THE DARWIN-NHULUNBUY TROPOSPHERIC SCATTER SYSTEM (PART 1)

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INTRODUCTION

This article is presented in two parts. Part 1 contains the feasibility study and design of the system. Part 2 in the next issue contains the description of the equipment, including power plant and buildings, and its installation and maintenance.

Australia's first commercial tropospheric scatter system began operation between the city of Darwin and the mining town of Nhulunbuy in the Northern Territory on the 24th December, 1971. This three hop tropospheric scatter system provides 120 voice circuits to give the subscribers in Nhulunbuy access to the Australian Post Office's National Telecommunications Network for telephone, telex and data services.

Nhulunbuy is a new town being established by Nabalco, a consortium of Australian and Swiss companies interested in the mining and processing of bauxite ore. The town is located on the Gove Peninsula in the North-east of Arnhem Land in the Northern Territory (see Fig. 1).

The system was installed to provide trunk access to the network on the basis of the Australian Post Office's new Spur Line policy which was approved by the Postmaster-General in August, 1969. Broadly, this policy requires the company developing a particular town or area, which requires communication, to make an unconditional contribution towards the costs incurred by the A.P.O. in the provision of the initial trunk installation. This initial installation will also include sufficient capacity to allow for five years' growth. The A.P.O.'s contribution includes a public exchange and subscribers' reticulation to complete the telecommunication facility for the new town or area.

An agreement, based on this policy, was reached between the A.P.O. and Nabalco in October, 1969. Tenders were called for the design and installation of the tropospheric scatter system, and a contract was eventually let to NEC Australia Pty. Ltd. for the provision of such a system.

ALTERNATIVES

Prior to the decision to use a tropospheric scatter system on this route, an economic study was carried out to find the best solution for the pro-

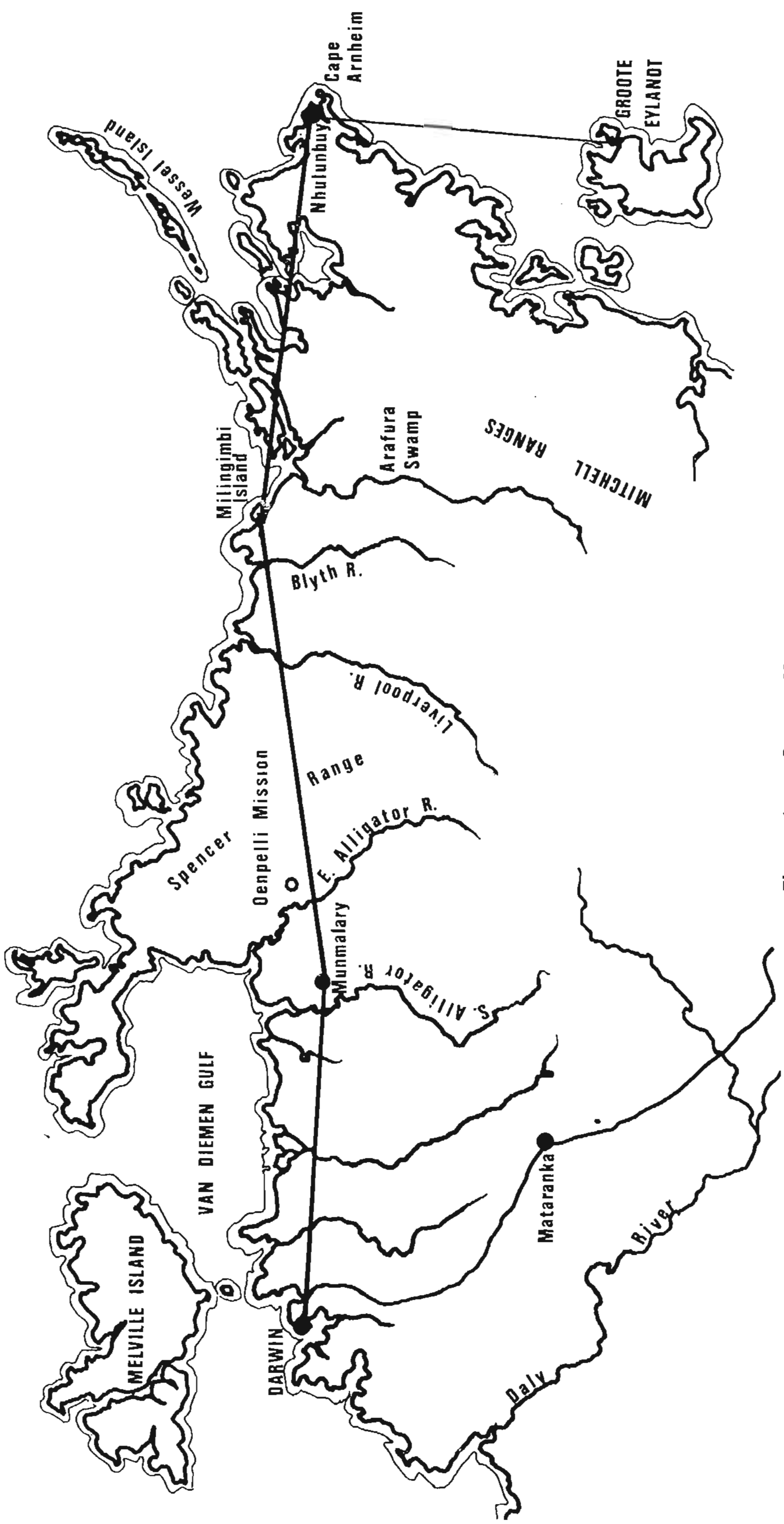

Figure 1. — System Map.

