating costs of the system.

(d) *Low noise Amplifier (type RPO-2G120-4A)*
The low noise amplifier used in this system consists of a parametric amplifier followed by a transistor amplifier which, together give a noise factor of less than 2.5 dB and a gain greater than 22 dB. The parametric amplifier is pumped by an 18 GHz signal derived from a Gunn oscillator. This oscillator has an output power of +20 dBm. The low noise amplifier has a band width of 40 MHz and amplifies the two incoming RF channels which are 28 MHz apart.

(e) *Receiver (type RO-2GA120-4A)*
The receiver bay contains two down-converters, an IF combiner and a threshold extension demodulator. The down-converters mix the incoming RF signals with a local oscillator signal to produce two intermediate frequency signals of 70 MHz. These two IF signals are kept in phase by a phase detector which senses differences between the two signals and varies the phase of the local oscillator to maintain the correct phase relationship be-

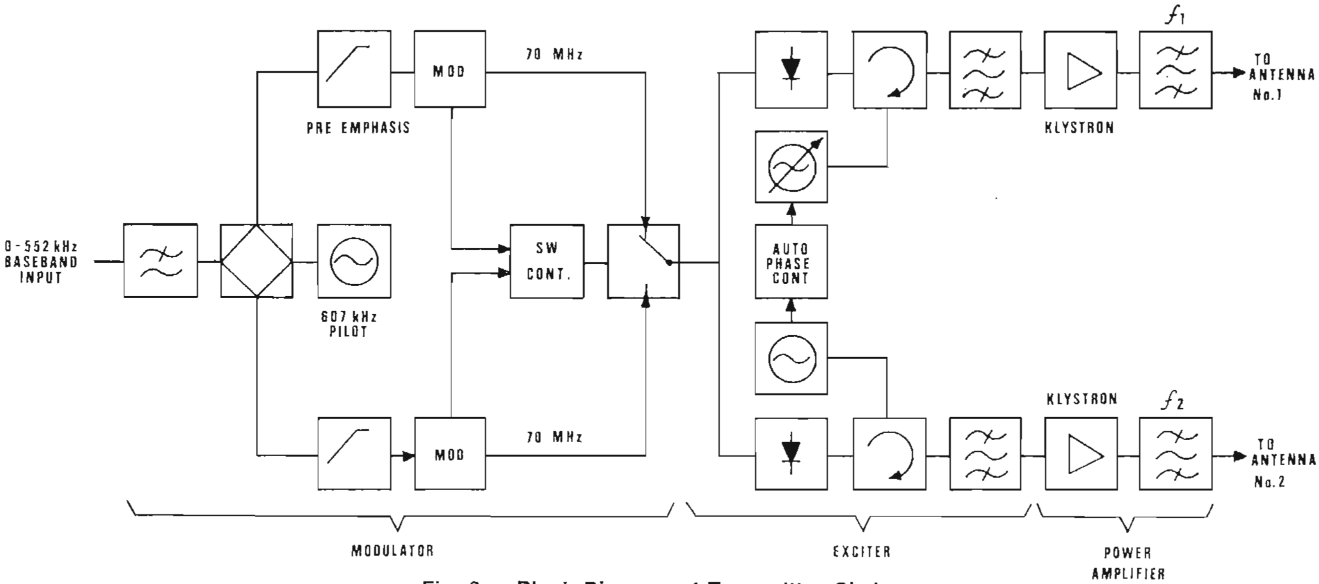

Fig. 8 — Block Diagram of Transmitter Chain.

