Madley–UK's latest Intelsat earth station

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Summary Marconi Communication Systems Limited was prime contractor for Madley 1, the first satellite communications earth terminal to be installed at the new British Post Office ground station complex in Herefordshire. The initial communications equipment is providing a large capacity for telephone, telex and TV traffic via an Indian Ocean Intelsat IVA satellite. Fourteen transmit chains have been provided, having 6 carriers with one-for-one redundancy plus non-redundant TV video and TV audio. In the receive path are 55 operational chains which can, if required, be configured on one-for-one redundancy by use of flexibility facilities.

This article aims at giving a broad appreciation of the overall system design and capability and is not intended to be an in-depth treatment of any specific topic. The introduction outlines the need for the station and gives a brief description of the equipment configuration, leading naturally into more detailed sub-system descriptions. These deal with the antenna, broad-band receiving and transmitting equipments, ground communications equipment and the station control and supervisory facilities. Some overall system aspects are then given, followed by a short section on project management and implementation, with a statement on further work to be carried out by the Company at Madley.

T. J. Canham

Born in Colchester and educated at Colchester Royal Grammar School, he joined Marconi as a student apprentice. Following a 5 year sandwich course he obtained his B.Sc. (Hons) in Mechanical Engineering, subsequently studying at the Anglian Regional Management Centre. Joining Space Communications Division in 1967, he worked on large steerable antenna design and installation until 1972, becoming site manager on large Earth Stations. As Project Controller he implemented the first North Sea Tropo project—B.P. Forties. In 1975 he was appointed Space Projects Manager, responsible for implementation of Earth Station contracts.

A. G. Ruddock

Alan Ruddock was educated at Nunthorpe Grammar School, York. After National Service in the R.A.F. he joined the Test Department of Marconi's Wireless Telegraph Company in 1952. He later transferred to the Works Engineering Division where he was primarily concerned with the design evaluation of multichannel line of sight links. In 1966 he joined the Company's Space Communications Division as a systems engineer and has been continuously involved in the Studies, Sales and Contractual aspects of satellite communications systems engineering.

Introduction

World-wide demand for international telephone and telex circuits continues to grow. The currently planned satellites will have increased capacities to satisfy this demand. Corresponding increases in the numbers of circuits available at satellite communications earth stations are therefore necessary, many of the receive chains in the large earth station complexes being devoted to the smaller carriers being transmitted by the earth stations now being acquired by the developing nations.

It was foreseen that the large station complex at Goonhilly Downs, in Cornwall, owned and operated by the External Telecommunications Executive of the British Post Office, would not be capable of supporting the additional traffic demands of the next two decades. A new station, at Madley in Herefordshire, was therefore planned. Marconi Communication Systems Limited were appointed prime contractor for Madley 1, the first of possibly six antenna systems at the new station. Madley 1 was handed over to the British Post Office during October 1978, and is working initially to an Intelsat IVA satellite in the Indian Ocean Region.

This is the fourth consecutive earth station project that the Company, as prime contractor, has implemented for the British Post Office. The previous installations were Goonhilly 2, 3 and 4.

The Post Office specification for Madley 1 required the design, provision, installation, commissioning and acceptance testing, together with associated documentation, of an Intelsat Standard A earth station, capable of working to Intelsat IV, IVA and possibly V satellites in either the Atlantic or Indian Ocean regions, for the purpose of international telephone and telex services plus international TV transmission and reception. To be provided under the contract were a number of discrete sub-systems comprising the complete earth station system. A fully steerable 32m parabolic antenna was to be supplied, with its own steering and control equipment installed in a building beneath the antenna. Also to be installed in the antenna building were the high-power transmitter amplifiers and i.f./s.h.f. transmit drives, with associated control logic, primary antenna feed and low noise, cryogenically-cooled broad-band receivers. A central building was to be supplied by the British Post Office in which Marconi Communication Systems were to install the associated Ground Communication Equipment (GCE), consisting of s.h.f. branching, s.h.f./i.f. downconverters, demodulators, modulators and baseband equipment, together with a cross-site make-up amplifier operating at the s.h.f. receive frequency, fixed station test facilities and all associated control and monitoring equipment.

Peripheral systems, such as public address, antenna building airconditioning, fire-detection and weather recording facilities were also needed.

As prime contractors, the Company has co-ordinated the efforts of the sub-contractors involved in supplying the various sub-systems. The antenna sub-system has been supplied from Japan, by Mitsubishi Electric Corporation; the low-noise broad-band receivers by Comtech in the U.S.A.; both sub-contracts being awarded as a result of international competitive tendering. Aside from the peripheral systems mentioned, the other sub-systems have all been supplied by Marconi, a substantial amount being new, state-of-the-art, equipment.

It is believed that the initial equipment fit comprises probably the largest original equipment supply ever provided for earth station receive equipment, being fifty-five discrete chains. In all, one hundred cabinets of communications, high-power and control equipment have been supplied. High degrees of project control and co-ordination have been required to implement the necessary design and development work, to provision the manufacturing supplies, to complete the installation systems design and to engineer the large volume of test specifications, as well as to maintain liaison throughout with the customer and the major sub-contractors.

The engineering disciplines involved in a large earth station are many and various, ranging from soil engineering, through civil, structural and mechanical engineering, electrical high-power supply, lightning protection and earthing, communications, thermionics, cryogenics, microwaves and software, down to the smallest miniature component, to name but a few. To do adequate justice to each within the scope of an article such as this is scarcely practicable. The object, therefore, of this article is to re-acquaint readers with the overall system capability of Marconi Communication Systems, particularly in the field of satellite communications, laying emphasis on current work. It is the intention that future issues of the journal shall feature articles which deal with some of the more recent developments embodied in the Madley 1 sub-systems.

The block diagram in figure 1 illustrates the major equipment sub-systems which are described in the following text.

Major sub-systems

Antenna sub-system

Structural and mechanical

The characteristic feature of an earth station for satellite communications, from the point of view of the outside world, is an array of one, two, three or more, large parabolic dish antennas, seemingly stationary but, nevertheless, having obvious means of movement over large angles in azimuth and elevation. A variety of supporting structures have been employed for the 30–32m diameter paraboloids used in Intelsat 'Standard A' antennas. The most common, until the early 1970s, has been the so-called "kingpost" elevation over azimuth (ALT-AZ) mount, or some variant of it. This consisted of a concrete tower, perhaps 60ft. high, the upper portion of which carried a strong steel "kingpost" supported in azimuth bearings. To the top of this were fastened the elevation bearings and the antenna elevating mechanism, the antenna itself being supported on the elevation bearings. In most cases, cassegrain antennas were employed with the s.h.f. transmitting and receiving feed located at the paraboloid vertex. To ensure minimum waveguide losses in receive path signals, already extremely weak (about 1 picowatt), the front end broad-band receivers were housed in elevated equipment rooms close to the antenna feed. This produced attendant capital cost and possible maintenance problems.

Nightview of the 32 metre antenna

World-wide antenna development has led to the production of an antenna configuration which permits close physical location of the broad-band low-noise receivers to the s.h.f. feed at ground level in a stationary main equipment hall. This configuration is known as the "elevation over azimuth, wheel on track, four-reflector beam-feed antenna." The physical arrangement described below and in Figure 2 is fairly typical of such an antenna, but has certain features unique to Madley 1, the entire construction of which from soil excavation to system handover has been supervised by Marconi Communication Systems in close co-operation with the supplier and the client. The antenna pedestal assembly consists of two major components, these being the base building and the azimuth rail assembly upon which the antenna turns about its vertical axis. The basic structure of the building, which is designed to react to the very large loads imposed by the antenna dead-weight and the dynamic effects of wind and antenna acceleration, consists of two octagonal reinforced concrete ring beams, one acting as a foundation, the other bearing the rail, separated by eight reinforced concrete columns. A series of radial beams run from the upper ring-beam to the centre, providing support for the azimuth journal bearing which absorbs the horizontal loads generated by wind. The pedestal structure is converted into a weatherproof equipment building by roofing the radial beams and bricking between the columns. In the case of Madley 1, additional building facilities were created by an annex to the pedestal building, in which are housed the main power boards, d.c. battery supplies, store rooms and toilets. The main pedestal building accommodates not only the s.h.f. feed and low-noise receivers, but also all the servo, tracking and control equipment required to drive the antenna. The high-power transmitter amplifiers, high-power transmitter combining, associated switching, power monitoring and the i.f./s.h.f. upconverters are also housed here. See figure 3.

As the feed supplied is for frequency re-use by dual polarization, the main equipment hall has adequate space for two duplicate sets of communications equipment. Rooms are provided for ancillary equipment such as the cryogenics associated with the low-noise receivers and the cooling equipment associated with the transmitters. Physical separation from the main equipment hall of these noise-generating equipments is required because of the very stringent acoustic level specifications (NR55) required by the station operating authority.

The rail, upon which the azimuth wheels roll, is secured to the upper surface of the top ring-beam of the building and permits ±270° azimuth rotation of the antenna structure.

Two steel assemblies make up the main features of the antenna mount, respectively known as the azimuth and elevation rotating structures. The first consists of two vertical 'A'-frames, joined as a fully determined structure and carrying the two eleva-