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Fig. 2. — Creek Crossing on Munmalary Road.

vision of up to 120 voice circuits between the two centres of Darwin and Nhulunbuy. A number of alternative transmission systems were available to the A.P.O., namely:

(a) quad carrier cable
(b) coaxial cable
(c) medium capacity line of sight radio relay system
(d) tropospheric scatter system.

All of these had to be considered against the background of the environment in which they would have to operate and so studies were carried out to investigate possible routes and locations for alternative systems.

The 640 km route between Darwin and Nhulunbuy traverses extremely harsh and rugged terrain. There are no all-weather roads which link the two centres and access to Nhulunbuy can only be gained via aircraft or shipping. The creek crossing shown in Fig. 2 is typical of the hazards encountered on roads in the area. The rainfall in the area ranges from 50-60 in. per year, most of which falls in the months November-March. Consequently, for these months (known locally as 'the Wet') the inland areas are entirely inaccessible to land vehicles. During this time of the year, there is a high probability of tropical cyclones with wind velocities up to 110 m.p.h. During the dry season, the country is ravaged by forest fires which cause considerable damage to property.

These natural hazards almost immediately preclude the use of conventional systems, since for all of them access to the route and intermediate stations is necessary to maintain the systems. Apart from these problems, Arnhem Land is virtually divided by the rugged and precipitous Spencer Range where access can only be gained by means of aircraft.

After a study of the terrain and the possibilities for alternative systems, it became quite apparent that only a tropospheric scatter system could provide the service required and consequently work began on preliminary studies to prepare for the system's installation.

TROPOSPHERIC SCATTER

Tropospheric scatter utilises the property of the lower atmosphere to bend and scatter U.H.F. radio energy over the radio horizon. Path lengths for such systems vary from 150-1000 km depending upon the particular system requirements. Tropospheric scatter systems are used to span inhospitable or inaccessible terrain and provide 1-300 voice channels.

A tropospheric scatter system operates in similar frequency bands to those used for conventional line of sight systems but because of the different propagation mechanism utilised the equipment configuration is somewhat different.

The scattering phenomenon is random and causes the path attenuation to vary over a range of 40-50dB in the short term. In addition, the median value of attenuation is very high and in order to accommodate these two conditions and provide good system signal to noise ratio, the equipment has to include high power amplifiers, high gain antennae and complex receiver chains. The transmitters which are used have output powers of the order of 1 kW and receivers have a noise factor of better than 3 dB. These receivers are associated with various diversity combining devices to overcome the short term fading phenomenon. The antennae which have to be used are usually parabolic with diameters from 5-30 metres. The photograph in Fig. 3