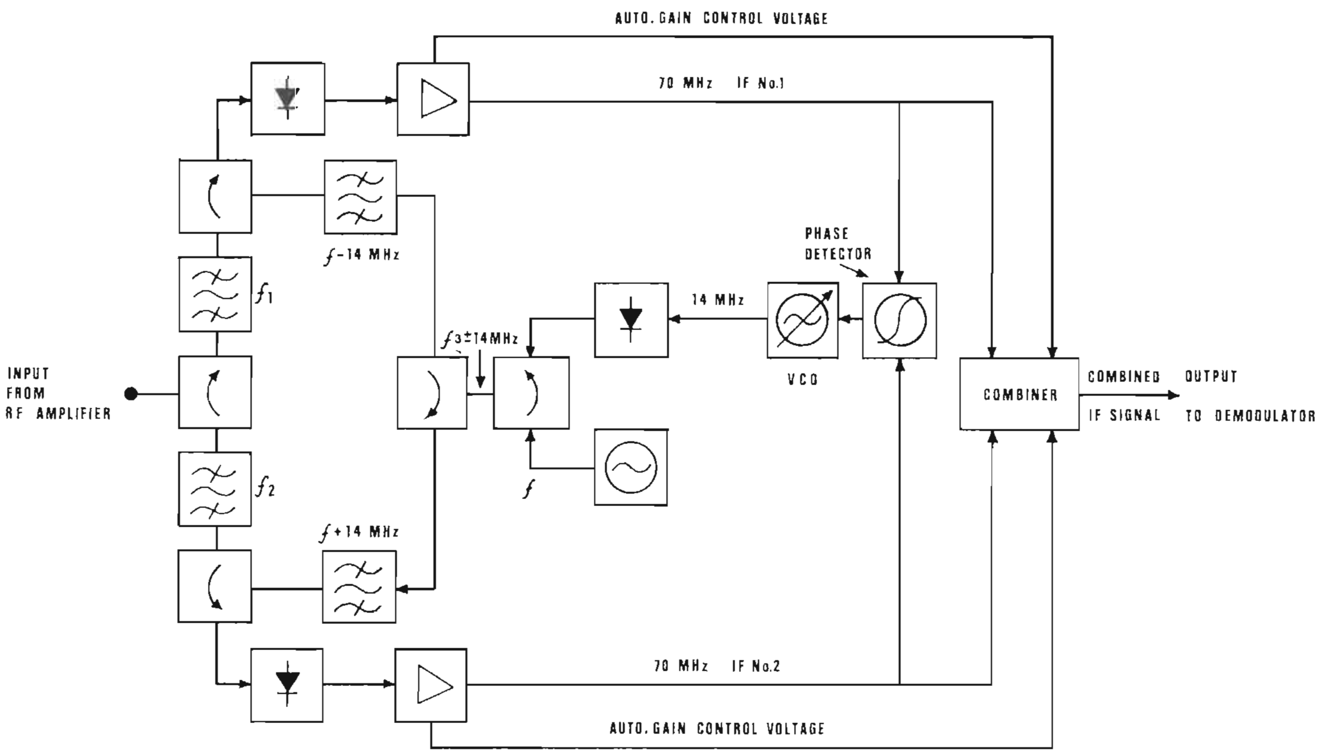

Fig. 9 — Block Diagram of Receiver.

tween the two signals. The phasing of the two signals is a necessary requirement for IF combining. The combination of the two signals is carried out in a non-linear adding circuit which derives its control voltages from the AGC circuits developed in each receiver. The output of the threshhold extension demodulator, which incorporates an appropriate de-emphasis network, is then fed to the baseband combiner.

(*f*) *Baseband Combiner* (*type CBO-120-3B*)
Baseband signals in the band 0 - 552 kHz from the two receiver chains are combined using ratio squaring techniques in the baseband combiner. Control voltages to determine the ratio of combination are derived from noise sensing circuits which measure, in effect, the top channel signal to noise ratio. The baseband combiner incorporates bypass and muting circuits to cope with failures within itself and high noise conditions on one of the receiver chains. The baseband combiner incorporates filters to remove the 607 kHz continuity pilot and to extract the sub-baseband circuits in the Band 0 - 44 kHz.

(*g*) *Supervisory Equipment* (*type NAR* 855, 856)
In order to satisfactorily monitor the system operation (see Equipment Maintenance section), it was necessary to provide supervisory equipment to indicate to the Darwin terminal the status of the system. In the first instance, the equipment provided 15 alarm indications from each station. However, this number proved to be inadequate for the maintenance policy to be adopted by the APO and modifications were made to the system to allow up to 28 alarms to be derived from the original supervisory equipment. The supervisory system extends alarms from the remote stations simply by identifying the particular station to the operator in Darwin who then interrogates that particular station.
All information is transmitted via a voice circuit derived from the sub-baseband system, which also provides omnibus and express order wires and wayside circuits which have been used to provide subscribers' services to the residents of Munmalary and Milingimbi.

(*h*) *Antennae*
The 10m and 12m antennae used on this system were made from sixteen panels bolted together to form a paraboloid on a galvanised steel structural frame. Each panel consists of an aluminium tube and angle frame covered with expanded aluminium mesh. A dual polarized horn is used as the illuminator which is supported at the focal point by 4 galvanized steel tubes. The specifications of each antenna are shown in Table 3.

Power Plant

It was decided to operate all the radio equipment from 3 phase 415-240 volts a.c. power because of the very high input power requirements of the power amplifiers which could not be accommodated by a battery installation. Some investigation was made into the provision of no-break plants but to supply up to 30 kVA from such plants in remote areas could have been troublesome, so the decision was made to provide primary a.c. power which was backed up by normally stationary diesel alternators.

Power Requirements

The A.C. input power of a typical repeater station is shown in Table 4.

The consumption of a terminal is approximately half that shown in Table 4 (11,029 VA).