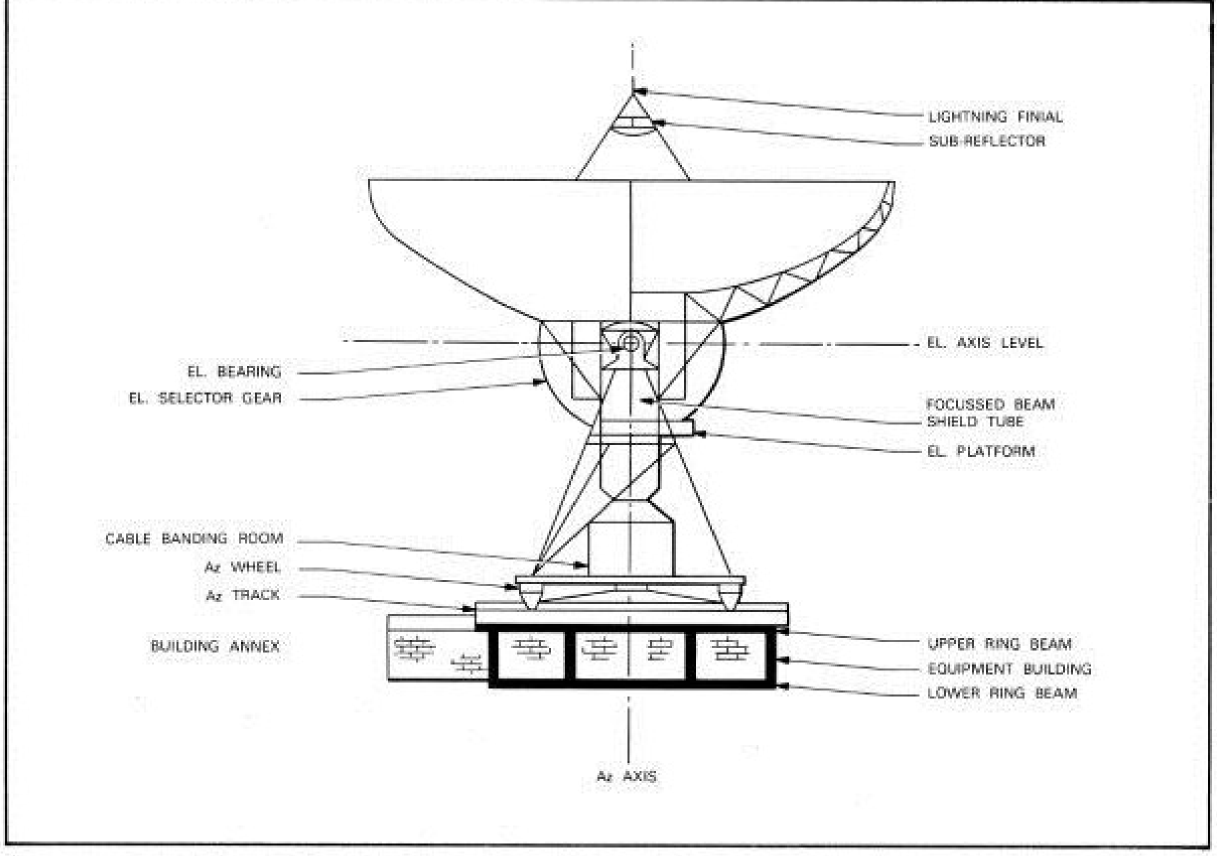


Fig. 2. Main antenna structural features

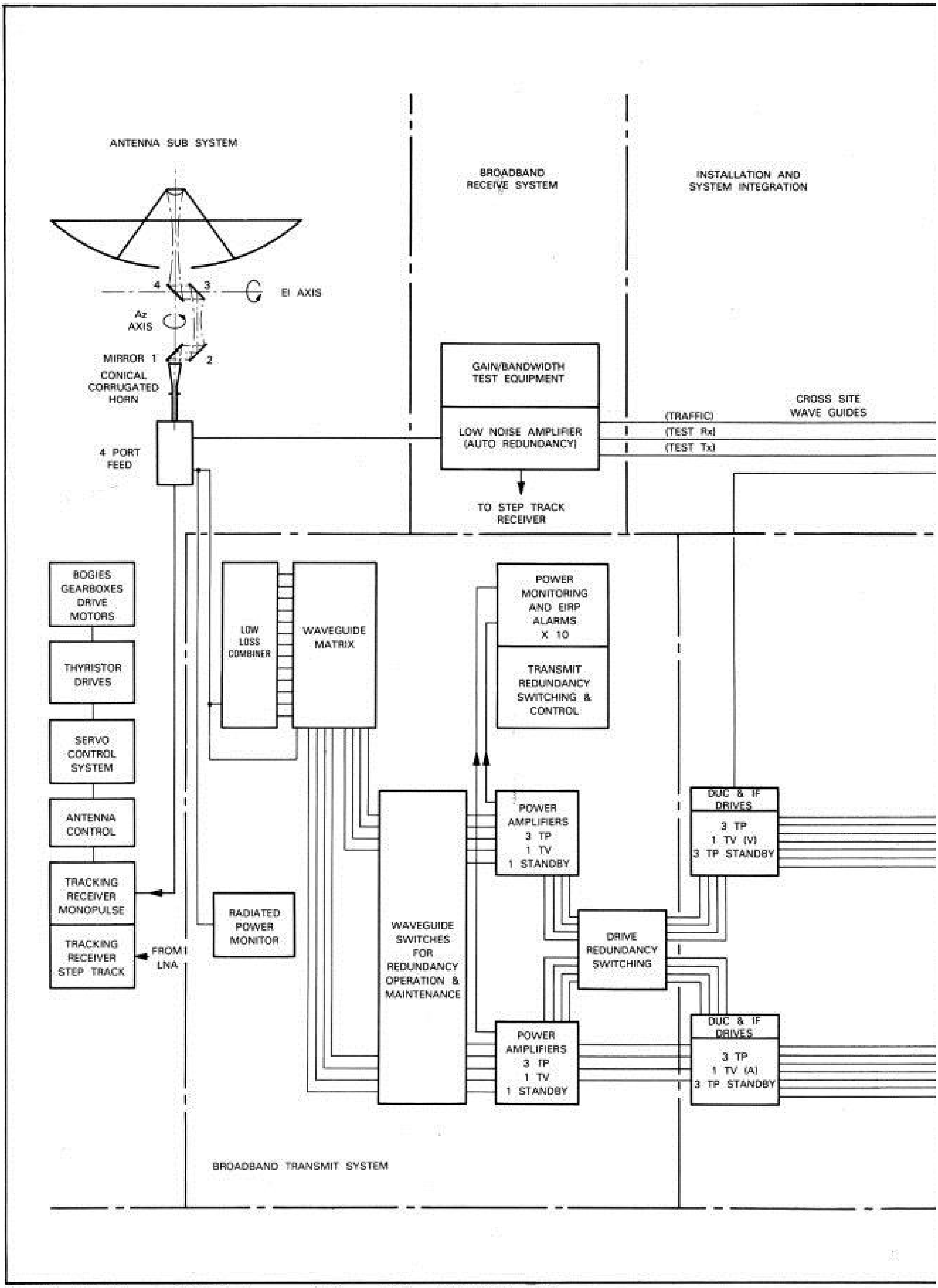
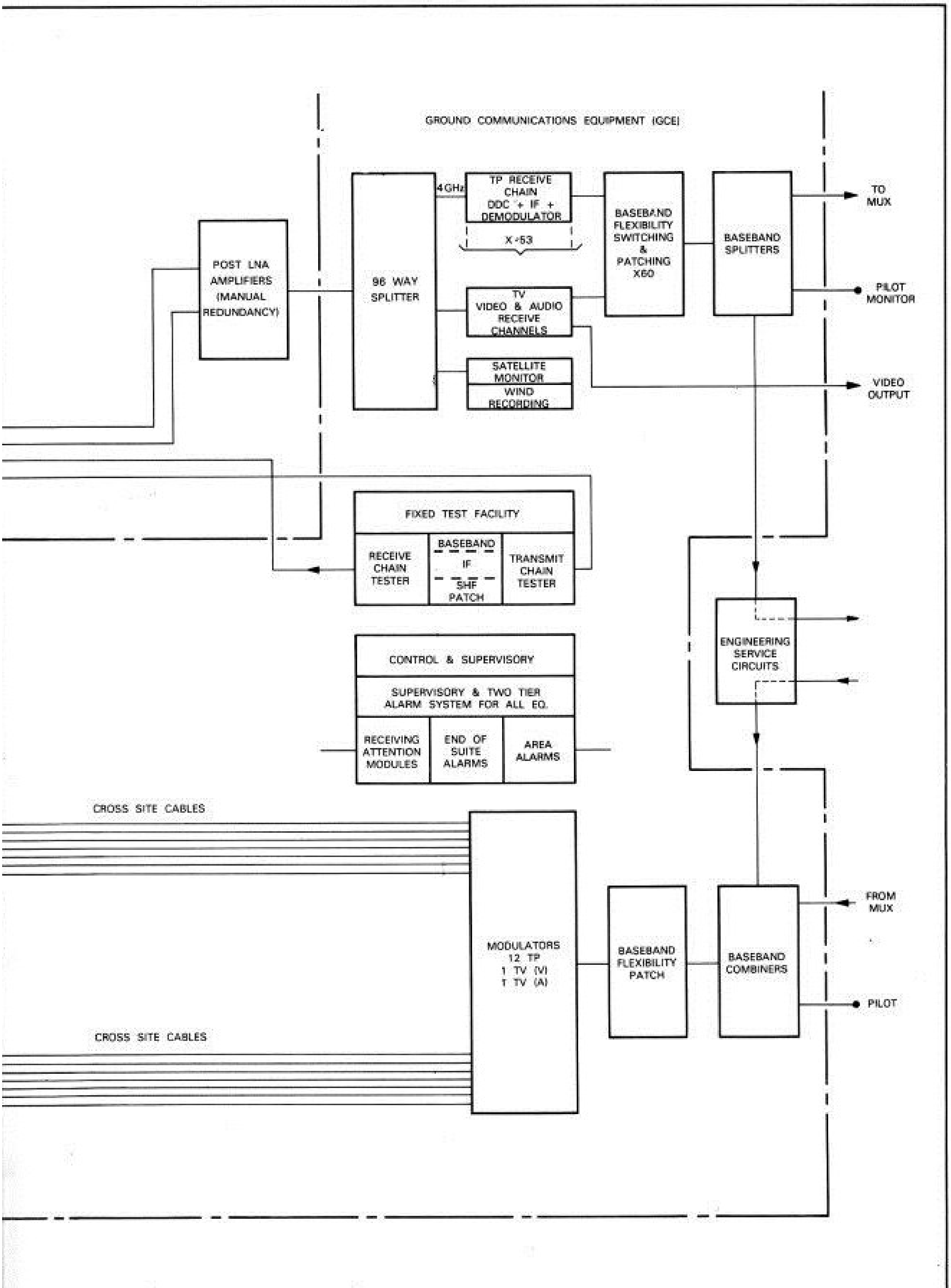


Fig. 1. Simplified diagram of Madley 1 communications satellite earth station terminal


GROUND COMMUNICATIONS EQUIPMENT (GCE)
POST LNA AMPLIFIERS (MANUAL REDUNDANCY)
96 WAY SPLITTER
4GHz
TP RECEIVE CHAIN DDC + IF + DEMODULATOR
X 53
TV VIDEO & AUDIO RECEIVE CHANNELS
SATELLITE MONITOR
WIND RECORDING
BASEBAND FLEXIBILITY SWITCHING & PATCHING X60
BASEBAND SPLITTERS
TO MUX
PILOT MONITOR
VIDEO OUTPUT
FIXED TEST FACILITY
RECEIVE CHAIN TESTER
BASEBAND
IF
SHF PATCH
TRANSMIT CHAIN TESTER
ENGINEERING SERVICE CIRCUITS
CONTROL & SUPERVISORY
SUPERVISORY & TWO TIER ALARM SYSTEM FOR ALL EQ.
RECEIVING ATTENTION MODULES
END OF SUITE ALARMS
AREA ALARMS
CROSS SITE CABLES
MODULATORS 12 TP 1 TV (V) 1 TV (A)
BASEBAND FLEXIBILITY PATCH
BASEBAND COMBINERS
FROM MUX
PILOT
CROSS SITE CABLES

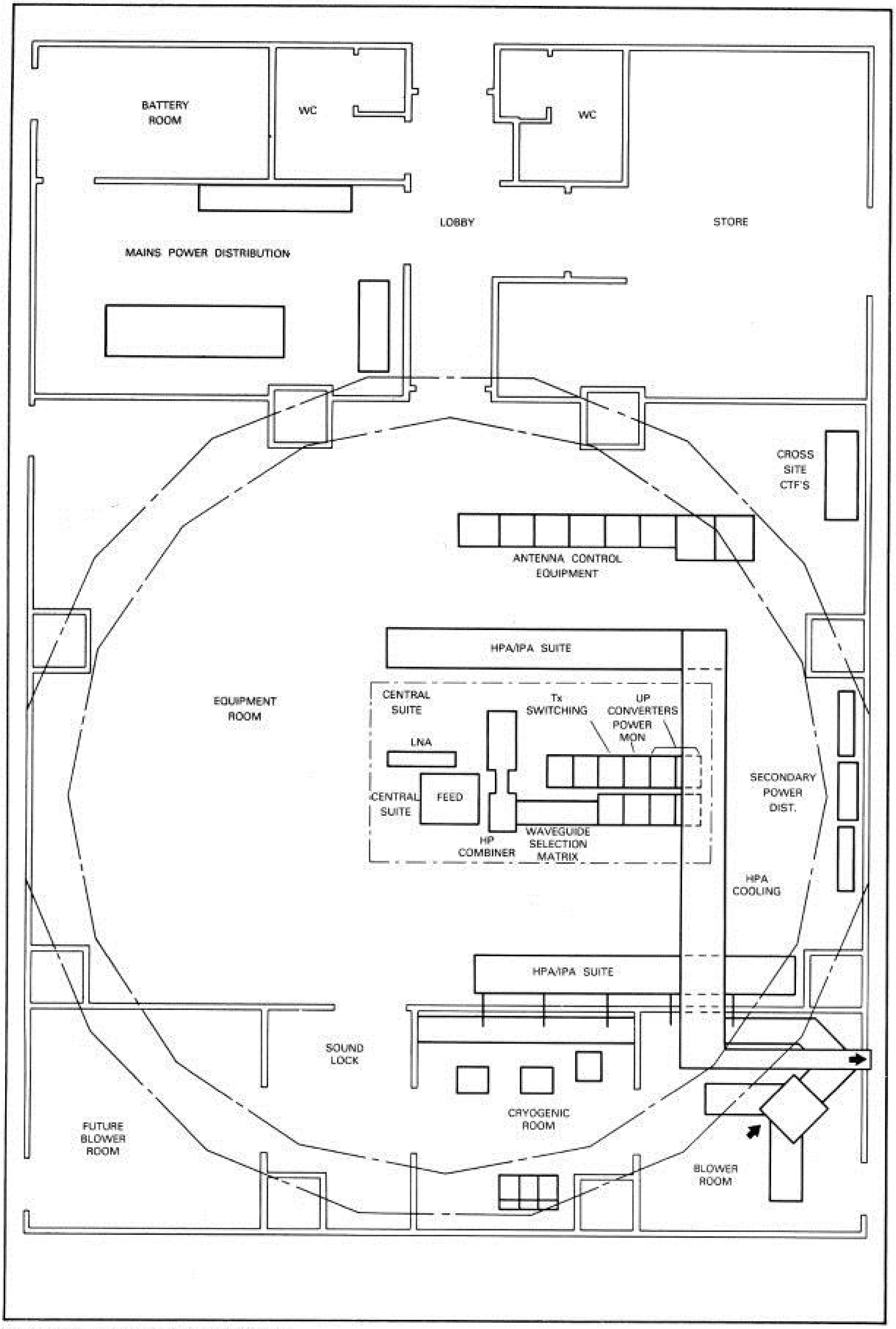


Fig. 3. Equipment layout, antenna building

tion bearings at the apexes. The base carries the azimuth wheels at the four corners, with the journal bearing at the centre. A large sector gear attached to the rear of the second structure provides elevation drive to the reflector itself.

The 32m quasi-parabolic surface is of aluminium alloy and has an accuracy of 0·54mm r.m.s. at the working elevation. A stainless steel tripod supports the 2·9m diameter cassegrain sub-reflector.

To achieve the required performance, under low temperature environmental conditions (−15° C), an anti-icing system is fitted behind the reflecting surfaces, this requiring up to 265kW of electrical power.

Power to the anti-icing panels and the elevation motors is fed via an azimuth cable wrap facility mounted above the azimuth bearing. This permits full ±270° rotation without exerting significant twist or tension on any cables.

Drive System

The drives in both azimuth and elevation are duplicated. Two sets of 5·5kW d.c. motors, gearboxes and final drive mechanisms are used on each axis. Apart from the benefits in operational reliability of this arrangement, the configuration removes almost all backlash from the system, so improving the tracking performance. One set of drives is working against the other, whatever the direction of rotation, in a "pre-loaded" condition. For high torque demands, the two motors are working together, but for low demands they are in opposition. This is quite a conventional counter-torque technique. (figure 3a).

