The Digital Radio Concentrator System

Simon Moorhead
Ericsson Australia and New Zealand

Abstract: A reprint of a technical paper from 1986 which details the design and development of the Digital Radio Concentrator System deployed by Telstra to provide automatic telephone services throughout outback Australia.

Keywords: Telecommunications, History, Digital Radio Concentrator System, Telecom Research Laboratories, National Rural and Remote Programme

Introduction

This historic paper (Martello, Lopes, Worsdell & Bannister, 1986) details the design and development of the Digital Radio Concentrator System (DRCS), which was deployed by Telstra's predecessor, Telecom Australia, to provide automatic telephone services to customers throughout outback Australia in the 1980s. Prior to DRCS, rural customers were connected to manual exchanges where operators physically connected calls and often relied on the vagaries of high frequency two-way radio.

Telecom's National Rural and Remote Programme at the time aimed to extend automatic telecommunication services to rural and remote areas by 1990. The DRCS was used to convert about 6,000 manual services and connect between 3,000 and 4,000 customers in remote areas.

The DRCS system was initially conceived by Telecom Research Laboratories and purposely designed to suit homestead-based customers and withstand Australian environmental extremes. The DRCS provided a connection from the local exchange to the customer using a pair of duplex, time-division-multiplexed, digital radio bearers. These bearers can carry 15 circuits and are shared between up to 127 customers via a concentrating switch at the exchange, hence the Digital Radio Concentrator name. The bearers are regenerated at repeaters typically 50 km apart, and there is a performance limit of around 13 repeaters in tandem, or a nominal range limit of about 600 km.

http://doi.org/10.18080/jtde.v7n4.242

Notwithstanding these limitations, Telecom installed about 1,000 repeaters and covered 2.8 million square kilometres by the end of the programme. See the map from Brass (1993), originally published in *Australian Geographic*, reproduced at the end of this article.

The significant distances encountered in remote Australia between telephone exchanges and subscribers essentially excludes cable connections due to the high cost of connection. This is why Telecom Research Laboratories specified a regenerative digital radio scheme with burst transmission to provide maximum system flexibility and minimal power consumption.

Telecom issued a worldwide tender for the DRCS equipment in 1980, including a staged development programme to industrialise the design and to demonstrate the equipment feasibility. NEC Australia was the successful tenderer; and extensive testing of prototypes and digital transmission studies were undertaken to prove performance. Telecom first trialled the DRCS in Western Australia at Meekatharra and Mt Magnet in 1985.

The paper provides readers with details of the digital frame structures and the switching and control arrangements. It also details the radio path surveys undertaken by helicopter to design the systems. The tower heights and system configurations are given, as well as the functions and responsibilities of the various Telecom installation groups who made this state-of-the-art project successful.

Solar power was provided at both the subscriber and repeater sites, ensuring the system continued to operate independently of the often-unreliable mains power. The DRCS systems operated for about 20 years and during that time went through an evolution to a higher capacity version. As recognition of its achievements in DRCS, Telecom was awarded the 1986 Engineering Excellence Award by the Institute of Engineers Australia, Queensland Division.

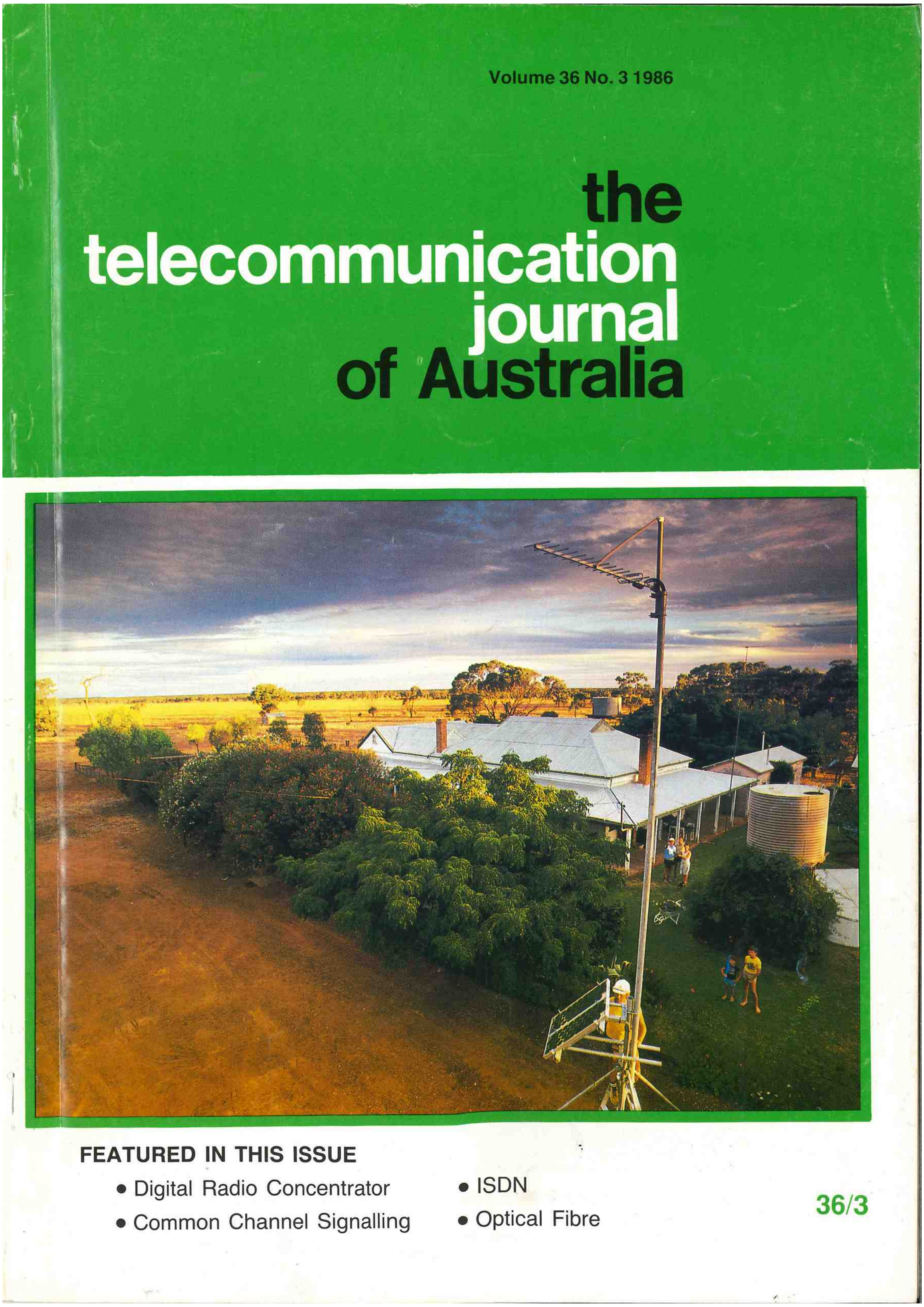
References

Martell, P. H., Lopes, P., Worsdell, G., & Bannister, G. P. (1986). The Digital Radio Concentrator System — DRCS, *Telecommunication Journal of Australia*, *36*(3), 3-22.

Brass, K. (1993). The phone goes bush, *Australian Geographic*, *29*, 56-75, January-March. The article was reproduced by Telstra and the Telstra reprint is available at http://www.coxhill.com/trlhistory/media/The%20Phone%20Goes%20Bush.pdf

The TJA Cover from March 1986

The cover of the *Journal* showed an outback family watching a DRCS installation.



The Historical Reprint

The Digital Radio Concentrator System — DRCS

P.H. MARTELL B.E. (Hons)
C. LOPES B.E.
G. WORSDELL A.I.T. (Comm Eng)
G.P. BANNISTER A.R.M.I.T.

The function of the DRCS is to form the basis of the local network for about 10 thousand of Telecom's existing and potential customers over much of Australia's habitable interior. The system is complex, employs new transmission techniques and is being used in a severe environment.

This paper describes the DRCS, its development and the installation of the first complete system.

INTRODUCTION

Telecom's National Rural and Remote Area Programme includes the extension of automatic telecommunications services to rural and remote areas so that all Australians will have access by 1990. The DRCS will be used for the conversion of about 6000 manual services in rural areas and the connection of the majority of 3000 to 4000 expected applicants in remote areas. About 850 DRCS Repeaters will be used to connect these customers and the area covered will be of the order of 3 million square km.

Initially conceived in Telecom's Research Laboratories, the DRCS has been designed specifically for the task. It is capable of providing the range of telecommunications facilities demanded by Telecom's customers, its configuration suits Australia's low density, homestead based population and it has been designed to withstand Australian environmental extremes.

GENERAL DESCRIPTION

The DRCS provides the connection from the local exchange MDF to the customer. It does this over a duplex pair of time division multiplexed digital radio bearers (refer to **Fig. 1**). The bearers can carry 15 circuits, which are shared between up to 127 telephone/data users by way of a concentrating switch located in the exchange. Up to 28 telex services can also be provided on one of the 15 circuits in lieu of telephone/data use.

System range

The radio bearers are regenerated at Repeaters, which may be arranged in any branching configuration. There is a limit, however, of 13 tandem-connected DRCS Repeaters, giving the system a nominal range of 600 km. Each Repeater receives the bearer coming from the exchange direction, referred to as the downward bearer, and re-broadcasts to the next Repeater and to Subscriber units located at or near the customer's premises. Each Repeater also receives the upward going bearer from Subscriber or Repeater units and re-transmits back toward the exchange. Radio path lengths from Repeater to Repeater or from Repeater to Subscriber can be up to 70 km but are typically 50 km and 30 km respectively.

System Components

The basic system components and their main functions are:

- The Concentrator — A software controlled device switching and concentrating 127 telephone/data lines to 15 analog circuits **(Fig. 2)**.
- The TDM Controller or TDMC — Converts the analog signals on 15 trunks to a digital stream and modulates a radio bearer **(Fig. 3)**.
- Repeater Units — Regenerate the upward and downward digital streams and retransmit the bearer on an appropriate frequency **(Fig. 5)**.
- Subscriber Units — Receive and transmit the upward and downward bearers **(Fig. 5)**.
- Drop Out Units or DOUs — Demultiplex, convert the digital information to analog and interface with the customer's terminal equipment. A DOU provides one service and is located in every Repeater and Subscriber unit but can be added by way of DOU Shelves to provide up to 20 additional services at a Repeater or Subscriber unit.

Facilities

All Subscriber and Repeaters units can provide an access point to all 15 circuits as required.

A range of services and customer terminal equipment can be supported, including the following:

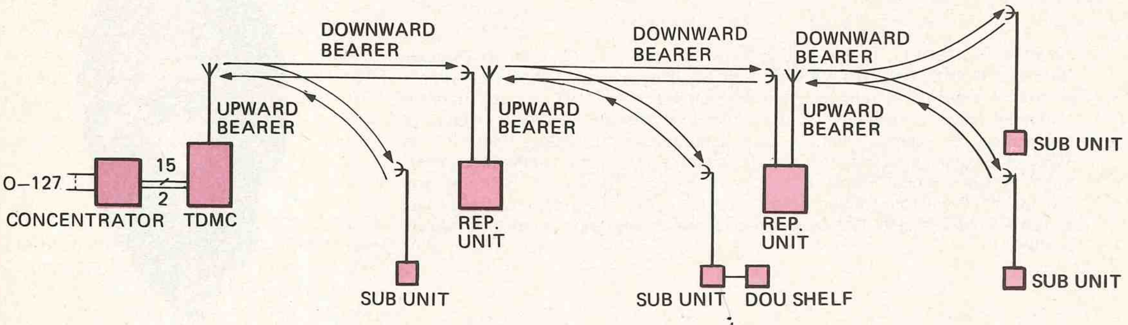


Fig. 1: System Upward and Downward Bearers

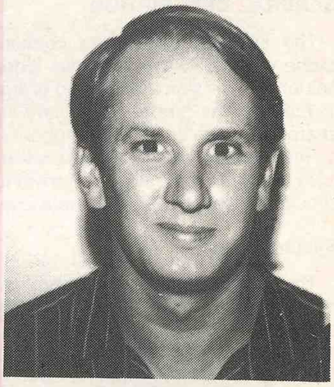
Journal of Telecommunications and the Digital Economy, ISSN 2203-1693, Volume 7 Number 4 December 2019

http://doi.org/10.18080/jtde.v7n4.242

- All automatic telephone services such as Subscriber Trunk Dialling, International Subscriber Dialling, etc.
- All telephone instruments currently marketed by Telecom (although there are some limitations in the case of combinations of instruments and extension alarms).
- Telex

GREIG BANNISTER is an acting Supervising Engineer in the Radiocommunications Branch. He joined the PMG's Department as a Technical Assistant in 1969 and as an Engineer in 1971. He has been involved in system design, evaluation and provisioning of subscriber, small capacity, mobile and paging systems.

PHILIP MARTELL is a Senior Engineer in the Customer Section of the Radiocommunications Branch in Telecom Australia Headquarters. After graduating from the University of Melbourne with a Bachelor of Electrical Engineering (Hons), he joined Telecom in 1981. He has been involved with the design and provisioning of single channel subscriber radio systems and the field trial and volume production phases of the DRCS.