Power Supplies

(*a*) *Darwin*
At the Darwin (Cox Peninsula) terminal, the station derives its a.c. input power from the essential bus provided for the Radio Australia receiving station. An emergency plant automatically starts to supply the whole receiver station and the Tropospheric Scatter terminal after a mains fail.

(*b*) *Munmalary*
At Munmalary the site is so remote that no commercial or private mains power is available and consequently provision had to be made to generate sufficient power locally. To cater for the power consumption as shown in Table 4, it was necessary to install 35kVA diesel generating plants. The power shelter layout is shown in Fig. 10.

This power generation installation had to be properly engineered to provide an extremely reliable supply. For this reason three diesel alternators were installed and incorporated a sequential start up procedure in the event of failure of one or two machines. The diesel engines (Lister HR6) were designed for continuous running and oil make-up tanks with float valve regulators were provided to obviate frequent oil changes and to allow the machines to run unattended for at least six weeks.

Fuel supplies for this site also presented considerable problems since the site was inaccessible for up to six months of the year during the wet season and so a 10,000 gallon overhead fuel storage facility had to be provided.

(*c*) *Milingimbi*
At Milingimbi Island, an agreement was reached with the local mission station that a.c. power would be available from their own supply and because of this a two mile underground cable was laid to connect the repeater station and the mission power house. To guard against failure of the primary supply, two 35kVA diesel emergency plants were installed. The diesels are arranged to start sequentially in the event of the failure of the first machine.

TABLE 4.—INPUT POWER FOR TYPICAL REPEATER

Bay/Unit	Number	Consumption/ Unit (V.A.)	Total (V.A.)
Parametric Amplifier	4	61	244
Receiver/Demodulator	4	96	384
Baseband Combiner	2	20	40
Modulator	2	46	92
Exciter	2	129	258
Power Amplifier	4	4,540	18,160
Dehydrator	1	20	20
Supervisory & Sub-baseband	1	20	20
Miscellaneous	—	—	400
Air Blower	1	3,024	3,024
Test Equipment (Intermittent)	—	—	1,000
Total			23,642

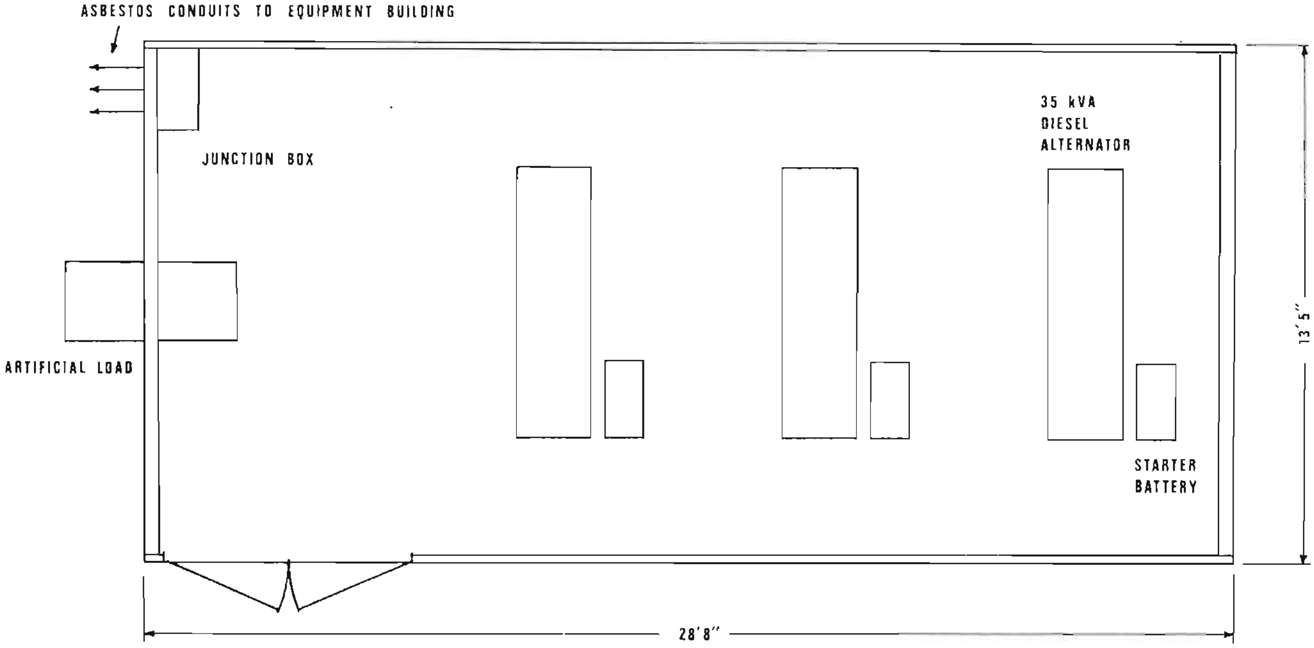

Fig. 10 — Power Shelter Layout.