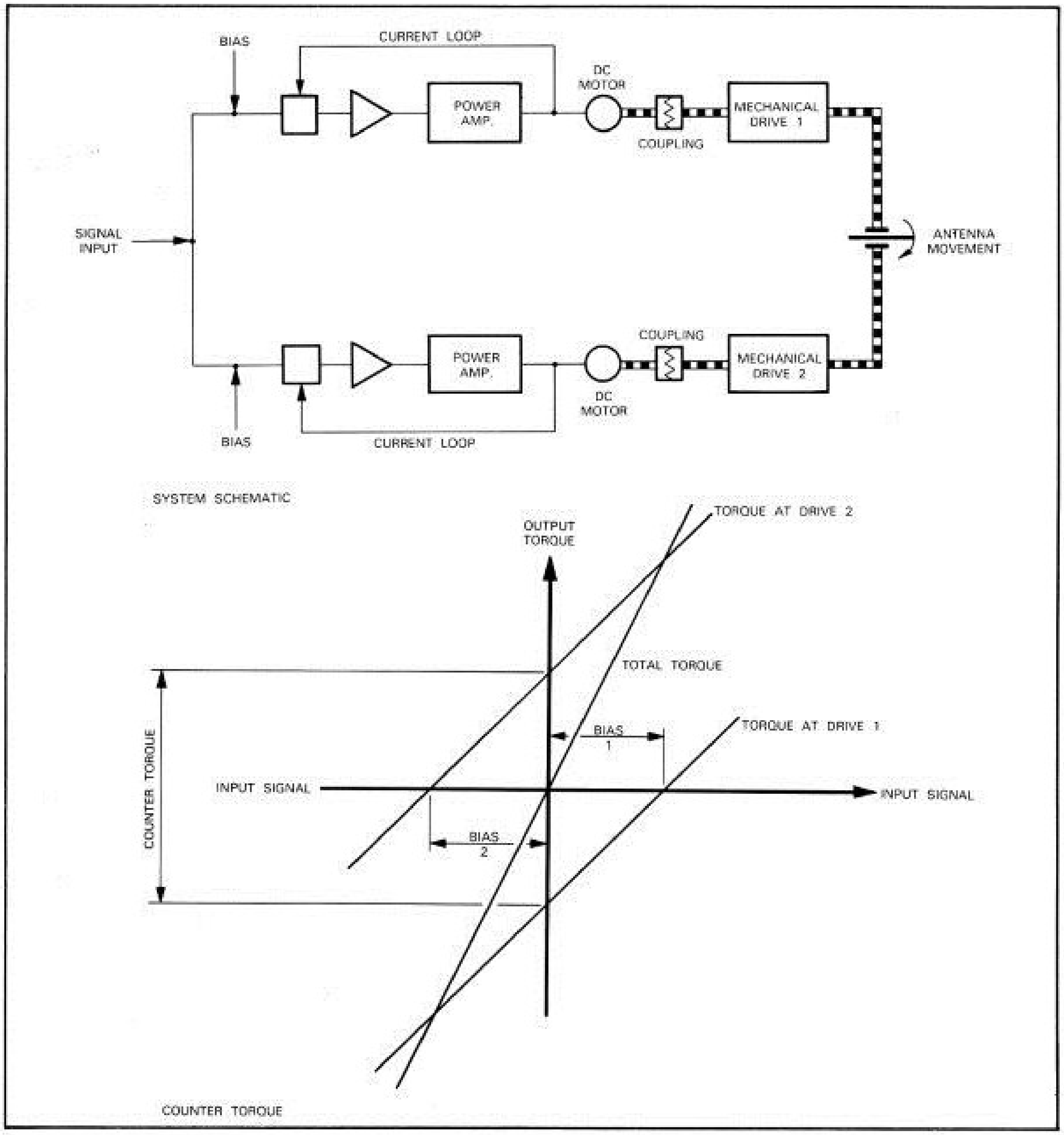


Fig. 3a. Antenna servo counter torque system

Power to the motors is delivered by thyristor power amplifiers with voltage and current feedback to control system linearity and motor torque.

In the servo control equipment itself, four servo electronic units are used, two per axis, the inputs to which may consist of tracking errors taken from the tracking receiver or other tracking errors taken from different modes, i.e. manual or program command. These commands are initiated either at the local control position in the antenna building or remotely in the central building, axis angle information being provided by servo-type synchros.

Operational modes

Although several operational modes have been mentioned, (e.g. manual, program, autotrack) the most important mode to the earth station user is the last, in which the antenna control system automatically tracks the satellite after the tracking receiver has locked on to the satellite beacon. In the case of loss of lock, an alarm is given and the system will revert to a preferred mode.

Should environmental conditions be forecast which could exceed the operational design conditions for the antenna structure the reflector can be remotely driven up to 90° elevation, where it presents least resistance to the wind. It can then be locked in this position by the insertion of a stow pin. In this way, relative rotation of the elevation platform and the elevation sector gear is prevented.

Tracking sub-system

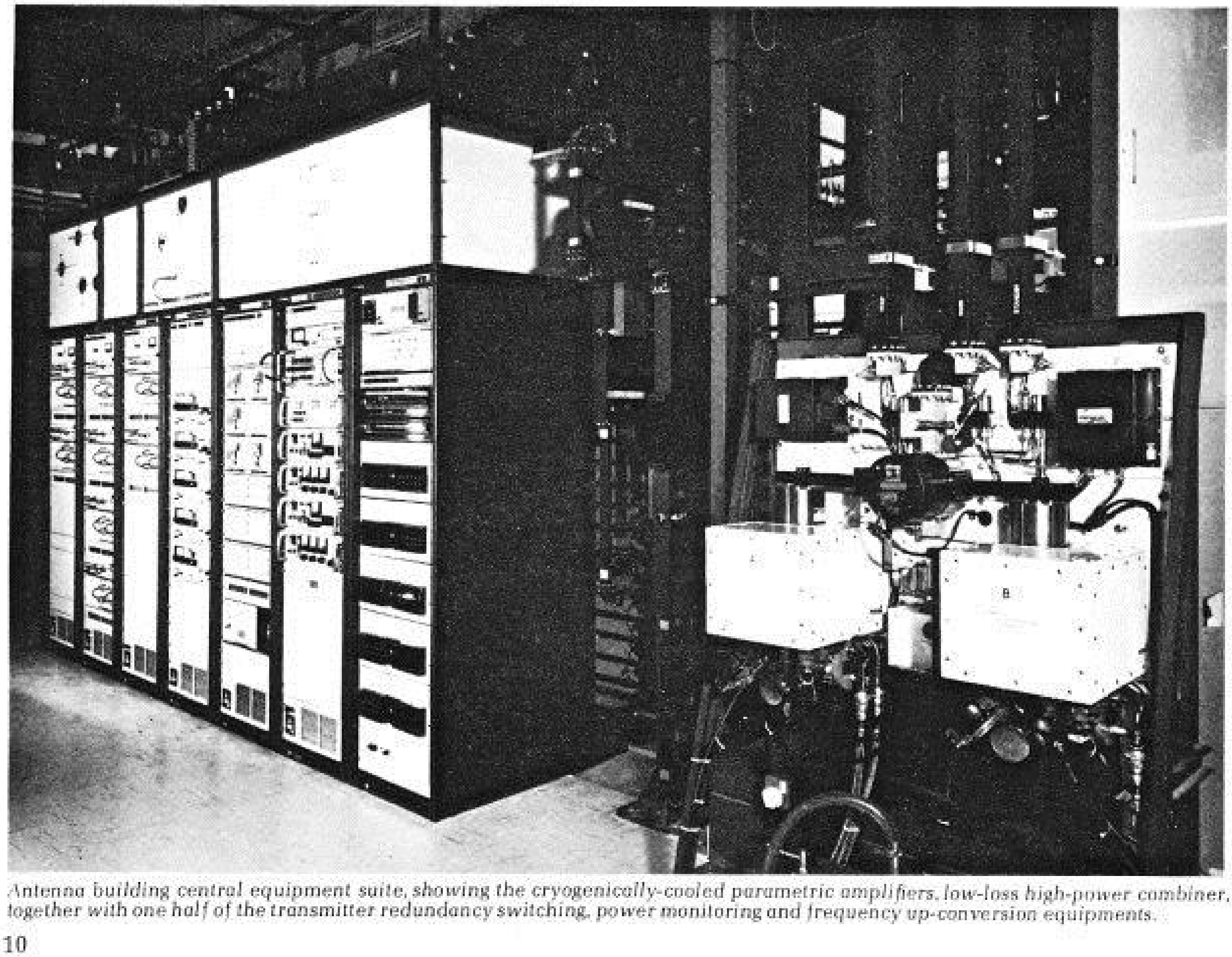
Two alternative auto-tracking systems are employed in this antenna, being respectively known as 'Monopulse' and 'Step-Track', a brief description of each being given:

Monopulse

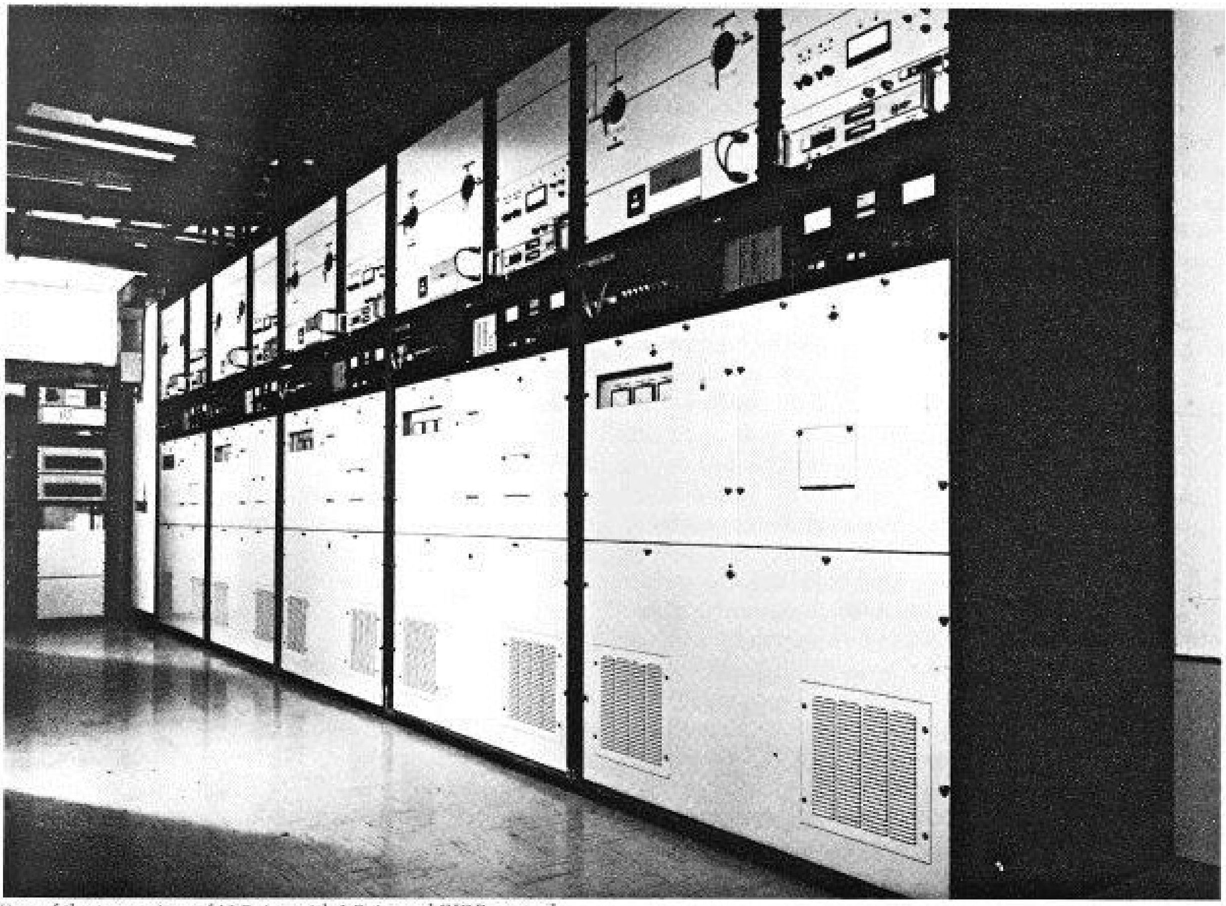
In the monopulse system of auto-track employed on Madley 1, only the primary horn is used, as against the multi-horn arrangement sometimes used elsewhere. The system is alternatively known as the "higher mode detection system" and relies upon obtaining the tracking error signal by picking up the higher mode component excited in the feed waveguide when the antenna boresight axis is offset from the direction of the satellite. Tracking is carried out by using the dominant mode, present when the antenna is on axis with the satellite, as the sum signal, and the higher mode as the error signal. The combined sum and error signals are fed to a single channel tracking receiver where they are converted into azimuth and elevation angle error signals, these being fed to the servo electronics so producing steering commands to the motors.

Step track

The philosphy of this system is simply that the antenna shall be moved step-by-step to a direction of maximum intensity of the radiated satellite beacon. This requires the following basic equipments: (a) a tracking receiver for receiving the beacon signal and (b) sample-hold



Antenna building central equipment suite, showing the cryogenically-cooled parametric amplifiers, low-loss high-power combiner, together with one half of the transmitter redundancy switching, power monitoring and frequency up-conversion equipments.