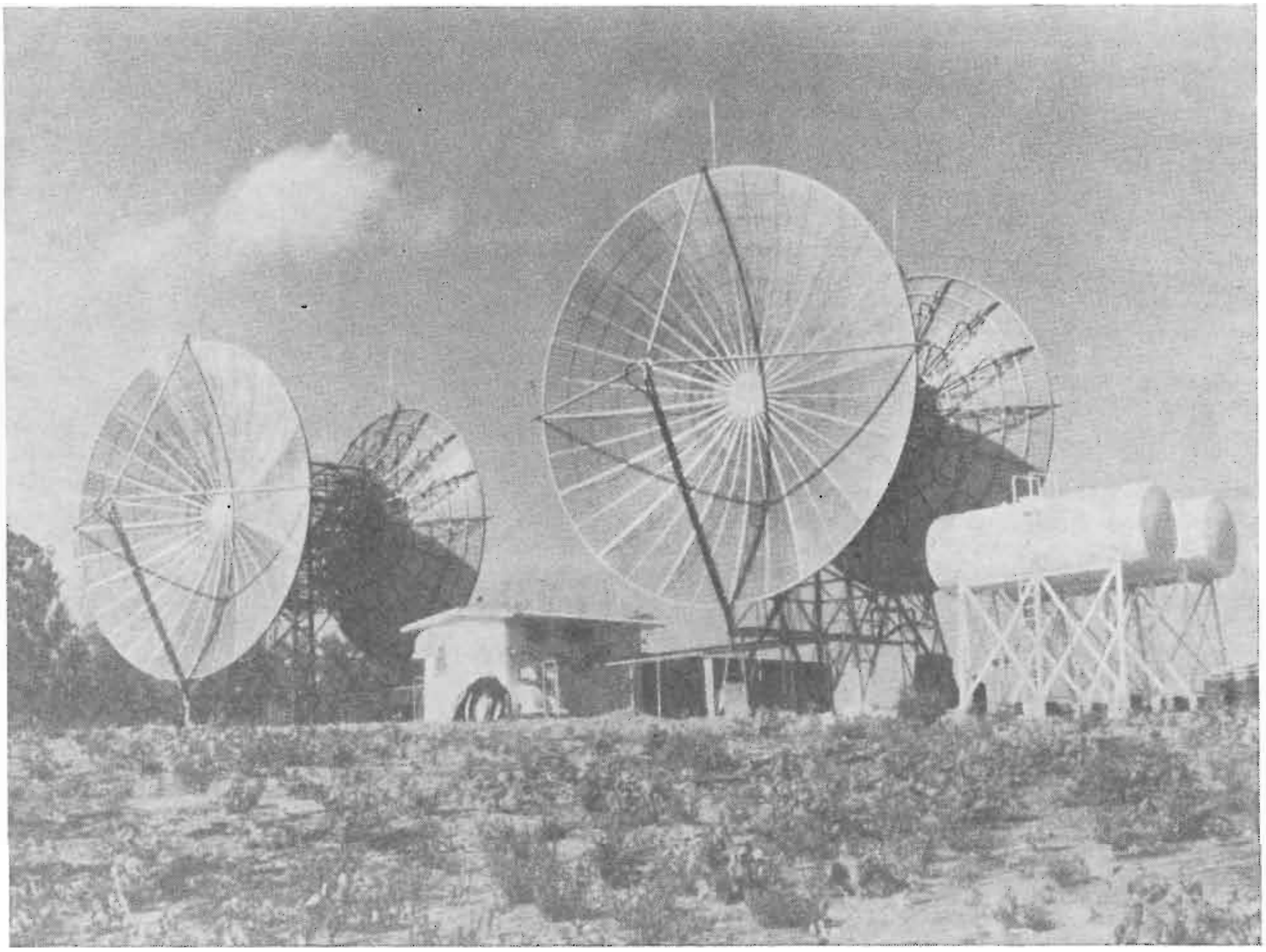


Fig. 3. — Munmalary Repeater Station.

shows typical 10 and 12 metre antennae which were used at Munmalary on this system.

The cost of this special equipment is high and the design of systems must incorporate a considerable amount of flexibility to allow the optimum use of this equipment. So, therefore, a considerable amount of work, including both field surveys and office design, was done by NEC and the A.P.O. before the system design was finalised.

DESIGN

Field Survey

The initial map studies indicated that there were a few possible locations for tropospheric scatter repeater stations between Darwin and Nhulunbuy. A preliminary feasibility study indicated that a three hop system offered the best solution. Based on this study, one terminal was located adjacent to the Cox Peninsula Radio Australia receiving station and the other terminal was to be located on either of two hilltops adjacent to Nhulunbuy. The repeater sites were to be situated in the general area of Munmalary station and on Milingimbi Island. (See Fig. 1.)

The final site selection was carried out by A.P.O. engineers and an engineer from NEC in February, 1970. As already outlined, access to all sites is difficult, the road to Cox Peninsula and Munmalary being impassable during the wet season and Milingimbi and Nhulumbuy being accessible only by sea and air. For this reason the complete survey was carried out utilising charter aircraft and relying on the local people to provide transport. Since permanent survey marks are rare in Arnhem Land, the determination of the exact latitudes and longitudes of the selected sites proved tedious involving sun shots and field calculations. The sites selected were in all cases compromise solutions to conflicting propagation requirements and such economic factors as site and ray-line clearing, access roads and general accessibility of the site from the nearest airport and/or barge landing. Being located in Arnhem Land, a major consideration was to ensure that the sites were not located on aboriginal sacred sites. To check on this, all sites were cleared with the respective tribal councils. Objections by the tribal council at Yirkala on Gove Peninsula to any structures being located on Mount Saunders, which to the local tribe is the sacred home of the Rainbow Snake, led to the location of the terminal for Nhulunbuy on Hill 1819 approximately 4 miles from Nhulunbuy. A photograph of the completed terminal station at Nhulunbuy is shown in Fig. 4. At Milingimbi the only feasible site was located on a sand ridge on the south side of the island which during the highest tides is completely surrounded by the sea. The initial site at Munmalary was selected only 1 mile from the air strip and homestead, but a more detailed survey which involved clearing a ray-line to determine the possible launch angles for the system found a ridge approximately 6.3 km towards Milingimbi which prevented a satisfactory system performance being obtained. After considering the alternatives of higher towers for the 10 metre and 12 metre antennae or re-locating the site, the latter course was selected. The site re-location involved the A.P.O. in the construction of a 700 ft. long causeway, including a 100 ft. wide spillway to cross a creek and approximately 4.2 miles of access roads.

The basic site information, including the amount of ray-line clearing, is shown in Table 1. From this basic