Because of certain difficulties regarding the supply of power from the mission, these two diesel alternators have been required to run continuously since the system was first installed and consequently provision had to be made to allow them to run in this way. However, this state of affairs is temporary only and it is expected that the station will run on mains supply from March 1972.

(*d*) *Nhulunbuy*

At Nhulunbuy, commercial mains supply is available to the terminal station from an adjacent 22kV line. Unfortunately this line feeds power to a conveyor system, large compressors and primary crushing plants, most of which utilise direct-on-line starting which causes severe voltage fluctuations. In order to overcome these variations, which are too fast and too large to be controlled satisfactorily by an electronic or magnetic regulator, a 15kVA motor alternator set was installed. This motor alternator set acts as a buffer between the station load and the mains supply. The set consists of a

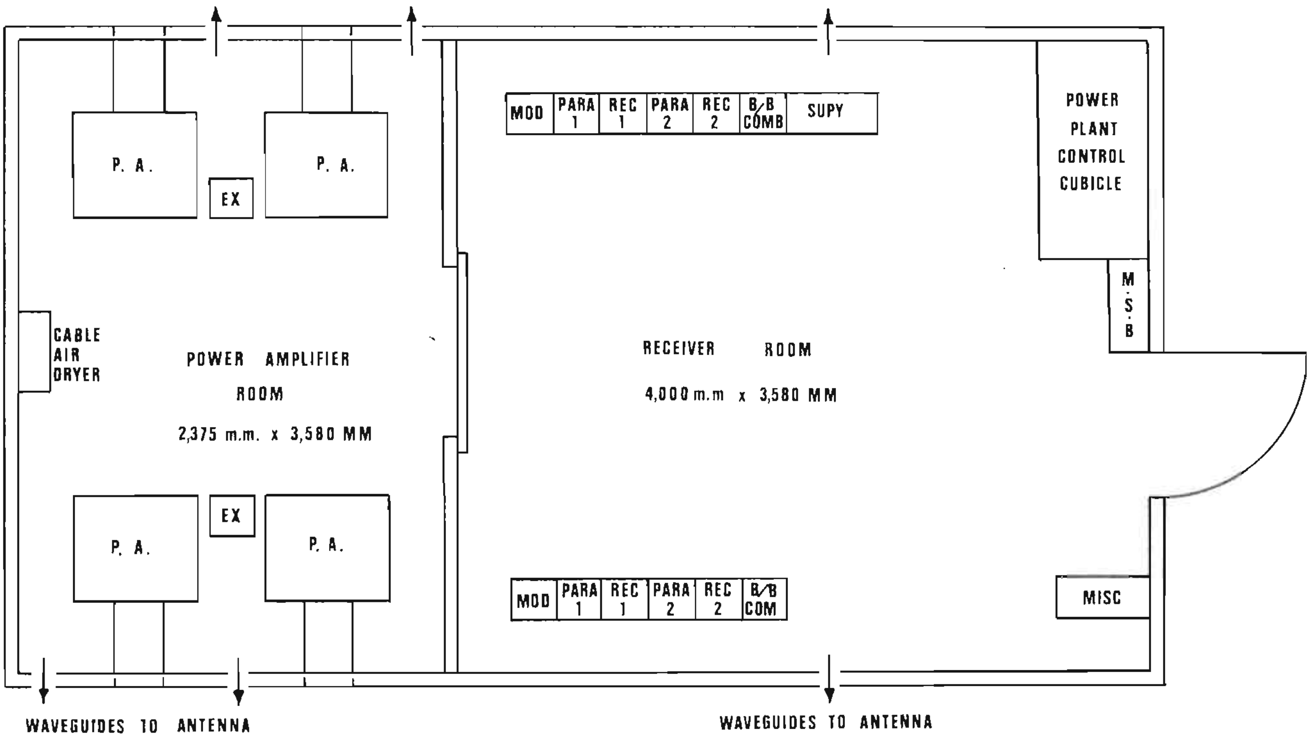

Fig. 11 — Equipment Shelter Layout.

25 h.p. induction motor driving a 15kVA alternator.

The motor alternator can be automatically or manually bypassed if a fault occurs in it and two automatic start diesel alternators are also provided in the event of mains failure. One of these two sets is in fact held as a replacement unit for any of the sets installed on the route. If a major fault occurs in a plant at either Munmalary or Milingimbi, facilities are available to transport the spare set by barge to either of those two sites.

POWER PLANT BUILDINGS

The power plant at all sites is housed in prefabricated sheds which were manufactured in Adelaide. These sheds are of open construction and allow free air circulation to cool the diesel alternators. This environment is unsuitable for the control cubicle and its related equipment so these units are installed within the dust free environment of the equipment building.