One of the two suites of H.P.As, with I.P.As and EIRP control.

circuity and a comparator for determining whether the last movements were in the correct direction for optimizing the beam. There will normally be two signal levels at the outputs of the sample holders, one being the level prior to the last movement and the other subsequent to the last movement. After comparison, logic decides the next step direction. The tracking accuracy obtained with this system is not as great as that obtained using monopulse, so the gain variation due to tracking errors is correspondingly increased, being about -0·15dB at 4GHz and -0·3dB at 6GHz in a 14m gusting 20m wind.

Feed system

This system is composed of two major elements: (a) the 4-reflector focused beam feed and (b) the 4-port dual-polarization feed.

4-Reflector Beam Feed

The basic function of this part of the system is to provide for the transmission of high grade (Ref. Intelsat BG-28-72E Aug. 1977) 4/6GHz communications from a stationary feed located close to the communications equipment, via the cassegrain configuration of the main antenna. To do this, the r.f. beam has to negotiate the azimuth and elevation axes and so arrive at the antenna focus in the correct modes. The mechanism used for this purpose consists of four mirrors, arranged as shown in figure 1, fed by a corrugated horn. In achieving a final design for Madley 1, heed was paid to a requirement that the station should be capable of operating the technique of frequency re-use by dual circular polarization. The need for this technique has been brought about by the steadily increasing demand for international traffic channels. Frequency re-use by this method requires good cross-polar isolation of the circularly polarized waves and this is not readily obtainable with all designs of feed-horn. The superior performance of a conical corrugated horn in achieving the necessary circularly symmetric amplitude field patterns at the horn aperture plane leads to good polarization isolation and thus also led to its selection for this application.

4-port dual polarization feed

Satellite communications in the 4/6GHz bands, particularly for Intelsat 'Standard A' ground stations, generally employ circularly polarized propagation. That is to say, the electric field vector, defined in a plane normal to the direction of propagation, rotates in a clockwise or anti-clockwise direction. Dual polarization frequency re-use requires two orthogonally polarized waves to be propagated at the same frequency along the same path. It is unlikely that the differing polarization characteristics of the antenna and satellite, plus variations in the medium of the transmission path itself will permit the polarization states of the two waves to remain unchanged. The voltage axial ratio (VAR), which is the ratio of the major to minor axes of the polarization ellipse is, for the truly circularly polarized wave unity. In practice, no wave will be truly circularly polarized. To achieve perfect cross-polar discrimination the two waves require equal VAR with opposite rotation and major ellipse axes perpendicular.

This being a new earth station, designed with both Intelsat IVA and V in mind, the mandatory 6GHz (Tx) VAR of 1·06 (0·5dB) had to be met. To achieve this for the whole earth station, the Madley 1 feed system itself has been designed to achieve 0·35dB VAR.

To cope with the specified broad-band transmit capacity, the four-port feed provided has been designed to handle a total input power of 10kW c.w. at 6GHz, and this can be either divided in any arbitrary way between the two transmit ports or applied to one port only.

Madley 1 is pioneering this particular feed, being a new design not previously used on Intelsat earth stations.

Broadband receive sub-system

This sub-system provides the initial amplification of the 4GHz signals received by the antenna sub-system, the antenna feed receive port waveguide flange being the input interface to the sub-system. Main and standby amplifiers are preceded by a waveguide switch which determines the traffic route from the antenna. A ganged coaxial switch, connected to the outputs of the amplifiers, ensures that the traffic bearing amplifier is connected to the correct cross-site waveguide and provides the output interface.

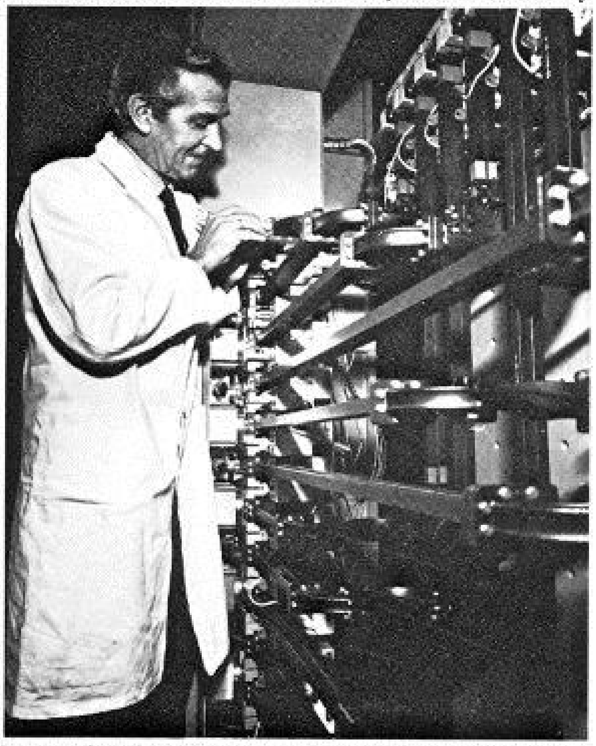
The use of redundant cryogenic amplifiers in conjunction with a 32m beam feed antenna is not essential in order to meet the requirements of the Intelsat system, but in view of the combined circumstances of low elevation and dual polarization operation it was considered prudent to select this arrangement and thus maximize the operational margins of the station.

The redundant amplifiers are identical in design and each consists of three helium cooled parametric amplifier stages followed by a transistor amplifier. The net gain of this arrangement at 4GHz is nominally 55dB and its noise temperature is typically 15–20K when referred to the input of the sub-system. Parametric amplifiers are particularly tolerant of input level variations and maintain linearity over a wide range. However, in the case of the transistor amplifier it is necessary to select a design which has a high intercept point (typically 30dBm) to maintain the required linearity of the system whilst maintaining a low noise factor (typically 3–5dB) in order that its contribution to the overall noise temperature may be minimized. The amplitude response of the amplifier configuration described is within 0·5dB over most of the frequency range 3·7 to 4·2GHz and the group delay response is within 2ns over this range. One of the major advantages of, and reasons for, the antenna beam feed system is that it allows the parametric amplifiers to be mounted in an equipment room the orientation of which does not vary with the attitude of the antenna. This eliminates the necessity for flexible waveguides and/or rotating joints whilst maintaining the amplifiers in close proximity to the feed. On this station, the amplifiers are mounted on a vertical plate for ease of access, the distance to the feed port being some 250mm. This short length of wave guide contributes approximately 0·1K to system noise.

The amplifiers have a comprehensive fault monitoring facility which includes power supplies, amplifier temperature and pump power. Failure of any of these indications provides a signal, via in-built control, to switch the system from "Main" to "Standby" amplifier and initiate appropriate alarms.

Amplifier temperature and pump power are also continuously displayed both locally and remotely and it is possible to select manually the amplifier in service at both locations.

Three compressors are provided for the refrigeration system, one for each amplifier and one spare. The helium pipework is arranged to enable rapid changeover to the spare unit in the event of failure of either operational compressor. In order to maintain low acoustic noise levels the compressors are situated in an acoustically shielded room. Test facilities, incorporated into the sub-system by means of additional switches, enable the standby amplifier gain/bandwidth to be displayed and measured. The output of the standby



Waveguide Selection Matrix, undergoing final inspection prior to shipment to site.

amplifier may also be switched to the "Test" cross-site waveguide so that test signals injected into the test coupler at the input of the amplifier may be received in the Central Building.

Broadband transmitting sub-system

The station was planned primarily for operation with Intelsat IV and IVA satellites and was required to be capable of supporting the simultaneous transmissions of ten services as detailed in Table 1.

Expansion of this system was not to be inhibited by the arrangement used and the station was to be capable of transmitting f.m./f.d.m. and single channel per carrier (SCPC) at any frequency in the range 5·925GHz to 6·425GHz.

Table 1

No. of Services	*Channel Capacity*	*Satellite Beam*	*Allocated Bandwidth MHz*	*EIRP* at 5° Elevation dBW*
3	132	Hemi	5	84.0
1	192	Hemi	10	83·4
1	252	Global	10	88·1
1	432	Hemi	15	86·5
1	972	Hemi	36	86·7
1	TV Video	Global	30	88·3
1	TV Audio	Global	25	75·0
1	SCPC (60)	Global	36	80·14

**Equivalent Isotropically Radiated Power*

In order to provide a transmitting system with an adequate expansion capability, whilst maximizing system availability and transmit frequency flexibility, Marconi engineered an arrangement using 3kW air-cooled klystron amplifiers. The difficulty normally associated with this type of transmitting system is that of combining the high-power outputs of the amplifiers (ten in this case) into a single output port without incurring unacceptable power losses. A novel solution to this problem has been adopted by the use of a specially developed low-loss combiner. The principles upon which the combiner works were pioneered on the Post Office trunk waveguide system, albeit at much lower power levels and in higher frequency bands.

The possible twelve 40 MHz bandwidth channels to be combined are split into two groups—six "odd" and six "even"—each group being separately combined by simple commutator networks followed by a multipole stage (see figure 4). The mode of operation of the commutators relies upon the provision of a different phase shift between two parallel paths interconnecting a pair of 3dB hybrids, the value of the phase difference being arranged so as to vary with frequency. The relative phase shift between two equal amplitude signals leaving one hybrid will, on arrival at the other, be alternatively 0° and 180° for alternative channels, thus giving the resultant grouping. The "odd" and "even" groupings are combined by a 3dB hybrid, giving an aggregate output to the antenna feed. Significant advantages of this combining system are that it avoids the use of high Q filters, is capable of combining microwave powers of 3kW presented simultaneously at each of the twelve input ports and does so without resort to any forced cooling techniques. The insertion loss between any input port and the output port (including the 3dB hybrid) is 4dB. The amplitude response of any 36MHz channel typically is: slope 0·01dB /MHz, curvature 0·0005dB/MHz^2. The group delay response of any channel typically is: slope 0·05ns/MHz, curvature 0·005ns/MHz^2.

In order to provide complete frequency flexibility, the high power-amplifiers are connected to the low-loss combiner via a waveguide matrix. This matrix not only allows any amplifier to be connected to any of the 12 combiner inputs, but also allows the outputs of any two amplifiers to be combined at the input to the matrix, thus giving access to any satellite transponder from two high-power amplifiers.

The use of 3kW air-cooled klystrons, which avoids the necessity for the proximity of high voltages and water, has significant advantages in terms of reliability and maintenance. The use of multiple power amplifiers inevitably increases the number of components in the system, but this feature is offset by the fact that any amplifier failure would only interrupt a proportion of the traffic carried by the station. Nevertheless, in order to meet the very stringent system availability requirements of earth stations, a redundancy system is needed. A maximum number of twelve high power amplifiers are planned to be used on the first transmit polarization, although ten have been initially fitted. These are divided into two equipment suites, each of which contains one amplifier which is designated for television. Of the remaining five h.p.a.s in each suite, four are operational amplifiers and the fifth is used as a standby in case of failure of any of the other four. Because the television amplifiers will not be in continuous use, the logic and switching systems have been designed to enable the TV amplifiers in each suite to act as telephony standby when the normally designated standby amplifier is not available; for example, during routine maintenance.

The klystron amplifiers, designed by Marconi Communication Systems, have a nominal 40MHz bandwidth and have six tuning positions, each of which may be pre-set to any position in the transmit frequency range. Four of the amplifiers (two redundant and two TV) are equipped with fast motorized tuners and are used in a "Hot Standby" mode.

Integral blowers are normally used for klystron collector cooling, but due to the extremely low acoustic noise level requirement in the equipment halls, a common ducted air system was designed for the complete suites of amplifiers. The blowing system uses redundant centrifugal fans, housed in a separate acoustically shielded room. It also incorporates a controlled feedback system to regulate the input air temperature in addition to a pressure regulating device.