COLIN LOPES joined Telecom Australia as a cadet in 1973 and after graduation worked for 5 years in Traffic Engineering, carrying out computer program maintenance. During that time he also filled the Engineering Computer Co-Ordinator's position for a short period. After three years in Switching and Facilities (Metro), he moved to the HQ Switching Development and Support Branch, based in Sydney, in his present position of Technical Specialist.

GARY WORSDELL is currently a Senior Engineer in Commercial Projects Section of Country Region in Western Australia. He joined the PMG's Department in 1968 as a technician-in-training, received a traineeship in 1971 and graduated in Communications Engineering in 1974 from the Western Australian Institute of Technology. He spent 7 years in Radiocommunications Design, from 1977 to 1983, on projects including the Kimberley Microwave System and the Meekathara/Mt. Magnet Digital Radio Concentrator System design. In 1984 he was promoted to Project Engineer to co-ordinate installation of Western Australia's first two DRCS. He completed the special project role in 1985 and moved to his current position.

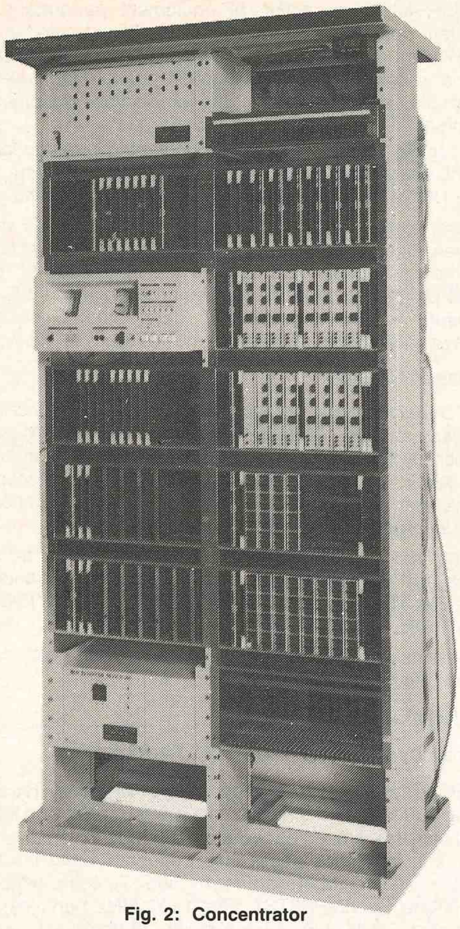


Fig. 2: Concentrator

- Data connected through modems up to 2400 Kbit/s (2 wire through the switched network, 4 wire as a leased circuit) — enabling the provision of such services as Videotex and Telememo.
- Telecom's range of coin telephones
- Facsimile

Power source

The power consumption of Repeaters and particularly Subscriber units has been kept to a minimum thus allowing the economic use of solar power at most stations. Only at Repeater station sites where there is a nearby, reliable supply will mains power be considered. At Subscriber stations, as a general rule, solar power is preferred because home generating plants are notoriously unreliable and in those cases where mains power is available, special arrangements need to be made regarding connection and access.

DEVELOPMENT

Conception

In 1978, Telecom's Research Laboratories considered the problem of how Telecom might technically go about meeting it's commitment in rural and remote areas and in particular, those more difficult areas where the cost of connection using cable is high. There were, of course, existing means available using a range of technologies

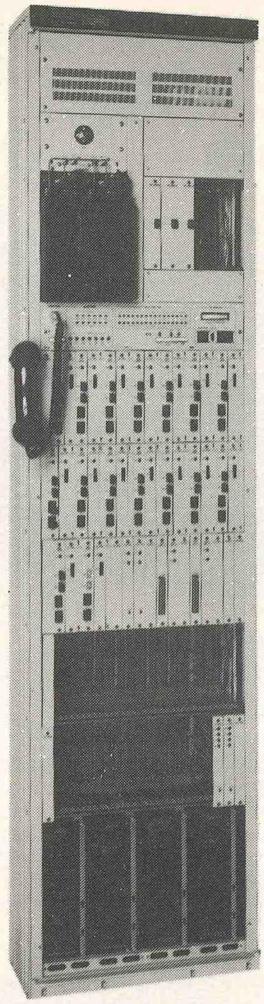


Fig. 3: TDM Controller

including a collection of Trunk, Small Capacity and Subscriber radio systems but an integrated and more economical system employing digital transmission, time division multiplexing and burst transmission was seen as most appropriate. These features enable Repeaters to regenerate indefinitely with negligible signal degradation, maximum system flexibility and minimal power consumption.

Design and Production

Following a feasibility study and facility specification, development and provisioning responsibilities passed to the Telecom's Development Division and in May 1980 a world wide request for tenders was prepared including a proposed development programme and detailed specification.

The successful tenderer was NEC Australia and the agreed development programme included the delivery of initially 3 field evaluation systems within two years and then after a further two years, the delivery of production equipment in bulk.

Field Evaluation

The field evaluation equipment was delivered in September, 1982, and installed in Telecom's Radiocom-

Journal of Telecommunications and the Digital Economy, ISSN 2203-1693, Volume 7 Number 4 December 2019

http://doi.org/10.18080/jtde.v7n4.242

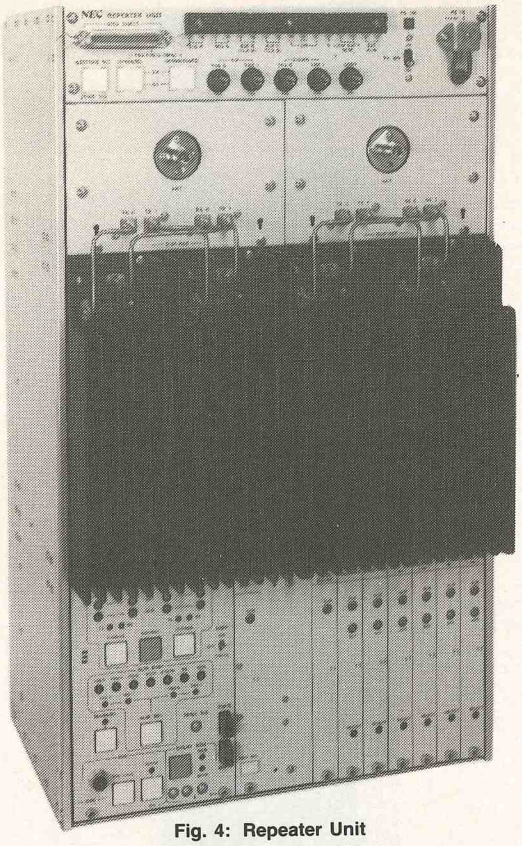


Fig. 4: Repeater Unit

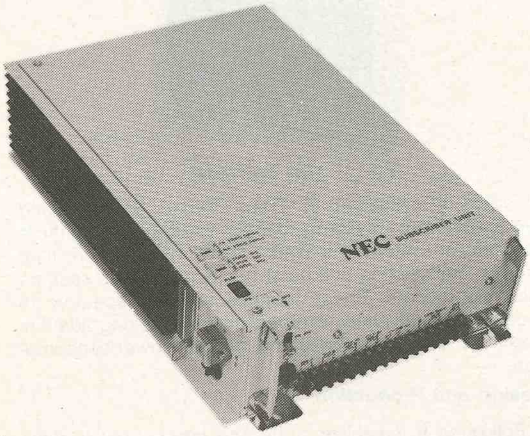


Fig. 5: Subscriber Unit

munications Laboratory, at Elliston in South Australia and at Charleville in Queensland. A fourth evaluation system was later installed at Berry Springs in the Northern Territory. All evaluation systems with the exception of the equipment installed in the Laboratory were used as working systems carrying customer traffic. In addition, propagation and equipment performance were extensively monitored at Charleville using equipment specially designed and constructed by Telecom's Research Department and Radiocommunications Laboratory.

There were two important aspects to Telecom's field evaluation programme:

- Firstly, intensive testing of equipment performance, system operation and new facilities. This resulted in a significant number of hardware and software modifications required in the evaluation equipment where possible, and changes in the production equipment design.
- Secondly, theoretical studies concerning propagation, particularly for potential interference paths inherent in the DRCS cellular frequency plan, were confirmed.

Masts, towers, shelters, antennas, power supplies and ancilliary equipment were also developed in conjunction with the radio equipment. Due to the magnitude of the DRCS programme and the remote areas in which it is to be used, special attention has been paid to design features that speed installation and reduce site visits.

Volume Production

NEC delivered the first production system in October 1984 and as in the case of the evaluation equipment was extensively tested in the Radiocommunications Laboratory. Again the equipment was subjected to intensive testing and both hardware and software modifications were incorporated by NEC.

The first installations were at Warren in New South Wales and at Meekatharra and Mt. Magnet in Western Australia. These systems were officially commissioned in June, 1985.

Systems are currently being ordered at the rate of over 50 per year.

TRANSMISSION ASPECTS

Frequency Planning and Radio Performance

DRCS systems can operate in two frequency bands, one at 500 MHz and the other at 1500 MHz. The 500 MHz band utilises a limited bandwidth of 30 MHz which gives a total of 7 frequency pairs. This frequency band is also used in major urban areas by the Telecom Mobile Telephone Service (MTS). The 1500 MHz band has a width of 100 MHz which can provide 22 frequency pairs. The full band, however, will not generally be available for DRCS. 13 frequency pairs have been set aside for normal use with the additional channels being set aside for special requirements.

Cellular Plan

In the areas of inland Australia for which the DRCS is intended there will be many systems, each having a number of repeating stations. As there are ony a limited number of frequencies to choose from, Repeater frequencies must be reused throughout the DRCS areas. This can be done by adopting a continuous cellular frequency plan in which frequencies are assigned to geographical zones on a repeating pattern. A Repeater or TDM Controller located in a particular zone must transmit on the frequency assigned to that zone. The determination of the cell pattern is governed by the interference between cells which have the same frequency. The DRCS cell plan and frequencies are shown in **Fig. 6.** Because the 1500 MHz band has more frequency pairs to choose from the distance between cells which have the same frequency is larger. This is an advantage in areas which have a high concentration of DCRS systems or are prone to the phenomenon of ducting which can allow interfering signals to travel large distances.

Antenna Radiation Patterns

In most cases, a Repeater will have two radiation patterns, one is generally circular or omnidirectional and is

Journal of Telecommunications and the Digital Economy, ISSN 2203-1693, Volume 7 Number 4 December 2019

http://doi.org/10.18080/jtde.v7n4.242

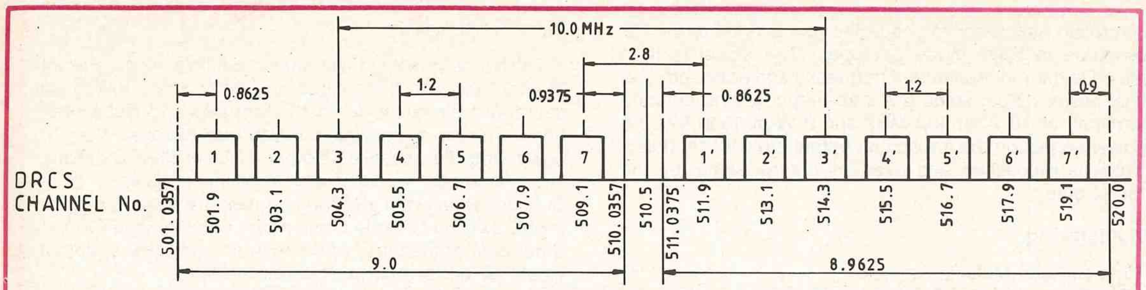


Fig. 6a: 500 MHz Frequency Plan

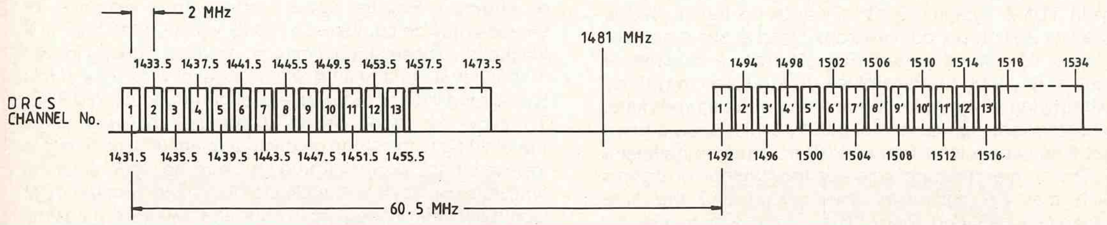


Fig. 6b: 1500 MHz Frequency Plan

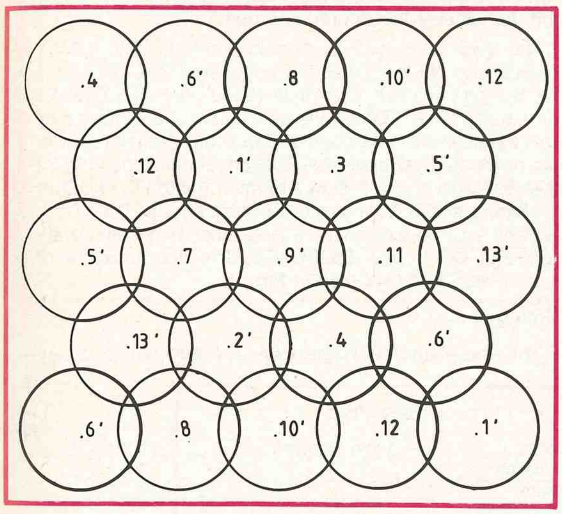


Fig. 6c: 1500 MHz Cell Plan

used to transmit to and receive from Subscriber stations in the surrounding cell and the next downward Repeater, the other is directional and is used to transmit to and receive from the preceeding Repeater. A Subscriber station's radiation pattern is directional to communicate with the appropriate Repeater.