EQUIPMENT BUILDINGS

Because of the short lead time in the provision of the system, transportable steel framed buildings were chosen to house the equipment. These buildings are of a type which is in common use in South Australia to house large country automatic exchanges. The floor dimensions of these buildings are 21 ft. by 12 ft., and the layout of equipment at a typical repeater station is shown in Fig. 11.

The building design was extensively modified to suit tropical conditions and was painted with a highly reflective long life vinyl paint to reduce surface temperatures. The buildings were also insulated with fibre glass, but this insulation is not entirely necessary for the satisfactory operation of the buildings, since no attempt is made to aircondition them. The heat dissipation within the building is extremely high (approximately 8.6 kW) and so it is obvious that with the power supply available there is no possibility of using demand air conditioning. However, the equipment temperature must be maintained below 45°C which in the worst case allows an approximately 5°C temperature rise above ambient within the building. In order to achieve this relatively low temperature differential, large blowers have been installed to circulate air through the building. The volume of air required is 4000 cu. ft. per minute and this is obtained by using 19 in. axial duct fans.

In order to limit the amount of dust ingested during the dry season and water during the wet season, an extensive air filtration system is utilised. Firstly, the air passes over turbulence inducing louvres which precipitate most of the air-borne water. The remainder of this water and some dust is removed in a viscous filter which follows the louvres. This filter in turn is followed by an automatic advance roller filter using a fibre glass medium.

The buildings were manufactured in Brisbane and transported to Darwin where the majority of equipment was installed in them. Subsequently they were transported to each of the sites by road or barge as described in the installation section of this article.

INSTALLATION AND TESTING

Because of the remoteness and inaccessibility of the system, installation and testing provided not only the usual technical problems, but also rather unusual logistic problems. The general installation problem was tackled by carrying out as much work as possible in Darwin and then transporting completed items, usually in parts, to site and re-assembling them. All materials for Millingimbi and Nhulunbuy were brought in by barge while men were usually moved by charter aircraft. The installation pro-