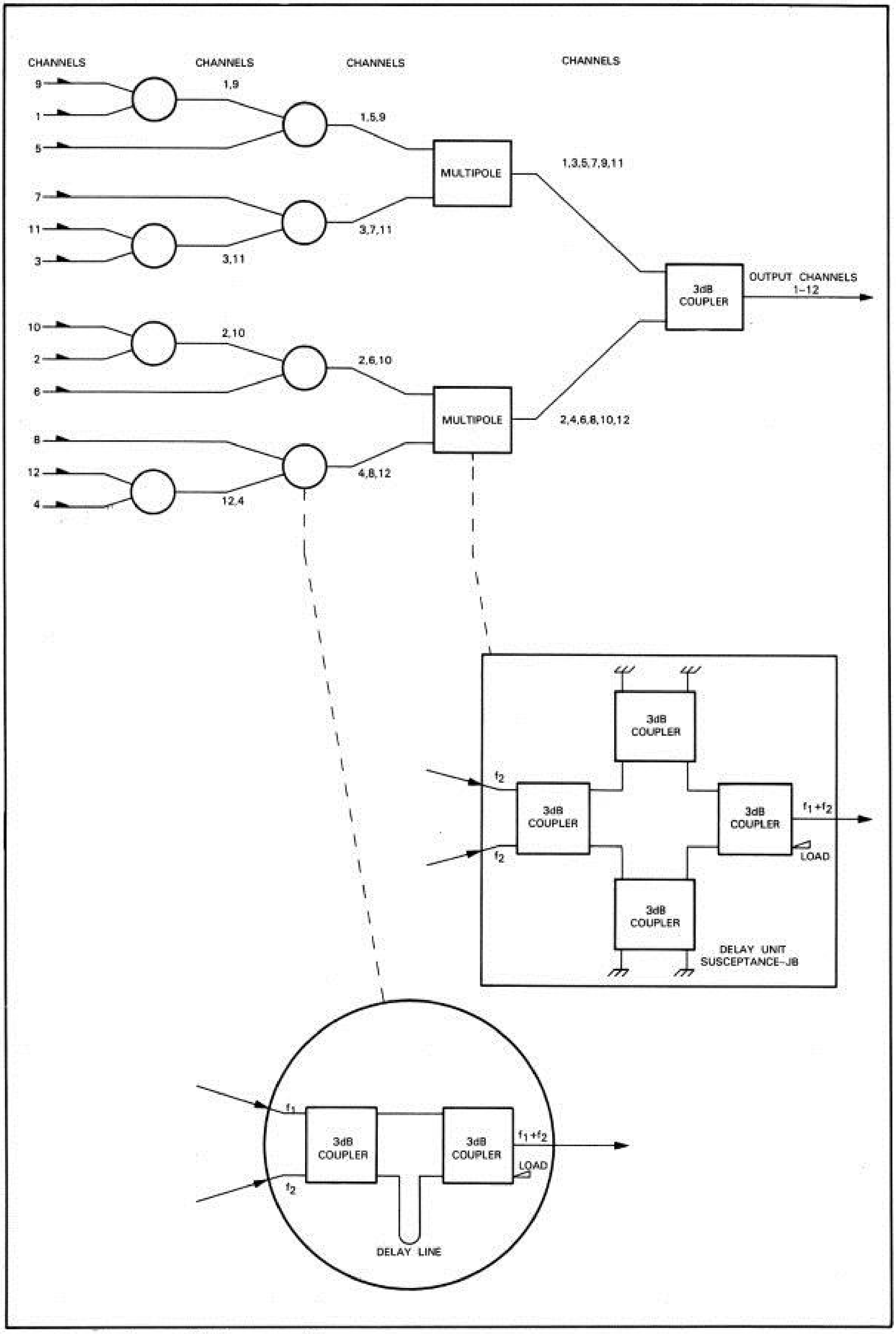


Fig. 4. Schematic diagram of high power combiner

The klystron amplifiers are driven by low-power travelling wave tubes which can be well backed off to ensure operation in a linear mode. The power level at the input of the travelling wave tube is controlled by a motorized variable attenuator, which is continuously variable in 0·1dB increments. It is this attenuator which is controlled (remotely) to adjust the carrier e.i.r.p.s under operational conditions.

The output power of each klystron amplifier is continuously displayed by a power monitoring system which incorporates a high accuracy power meter using a thin-film thermoelectric head. The monitor indicates power levels from 10W to 10kW in three ranges. For the standby and television amplifiers auto-ranging is incorporated. The monitoring system has pre-set primary and secondary 'windows' which cause alarms to be initiated when exceeded. Six pre-set values for each window may be selected, suitable for the transmission of different carrier levels. Initiation of a primary e.i.r.p. alarm causes the standby amplifier to be automatically brought into service, the output of the normally operational amplifier being switched to its dummy load. Outputs from the power monitor are also available for data acquisition.

Ground communications equipment sub-system (G.C.E.)

General

Reference to figure 1 shows the equipment included in this sub-system. Broadly, it contains all the equipment which is specific to a particular radio frequency (r.f.) carrier and therefore interfaces at one end with the baseband terrestrial multiplexing equipment and at the other end with either broad-band transmit or the broad-band receive equipment.

Although all transmit and receive equipment chains are capable of quick and easy reconfiguration in terms of frequency, capacity and bandwidth, Table 2 shows the number of equipment chains and their initial configuration. In common with many 'Standard A' stations, non-redundant equipment facilities are provided for both television transmission and reception. A special feature of the station is the provision of three sets of TV video modem equipment. The equipment is located in a separate TV room and gives the station the capability of simultaneous transmission and reception of two TV video carriers in addition to an in-station test loop.

Transmit equipment

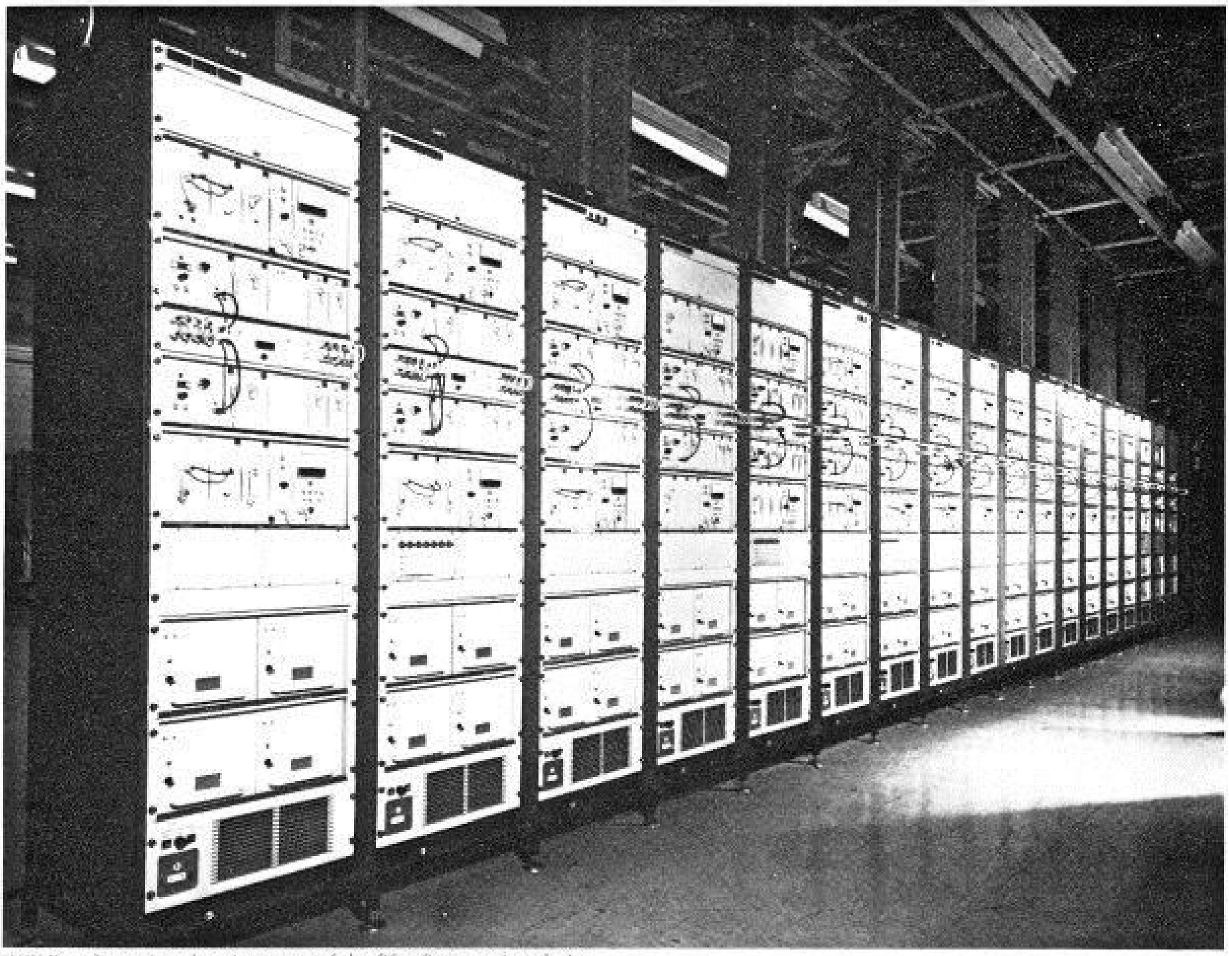
The station is initially fitted for fourteen transmit chains; six telephony carriers using one-for-one redundancy and two non-redundant carriers:– TV video and TV audio. All the telephony chains are equipped for the transmission of frequency modulated, frequency division multiplexed carriers (f.m.-f.d.m.), although it is anticipated that, at an early operational stage, one service operating on single-channel-per-carrier will be required. However, with the exception of this service, the station operates in the f.m.-f.d.m. mode and an outline description of the processing of these carriers follows.

Table 2—GCE Initial Test Plan*

	No. of Equipment Chains	*Channel Capacity*	*Bandwidth (MHz)*
RECEIVE	2	612	20
	2	312	10
	2	252	10
	4	252	15
	8	192	10
	2	192	10
	2	132	7·5
	4	96	7·5
	5	96	5·0
	2	72	5·0
	11	60	5·0
	3	60	2·5
	3	24	2·5
	1	Video	17·5
TRANSMIT	2	432	20
	2	432	15
	2	972	36
	2	792	25
	2	252	15
	2	312	15
	1	TV Video	17·5
	1	TV Video	2·5

**This configuration is subject to change for operational service.*

Each carrier to be transmitted has three components. At the low frequency end of the baseband are the Engineering Service Circuits. As the name suggests, these circuits are used by the engineers concerned with the operation and maintenance of the station and they occupy the end of the baseband from 4·3-11·7kHz. Both telephony and telegraphy circuits are used in this part of the baseband. With the exception of a small slot at 60kHz, the rest of the baseband is devoted to the f.d.m. telephony channels. The bandwidth used is dependent upon the channel capacity of the carrier and varies from 108kHz for twenty four channel carriers to 5884kHz for one thousand three hundred and seventy-two channel carriers. At 60kHz an unmodulated c.w. tone is transmitted. This pilot is used to monitor the status of the carrier throughout the transmission. The interface unit on the earth station which accepts these signals is the baseband combiner, the function of which is to combine the incoming terrestrial signals into a composite baseband. Its other primary functions are to ensure that the telephony basebands are restricted to their designated frequency ranges and that the telephony baseband has a clean slot at 60kHz so that a clean pilot (free from spurious and noise) may be transmitted. At the high frequency end of the baseband a noise band stop filter ensures that a clean "out of band" slot is generated.



GCE Receive suite, showing some of the fifty-five receive chains.

When the carrier is demodulated this slot is used to assess the signal-to-noise ratio of the carrier.

The composite baseband signal at the output of the combiner is passed to a flexibility cabinet which enables the signal to be patched to the designated modulator. The modulator is in fact a shelf of equipment which provides pre-emphasis, energy dispersal and baseband amplification in addition to frequency modulating the carrier. Energy dispersal (ED) is a low frequency triangular waveform which is used to maintain the power density of the transmitted carrier within defined limits. Thus, ED is switched on when the level of the multiplexed signal (which depends upon how many telephone channels are active) falls below a specified level. Pre-emphasis is used, as in most f.m. systems, to obtain a substantially uniform signal-to-noise ratio across the baseband. The baseband amplifiers are adjusted to provide the correct level to the modulator so that the frequency modulated carrier produced has the specified deviation per channel. As in the system as a whole, a high standard of linearity is required of the modulator, in addition to a requirement for a suitably low contribution to channel noise. All units must be able to cope with: (a) the high deviations experienced when large channel capacities are transmitted, and (b) the low noise requirements of the low channel capacities.

The modulator has normally flat i.f. amplitude and group delay responses and has a deviation non-linearity of less than 1·5% over its operating bandwidth. The output of the modulator, which has constant level, irrespective of the channel capacity being transmitted, is directly connected to the i.f. input of the drive (i.f./s.h.f. upconverter) cabinets by means of the cross-site i.f. coaxial cables.

The drive equipment, which is located in the antenna building, consists of 70MHz i.f. processing and a double upconverter which frequency changes the 70MHz i.f. into a suitable microwave carrier in the 6GHz band. Within the i.f. equipment are contained the station and system transmit equalization networks.

The reason for the choice of i.f. equalization is that signal processing, such as amplification and equalization, can be most conveniently designed and economically produced in this frequency range.

Signals transmitted via the cross-site i.f. cables undergo attenuation which varies over the bandwidth of the carrier. Therefore, the first unit within the drive equipment is a cable equalizer which compensates for the losses incurred and re-establishes a flat amplitude response. Two group delay equalizers (g.d.e.) are included in the i.f. section. The first one is a station g.d.e. adjusted to equalize the group delay of the complete transmit chain, its main function being to compensate for the small but significant amounts of group delay inherent in the broadband transmit system. The second equalizer pre-equalizes the satellite transponder group delay and this may require comparatively large values of equalization depending upon the size of carrier and its position within the frequency band of the satellite transponder. The actual value required is specified by Intelsat. Both equalizers provide both first and second order equalization. Finally, there is an amplitude equalizer which compensates for the small amounts of first and second order amplitude distortion occurring in the transmit system. This equalizer is necessary to ensure that the very stringent amplitude response limits, imposed by Intelsat specifications, are met. In addition to i.f. amplification which ensures that the upconverter is driven at the correct level, there is an i.f. filter which effectively defines the complete amplitude and group delay response of the transmit system. Again, the actual responses are defined by Intelsat and it is the system company's responsibility to obtain a design of i.f. filter which enables the complete transmit system to meet this specification. The filters are characterized by very flat in-band amplitude and group delay responses and by a very strictly controlled cut-off at the edges of the pass band. The filters manufactured by Marconi are designed to even more stringent criteria in order to provide the necessary margins for the rest of the transmit system.