Generally, the antennas used are commonly available or are adaptions of already developed antennas. In specifying DRCS antennas, special attention is paid to the need to minimise co-channel interference and to control wind loads, particularly on the structure located at the Subscriber station.

Both horizontal and vertical polarisation omnidirectional patterns are used so that cross polarisation protection can be used where required. All directional antennas can be adjusted to either polarisation.

In some cases where the propagation losses between adjacent Repeaters is high, it is advantageous to use a third radiation pattern at a Repeater. This is a narrow beam directed toward the downward Repeater. The signals transmitted and received are the same as those associated with the omnidirectional pattern and so, to avoid phase cancellation, the two antennas are cross polarised.

Performance Objective

The DRCS availability objective is 99.5 per cent of the year or better for each Subscriber. This corresponds to an unavailability of 44 hours in a year and includes equipment outages as well as unavailability due to anomolous propagation. Further objectives in terms of Bit Error Rate apply during the time the system is available to control transmission quality.

Digital Transmission

The radio bearers used in the DRCS have a data rate of 704 Kbit/s. The modulation scheme is two level Frequency Shift Keying (FSK) with discriminator detection. Binary FSK was chosen because it satisfied the cell pattern requirements, gave the simplest equipment realisation and allowed the use of efficient class C Radio Frequency (RF) power amplifiers. The use of simple modulation/demodulation techniques was of particular importance as it reduced the overall power consumption thus allowing the Subscriber and Repeater equipment to be solar powered.

The baseband Nyquist filtering for each hop is performed at the transmit end only. A simple digital filter is used. This approach has advantages in that a simpler filter can be used, no filtering is required at the receive end, emission bandwidth is slightly reduced and there is less manufacturing variation in the Bit Error Ratio (BER) performance.

Both 500 MHz and 1500 MHz receivers have Intermediate Frequencies (IFs) of 70 MHz and 2.1 MHz. The 500 MHz receiver has an additional IF of 10.7 MHz. Surface Accoustic Wave filters are used in the 70 MHz and 10.7 MHz IF circuits. A pulse count type discriminator is used.

Modulation in the DRCS transmitter section occurs at 80 MHz for the 500 MHz equipment and 130.5 MHz for the 1500 MHz equipment. The modulated signal passes through a "burst gate" which functions as a voltage

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controlled attenuator to shape the rise and fall of the RF envelope in burst mode operation. The signal is then mixed to the required output frequency and amplified. The final power output stage gives an output (at the antenna terminal) of 10 W at 500 MHz and 2 W at 1500 MHz. A power sensor on the transmitter output provides feedback which is processed and used as control signal by the "burst gate".

Multiplexing

Time Division Multiple Access

The key transmission characteristic of the DRCS is its use of Time Division Multiple Access (TDMA) multiplexing. In TDMA systems each signal to be transmitted is stored for a short period then transmitted at some number of times its normal speed. Signals from a number of sources may thus be transmitted on the same frequency each arriving at the receiving antenna at a different time. To ensure that signals do not interfere with each other a strict time schedule or frame structure must be maintained. The frame structure sets out the number of signals which may be sent over the system and the time relationship between them. The period which may be occupied by a particular signal is referred to as a timeslot.

Frame Structure

In the DRCS frame structure each speech channel has a data rate of 32 Kbit/s and uses Adaptive Differential Pulse Code Modulation (ADPCM). ADPCM encodes only the differences between successive voice samples and continuously adjusts the quantising step size depending on the input voice signal level. Speech at 32 Kbit/s is stored for 4 ms then transmitted at 704 Kbit/s for 236 usec. There are 16 timeslots in the DRCS, 15 for speech and signalling and one, time slot 0 (TSO), for supervision and signalling. The signalling information associated with speech timeslots is sent either at the end of the timeslot or within the speech timeslot when speech is not being transmitted. **Table 1** lists the signal types and their position in the frame structure.

Burst Transmission

To reduce power consumption timeslots which are not in use are not transmitted in either the upward or downward directions for both Repeater and Subscriber units. This is a significant advantage because the RF power amplifier, despite being an efficient class C design, still consumes a significant amount of power. In a Subscriber unit with a call in progress the power amplifier is only switched on and consuming power for 236/4000 = 6 per cent of the time, whereas in an analogue system it would be on for 100 per cent of the time.

The frame structure for each of the two directions of transmission, upward and downward, are shown in **Fig. 7.** As shown in **Fig. 8a,** upward signals from a number of sources may be combined at each repeater and the TDM Controller. These signals may be at widely varying levels. To provide a rapid response time to level variations of this type a hard limiting receiver is used throughout the DRCS. To allow for small timing differences between sites transmitting to the same receiver, a guard time of 16 bits is inserted in the upward frame structure between adjacent timeslots. Downward signals are broadcast from the TDM Controller and Repeaters. Thus, all downward timeslots are available to all stations on the system, as shown in **Fig. 8b.** Stations using a particular timeslot simply select and demultiplex the appropriate one.

The two units which actually perform the TDMA multiplexing are the Timeslot Controllers (TS CONT) and the Subscriber Drop Out Units (DOU). The TS CONTs form part of the TDM Controller, each one supervising both transmission directions of a particular timeslot. DOUs can be located in Repeaters, Subscriber units and in DOU shelves. DOU shelves allow a number (up to 20) of DOUs to share a single Repeater or Subscriber unit. The whole system may be viewed as a data bus which effectively connects DOUs and TS CONTs. The bus structure of each DRCS unit is shown in **Fig. 9.**

Timing

The operation of a TDMA system of this type requires

TYPE	DOWNWARDS	UPWARDS
Timeslot 0	— Battery Saving Control — Terminating Call Information — Idle Timeslot Assignment — Orderwire Control — Delay Adjustment Information — Polling for Alarm Information	— Alarm Information
Speech Timeslot (Nos. 1-15)	— Page — Release — Originating Call Accept — Test Call — Delay Information — Remote Delay Check — Codec On — Disconnect — Orderwire Interrupt	— Page Response — Release Guard with Hook Information — Connect Request with Category Check — Originate — Line Lock Out Release
E&M (at end of speech timeslot)	— Metering Signal (Originating) — Ringing Control (Terminating)	— Dial Pulses (Originating) — Off Hook
INS (at end of speech TS)	— Polarity Reversal	

Table 1 — Signalling in the Frame Structure

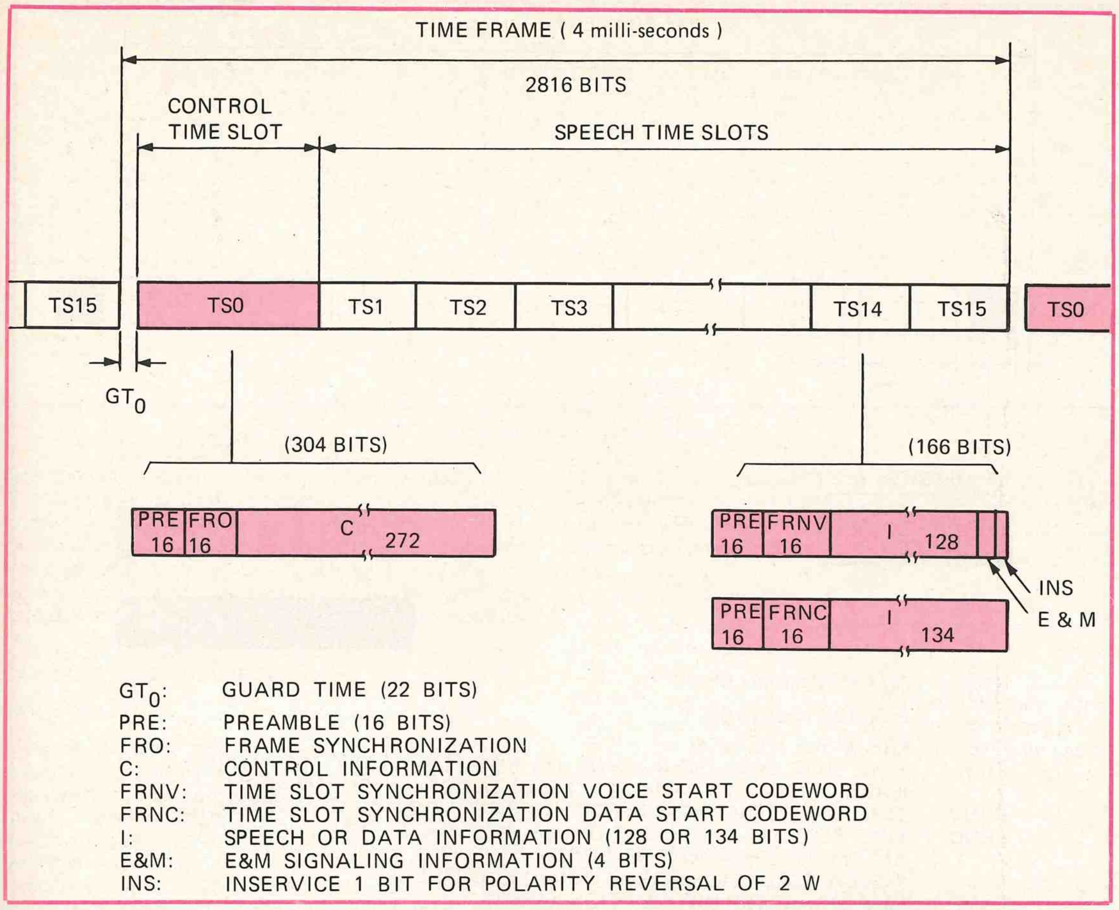

Fig. 7a: Downward Frame Structure

precise timing. Each radio unit must synchronise its internal frame clock to the rest of the system. The timing system chosen by NEC is based on the following principles:

- The TDM Controller is the master clock of the system. All units derive their timing from the synchronising word in downward TSO.
- The effective transmission time for each hop shall be the same.
- The addition of a new Subscriber or Repeater unit shall not require adjustment of the existing equipment.

Subscriber units may be any distance from 0 to 70 Km from their parent station (a Repeater or the TDM Controller). This corresponds to a propogation time variation of 122 us or approximately one complete timeslot. The DRCS gets over this problem by delaying the instant of transmission as a function of distance from the parent station. The closer in the station, the longer the delay and vice versa. Thus if a number of stations transmit on the same timeslot at the same time they will all arrive at the parent station at the same time because each unit will be delaying its transmission to allow for its distance from the parent station. Each unit must know the distance to its parent station to calculate the required delay. When a Repeater or Subscriber unit is installed this distance will be known, approximately, and this first guess is set in a distance switch on the radio unit. A system function known as a delay check is then initiated. A delay check request causes the radio unit to send a small RF pulse in the middle of an unoccupied timeslot. The TDM Controller then sends back a signal in the downward timeslot indicating whether the pulse arrived too early to too late. This is displayed in the radio unit by means of increase (INCR) and decrease (DECR) LEDS which prompt the person installing the unit to adjust the distance setting. This process enables the distance to be set to a resolution of 0.1 km with an overall accuracy of approximately 0.4 km.

As signals travel down the Repeater chain the phase relationship between the upward and downward frames change. As each additional hop is added the downward frames arrive later by the transmission delay of that hop and the upward frames must be transmitted earlier by an equivalent amount to stay in phase at the TDM Controller. Because downward TS0 is used as the timing reference, this means that the upward frame must be transmitted two hop delays earlier for every hop away from the TDM Controller. Each Subscriber and Repeater unit thus needs to know how many hops away from the exchange it is. This is done using a zone switch, which is set at installation. Zone 1 corresponds to 1 radio hop, Zone 2 to 2 hops etc.