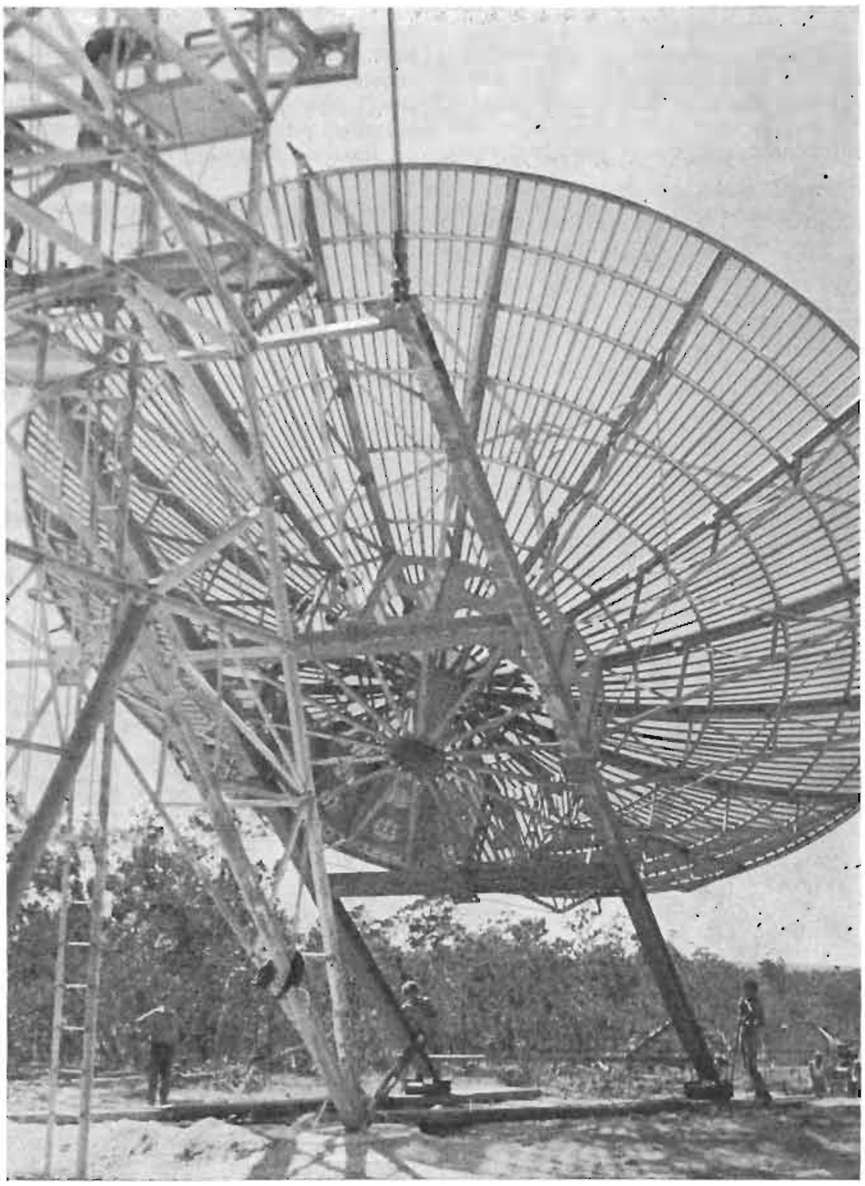

Fig. 12 — Lifting 12m Dish at Munmalary.

gramme was timed so that all heavy construction work was carried out during the period April to September 1971 so that Munmalary and Cox Peninsula were accessible by road. Because of the remoteness of all sites and the complete absence of any reliable and readily available communication system the APO provided a H.F. network utilising AWA SS 220 H.F. transceivers. This system was used extensively by both the APO and contractors and, without it, the project would not have been completed on schedule.

TOWERS AND ANTENNAE

The installation of towers, antennae, earthing system and all foundations was carried out by Electric Power Transmission Pty. Ltd. (EPT) of Sydney operating as sub-contractors to NEC Australia. EPT commenced work at Nhulunbuy late in April 1971 only a few days after the site works and access road had been completed. The installation of the towers presented no difficulties but the assembly of the parabolic dishes and their installation on the towers caused a number of technical problems. The surface accuracy of the reflector had to be within ± 5 mm so that great care had to be taken during assembly and installation. The antenna was checked by measuring the radial distances from the feed horn to points on equal chord distances from the parabola's centre. The problem of distortion during erection was overcome by utilising a heavy erection frame on which the dish was assembled and, after careful checking, lifted into position. A 30 ft. extension was added to the basic antenna support tower, and this enabled the frame plus antenna to be lifted into position by means of winches. An intermediate stage in the antenna erection procedure is shown in Fig. 12. Once in position the frame was dismantled and the antenna was attached to the tower by its four mounting points.

Since all sites are in areas with extremely high isoceraunic levels, extensive earth systems were designed by the APO and installed by EPT to bring earth resistances below 5 ohms. Installation by EPT took approximately one month per station and was completed by late August, 1971.

POWER INSTALLATION

This installation was carried out by APO staff and followed EPT across from Gove since it took approximately three weeks to erect the power shelter, install the plants and control cubicles and finally test the power installation.

EQUIPMENT INSTALLATION

The equipment shelters were handed to NEC for equipment installation in Darwin on April 18th, 1972. NEC and APO staff then completely installed and tested the equipment in each shelter. Once all shelters were completed and all equipment operated

Fig. 13 — Loading Milingimbi Shelter on Barge at Darwin.

correctly, simulated hop tests were carried out by interconnecting transmitters and receivers via lossy cables. In this way all possible tests were carried out to ensure that the system would operate satisfactorily.

Since the shelters are not airconditioned, the performance of the equipment up to its guarantee limit of 45°C (113°F) was of vital concern. During factory tests NEC had heat cycled all panels but the APO insisted on an additional test to ensure that no interface problems arose during operating conditions. Consequently each shelter was heat cycled twice between ambient temperature and 45°C and kept at 45°C for 14 hours. During this temperature cycling the line-up levels of the equipment, its noise performance and all in built meter readings were monitored, also the base band was continuously scanned for spurious signals but none was found above the threshold noise level. After completely testing the system on a hop basis all panels were removed and repacked for transport to site.

Transporting of the shelter to site proved one of the major problems since by their sheer size and weight they are best handled by large cranes both during loading and unloading. The problem was finally overcome by shipping the shelters to Nhulunbuy and Milingimbi on trucks which drove from the barge to site and were unloaded by using four heavy duty jacks. The loading of truck and shelter onto a barge for transport to Milingimbi is shown in Fig. 13. The shelters for Munmalary and Cox Peninsula were shipped on low loader and also unloaded utilising the jacking technique. Cranes were used to load the shelters onto the low-loaders in Darwin (see Fig. 14). The trip to Munmalary proved to be the most difficult, since the road was narrow and obstructed by overhanging trees. It took five days to travel the last 100 miles to the site.

As each shelter was installed on its foundations APO staff installed the power control cubicles in them to provide continuous power. Again instation tests were carried out and no marked variations from the Darwin tests were found. Before hop tests could commence the 10 and 12 metre paraboloids had to be adjusted to obtain best received signal strength. The paraboloid could be panned in the azimuth for ±2.5° by means of two large azimuth adjusting screws, while in the vertical plane the beam was shifted by changing the position of the illuminator. The vertical adjustment was ±1.5°. Due to the variable nature of the received signal it was recorded for approximately 15 minutes and its average level used in determination of received signals level against angular position. It took four to six days per hop to adjust all four antennae.