The double upconverter (d.u.c.) has been designed using microwave integrated circuits and includes two stages of frequency upconversion. This allows all necessary in-band filtering to be performed at the second intermediate frequency (700MHz band). In this way the second upconversion stage may be tuned to any frequency in the 500MHz transmit band, the output of the upconverter having a covering filter of 500MHz bandwidth. Featured in the design are the local oscillators which, for f.m.-f.d.m. carriers, are referenced to a 100MHz ovened crystal oscillator.

However, by the addition of further components, the 100MHz crystal is locked to a 5MHz internal standard which gives the carrier the higher stability for SCPC working. The d.u.c. is also designed for synthesizer operation although synthesizers are not normally used on the Madley 1 transmit system. As previously mentioned, carrier filtering is necessary to reject first oscillator breakthrough and many other forms of generated spurious signals. For this purpose a 40MHz bandwidth linear phase filter is used which combines the in-band amplitude and group delay response linearity with the sharp cut-off and high rejection needed to meet the requirements of the Intelsat system. The d.u.c. has an output level of nominally -10dBm which gives sufficient drive to enable the broadband transmit system to be driven to saturation (for test purposes). Its intercept point is +7dBm.

Physically, the d.u.c. is contained within a 482mm cabinet-mounted shelf, complete with its own power supply unit and up to four units are contained within one 1·8m cabinet.

Receive equipment

The output of the post low noise amplifier provides the input to the sub-system. The input bandwidth covers the complete 500MHz satellite transmit frequency band and therefore all signals received from the satellite are available at the 96-way splitter (Fig. 1 refers). The splitting arrangement uses stripline techniques and has no active components. The outputs are connected, via low-loss coaxial cable, to the double down converter (d.d.c.) located at the input of each of the 55 receive chains. The d.d.c., which extensively uses microwave integrated circuit techniques, has an input filter of nominally 500MHz bandwidth. The first oscillator, which is frequency controlled by an ovened crystal of about 100MHz can, by choice of appropriate crystal frequency, tune the centre frequency of the first mixer to any frequency in the 500MHz receive band. The output of the first mixer is followed by a covering filter which limits the received bandwidth to 40MHz. Amplification is provided at the first i.f. frequency (700MHz band) followed by the second down converter which also uses an ovened crystal oscillator.

The output of the second mixer has a centre frequency of 70MHz and a nominal bandwidth of 40MHz. As in the transmit system, group delay equalization for the station receive system is provided at 70MHz. Second i.f. filtering, necessary for protection against adjacent channel interference, is provided by the use of filters with identical performance to those used in the transmit system. The bandwidth of this filter must, of course, be matched to the bandwidth of the carrier being received. These filters which also conform to mandatory masks for the Intelsat transmit carriers, have their own in-built group delay equalizations. Over 60dB of amplification is available at 70MHz and this includes an automatic gain controlled (a.g.c.) amplifier which compensates for variation in the received signal level and also for variations (mainly attributable to temperature changes) which may occur within the receive system as a whole, in order that the demodulators may operate under optimum signal level conditions.

The basic demodulator contains a conventional f.m. discriminator circuit from which the carrier baseband information is recovered. The demodulator is designed to operate over the range of Intelsat carrier capacities 24–1872 channels.

A detected carrier level from this unit is used to control the a.g.c. amplifier in the i.f. section preceding it. In the Intelsat system, some low capacity carriers (24–252 channels) operate at a low carrier-to-noise ratio, very little above the threshold of a convential f.m. demodulator, and it is therefore necessary to extend the normal operating range of the demodulator when it is being used with these carriers. This technique is called 'Threshold Extension' and in the equipment used on Madley 1 it is achieved by frequency modulation feedback (f.m.f.b.) which involves the addition of two modules which precede the f.m. discriminator.

Connected to the output of the demodulator is a receive baseband unit which provides the necessary processing of the demodulated carrier. The unit contains a de-emphasis network, which compensates for the pre-emphasis applied prior to f.m. modulation, and a high pass filter which is used to remove the low-frequency energy dispersal waveform. Amplification is also provided to establish the standard levels necessary for onward transmission of the baseband signals. Outputs from the baseband unit are also connected to pilot and noise monitors. The pilot detector, which operates at 60kHz, gives a local indication of pilot level and an output for data acquisition purposes. An alarm is given when the pilot level falls below a predetermined value.

The noise detector measures the noise level in the out-of-band noise (o.b.n.) slot. As this o.b.n. slot was 'cleaned' at the input of the transmission system, the noise level detected gives a good indication of the signal-to-noise ratio of the transmission path. The o.b.n. detector has two associated pre-set alarm levels, complete with preset time delays, so that alarms will be initiated when specific levels of o.b.n. degradation have been experienced for a pre-determined length of time.

All telephony baseband outputs are now passed on to the baseband flexibility cabinets. In these cabinets are mounted patching links for each receive chain and two types of modules which are physically interchangeable. Module A contains a solid-state changeover switch with associated drive logic. The basebands of two receive chains are connected to the inputs of the module and the outputs of the switch are connected to their respective baseband splitting units. When the baseband switch is operated the baseband outputs are interchanged. In this way, a one-for-one redundancy system is obtained. The switch operates in automatic mode from information received from the pilot detector units of the two receive chains, these detectors being located in the baseband splitter units. The switch may also be operated manually to effect changeover between the two paths. Module B contains simple input to output coaxial connections and is used in place of module A for carriers which require manual patching facilities only. This flexibility facility, which was a mandatory requirement of the client's specification, enables the operator to select quickly and easily any two equipment chains for operation in an automatic one-for-one redundancy system and also enables any receive chain to be patched to a particular terrestrial interface point.

As already mentioned, the outputs of the flexibility cabinets are connected to cabinets housing the baseband splitter units. At the input of each unit is an amplitude equaliser which compensates for the amplitude frequency response of all the baseband cable between this point and the output of the receive baseband unit. Also incorporated in the splitter units is a pilot detector, the output of which is used to control the status of the baseband switch. A feature of the detector is its closely matched transfer characteristics over a wide operating range.

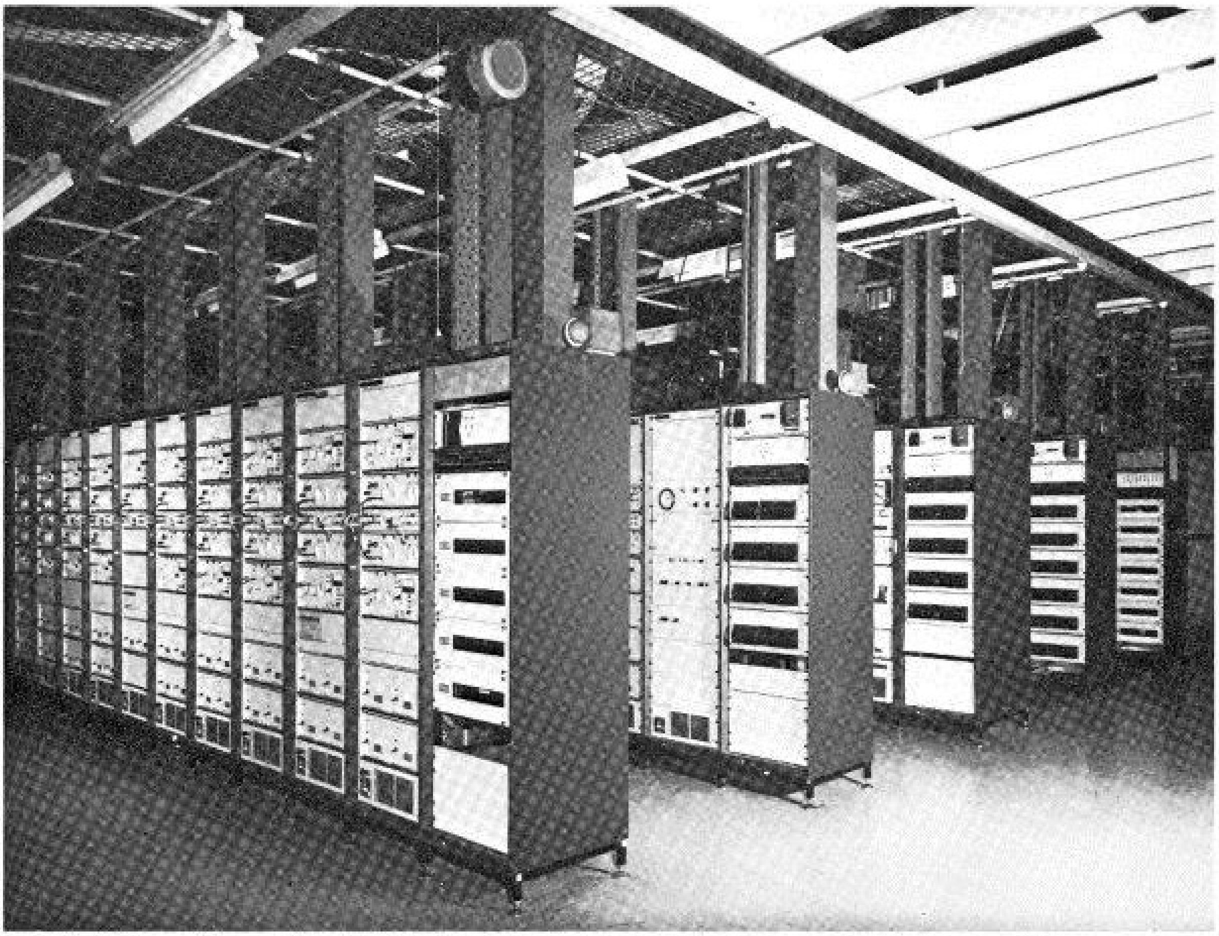
The baseband output from the cable equalizer also undergoes suitable hybrid splitting and filtering in order to provide three outputs: the traffic baseband, the engineering service circuits and a 60kHz pilot monitor point.

Station test facilities

The station is equipped with what are termed 'Fixed Test Facilities.' These facilities are almost entirely located in the Central Building but enable a wide variety of loop tests to be performed on both transmit and receive equipment chains. An advantage of this arrangement is that the facility can be made available to further satellite earth terminals at Madley using the same Central Building. The test facilities include a transmit chain tester (TCT), a receive chain tester (RCT) and a patching cabinet.

Transmit chain tester

The transmit chain tester is a 6GHz receiver, consisting of a 6GHz/4GHz translator and a 4GHz receiver which is identical, in terms of equipment design, to those fitted to the 55 operational receive chains. It can be seen that such an arrangement has many advantages associated with commonality of equipment, spares holding and maintenance. It is also possible to use this chain as an operational receive chain by by-passing the input translator. There are of course certain differences. As a fixed test facility, only a conventional (as opposed to threshold extension) demodulator is required. In order to tune to the various frequencies of the transmit carriers which must be received the first local oscillator is synthesizer-controlled. To cope with the channel capacities of the transmit system switch-selectable de-emphasis networks are provided. For normal test purposes a 70MHz filter for adjacent channel protection is not necessary, but the capability to fit the filter is retained. Tests normally associated with this type of tester are response measurements (amplitude and group delay) and channel noise measurements (n.p.r. tests). These tests may be performed in a 70MHz loop or an s.h.f. loop from the output of the upconverter equipment, or an s.h.f. loop from the output of the h.p.a. before or after the low-loss combiner. By a combination of patching and switching within the antenna building, remotely controlled from the central building, all these test loops may be used on all transmit chains. Any chosen s.h.f. monitor point in the antenna building is connected to the 6/4GHz translator in the central building via a 6GHz elliptical cross-site test waveguide.



Central building satellite area, showing GCE suites.

Receive chain tester

The receive chain tester is a 4GHz low-power transmitter. It consists of a modulator, i.f. equipment and double upconverter of identical design to the operational transmit chains. As in the transmit chain tester, capacity and frequency flexibility is in-built by the provision of a switchable pre-emphasis unit and synthesizer, the latter controlling the output frequency of the double upconverter. The output of the double upconverter is converted to the 4GHz band by a test translator. In this way, commonality of equipment is maintained and the receive chain tester can also 'double' as an operational transmit chain. In order to perform this function, switching is provided to route the output of the double upconverter (6/4GHz translator by-passed) via the 6GHz elliptical cross-site waveguide, to the antenna building, where it may be patched into the appropriate broadband transmit chain. If this mode of operation is chosen, then the 6GHz waveguide is being used for transmissions in the opposite direction to which it operates when used as a test facility; the two modes of operation are therefore mutually exclusive. When fulfilling its normal test function the RCT can be connected to the receive system by several s.h.f. and i.f. patching facilities all of which are contained in the patching cabinet. Tests via the standby parametric amplifier are conducted by connecting the RCT to the 4GHz 'Test Tx' cross-site waveguide. Suitable switching in the broadband receive sub-system connects the waveguide to the standby parametric amplifier. The output of the amplifier is transmitted cross-site by a second 4GHz 'Test Rx' waveguide which is routed to the patching cabinet by way of the standby post l.n.a. amplifier. An s.h.f. and i.f. cable is routed to each pair of receive chains so that by suitable patching a complete receive chain test may be performed on any chosen chain of equipment. Additionally, within the central building, each GCE receive chain may be connected in a test loop with the RCT at s.h.f. or at i.f. To complete the test patching facilities, baseband cables are wired from the patch to each transmit and receive chain so that simple patching enables a full test evaluation of the baseband to be performed.