Telex

Up to 28 telex services can be provided by dedicating one timeslot (timeslot 1) to telex transmission. A multiframe is established in which each telex service has access to timeslot 1 in every 28th frame. This gives a data

MARTELL, LOPES, WORSDELL, BANNISTER — DRCS 9

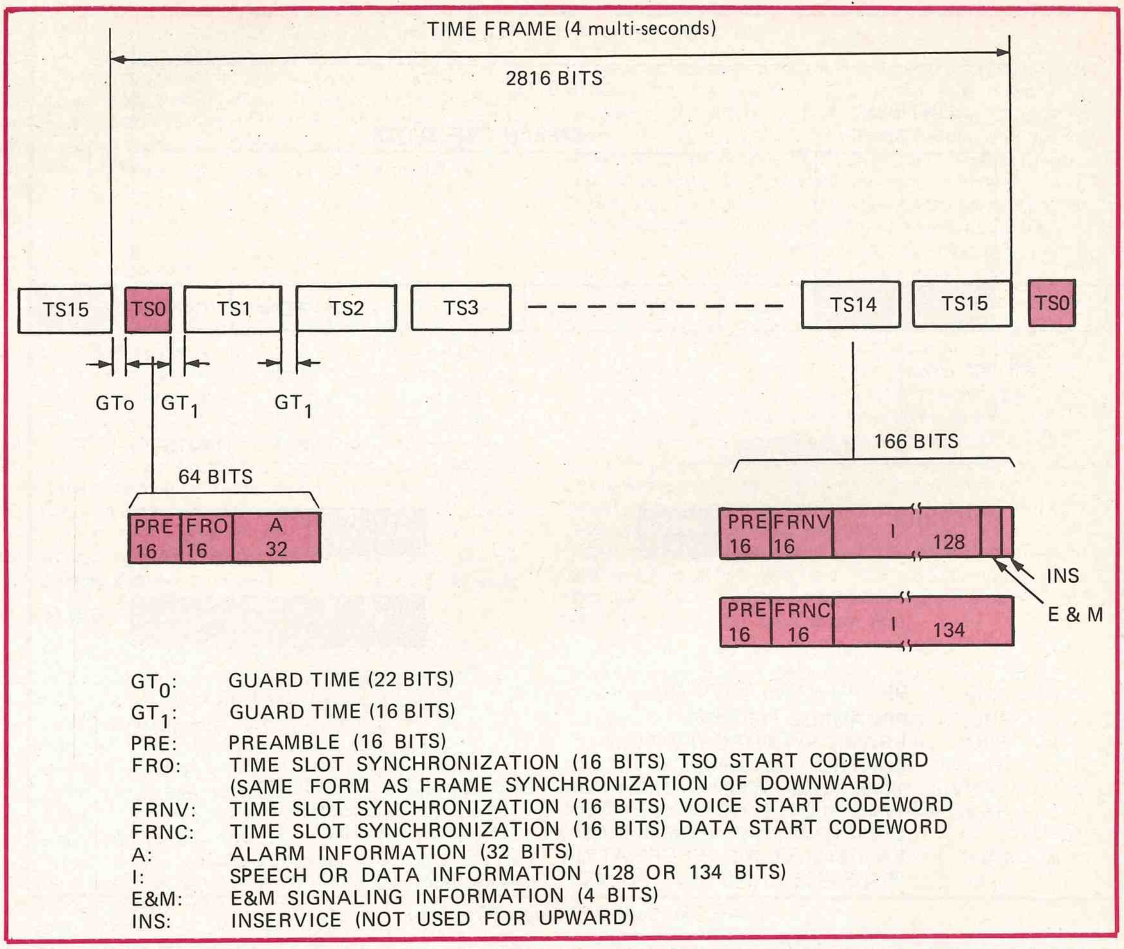

Fig. 7b: Upward Frame Structure

rate of 1 Kbit/s which allows telex transmission of up to 300 baud. The telex multiframe structure is shown in **Fig. 10.**

Battery Saving

As with analogue radio Subscriber systems, DRCS Subscriber units which are not in use cycle between a low power consumption OFF state and a higher power consumption READY state. This is known as battery saving operation. If an incoming call is signalled or the customer lifts his/her handset the unit goes into the fully active state. The ready period lasts 144 ms and the off period 720 ms. Repeater units also battery save. To ensure that terminating call signals actually manage to

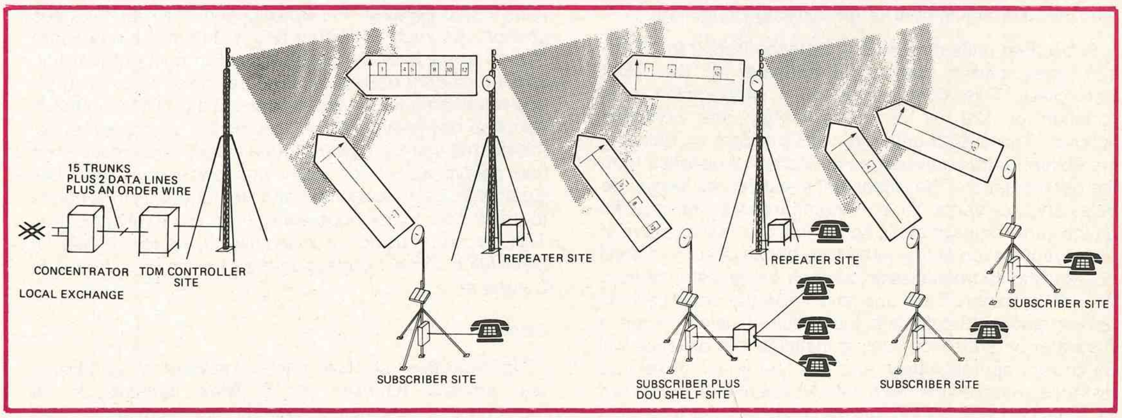

Fig. 8a: Downward Timeslot Transmission

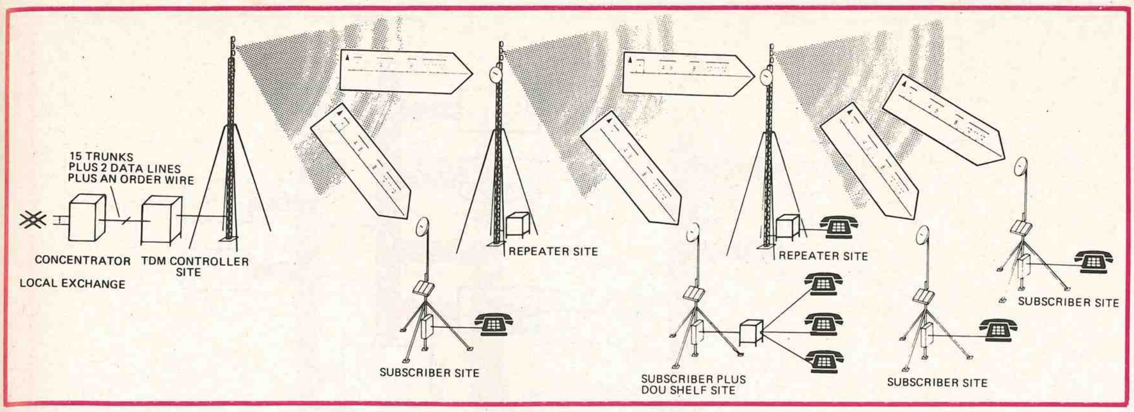

Fig. 8b: Upward Timeslot Transmission

pass through a chain of battery saving Repeaters the TDM Controller sends out a battery saving synchronising signal which causes the entire system to battery save at the same time. The battery saving system is so designed that only those units which are actually in use are not battery saving. As shown in **Fig. 11,** Repeaters which do not have calls passing through them remain in battery saving.

SWITCHING AND CONTROL

Switch Blocks

The switch block used by the DRCS is a two stage remnant reed relay switch using the NEC FRC21 unit. This has been used extensively in the ND20 and MOPAX (Mobile Telephone System) switching systems. The switch is arranged in two modules with each module serving 64 exchange Line Connect Units (LCU), giving full availability access to all 15 Trunk Connect Units (TCU). While the switch provides full availability, it is theoretically possible that congestion can occur as the arrangement of the switches within each module only allows 8 internal lines for 32 LCUs.

Control

The major components of the exchange and equipment, the Central Processor Unit (CC), the Concentrator regional processors, the Visual Display Controller (VDC) and the Data Transmission Controller (DTC), can be seen in **Fig. 9b.** The VDC is the supervisory processor for the man-machine interface and is able to support two VDUs. The DTC is the means by which the CC communicates with the TDM Controller and, via the TDM Controller, the rest of the system. Because of its importance to the systems integrity, the DTC, together with the data transmission path between DTC and the Data Controller (DC) in the TDM Controller, is fully duplicated. When the Concentrator and TDM Controller are co-sited, the links between the two are physical connections of a maximum of 15m in length. Greater distances are accommodated with RS232, 1200 bit/s modems connected over physical pairs or derived circuits.

The system software for the DRCS is based on the 780D (Z80/8080 Compatible) microprocessor for the CC, VDC and DTC. For the TDM Controller, Repeater and Subscriber units, the 80C39 is mainly used because of its lower power consumption. In a few instances the 8748 or 8085 is used. The CC and DTC are fully duplicated. All program software is contained on Ultraviolet Erasable PROM (EPROM) except for the office data which is stored in Electrically Erasable PROM (EEPROM). In this way, the system software can be easily updated by the supply of new EPROM's. In the case of the office data the advantages of EEPROM are:

- Non volatile.
- Easily updated/copies (by keyboard command).
- Minimised reload time in the event of a system failure that requires a restart.

In addition to all program being EPROM resident, extensive use is made of EPROM storage for transmitter and receiver sequencing data and preamble/identity code generation. Some use is made of ROM in programmable logic array situations.

Call Sequence

Line Supervision

As is general practise in telephony the DRCS monitors the loop status of each customer's telephone and monitors the line status of the exchange interface. Under normal circumstances while the customer's telephone is in the off-hook condition, the timeslot will remain assigned and active for that call but if the DRCS detects Line Lock Out condition (exchange Busy Tone), then after 10 seconds the timeslot is dropped, allowing it to be used for another call. In this way timeslots are not held indefinitely by a customer leaving his telephone off the hook. Prior to the timeslot being dropped, the DRCS tests the customer's telephone hook status. If the off-hook condition still exists, the loop condition is repeated to the exchange from the respective LCU and local Busy Tone is generated at the DOU. If the customer's telephone is placed on-hook then local Busy Tone is stopped. The condition is repeated to the exchange end via a free timeslot and the loop is removed from the LCU. The exchange then detects on-hook and Line Lock Out is released.

Timeslot Assignment

The usage of the timeslots for originating/terminating calls and delay adjustment is controlled by the CC. Under normal circumstances when there are four or more timeslots idle, the CC assigns two for originating calls, one for delay adjustment and the rest for terminating calls. The CC then uses TSO to inform all Repeater and Subscriber units of the originating and delay assignments. As timeslots are used, the system maintains two originating and one delay until there are only three timeslots free, at which stage it assigns one for originating and one for terminating calls. If there are only two free timeslots, it

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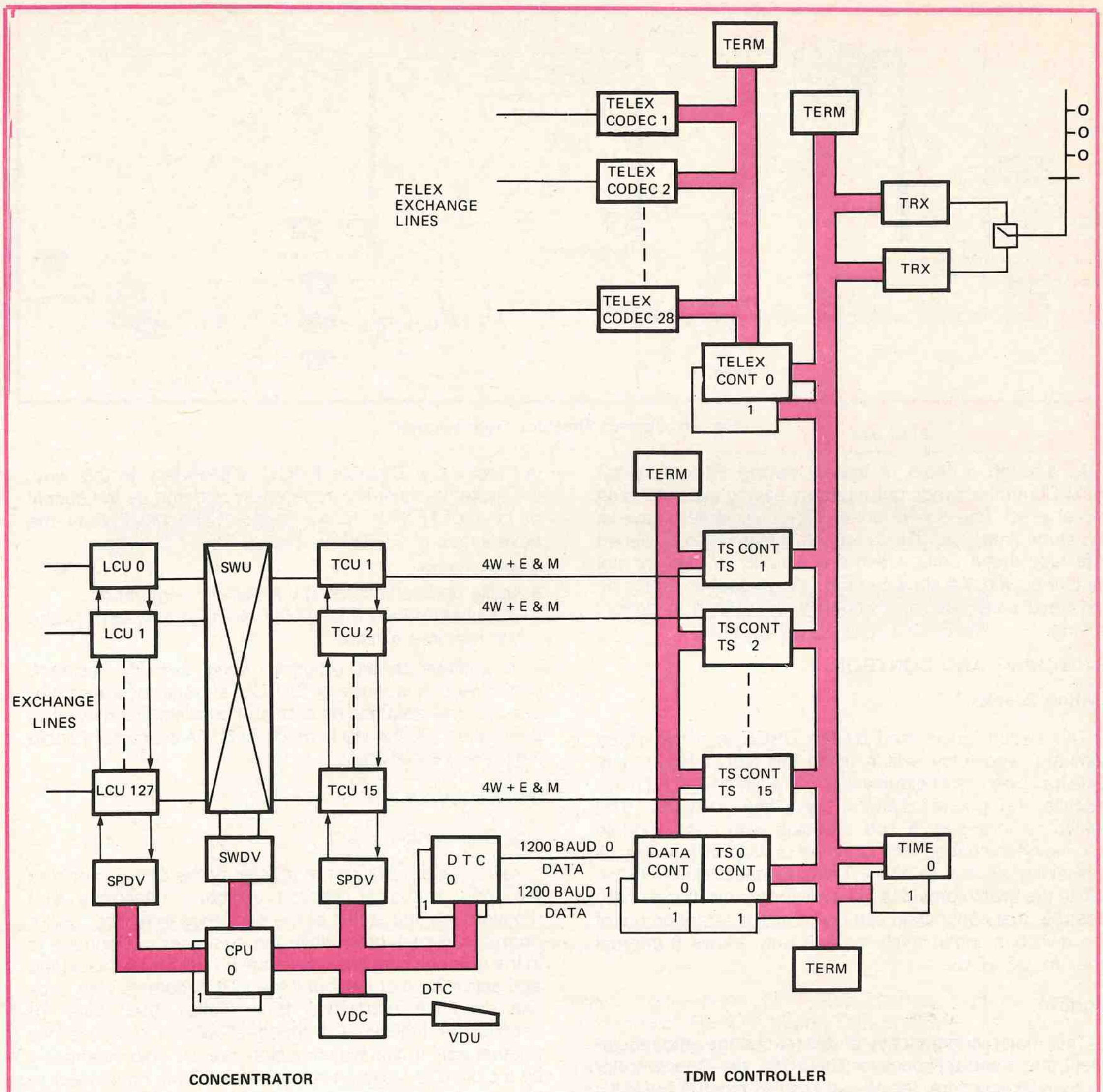