Hop tests were carried out commencing September 1971 and, except for overall total signal to noise, the results were as expected.

Fig. 14 — Loading Fully Equipped Shelter for Nhulunbuy at Darwin Depot.

SYSTEM MAINTENANCE

The problem of system maintenance had to be given special consideration since each maintenance trip involves the use of charter aircraft. Since it employs quadruple diversity the system has a high degree of redundancy, and will therefore continue to carry traffic, with perhaps slightly degraded noise performance, while the faulty unit is repaired.

To enable effective supervision of the system from its control station, 28 alarms per station are extended on the sub-baseband. These alarms enable the route controller to identify a group of panels constituting a 'maintenance unit' which is then despatched with the maintenance staff. Adjustments on site are restricted to klystron, all other panels being replaced on a plug-in basis, with repair being carried out in the depot-spare and repair facility established at Cox Peninsula Radio Australia receiver site.

The major problem to system reliability arises from the power plant. Due to locality and maintenance problems as well as power requirement (30 kVA) the installation of no-break plant was ruled out during initial investigation into system feasibility. Hence should our primary power supply fail there will be a power break varying of 0.5 sec. to 8 sec. depending on control circuits for the power plants. Since any power break beyond 2 sec. necessitates the complete preheat cycle of the klystron of two minutes, considerable traffic time can be lost during automatic diesel change-overs. If all diesels should fail the station and with it the system closes down. The only communication in that case is via the H.F. emergency order wire, which utilises battery operated AWA SS 220 transceivers and operates between the repeaters, Nhulunbuy and Darwin. As well as the above emergency orderwire, the route controller at Cox Peninsula also has an omnibus order wire, an express order wire direct to the Nhulunbuy exchange and also has access to two official services installed at Milingimbi and Munmalary. The latter enable communication between APO staff and the nearest available help in case of fire alarms or similar problems. While the remoteness and inaccessibility of stations are proving a problem, system performance, except for some power plant problems, over the first three months of operation has been gratifying with no equipment faults occurring.

Until the time of writing the only problem encountered during the operation of the system has been the frequent failure of the Gunn oscillator which is the 18 GHz pump source for the parametric amplifier. A total of eight of these units failed before the fault was traced to unsatisfactory mounts for the Gunn diode. This has been rectified and none of the modified units has failed. The overall signal to noise ratio for each hop just met the specification and since according to Unthank and Barton (Ref. 7) the tests were being carried out during the best time of the year, this caused considerable concern. Since hop tests were of necessity short (two days only) it was decided that no action could be taken until more data was available. Another factor brought out during these tests was that the 1 kW klystron was difficult to adjust and had to be adjusted to obtain minimum S/N on an internal R.F. loop using a 116 MHz frequency shifter. This meant that for future replacement, the departmental policy of 'plug in' replacements without adjustments could not be used for these units.

A detailed investigation showed that the klystron exhibited a very steep parabolic group delay characteristic which was sufficiently constant from tube to tube to allow correction by a fixed IF equaliser between modulator and exciter. This was suggested as a solution to NEC, but subsequent system modifications removed the necessity of group delay equalisers.

Overall system tests commenced late October 1971 and after approximately one week of noise recording it was obvious that the deviation per channel had to be reduced to reduce path intermodulation noise. In accordance with CCIR Report 446 (New Delhi 1970), the deviation per channel was optimised to achieve the best balance between thermal and path intermodulation noise. The deviation was reduced from 1 to 0.6 radian channel. This had the two-fold effect of improving system noise performance as is shown in Figs. 15 and 16, and secondly it largely eliminated the klystron intermodulation problem.

Overall system tests were completed on 20th December, 1971 and the system began carrying interim traffic, awaiting completion of the Nhulunbuy crossbar exchange on 24th December, 1971.

CONCLUSIONS

Since the Darwin to Nhulunbuy tropospheric scatter system was the first of its type in Australia it was necessary for the APO to learn much about the installation and operation of this type of system in a short time