Control and supervisory sub-system

The complete earth station complex at Madley is ultimately intended to cater for up to six separate antenna systems, and a requirement of the specification was that a standardized philosophy should be employed for this sub-system, compatible with intended operations and maintenance of the station as a whole, but nevertheless standing in its own right.

The provision philosophy employs two basic functions, these being (a) alarms, (b) control and supervisory facilities.

Alarms
Two degrees of alarm condition are provided, each separately networked throughout the station and known as primary and seconday alarm highways. The system is designed to ensure that faults can be located in the shortest possible time, leading to minimum risk of traffic outage. A loss or major degradation of service initiates a primary alarm, this being indicated by a continuous audible and visual display. A secondary alarm is initiated by degradation of performance insufficient to cause loss of service and is indicated by audible and visual displays at about 1 pps. Each of the two degrees of alarm is taken to five levels, these being briefly described below.

(i) Local alarms
These indicate failure of a particular unit in any equipment cabinet e.g. p.s.u. failure, signal level failure etc. The indicators are mounted on individual units.

(ii) Equipment alarms
The local alarm outputs are fed to these alarms which extend the alarm condition by means of alarm relay contacts. A red alarm lamp, indicating the failed equipment section, lights at the top of the cabinet. A receiving attention facility is built into this alarm level, permitting display of a green "Receiving Attention" lamp once an alarm has been raised and is being dealt with. The operation of the "Receiving Attention" key cancels all higher level alarms. Under this condition clearance of the fault will reinitiate the higher level alarms until the "Receiving Attention" key is normalized.

(iii) Suite alarms
The primary and secondary alarm highways from the equipment level are taken out to visual suite alarms, one at the end of each suite of equipment.

(iv) Area alarms
These are both audible and visual and are placed at positions such that at least one can be seen from any position within designated equipment areas. Operation of any suite alarm will initiate the appropriate area alarm. Additional contacts provide for extensions into the central alarm unit. In the antenna building, a display panel is provided which indicates which particular equipment sub-system has failed.

(v) Central alarm units
These are located in the operations area of the central building, each unit handling the primary and secondary alarm outputs from two areas. The outputs from the units are fed to a central display, which is of modular construction, each module indicating the area of failure. Power failure, or disconnections of alarm units, will automatically initiate alarm indications.

Control and supervisory
Remote control of the various sub-systems is handled from the operations area in the central building, using the following cabinets.

(i) An antenna control cabinet provides facilities for remote control of the various antenna steering functions including selection of the drive modes in azimuth and elevation.

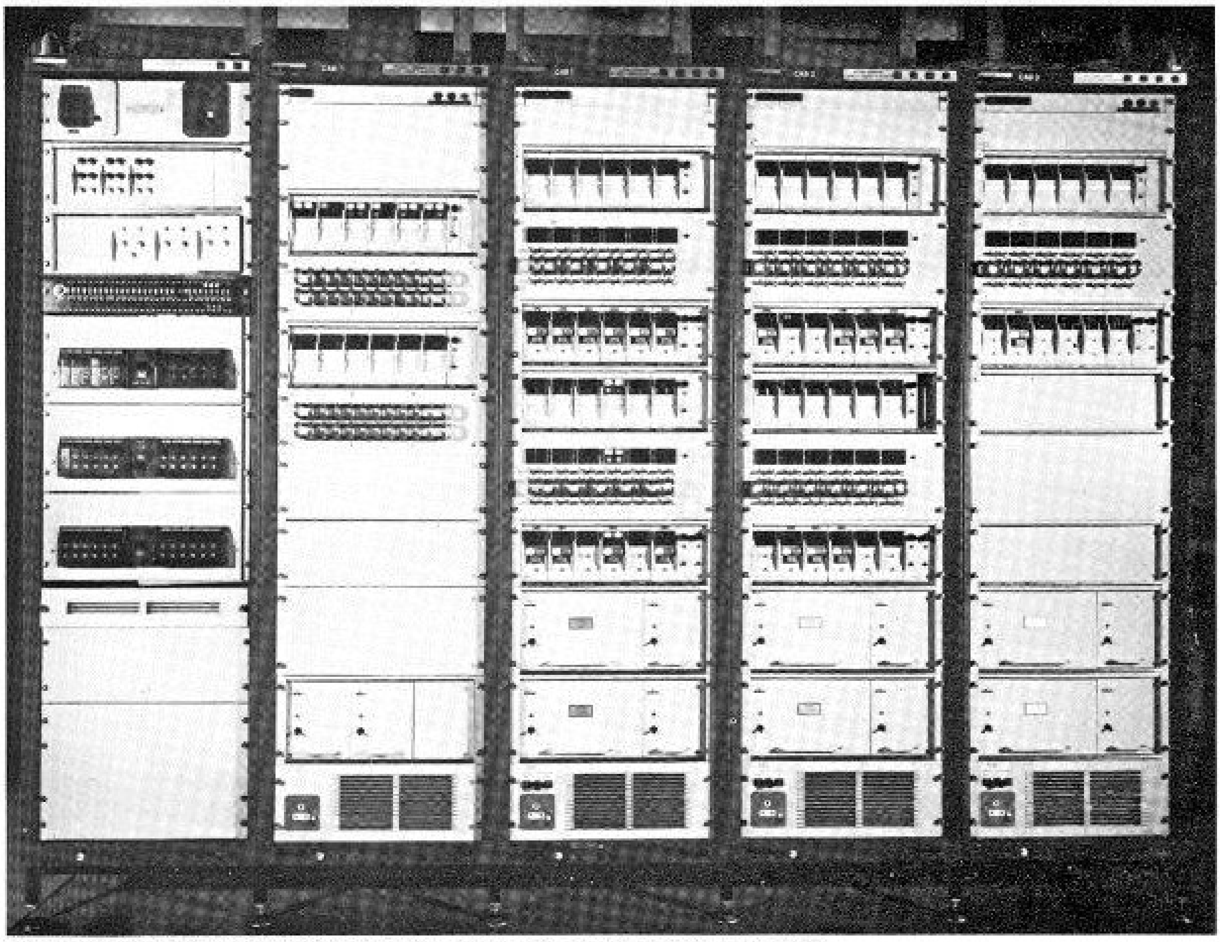
(ii) A second cabinet associated with the antenna houses the remote controls for the antenna anti-icing system.

(iii) Remote control facilities for the transmit switching cabinets, which are situated in the antenna building, are provided in a supervisory cabinet which also monitors and controls the output power of the high-power amplifiers. The transmit switching cabinet has three major functions. Firstly, it controls the waveguide switches in the transmit power amplifier chains. Secondly, it interfaces with the high power amplifiers to provide fast muting signals in the event of an unavailable path. Thirdly, there is an interface with the power monitors to control the frequency of the standby amplifier and to detect when power is outside specified limits.

(iv) A fourth cabinet houses a spectrum analyser, GCE TV remote control and remote controls for the cross-site make-up amplifier.

Some systems aspects
Before an earth station can achieve operational status within the INTELSAT satellite communications system, there are mandatory performance parameters which must be met. These, in addition to many recommended parameters are defined in a series of formal documents issued by the INTELSAT Board of Governors. For a systems or a manufacturing company to operate effectively in the earth station business a good working knowledge of these requirements is essential as the specifications are frequently reviewed and can have significant impact upon system and equipment design.

In addition to these international specifications, each prospective purchaser, almost without exception, issues a comprehensive specification which details the particular characteristics and requirements of his station. In the case of Madley 1, where the technical competence and capability of the customer is renowned, the demands made upon the resources of the contractor are correspondingly high, from the receipt of the Invitation to Tender (ITT) through to the "Ready for Service" date and throughout the warranty period. The system design is formulated immediately the customer's requirements are known and particular emphasis is placed upon the definition of any sub-system in which novel solutions or new development specific to the contract is needed to meet the customer's requirements. It is in these areas that considerable benefit is obtained by dialogues with the customer's Planning and Operational staff in recognizing problems and proposing cost-effective solutions.



Transmit and Receive Baseband Flexibility suite showing the receive cabinets to the right.

Madley 1 is in terms of traffic capacity one of the largest, if not the largest, satellite earth stations operating in the INTELSAT system and has been supplied to a most rigorous and comprehensive testing and documentation programme. An insight into the programme may be obtained by outlining some of the relevant features.

Environmental testing of a complete GCE transmit and receive chain, in working configuration, has been performed to detailed specifications of such parameters as amplitude and group delay response, channel noise and frequency stability. Over and above the normal unit, shelf and cabinet factory testing, required for the Company's quality assurance system, detailed and comprehensively documented customer proving tests have been demonstrated on each cabinet of equipment. After installation of the equipment an exacting programme of commissioning and acceptance testing has been performed. These tests, involving an estimated 2,500 individually recorded and certified sets of measured data, give some idea of the level of activity demanded of the engineering groups involved and the very close working relationship which is needed between the Company's engineers and those of the customer, especially when it is realized that each test document, and installation drawing, was required to be submitted for customer approval prior to it being used. Mention has been made of mandatory performance requirements. The following paragraphs discuss some of these and other important parameters with an indication of how they were achieved.

(i) Figure of merit

Otherwise known as the Gain-to-Noise Temperature Ratio (G/T) of the station; in a well designed station, this will almost entirely depend upon the antenna and feed design and the performance of the low-noise broadband receiver. For a given antenna aperture, some optimization of G/T is possible by careful design of the antenna components. For example, shaping the main reflector from a true paraboloid to a modified or quasi-paraboloid, and at the same time suitably shaping the subreflector, is one way of obtaining a good compromise between gain and noise temperature resulting in a high G/T. Most antenna suppliers recognize these techniques and such features are almost standard, differing only in detail and degree.

For the purposes of specifications and measurements, it is standard practice to refer both the antenna gain and the system noise temperature to the input flange of the low-noise receiver.

Standard "A" stations, operating in the

INTELSAT system, obtain approval if the following minimum condition is met in the direction of the satellite, and for the polarizations chosen for the satellite, under clear sky conditions, in light winds, and for any frequency in the band 3·7 to 4·2GHz.

$$G/T \geqslant 40{\cdot}7+20\log_{10}f/4 \mathrm{dB/K}$$

where f is the receive frequency expressed in GHz. In order that stations may have maximum operating flexibility, many users specify this minimum condition to the contractor at a 5° elevation angle.

Measurement of G/T usually relies upon the use of radio stars as known calibrated noise sources. This method was used on Madley 1 and the mandatory performance was easily exceeded at 5° elevation. (G/T = 43dB/K at 4GHz). A high efficiency was shown in both the transmit and receive frequency bands, for the complete antenna, including main and sub-reflectors, four-mirror beam-feed and four-port feed. However, the contribution to the high G/T by the cryogenically cooled receivers, having a noise temperature of 15K, should not be forgotten in the measurement of the system noise temperature, which in this case was 63K at 4GHz and 5° elevation.

(ii) Radiation patterns

Whilst considering the antenna in a system and operating context, the requirements for radiation pattern performance should be included.

To avoid interference with neighbouring satellites and terrestrial communications systems which share the same frequency band it is necessary to keep the side lobes in the radiation pattern as low as possible. Although there is no mandatory performance for the level in the first side lobe as such, side lobes at 1° off the main lobe axis are required to be -29dB or lower with respect to the main beam maximum gain, on transmit. (The requirements for new earth stations, after Madley 1, are slightly different, being revised in 1976, but these requirements were also adequately met). Provided that due care has been exercised in the design of the antenna and feed system, good radiation patterns can only be achieved by extreme care in the precision alignment of the various antenna reflecting components. By careful monitoring of each stage of assembly and alignment of the focussed beam feed and the cassegrain antenna surfaces, excellent radiation patterns were obtained during transmission tests with a boresight transmitter specially set up in the antenna far-field. Further tests of the cross-polar performance, using an INTELSAT IVA Satellite have also been successfully completed.

(iii) Receive noise temperature and linearity

In a well-designed receive system the receive stages after the l.n.a. should make little contribution to receiver noise temperature.

Reference to figure 1 shows that an additional amplifier has been included between the l.n.a and GCE receive chains. This amplifier fulfills the dual function of compensating for the transmission losses so that adequate signal level is available at the receivers. It also reduces both the noise contribution due to the splitter and the receive chain noise factor when referred to the input of the l.n.a. These considerations dictate the minimum gain of the amplifier and its noise factor. However, if the amplifier were located directly at the output of the l.n.a, the signal levels in the output stage of the amplifier could be high enough to cause significant distortion, and hence contributions to channel noise, due to operating over a non-linear portion of the transfer characteristic. By locating the amplifier at the central building end of the cross-site waveguide, signal levels into and out of the amplifier are kept at a level which gives acceptable linearity and at the same time limit the 'back end' contribution to receive noise temperature to less than 3K.

(iv) E.i.r.p. capability

The station is required to have a high degree of frequency flexibility and to be able to transmit carrier(s) at e.i.r.ps specified by INTELSAT. It is also required that the e.i.r.ps should be controlled over a specified range of levels.