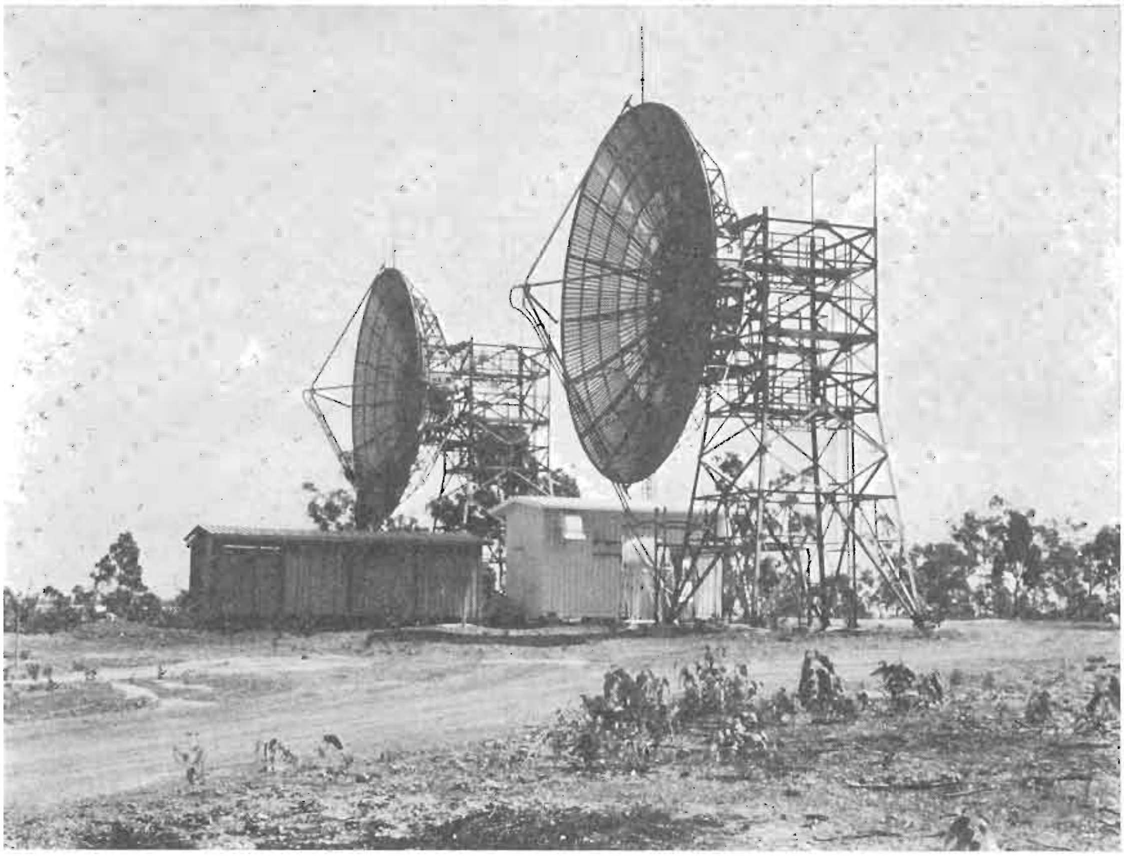


Fig. 4. — Nhulunbuy Terminal.

TABLE 1.—SITE INFORMATION

Site	Lat. (S)	Long. (E)	Elevation (Metres)	Access Road Required	Site and Ray-line Area to be Cleared
Cox Peninsula	12° 28' 42"	130° 44' 16"	12	Nil	20 acres
Munmalary	12° 28' 09"	132° 33' 20"	70	4.2 miles and causeway	73 acres
Milingimbi	12° 6' 50"	134° 54' 8"	8	1.8 miles	43 acres
Nhulunbuy	12° 12' 46"	136° 48' 00"	70	0.25 miles	2 acres

information the great circle distances between stations and ray-line bearings given in Table 2 were calculated. This data formed the basis for the system design.

TABLE 2.—PATH INFORMATION

Path	Length	Bearing	Beam Angle
Cox Peninsula to Munmalary	189.7 km	89° 54' 01.7"	0
Munmalary to Milingimbi Island	252.7 km	81° 26' 35.6"	0
Milingimbi Island to Nhulunbuy	207.0 km	87° 08' 56.5"	0

System Design

The basic design criteria were the relevant C.C.I.R. recommendations regarding system noise performance. Since a tropospheric scatter system was the only economical solution for the Darwin-Nhulunbuy system, and since C.C.I.R. Recommendation 393.1 could not be met, the following general conditions for a hypothetical reference circuit of 2500 km as given in CCIR Rec 397.1 apply:

(a) The mean noise power during one minute must not exceed 25,000 pWOp for more than 20% of any month.

(b) The mean noise power during one minute must not exceed 63,000 pWOp for more than 0.5% of any month.

(c) The unweighted noise power (with an integration time of 5 msec) must not exceed 1,000,000 PWO for more than 0.05% of any month.

From the above figures the actual allowable system noise can be calculated once overall system length has been determined.

Design Calculations: As well as the location of terminal and repeater stations, the system capacity was selected at 120 circuits before detailed design commenced (Refs. 1 to 5). Based on the survey information and relevant C.C.I.R. recommendations the following system noise specification applied:

(a) the mean noise power during one minute must not exceed 6,760 pWOp (S/N = 51.7 dB) for more than 20% of any month.

(b) The mean noise power during one minute must not exceed 31,600 pWOp (S/N = 45 dB) for more than 0.5% of any month.

(c) The unweighted noise power (with an integration time of 5 msec.) must not exceed 250,000 pWO (S/N = 36 dB) for more than 0.05% of any month.

The basic equipment specifications considered necessary to achieve the above specifications are given in Table 3. Based on this data, it was necessary to determine the median received signal levels and their statistical variation on all paths to ensure that the design criteria were met. An important word of caution must be added at this stage, the theories and equations formulated for the design of troposcatter systems are mainly empirical, based on observed phenomena, rather than explicit analytic relationships.

Mean Receiver Input Power: The mean receiver input power is obtained from the following equation.

$$Pr = Pt + (Gt + Gr) - L(50) - Lf - Lc \quad \ldots \quad (1)$$

where

Pr = median input power level to receiver (dBm)

Pt = transmitter output power (dBm)

Gt, Gr = gain of transmitting and receiving antennae (dB)

L(50) = median transmission loss (dB)

Lf = fixed losses at transmitting and receiving end (dB)

Lc = Antenna to medium coupling loss (dB).