LEGEND

LCU = LINE CIRCUIT UNIT		TERM = BUS TERMINATION	
TCU = TRUNK CIRCUIT UNIT		TELEX CONT = TELEX CONTROLLER	
SPDV = SPEECH PATH DRIVER		TRX = TRANSCEIVER	
SWDV = SWITCH DRIVER		TS CONT = TIMESLOT CONTROLLER	
DTC = DATA TRANSMISSION CONTROLLER		DATA CONT = DATA CONTROLLER	
CPU = CENTRAL PROCESSING UNIT		TS O CONT = TIMESLOT ZERO CONTROLLER	
VDC = VISUAL DISPLAY CONTROLLER		TIME = TIMING CONTROL	
VDU = VISUAL DISPLAY UNIT			

Fig. 9a: Exchange Unit Bus Structure

assigns one originating and one terminating. Finally if there is only one free timeslot it assigns it for originating calls and if there is a terminating call the system will wait 600ms to check for any originating requests (which take precedence) before assigning the timeslot to the terminating call. In the case of all timeslots being busy, any originating requests are given local busy tone while terminating calls are detected at the LCU and are queued by the CC while awaiting a free timeslot.

Customer Terminated Call Sequence

- The LCU detects ring current from the exchange. The CC passes this information plus the timeslot assignment information through the DTC serial common control line to the DC within the TDM Controller. The TDM Controller then sends a Page code, DOU Identity code and Timeslot Assignment code through control TSO.
- When the Page code is detected and the Identity code matches that of a DOU at a Subscriber or Repeater unit,

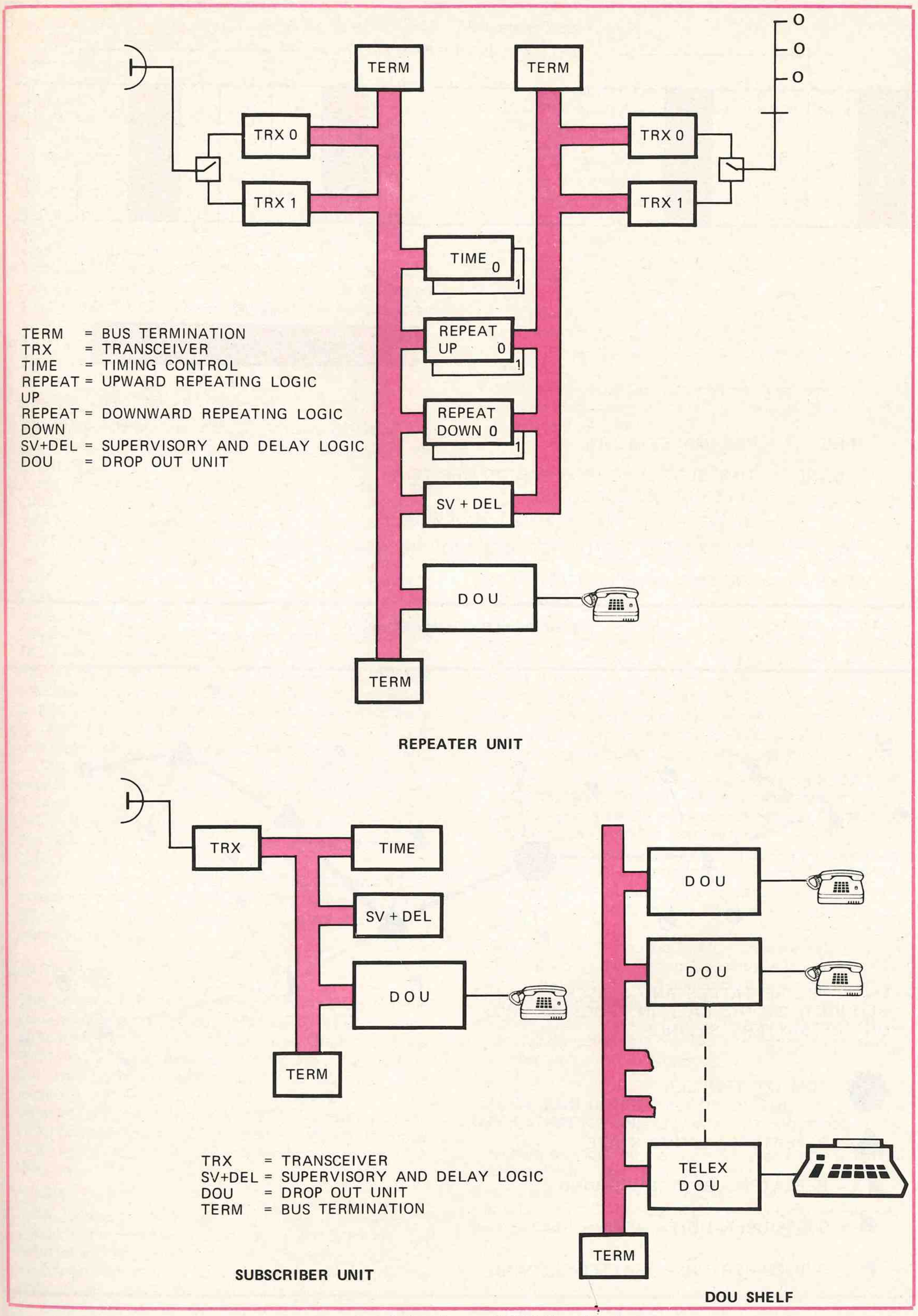

Fig. 9b: Repeater, Subscriber and DOU Bus Structure

MARTELL, LOPES, WORSDELL, BANNISTER — DRCS 13

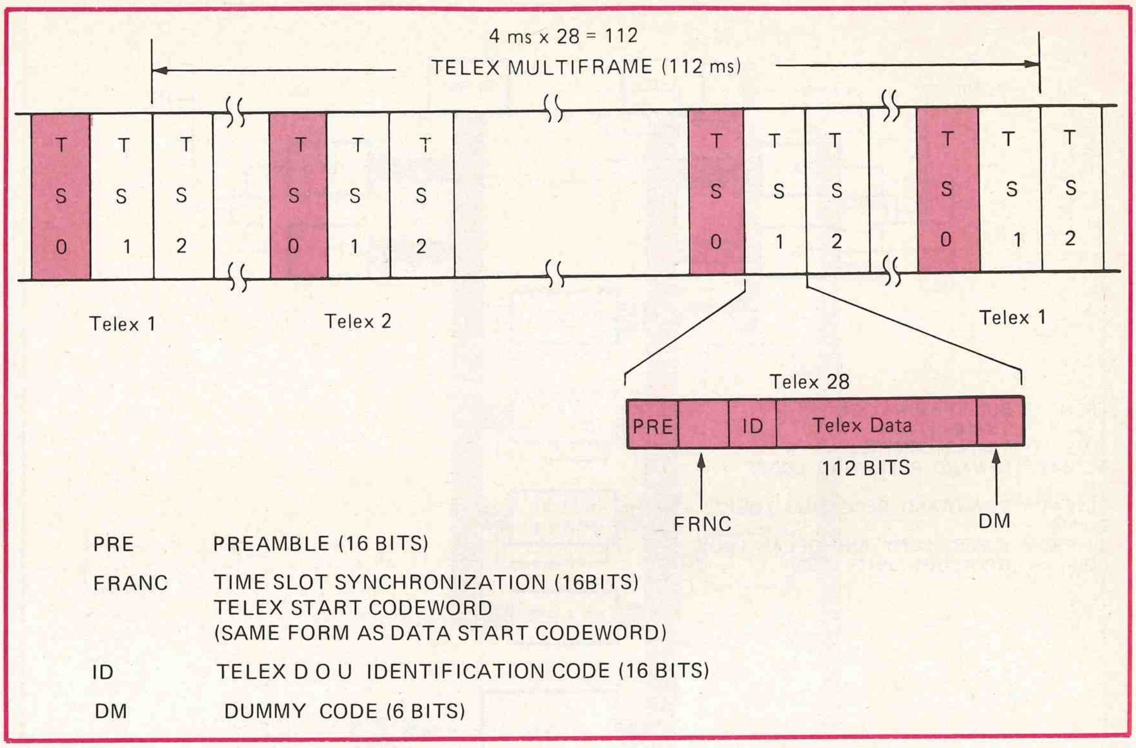

Fig. 10: Telex Multiframe Structure

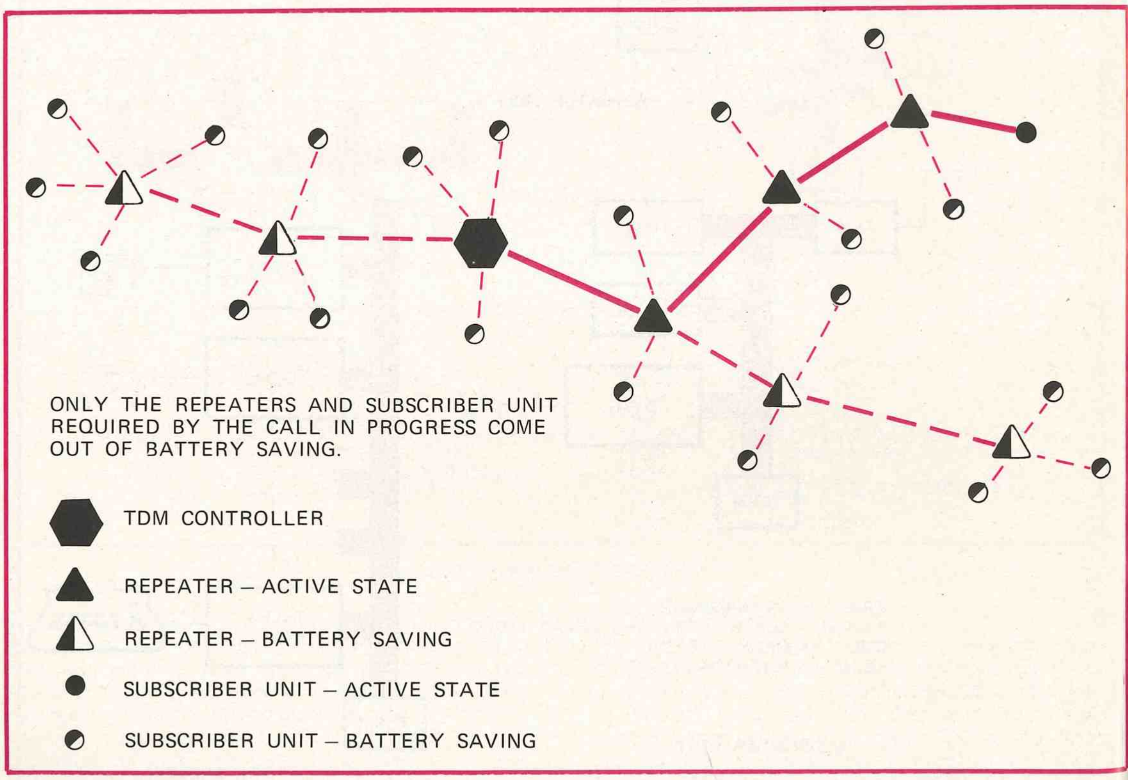

Fig. 11: DRCS Battery Saving

the DOU sends a Page Response code and the Identity code through the timeslot assigned by the Timeslot Assignment code. Then the chosen TCU (timeslot) is switched to the respective LCU to allow the detection of ring cadence.

- When the Page Response code is detected by the Concentrator, it forwards ring information via the M lead of the assigned timeslot (the cadence of the ring is synchronised with the M lead signal). This continues until either, the DOU telephone is taken off-hook or the exchange returns to idle polarity. At the DOU, the ring signal is detected on the E lead and ringing current is sent to the telephone in sympathy.
- The DOU detects the telephone off hook condition and signals the concentrator via the M lead. At the same time a speech path between the DOU and the telephone is set up.
- The Concentrator detects the E lead signal in the TCU and a DC loop to the Exchange is established.