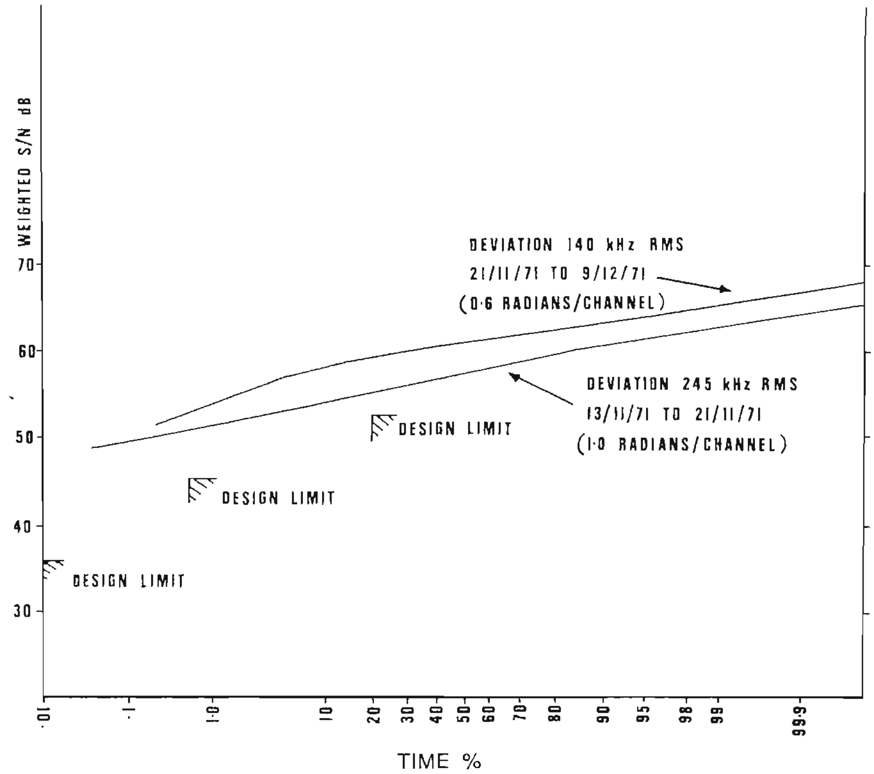

Fig. 15 — One Minute Mean Signal to Noise (Darwin to Nhulunbuy).

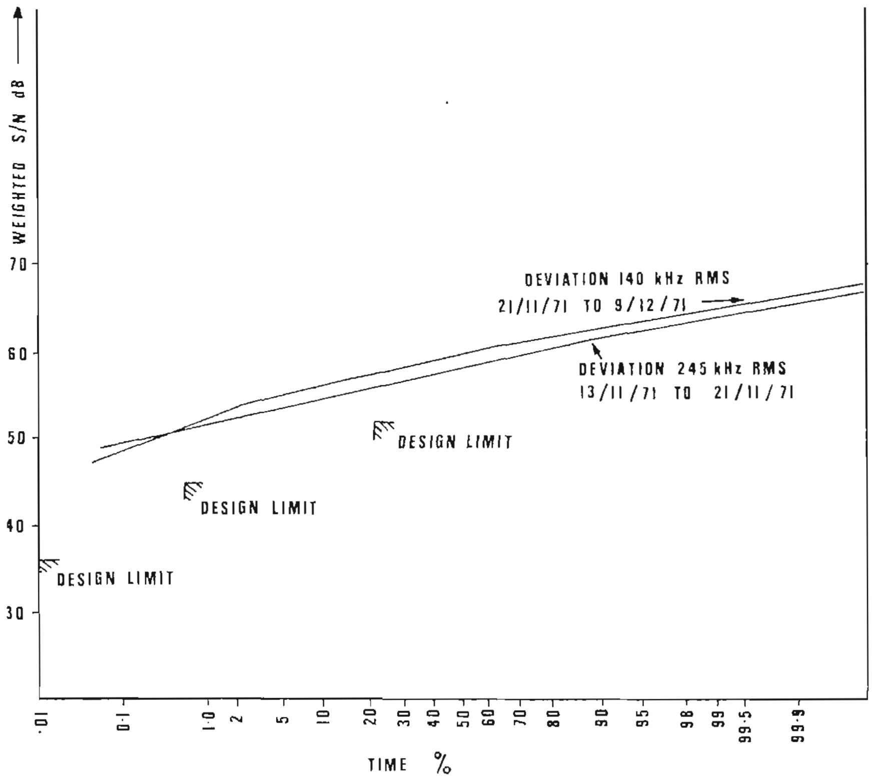

Fig. 16 — One Minute Mean Signal to Noise (Nhulunbuy to Darwin).

and with the assistance of its contractors was able to install a satisfactory and well engineered system. The system met its specifications and is continuing to operate satisfactorily despite the remoteness of the sites and the harsh conditions in which it operates.

ACKNOWLEDGMENTS

The authors, who controlled the installation of the system, are particularly grateful for the co-operation received from the engineers and technicians working with NEC, since it was through them that we learnt so much about tropospheric scatter systems and problems associated with the equipment. The authors are also grateful to the residents of Munmalary Station and Milingimbi Mission for the assistance afforded to the APO and its contractors during the installation of the project for without that assistance the installation would have been far more difficult.