Since the received signal level and its statistical variation are of prime importance in determining system performance a more detailed consideration of equation (1) is warranted. The transmitted power Pt is purely a function of equipment type and within economic constraints is readily varied by the designer. Similarly the gain of transmitting and receiving antennae are variables directly under the designer's control. The gain selected, which is proportional to antenna size and operating frequency, is determined by the system noise objectives. Careful consideration to capital cost must also be given since any increase in size represents an almost exponential increase in cost. Another factor which effectively limits the size of antenna selected is the reduction in actual antenna gain below the theoretically available gain due to the phenomenon referred to as antenna to medium coupling loss (Lc). Opinions vary considerably on the magnitude of this additional loss factor. All authors (Refs. 2, 3, 4, 5) agree that it is directly dependent on antenna size but some later experimental studies (Ref. 4) have shown that path parameters such as distance and scatter angle also have considerable effect on the antenna to medium coupling loss. The calculations for antenna to medium coupling loss were based on the following empirical equations advanced by NEC engineers and have shown good agreement with experimental investigations.

The antenna to medium coupling loss:

$$Lc = Lch + Lcv \quad (2)$$

where Lch: partial antenna to medium coupling loss associated with the horizontal antenna pattern.

Lcv: partial antenna to medium coupling loss for vertical pattern.

They are evaluated as

$$Lch = \sqrt{[1 + 0{\cdot}4\{(\alpha/\varphi_{th})^2 + (\beta/\varphi_{rh})^2\}]} \quad (3)$$

and

$$Lcv = \exp\{(\theta_{tm}/\varphi_{tv})^2 + (\theta_{rm}/\varphi_{rv})^2\} \quad (4)$$

where

θ_{tm}, θ_{rm}: Optimum elevation angles of transmitting and receiving antennas beam axis.

$\varphi_{th}, \varphi_{rh}$: 0·6 × (horizontal 3 dB beam width of antennae)

$\varphi_{tv}, \varphi_{rv}$: 0·6 × (vertical 3 dB beam width of antenna)

For the antenna sizes selected and the various path length of the system equations (2) to (4) yield values ranging from 4·9 to 8·1 dB.

The median transmission loss (L(50)) is a random quantity dependent upon frequency of operation, topographical and climatic conditions as well as the length and profile of the path. The behaviour of transmission loss can only be predicted by statistical means and this is further complicated since independent long and short term variations have been observed. The predictions made are based on actual propagation measurements where it was found that the long term variation of transmission loss followed a log-normal distribution, while in the short term variations followed a Rayleigh distribution. These variations exhibit seasonal and diurnal patterns with long term attenuation decreasing during the wet season on tropical paths since it is largely dependent on prevailing meteorological conditions. The short-term or Rayleigh fading is produced by multipathing effects. Hence to estimate the fading depth of a troposcatter path both the long and short term fading distribution must be combined into a composite distribution. The median transmission loss can be expressed as:

$$L(50) = F(d\theta) + 30 \log f - 20 \log d + A - Vde \quad (5)$$

where

$F(d\theta)$ = Attenuation function

f = Frequency in MHz

d = Path distance in km (See Fig. 5)

θ = scatter angle in radians (See Fig. 5)

A = Atmospheric Absorbtion (dB)

Vde = Adjustment for climatic conditions (dB) (Ref. 2)

The attenuation function $F(d\theta)$ is dependent upon surface refractivity of the atmosphere, path length, scatter angle and path symmetry. It is an empirical function derived from observed phenomena and a number of authors have produced curves relating these parameters. The curves receiving most use are those published in

TABLE 3.—BASIC EQUIPMENT SPECIFICATIONS

Item	Specification
Operating Frequency Range	2450-2690 MHz.
RF Output Power	1 kW
Receiver Noise Figure	2.5 dB
Baseband Frequency	60-552 kHz
Diversity Configuration	Quadruple
Combining Techniques	IF and Baseband non-linear combination
Frequency deviation	245 kHz r.m.s. per channel
Antenna Gains:	
10m	45.7 dB at 2600 MHz
12m	47.2 dB at 2600 MHz
Antenna 3 dB Beam width:	
10m	13.6 milliradians
12m	11.4 milliradians

Technical Note 101 of the National Bureau of Standards (Ref. 5).

The surface refractivity (Ns) varies with both height and geographical location and in the Darwin–Nhulunbuy area rises to a value of approximately 350. In general terms the median transmission loss decreases as the value of surface refractivity increases. Path length has a directly proportional effect on the attenuation function, and the function value also increases as the scatter angle increases. The attenuation function $F(d\theta)$ accounts for the difference between line of sight path loss over the same distance and actual encountered losses. Atmospheric absorbtion is due mainly to the presence of water vapour and oxygen (Ref. 5) and accounts for approximately 1 to 2 dB at 2·6 GHz and over path length varying 150 to 250 km. In addition to all losses mentioned above there are certain fixed losses (Lf) due to feeder and filters which must be taken into consideration.

Statistical Variations of Receiver Input Power

To be able to effectively determine the behaviour of received signal strength and hence diversity requirements it is essential to determine the fading characteristics of each path. As stated earlier, fading on a transhorizon path is a combination of the long term log normally distributed fades due to meteorological conditions and the short-term fades due to multipathing, which exhibit a Rayleigh distribution.