Customer Originated Call Sequence

- The TDM Controller, through TSO, broadcasts the numbers of the two timeslots which are assigned for originating calls to all DOUs.
- Upon detecting the telephone off hook condition, the DOU sends an Originating code and an Identity code through one of the assigned timeslots. In response, the TDM Controller sends back an Originating Accept code and the Identity code through the chosen timeslot.
- When these codes are received, the DOU sends a Connection Required code. If the Originating Accept code is not received, the DOU continuously sends the Originating code up to a preset time limit after which the DOU attempts the originating call through the other of the two assigned timeslots. If this also fails, the call attempt is abandoned and local Busy Tone is switched to the telephone. When the Connection Required code is received at the Concentrator, a DC loop to the exchange is made at the respective LCU corresponding to the DOU originating the call. Dial tone from the exchange is then sent to the DOU via the speech timeslot.
- At the DOU, dial pulses are sent through the M lead to the TCU which converts the E lead signals back to dial pulses on the two wire exchange loop.
- If all 15 speech timeslots are busy, the downward TSO is used to broadcast an All Timeslots Busy code. Local Busy Tone is then switched to the telephone whilst it remains off hook.

Call Clearing

- The on hook condition is detected at the DOU and the Concentrator signalled via the M lead. The Concentrator then removes the DC loop to the exchange and the exchange line is monitored for the idle condition. When the idle condition (unbalanced line impedance) is received a Release code is sent to the DOU and the timeslot is cleared. The connection is cleared at the DOU on the reception of the Release code and for some DOU types the unbalanced idle condition is repeated to the line.

— OR —

- If the Concentrator detects Busy Tone (LLO) after 10 seconds the Release code is sent to the DOU and the timeslot is cleared but the LCU maintains the loop to the exchange. When the Release code is detected at the DOU, Busy Tone is switched to the telephone until the on hook condition is detected. The LCU loop is then cleared.

System Supervision

Operation

The system can be controlled via either of the two VDU ports. One is designated "local" and the other "remote". An in-built 1200 bit/sec modem is provided to drive the remote port.

The VDU operator can perform the following:

- Perform supervisory tests on all remote equipment including a "capacitive kick" and leakage test on the customer's line and terminal equipment.
- Changeover duplicated items.
- Change switching parameters (e.g. timing for time supervision signals).
- Change Office Data (Repeater unit, Subscriber unit and individual service registration) and if required "write" the ammendments to EEPROM.
- Check the system TDM delay adjustments at individual stations.
- Initialise testing of all Concentrator functions.
- Display system status for all subsystems including the status of duplicated items.

Alarms

All remote subsystem alarms are reported to the Concentrator where they are categorised as "Urgent" or "Non-urgent" and the respective system alarm raised. The VDU operator can interrogate the system for further information using the VDU and if necessary carry out further tests.

In addition to raising alarms, the system classifies certain Concentrator faults and depending on that classification chooses an appropriate signalling retry or system restart sequence. The underlying philosophy is, firstly, to cause as little disruption to customer calls as possible, secondly, to establish all calls if at all possible, and finally, to keep the system operational. The classifications and the resulting actions are as follows:

- Phase 1 fault: Includes all hardware and DTC-DC signalling faults. They are typically minor only affecting, for example, a single call and they usually involve an automatic re-try that is successful.
- Phase 2 fault: Usually caused by a software abnormality or where a Phase 1 fault counter's limit is exceeded. The system is automatically reset and all established calls are lost. The reset is on the same CC and DTC-DC link.
- Phase 2.5 fault: Caused by CC hardware failure or the occurrence of four Phase 2 restarts within a specified time. The system is automatically reset and the CC changed. All established calls are lost.
- Phase 3 fault: This is a manual restart of the system. All calls are cleared and the CC is selected by a switch setting on the Concentrator.

DESIGN AND CONSTRUCTION OF THE MEEKATHARRA AND MT. MAGNET SYSTEMS

Communication requirements for the remote pastoral districts of the upper Gascoyne and Murchison in Western Australia are now serviced by two Digital Radio Concentrator Systems. These terminate at the local community service towns of Meekatharra and Mt. Magnet.

When commissioned by the Minister of Communications, Mr Duffy, at a commemorative ceremony on 19-20 June 1985, the Meekatharra and Mt. Magnet DRCS became the first operational, volume production systems in Australia. These initial systems operate at 500 MHz.

Journal of Telecommunications and the Digital Economy, ISSN 2203-1693, Volume 7 Number 4 December 2019

http://doi.org/10.18080/jtde.v7n4.242 80

System Overview

Both systems were been programmed for construction in two stages. The Meekatharra DRCS initially provided 57 individual services via 8 Repeaters and 43 Subscriber radio units. During 1985/86 it was expanded to 13 Repeaters providing 67 services. Mt. Magnet DRCS initially provided 58 individual services via 10 Repeaters and 38 Subscriber units. During 1985/86 it was expanded to 13 Repeaters providing 71 services. The initial installations operate at 500 MHz and the expansions operate at 1500 MHz.

Together the systems encompass an area of some 200,000 square kilometres **(Fig. 12)**

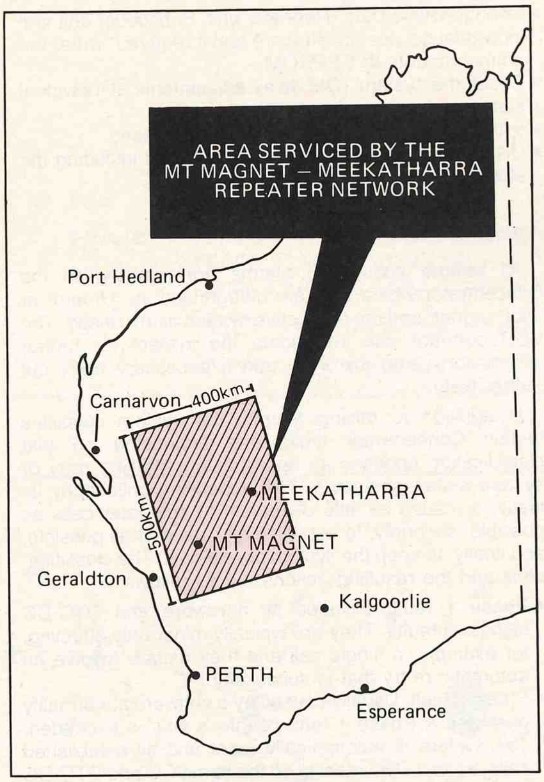

Fig. 12: Meekatharra and Mt. Magnet System Area

Predominant activities in the area include the pastoral industry based on wool production, mining, specifically for gold, and tourism. The total population is less than 3000 people, accommodated largely in the towns of Meekatharra, Cue, Mt. Magnet, Sandstone, Yalgoo and the hamlet of the Murchison shire.

Apart from the bitumised great Northern Highway, all roads in the vast area are gravel of varying quality. This, together with limited telecommunications infrastructure at even major towns, presented some special challenges in the design and installation of appropriate communications facilities.

Meekatharra

Situated 764 km from Perth on the Great Northern Highway, the town is a regional centre, serviced by road and air. The airport can handle large aircraft in emergencies, as an alternative to Perth.

The Royal Flying Doctor Service (RFDS) has a base station in Meekatharra which originally provided the only facility available for communications to pastoral station homesteads and mining camps. Since the introduction of DRCS, the RFDS radio station primarily conducts School of the Air broadcasts.

Mt. Magnet

196 km to the south of Meekatharra and also on the highway, Mt. Magnet is situated 569 km from Perth and is serviced by road transport.

Although older than Meekatharra, Mt. Magnet (named in 1854) is the smaller of the two towns. Both towns flourished in the 1890's with the discovery of gold, then declined in the late 1940's. With the escalation of gold prices in the late 1970's and the end of a seven year drought in 1984, a revival in the mining and pastoral industries is current.

Telecommunications Infrastructure

The upper Gascoyne/Murchison is one of the last areas in Western Australia to be wholly serviced by open wire transmission systems. A fully utilised route extends 523 km easterly from Geraldton to provide trunk circuits to the 400 line ARK521 type exchanges in Mt. Magnet and Meekatharra (and smaller exchanges at Yalgoo, Cue and Wiluna). See **Fig. 13.**

Introduction of DRCS severely taxed these existing transmission and switching systems, requiring the following supplementary actions:

- Doubling of the power supply at each telephone exchange, including complete replacement of the rectifier and battery banks.
- Installation of trunk line doubling equipment employing time assignment speech interpolation techniques, to achieve increased circuits to the parent exchange in Geraldton.
- Expansion of the telephone switch numbers from 300 to 400 at Meekatharra and Mt. Magnet, plus rearrangements in the Geraldton minor exchange.

Future developments include the proposed installation of an optical fibre route to provide trunk circuit relief from Mullewa to Mt. Magnet in 1987 and subsequent extension to Meekatharra and Newman in later years. The fibre will be supplemented by a 34 Mbit/s radio bearer from Geraldton to Mullewa and an AXE type exchange to be installed at Geraldton during 1986/87.

Design

General

Planning the introduction of the DRCS in Western Australia commenced in 1982/83 and from June 1983 the Western Australian Radiocommunications Design Group of Telecom began the radio network design specifically to suit Meekatharra and Mt. Magnet pastoral districts.

Also about this time Telecom announced the Rural and Remote Area Programme and later introduced Country Wide calling. Initial customer locations were identified by Customer Services Section of the Local Operations District (the task is now undertaken by Marketing Branch).

Radio network design followed the familiar steps of field visit, map, study, site selection, propagation test, detailed design, field site survey, Aboriginal heritage impact study, commencement of site acquisition and minor adjustments to site relocations and design assessment.

Helicopter Surveys

Due to the vast distances to be travelled and the lack of

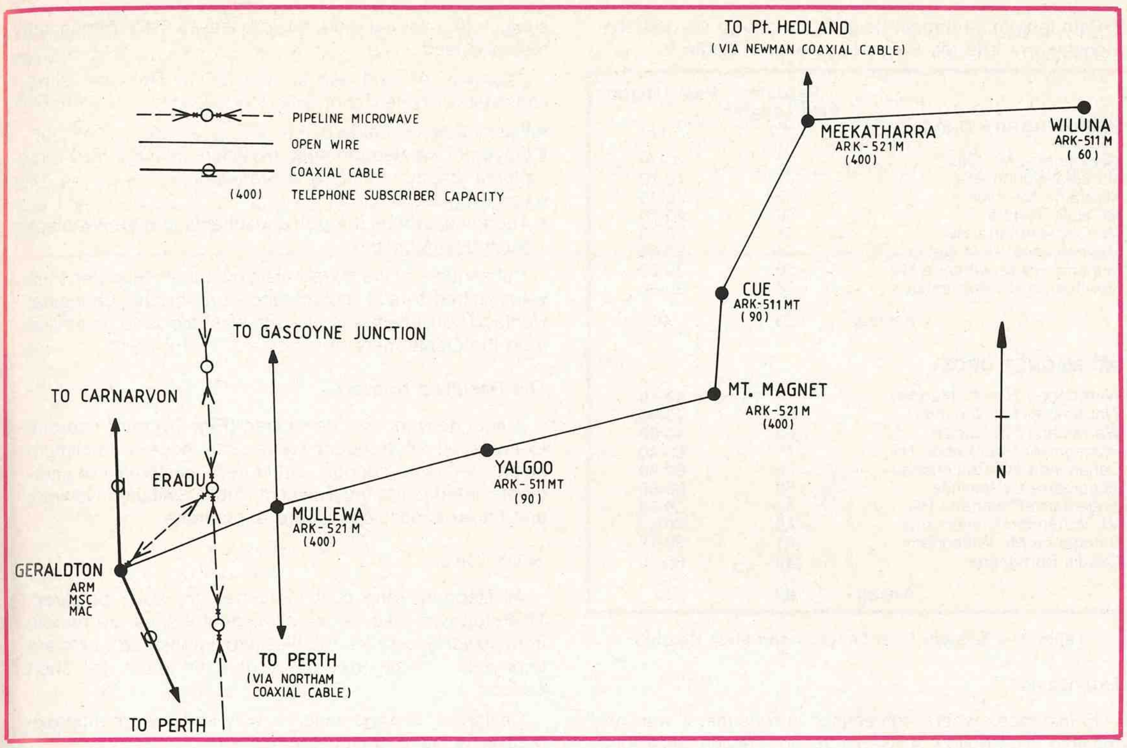

Fig. 13: Murchison District Communications Network

detailed maps, helicopters were employed extensively during the field visits and the propagation testing phase.

A new technique involving the use of two helicopters, was successfully applied to check possible radio paths by propagation testing. The simple but effective concept is illustrated in **Fig. 14.**

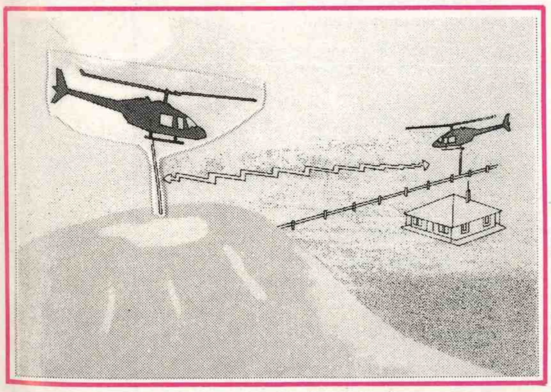

Fig. 14: Helicopter Radio Path Survey

Radio equipment mounted in each helicopter, and omni directional antennas, (lowered in the helicopter hover position) were selected to test marginal paths. Attachments to each aircraft were approved with the Department of Aviation.