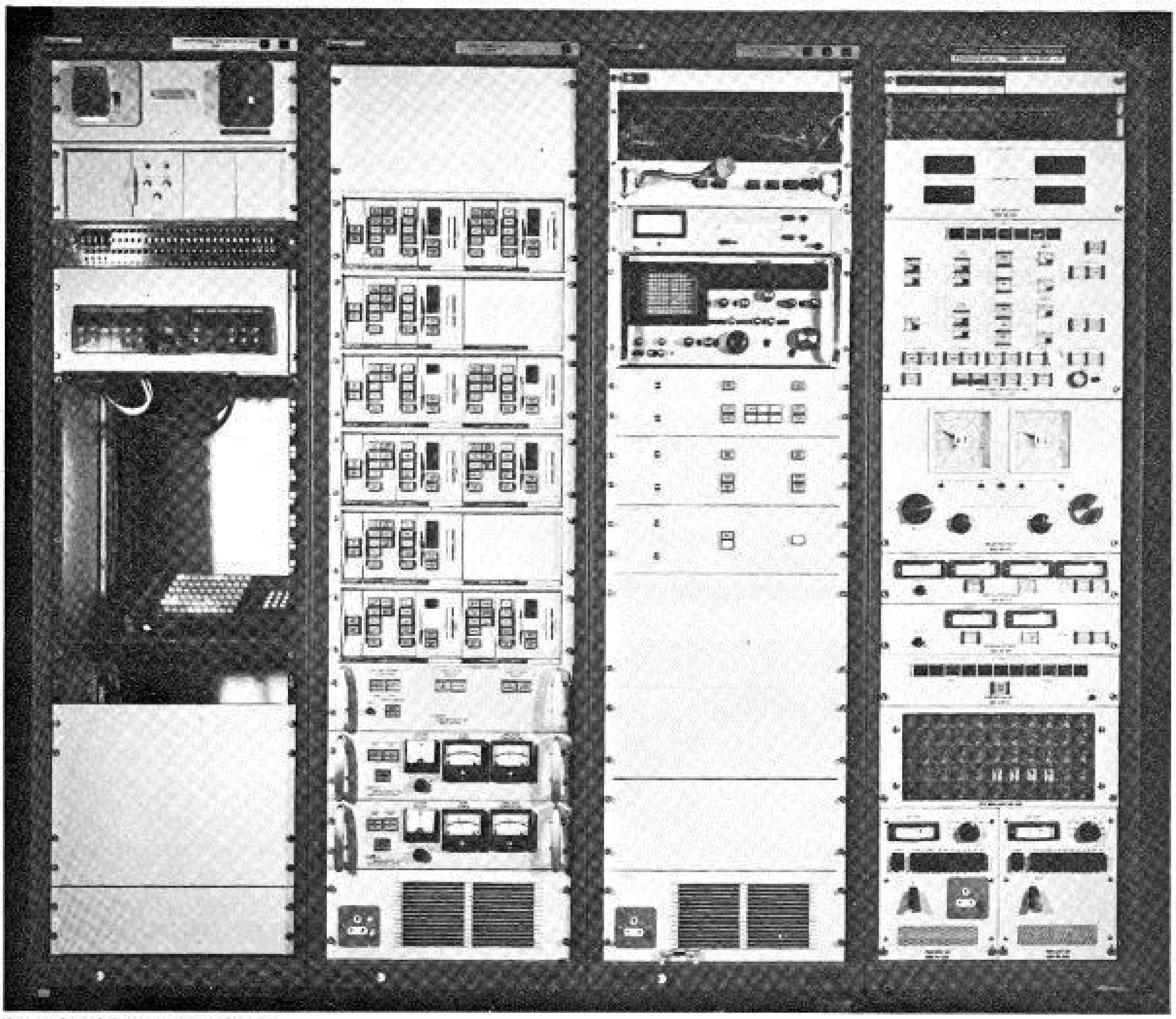
Due to the low-loss combining system used at Madley and the close proximity of all amplifiers to the transmit port of the feed, the insertion loss between any amplifier and the feed is nominally 5·5dB.

The transmit system design thus gives the station the capability of transmitting 12 carriers each with an e.i.r.p. of 93dBW. This capability is far in excess of any requirement that the station may experience in the INTELSAT IVA system.

(v) E.i.r.p. stability

All stations in the INTELSAT system are required to maintain their e.i.r.p.s within ±0.5dB of a nominal value except under adverse weather conditions. This requirement is not only necessary to ensure that the carrier flux densities re-transmitted by the satellite are at an optimum level but also because variation in e.i.r.p levels transmitted by earth stations can cause undesirable re-distribution of intermodulation product levels in the satellite transponder.

All equipments within the station's transmit system, including the antenna, contribute to the total variations generated and it is a system design responsibility to ensure that equipment performance specifications are consistent with the overall requirement. There are various ways in which the overall stability of transmit chains can be improved, the electronic stabilization of power supplies for the equipment being one such way. The only equipments on the station not using this method are the high-power transmitter



Control and Supervisory Suite.

amplifiers which are fed from automatically controlled mains voltage regulators. On previous stations built by Marconi automatic level control (a.l.c) of the power amplifiers has been used to reduce the e.i.r.p. variation. In the case of Madley 1, as with many other stations, reliance is placed in the inherent level stability of the equipment.

There are of course many other important parameters to be considered, including over 20 international mandatory requirements, all of which feature in the programme of tests performed on the station.

Project Implementation

The design and construction of large earth stations involves a broad spectrum of engineering disciplines, including civil, mechanical, electrical and communications.

It is normal for a national civil engineering contractor to be chosen for such projects, but it is by no means certain that the mechanical or electrical engineering design and/or construction capability exists within the country in which the station is to be built. It is therefore almost inevitable that the ingredients of high capital cost, international commerce and multiple complex sub-contracts will be involved. Madley 1 is no exception and high standards of project control and liaison have been necessary to co-ordinate the activities of the various contractors and sub-contractors in the design and provision of the system elements.

Although MCSL was awarded the prime contractorship by the British Post Office, all major subsystems were subject to international competitive tender, the various sub-contractors to be coordinated by MCSL who would also supply the system integration, system engineering and installation requirements. In the event, two major sub-systems (Ground Communications Equipment (GCE) and broadband transmit equipment) were also awarded to the company.

The logistical problems foreseen due to the involvement of overseas sub-contractors in the provision of large and diverse equipments for Madley 1 made the setting up of regular contract reviews between all the involved parties a necessity.

As prime contractor, MCSL has been responsible for all aspects of the project including, for example, budgetary, technical performance, quality, and time-scales. To ensure that the standards set for all parameters were being met, the project management team established methods of securing information at regular and frequent intervals on the various sub-systems. The basic programme planning was carried out using computerized PERT techniques at three levels of detail, the lowest level being used mainly for local control purposes in the operating areas.

Each operating area involved with the project, including the major sub-contractors, established their own project teams dedicated to Madley 1, each team reporting to the MCSL Project Manager.

The following list gives the spectrum of activities which have required planning, co-ordination and control:

- System planning, including on-site test specifications
- Equipment development and design
- Sub-contract supervision
- Component supply
- In-house fabrication of parts
- Equipment assembly
- Equipment test, including environmental
- Installation planning and design
- Equipment installation and commissioning
- Quality verification
- Spare parts and components supply
- Handbooks and documentation preparation
- Customer training

Detailed reports on each of the above were produced at monthly or weekly intervals, these reports forming the basis of monthly contract reviews with the customer and permitting the customer's Project Manager to keep abreast of all real and potential problems which could prejudice the station into-service date and cost.

Very close liaison was maintained with the customer project team to ensure that there was no disagreement with interpretation of the specification and that any changes to the requirements of the contract were quickly assimilated into the ongoing programme of work.

Such changes are inevitable in complex projects and in the case of Madley 1 over one hundred formal contract variations were raised.

To be successful, all projects need planning, motivation, co-ordination and control and to provide these essential features the project has been handled by an Operations Unit within the Company, this unit having specific responsibilities for satellite communications earth stations.

The project teams within this Space Operations Unit are constantly looking towards and planning for future trends in the earth station business. As the growth in demand for satellite communications continues, so earth station traffic capacities will continue to increase. Even before Madley 1 entered service, a significant increase in its already large receive capability had been planned. With the advent of frequency re-use by dual-polarization, becoming operational with Intelsat V, a second expansion for transmit and receive equipment is likely. In addition, work is already well advanced for a second 'Standard A' at this station, Madley 2, and MCSL are again playing a major role.

It is perhaps fitting that, in the year of the seventy-fifth anniversary of the historic first two-way transmission across the Atlantic, arranged by the Company's founder, The Marconi Company has completed a project which is also of great significance to the capability of the UK in communications with overseas nations.

Acknowledgements

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RESUME

Marconi Communication Systems Limited était l'entrepreneur principal pour Madley 1, le premier terminal terrestre de communications satellites qui soit installé dans le nouveau complexe de stations terrestres des Postes Britanniques dans l'Herefordshire. Le matériel de communications initial assure une forte capacité pour le trafic téléphone, télex et télévision via un satellite IVA Intelsat dans l'Océan Indien. Quatorze chaînes d'émetteurs ont été implantées, disposant de 6 porteuses avec redondance une-pour-une, ainsi que des chaînes vidéo TV et audio TV non redondantes. Dans le circuit de réception, on trouve 55 chaînes opérationnelles qui, si besoin est, peuvent etre disposées en redondance une-pour-une grâce à des systèmes souples.

Cet article a pour objet de donner une vue d'ensemble de la conception et de la capacité du système et non un traitement en profondeur d'un sujet spécifique. L'introduction présente d'une manière générale la nécessité qu'il y a de disposer d'une telle station et donne une brève description de la disposition du matériel, conduisant naturellement à des descriptions plus détaillées des sous-ensembles. Celles-ci traitent de l'antenne, des matériels de réception et d'émission à large bande, de l'équipement de communications au sol et de la station de contrôle et des installations de surveillance. Certains aspects du système d'ensemble sont ensuite abordés, suivis d'un bref passage sur la gestion et la mise en oeuvre du projet, avec mention des travaux futurs que doit mener à bien la Société à Madley.

ZUSAMMENFASSUNG

Die Marconi Communication Systems Limited war die Hauptvertragsfirma für Madley 1, die erste britische Satelliten-Erdfunkstelle, die im neuen Bosenfunkkomplex der britischen Post in Herefordshire installiert wird. Die anfänglich gelieferten Anlagen bieten eine erhebliche Kapazität für den Telefon-, Telex und Fernsehverkehr über einen Intelsat-IVA-Satelliten, der über dem Indischen Ozean stationiert ist. Vorgesehen sind vierzehn Sendeaggregate mit 6 Trägern von je eins-zu-eins-Redundanz, sowie Fernsehbild- und-tonkanäle ohne Redundanz. Durch Einsatz der anpassungsfähigen Einrichtungen lassen sich auf dem Empfangsweg 55 Betriebsaggregate falls erforderlich mit eins-zu-eins-Redundanz betreiben.

Dieser Artikel soll ein allgemeines Verständnis des Gesamtsystem-designs und des Leistungsvermögens vermitteln und geht nicht näher auf spezifische Themen ein. In der Einführung wird die Notwendigkeit für eine derartige Erdstelle umrissen und eine Kurzbeschreibun der Ausrüstung gegeben, was zwangsläufig zu einer eingehenderen Behandlung der Untersysteme führt. Hierbei handelt es sich um Antennen, Breitbandempfänger und—sender, Erdfunkanlagen und die Überwachungs-und Steuereinrichtungen der Erdfunkstelle. Ebenfalls behandelt werden einige Aspekte des Gesamtsystems, gefolgt von einem kurzen Abschnitt über Projektverwaltung und-implementierung, zusammen mit kurzen Angaben über weitere Arbeiten, die von der Gesellschaft in Madley noch durchzuführen sind.

SUMARIO

Marconi Communication Systemas Limited ha sido el cotratista principal de la estación Madley 1, el primer terminal de tierra de comunicaciones por satélite que se ha instalado en el nuevo complejo de estación de tierra de los Correos Británicos en Herefordshire. El equipo inicial de comunicaciones está proporcionando una gran capacidad para tráfico telefónico, de telex y de TV a través de un satélite Intelsat IVA del Océano Indico. Se han provisto catorce cadenas de transmisión, con 6 portadores de redundancia uno por ono, más video y audio de TV no redundante. En el trayecto de recepción hay 55 cadenas operativas que pueden, si es necesario, configurarse en redundancia de uno por uno mediante el uso de dispositivos de flexibilidad.

Este artículo pretende ofrecer una amplia consideración del diseño general del sistema, de su capacidad, y no trata de ser una exposición profunda de ningún tema específico. La introducción subraya la necesidad de la estación y da una breve descripción de la configuración del equipo, llevando naturalmente a descripciones más detalladas de los subsistemas. Estas tratan de la antena, equipos de recepción y transmisión de banda ancha, equipo de comunicaciones de tierra y las instalaciones de la estación de control y dispositivos de supervisión. Luego se indican algunos aspectos del sistema en general, a lo que sigue una corta sección sobre dirección y realización del proyecto, con una relación de los trabajos ulteriores que ha de realizar la Compañía en Madley.