The probability density function of the Rayleigh distribution $P(\gamma)$ is given by

$$P(\gamma) = (\gamma/\sigma^2).\exp(-\gamma^2/2\sigma^2) \text{ for } \gamma \geqslant 0 \qquad (6)$$

where

γ = input level
σ = standard deviation

The median value (γ_0) is given by:

$$\gamma_0 = (2\sigma^2 \log 2)^{\frac{1}{2}} \qquad (7)$$

The log-normal distribution is then considered about the median value (γ_0) of the Rayleigh distribution so that the log-normal density function $q(\gamma_0)$ becomes

$$q(\gamma_0) = [K/\{\sqrt{(2\pi)}\sigma^2] \exp [-\{K \log (\gamma_0/R)\}^2/2\sigma^2] \qquad (8)$$

where

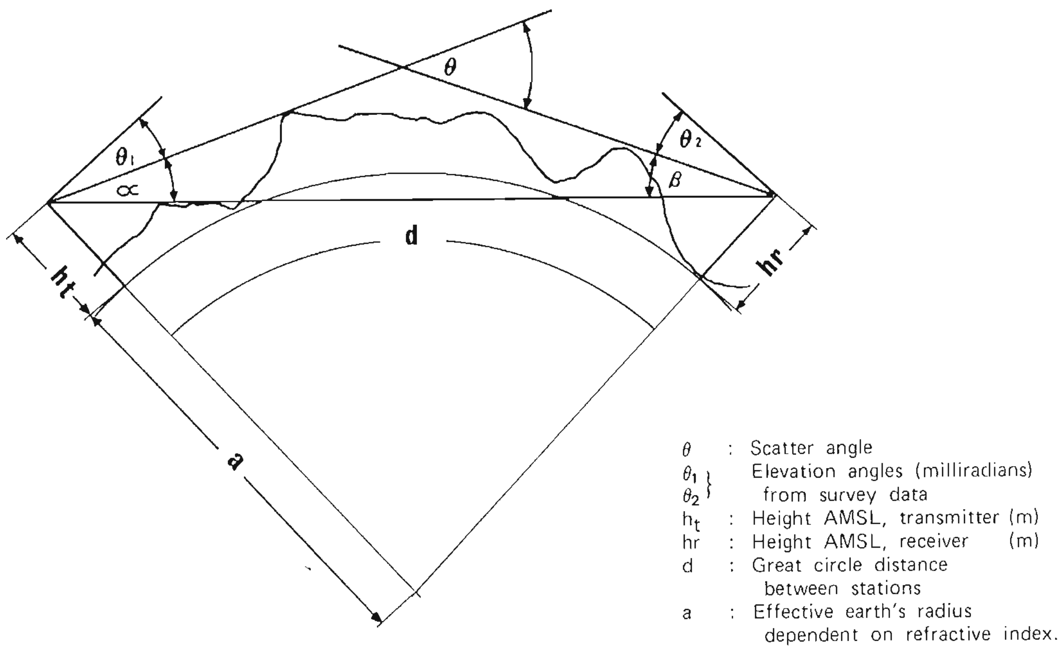
R = mean value of γ_0
K = transfer constant

Using the expression for median value given in equation (7) the probability density function for the Rayleigh distribution becomes

$$P(\gamma : \gamma_0) = \{(2\gamma \log 2)/\gamma_0\} \exp . \{-(\gamma/\gamma_0)^2 . \log 2\} \qquad (9)$$

Hence the density function $f(\gamma)$ of the composite Rayleigh–log normal distribution is obtained from

$$f(\gamma) = \int_0^\infty P(\gamma : \gamma_0).q(\gamma_0)d\gamma_0 \qquad (10)$$



$$\alpha = \frac{d}{2a.10^{-3}} + \theta_1 + \frac{h_t - hr}{d.10^{-3}}$$

$$\beta = \frac{d}{2a.10^{-3}} + \theta_2 + \frac{hr - h_t}{d.10^{-3}}$$

$$\theta = \alpha + \beta$$

$$S = \frac{\alpha}{\beta}$$

Fig. 5. — Tropospheric Scatter Path Configuration.

with the distribution function $F(\gamma)$ given by

$$F(\gamma) = \int_0^\infty \gamma f(\gamma) d\gamma \quad (11)$$

For design purposes, curves published in C.C.I.R. report 244·1 are usually used. These curves exhibit close agreement with above theoretical results. From these the fading depth of a troposcatter link can be determined. Once the fading distribution, and hence received signal distribution, has been determined, the effect of diversity reception on the received signal strength and hence system noise performance can be determined. By proper choice of antenna spacing and frequency spacing the correlation co-efficient for the Rayleigh distribution for the various received signals approaches zero. Experience has shown that for effective space diversity the antenna centres must be separated at a distance in excess of 100 wavelengths, while effective frequency diversity is obtained if the received frequencies differ by 1%.

There are various techniques available for combining received signals such as by switching, linear or non linear combining. The system selected for the Darwin–Nhulunbuy link utilises quadruple diversity with non linear signal combining techniques. From published curves (Refs. 2, 4) the standard deviation of each link was calculated and hence the fade depth for the various links, which are summarised in Table 4.