Tests at 150,500 and 1500 MHz have been successfully conducted by this technique. For example, a maximum path loss of 130 dB at 520 MHz was sought on Repeater to Subscriber Unit paths and free space loss on Repeater to Repeater paths by increasing hover height until the target loss was bettered.

The main benefits of helicopter testing are:

- A large range of height/gain tests can be conducted in a short time scale.
- Significant cost savings in the order of 50 per cent can be realised in comparison with ground based techniques involving pump-up masts.
- Reduced wear and tear on vehicles, test equipment and personnel.

Repeater Site Selection

Two main factors contributed to the selection of Repeater sites.

- Terrain Type
  The Murchison area consists of mainly flat, open ground with occasional hills rising up to 50 metres or more above the surrounding plains. The area is characterised by sparse vegetation and reasonably accessible (by four wheel drive vehicle) flat topped hills and granite outcrops. Such hills provided excellent elevation for Repeater sites and contributed to a reduction in mast heights.
- Overshoots
  The limited number of channels in the 500 MHz band and the terrain type required that particular attention be paid to cochannel overshoot. Frequency reuse was based on a cellular plan and kept to an absolute minimum. Where appropriate, the omnidirectional patterns were offset to a near cardioid shape to further reduce the possibility of interference.

Repeater sites were initially selected on 1:1,000,000 maps as a best fit to customer distribution (very sparse) and terrain advantage. These sites were optimised during field visits, further design and site survey. Several radio paths approach the equipment's specified maximum of 70 km in length (one path is 71.2 km).

Path lengths and mast heights are shown for both the Meekatharra and Mt. Magnet systems in **Table 2.**

MEEKATHARRA DRCS	Repeater Path Lengths (km)	Mast Heights (m)
Meekatharra-Mt. Obal	17	20-70
Mt. Obal-Koonmarra	71	70-70
Koomarra-Mt. Hale	52	70-40
Mt. Hale-Yundra	58	40-70
Mt. Obal-Munarra Hill	51	70-30
Munnarra Hill-Weld Range	54	30-20
Munarra Hill-Nowthanna Hill	50	30-30
Nowthanna Hill-Barrambie	68	30-80
Average	53	48
MT. MAGNET DRCS		
Warramboo Hill-Mt. Magnet	4	40-10
Warramboo Hill-Coolarda	62	40-70
Warramboo Hill-Carron	62	40-80
Bracegonier-Warramboo Hill	55	60-40
Carlaminda Hill-Bracegonier	55	50-60
Jingemarra-Carlaminda	50	50-50
Jingemarra-Poondarie Hill	44	50-50
Mt. Wittenoom-Jingemarra	45	70-50
Burriganna-Mt. Wittenoom	61	90-70
Caudle-Burriganna	49	60-90
Average	49	57

Table 2 — System Path Lengths and Mast Heights

Extensions

In instances where, for economic reasons, it was not feasible to provide a Repeater to service only one customer, extension by Single Channel Analogue Radio Systems operating at 150 MHz was implemented.

Approval for Land Use

The Murchison area is wholly owned Crown land subject to pastoral and mining leases and Aboriginal reserved land.

Approval for land use for the DRCS Repeater sites consisted of consultation with the following:

- Pastoral lease holders
- Government departments (Aviation, Mining, Environmental Impact, Lands and Surveys)
- Local Shires
- Aboriginal groups through consultants and the Western Australian Museum.

Subsequent to the initial selection, three Repeater sites were shifted to suit recommendations by the Aboriginal Heritage consultant and one site was relocated on advice from the Department of Mines.

The Resulting Network

A final network was developed **(Fig. 15)** after rigorous examination of frequency use, site access, minimum height antenna support structures, customer requirements, interface to the Telecom Public Switched Network and future expansions where appropriate.

Solar Power

All Repeater and customer sites are solar powered. This step was taken since all Repeater sites are remote from power generation facilities and homestead plants are unreliable, usually run on a demand basis for short periods.

Designed average solar power loads were approximately 54 watts at Repeater sites.

Installation

General

The first DRCS in Western Australia were implemented on a special projects basis with a Project Engineer

Function	Group	Responsibility
• Survey	Telecom Drafting Group	Site survey including block contour and plant layout.
• Access and Site Clearing	Department of Construction	Construction of 4 wheel drive quality roads and cleared block.
• External Plant at Repeaters	Telecom Radio-lines and Electric Power Transmission Ltd. (EPT)	Mast construction and installation of Repeater shelter, solar array frame, antennas and feeders, earthing and site security fencing. Radio-lines-Meekatharra. EPT-Mt. Magnet.
• External Plant at Customer End	Telecom Great Northern District Operations	10 metre pole, equipment shelter, solar array and house cabling.
	Telecom Radio-lines	Antenna support structure greater than 10 metres in height plus shelter and array frame.
• Solar power equipment and power upgrade at Exchanges	Telecom Telepower Group	Solar panel mounting, interwiring, battery installation and voltage regulator commissioning at repeaters plus rectifier and battery bank. Installation at Exchanges.
	Telecom Country Installation	Solar power at Customer premises.
• Internal Plant (Radio Equipment)	Telecom Country Installation	Installation and commissioning of all radio equipment and exchange Concentrator.

Table 3 — Project Functional Groups

responsible for several functional groups — each with special expertise. These groups are shown in **Table 3.**

Schedule

Installation began in September 1984 extending outward from the exchange toward Subscriber stations. Despite some material delivery delay in the early stages and later, a number of "teething" problems, the system was commissioned on schedule in June 1985.

Installation activity was not hampered by bad weather to any significant degree, however, travelling distances were enormous. For example, the technical staff (only one of several groups) recorded travelling 120,000 km during a seven month period. This represents more than 2400 manhours spent simply driving. There were no lost time accidents, however, due to driving or for any other reason.

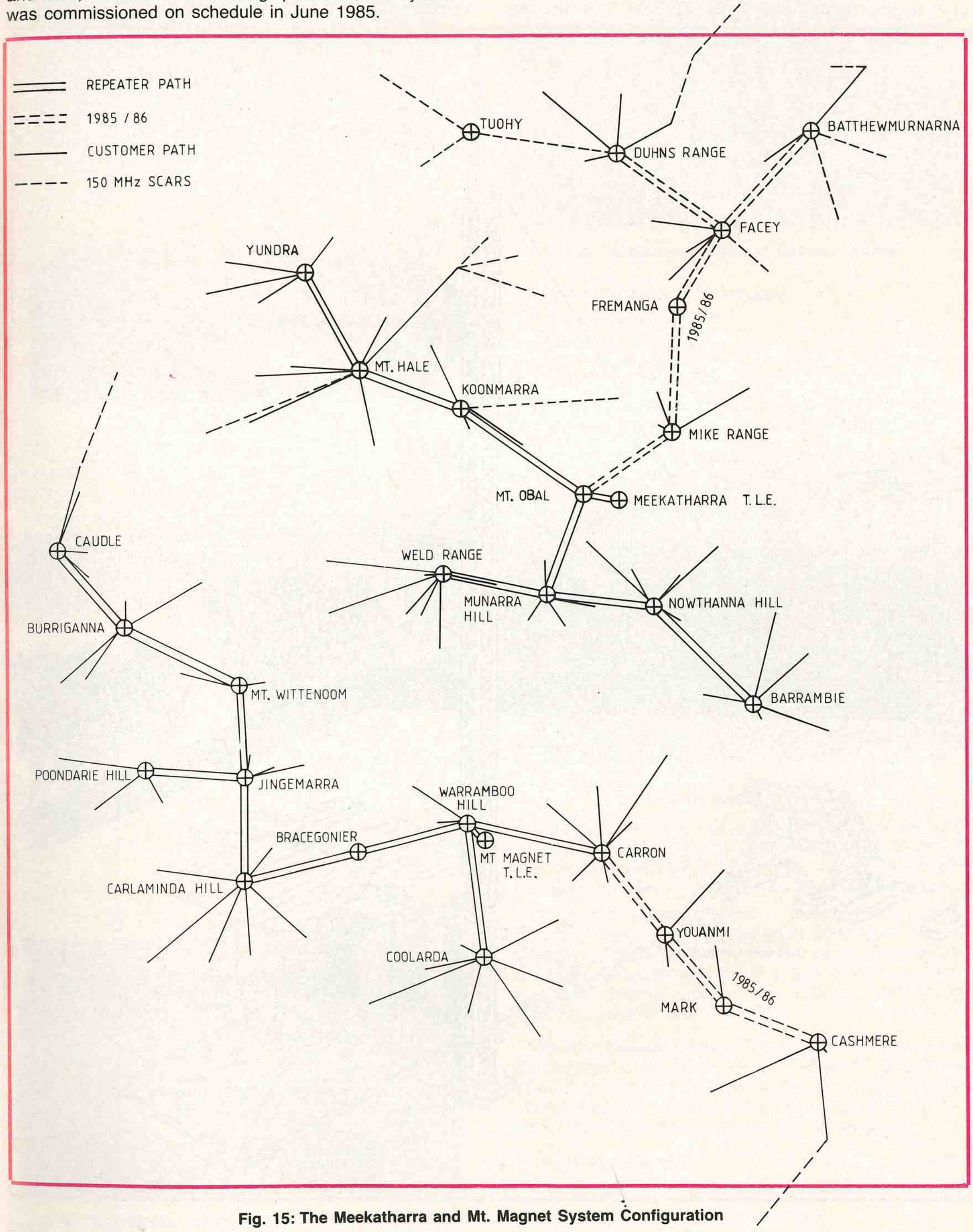

Fig. 15: The Meekatharra and Mt. Magnet System Configuration

Journal of Telecommunications and the Digital Economy, ISSN 2203-1693, Volume 7 Number 4 December 2019

http://doi.org/10.18080/jtde.v7n4.242

External Plant

The Repeater layout used at Meekatharra and Mt. Magnet is shown in **Fig. 16** and will form the basis for future installations. A typical site is shown in **Fig. 17.** On average, external plant at a Repeater site can be completed in three weeks.

The Repeater solar array frame was located a minimum of 6 metres north of the mast. This distance will be increased for WA installations north of the Tropic of Capricorn to avoid midday shading during the summer solstice. The mast and solar array frame are sufficiently robust for installation in cyclonic areas.

The Repeater shelter comprised a thermally transparent, free standing, cabinet fabricated by Siemens Ltd. Manproof security fences were erected around all Repeater sites on the Mt. Magnet DRCS and low cost cattle proof fences were erected around all Repeater sites

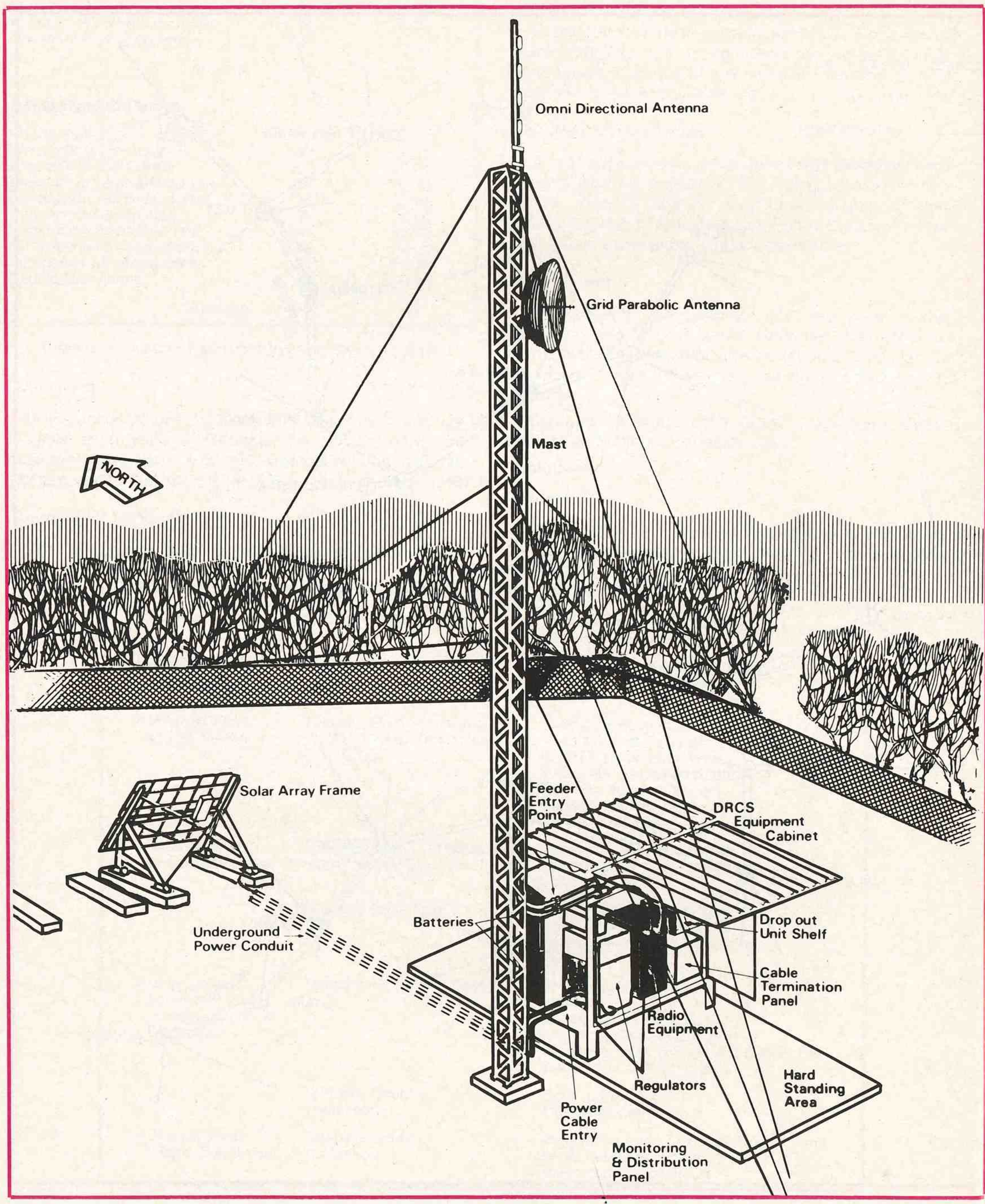

Fig. 16: Repeater Site Layout

Journal of Telecommunications and the Digital Economy, ISSN 2203-1693, Volume 7 Number 4 December 2019

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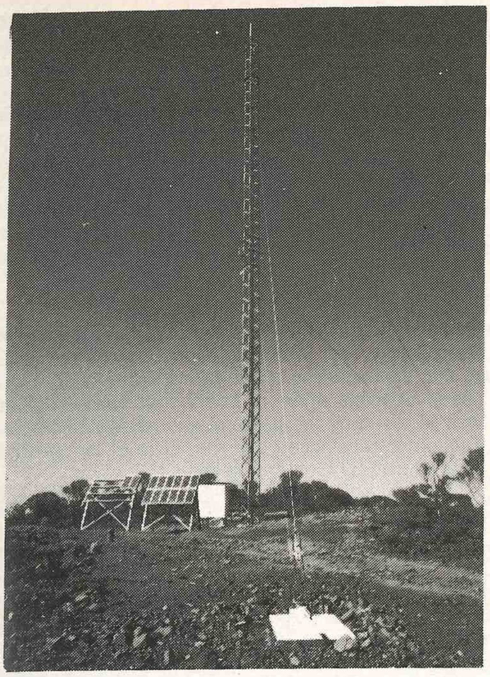


Fig. 17: Typical Repeater Site

on the Meekatharra DRCS. In this way a comparison between the systems can be made and a judgement made on the extent of security for future systems.

Typical external plant at customer sites is shown in **Fig. 18.** A sectionalised tubular steel pole, antenna, environmental shelter, and solar panel array were located as near as practicable to the station homestead.

Fig. 18: Customer Equipment at Milly Milly Station

Internal Plant

Electronic equipment was installed on the South facing side of the Repeater shelters **Fig. 19).**

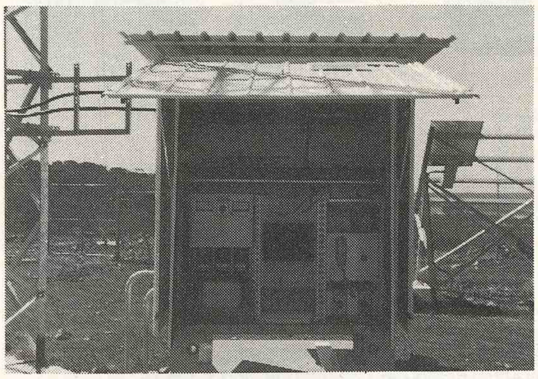


Fig. 19: Equipment Side of Repeater Shelter

A typical Repeater site included:

- The radio Repeater unit
- Solar power regulators
- A shelf for DOUs
- A technicians telephone

12 Volt, 1000 Ampere hour battery banks were installed on the north facing side of the shelter **(Fig. 20).**

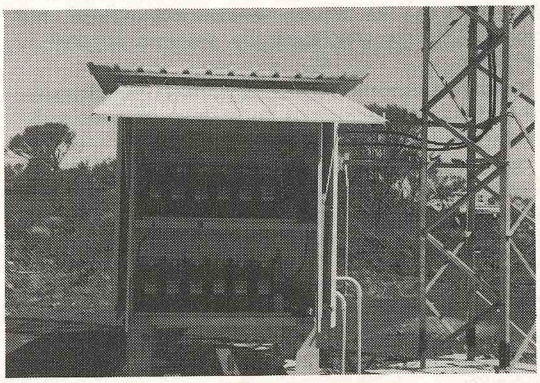


Fig. 20: Battery side of Repeater Shelter

Generally, the equipment at customer sites consisted of a Subscriber radio unit fitted with one DOU, a solar power regulator and lightning arrestor. Two, 6 Volt, 90 Ampere hour batteries are charged by two 30 watt solar panels.

For customers requiring two or more services a DOU shelf was installed. Additional solar panels and battery storage was often necessary in these cases. Six separate combinations of environmental shelter type, solar array type and battery storage dimensioning catered for differing customer requirements.

For both Meekatharra and Mt. Magnet, the Concentrator and the TDMC were co-located **(Fig. 21).** A width of about 4 rack units was required in a suite which allowed access front and rear. The supervisory VDU was mounted on a small table adjacent to the Exchange unit.

Current Performance

A wide range of customer terminal equipment has been tested successfully on DRCS including:

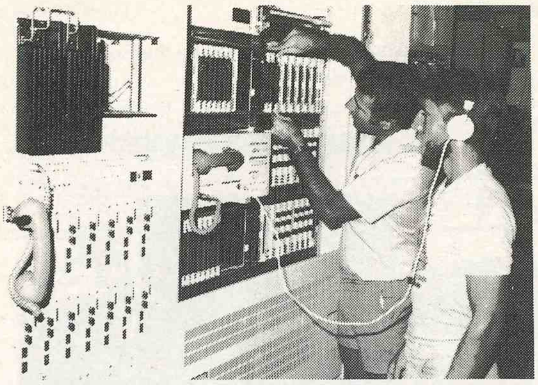


Fig. 21: Installation of the Mt. Magnet Exchange Units

- Standard Telephone Instruments
- Coin Telephone (Goldphone and CT3)
- Computer Phone
- Telex
- Parallel Services (up to three instruments)
- Extension Bells
- A Weather Observation Terminal (WOT) supplied by the Bureau of Meteorology
- Small Business Systems including solar powered commander T105s at several locations.

NEC Engineers visited the system to assist with the resolution of problems associated with the introduction to the field of the first volume production equipment. The problems mainly concerned the system's supervisory functions.

System transmission performance has been assessed by 36 hour data recordings on sample paths, using Bit Error Rate Testers (BERTS).

Both systems meet overall service objectives although a small number of stations have experienced unavailability outside specification due to individual unit malfunction. Background Bit Error Rate (BER) is well within specification. Short and long term BER due to propagation performance is also within specification.

The data recordings have shown a slight susceptibility to lightning discharge in the form of small bursts of errors. These bursts, however, are not noticeable during conversation.

A traffic measurement unit has been designed by the Western Australian Telecom Electronic Design Group and installed on both systems. The device records data on All Time Slots Busy (ATB) and Time All Time Slots Busy (TATB) by incrementing in 6 second intervals. Due to the high ratio of Time Slots to Services for the initial phase of the system, no registrations of congestion have been noted.

Solar power equipment on both Meekatharra and Mt. Magnet DRCS is performing reliably and has a safe margin for increased telephone traffic.

Early results from data logged at 4 sample sites, indicate the Repeater shelters are easily dissipating the excess heat generated by current traffic levels. The inside temperature rise near the roof of the shelter is of the order of 1 degree C relative to the outside shade temperature. This performance is to be expected since the shelters and radio equipment are designed to operate with a 5 degree C rise for the dissipation associated with the maximum traffic possible i.e. 15 time slots continuously active. These shelters have been well accepted by installation and maintenance staff as the lift-up door provides protection from the sun whilst allowing the free flow of air.

Customer Reaction

As might be expected, the provision of an automatic telephone facility, with trunk and international Subscriber dialling and the capability of interfacing with modern data services to locations where no telephones existed before was well received by the pastural and mining communities. Customer satisfaction and the value of the service has been shown by high calling rates.

During installation, customers were progressively cut into service on the understanding that some interruption to service may occur prior to formal commissioning. No charges were levied although outgoing calls were restricted to local access (STD barred). Many calls were initiated in this phase helping with the early detection of equipment design faults. Telecom installation staff were treated with great hospitality while in the field.

On Commissioning day, the commemorative functions were attended by capacity crowds at the Murchison, Meekatharra and Mt. Magnet Shire Halls and a special function at the Mileura station homestead.

Expansion

Work has already been completed on extensions to both the Meekatharra and Mt. Magnet systems, and other projects have commenced.

The installation of the first phase has served as an excellent training and debugging model for future installations. A further 9 large scale systems are to be installed in Western Australia by 1989.

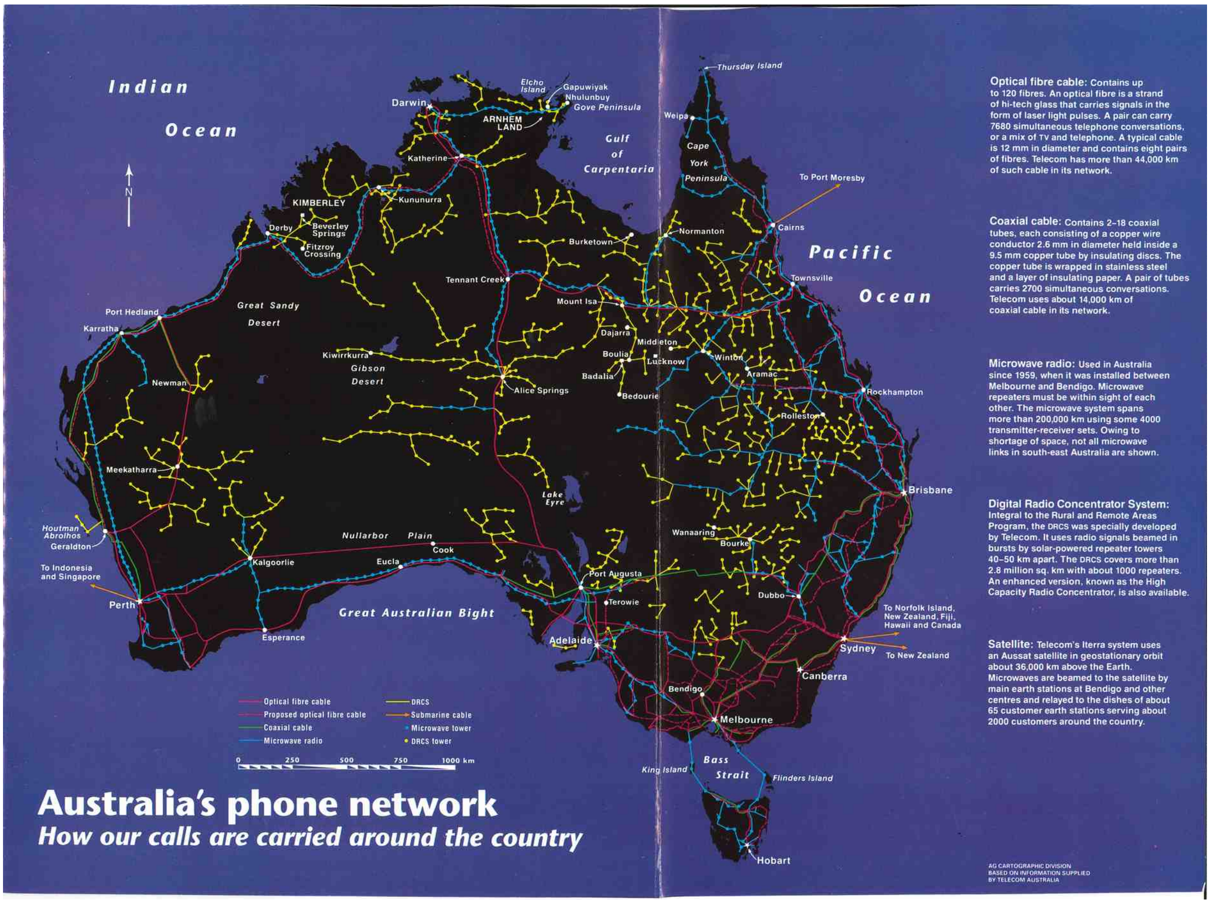
CONCLUSION

Telecom is committed to providing access to modern telephone services to all Australians by 1990. The DRCS is a major part of this plan. It is a large project with many systems to be installed in the most remote parts of Australia. As such it has required innovation in many areas including installation and maintenance practices as well as internal and external plant design. At the time of writing, 25 DRCS Projects have been successfully commissioned in four States, demonstrating Telecom's committment and ability to reach its goal.

As recognition of its achievements in the DRCS, Telecom was awarded the 1986 Engineering Excellence Award by the Institute of Engineers Australia, Queensland Division.

The Australian Telephone Network in 1992

This map, reprinted from Brass (1993), highlights the extensive geographical reach of the Digital Radio Concentrator System (shown in yellow).



http://doi.org/10.18080/jtde.v7n4.242