System Noise Performance

There are three readily distinguishable components of system noise performance, they are:

(a) thermal noise
(b) path intermodulation noise
(c) basic equipment noise

Of these, the basic equipment noise is a fixed quantity but both thermal and path intermodulation noise must be determined for each path. Signal to thermal noise ratio is given by

$$S/N_T(p) = 10 \log (Pr/2kTF).(1/f_b).m_c^2 .W.U.(1/Fd(p)) \quad (12)$$

where

k = Boltzmann's Constant
T = Temperature in degrees Kelvin (e.g. 300°K)
F = receiver noise figure (2·5 dB)
f_b = channel bandwidth (3·1 kHz)
m_c = modulation index per channel (1 rad/channel)
W = psophometric weighting factor (2·5 dB)
U = diversity improvement (6 dB)
$Fd(p)$ = fade depth for p% of time

Equation 12 can be reduced to

$$S/N_T(p) = 142{\cdot}1 + P_r - Fd(p)(dB)$$

The calculation of the signal to path intermodulation ratio is less well defined and while a number of theories have been advanced, none gives the complete answer. All theories agree that under the usually prevailing conditions

$$S/N_I \propto \tau^{-4} m_c^2$$

where

S/N_I = signal to intermodulation noise ratio
τ = relative time delay
m_c = modulation index

The difference between the various theories arises in the calculation of τ. The technique selected is based on the work of Beach and Trecker (Ref. 6) and NEC design report (Ref. 4). The median signal to path intermodulation ratio can be evaluated from

$$S/N_I(p\%) = 107{\cdot}8 - 40 \log(f_m.\tau) - 20 \log M_t + Z_n + W + U - FdI(p\%) \quad (14)$$

where

f_m = top modulating frequency
M_t = total modulating index (radians)
Z_n = combined loading factor
$FdI(p\%)$ = fading depth of intermodulation noise for p%
τ = delay time (μ sec)

$$M_t = 0{\cdot}41 m_c La \quad (15)$$

where

m_c = Modulating index (rad/channel)
La = loading factor

$$\tau = 5{\cdot}6.10^{-7} d(\alpha + \theta_m)(\theta + \alpha + \theta_m) \quad (16)$$

where θ_m = optimum beam elevation angle.

$$Zn = 10 \log N - La \quad (17)$$

where

N = number of channels
$La = -1 + 4 \log N$ if $60 < N < 240$ (18)

Hence for the Darwin–Nhulunbuy system equation (14) reduces to

$$S/N_I(p\%) = 130{\cdot}3 - 40 \log (f_m.\tau) - FdI(p\%) \quad (19)$$

Path intermodulation noise also varies with time, but its distribution differs slightly from that of thermal noise. Assuming that σ_I is the standard deviation of thermal noise and σ_2 that of path intermodulation noise then it has been found that

$$\sigma_2 \doteqdot 0{\cdot}7\sigma_I \quad (20)$$

By using the results of the foregoing discussion the total noise power for each hop can be obtained by adding thermal, intermodulation and basic equipment of noise power in tandem connected tran-horizon links. Statistical techniques and approximations must be utilised to obtain the overall noise distribution of the system. The basic assumption is that each path can be considered as an independent entity so that the mean and variance of the total distribution is the sum of the respective means and variances of the paths constituting the total system. Hence once the mean and variance of the noise distribution of each path is evaluated, the mean and variance of the distribution of the overall system can also be calculated. By approximating the mean and variance with a particular distribution the system noise power for any desired percentage of time can be determined. The distribution utilised is the log normal distribution and its probability density function (q(x)) from equation (8) becomes

$$q(x) = 4{\cdot}343/(\sqrt{2}n.\sigma.x) \exp[\{-4{\cdot}343 \log (x-m)\}^2/2.\sigma^2] \quad (21)$$

where

m = mean value
x = probability
σ^2 = variance

Hence the true mean value and variance of each link is given by

$$M_I = \exp\left\{\left(\frac{m_I}{a} + \frac{\sigma_I^2}{2a^2}\right)\right\} \quad (22)$$

$$S_I^2 = \exp\left\{\left(\frac{2m_I}{a} + \frac{\sigma_I^2}{2a^2}\right)\right\}.\left\{\exp\left(\frac{\sigma_I^2}{2}\right) - 1\right\} \quad (23)$$

Where m_I and σ_I are in dB and $a = 4{\cdot}343$.
The mean and variance for the system become the sum of the individual paths.

$$M = \sum_{i=1}^{n} M_I \quad (24)$$

$$S^2 = \sum_{i=1}^{n} S_I^2 \quad (25)$$

So mean and variance of the overall system can be found from

$$m_0 = 10 \log M - 5 \log (1 + (S/M)^2) dBm \quad (26)$$

$$\sigma_0^2 = (43{\cdot}43 \log (1 + (S/M)^2) dB \quad (27)$$

TABLE 4.—FADE DEPTH FOR PATHS OF DARWIN-NHULUNBUY SYSTEM WITH QUADRUPLE DIVERSITY.

Time	Darwin to Munmalary	Munmalary to Milingimbi	Milingimbi to Nhulunbuy
80%	4.5 dB	4.2 dB	4.5 dB
95%	9.2 dB	8.5 dB	9.0 dB
99.5%	15.5 dB	13.5 dB	15.0 dB
99.95%	20.5 dB	19.0 dB	20.0 dB
99.99%	24.0 dB	22.0 dB	23.0 dB

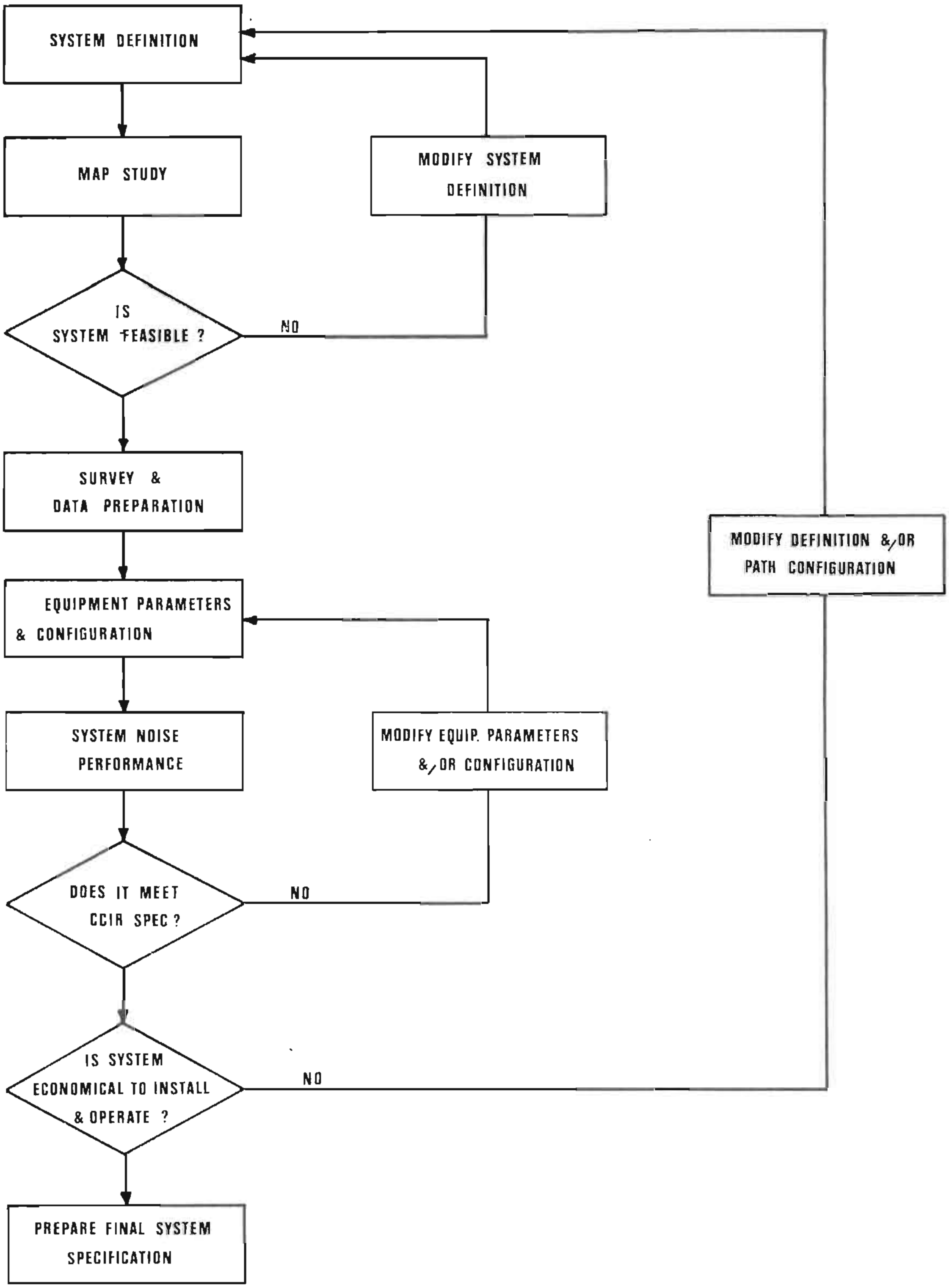


Fig. 6. — Design Flow Chart.

TABLE 5.—SUMMARY OF SYSTEM DESIGN

Link Item	Path Length (km)	Scatter Angle (m rad.)	L(50) (dB)	Gt + Gr (dB)	Lc (dB)	Lf (dB)	Po (dBm)	Pr (dBm)	S/Nt 80% (dB)	S/Nt 99.5% (dB)	S/Nt 99.99% (dB)	S/Ni 80% (dB)	S/Ni 99.5% (dB)	S/Ni 99.99% (dB)	S/N Total 80% (dB)	S/N Total 99.5% (dB)	S/N Total 99.99% (dB)
Cox Peninsula to Munmalary	189.7	19.4	212.0	91.4	4.9	5	60	—70.5	67.1	56.1	47.6	71.5	63.6	56.1	63.2	55.1	47.4
Munmalary to Milingimbi Island	252.7	31.7	220.8	94.4	8.1	5	60	—79.5	58.4	49.1	40.6	60.4	53.4	46.9	55.9	47.7	39.0
Milingimbi Island to Nhulunbuy	207.0	24.4	215.2	91.4	5.8	5	60	—74.6	63.0	52.5	44.5	65.7	57.8	50.3	60.1	51.3	45.0
Overall	649.4								56.0	46.8		58.0	51.8		53.0	45.3	37.5

Note: Basic Equipment Noise for each hop is 200pW.

The mean and variance are calculated separately for the thermal and path intermodulation noise and the overall noise distribution for each is obtained by applying the log-normal law to each distribution. The total noise for the system is the sum of all component totals.

The methods outlined above were used in the design of the Darwin–Nhulunbuy system. The design approach is an iterative process and the basic flow chart is shown in Fig. 6. A summary of results is given in Table 5.

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