POINT TO POINT

TELECOMMUNICATIONS

A JOURNAL FOR THE TELECOMMUNICATIONS ENGINEER

VOLUME ELEVEN · NUMBER FOUR · OCTOBER 1967

Five shillings

POINT TO POINT

TELECOMMUNICATIONS

Volume Eleven Number Four October 1967

Editor: V. O. Stokes
Production: K. Jowers, O.B.E

Published by
THE MARCONI COMPANY LIMITED, CHELMSFORD, ENGLAND
An 'English Electric' Company

THE QUEEN'S AWARD TO INDUSTRY
1966 1967

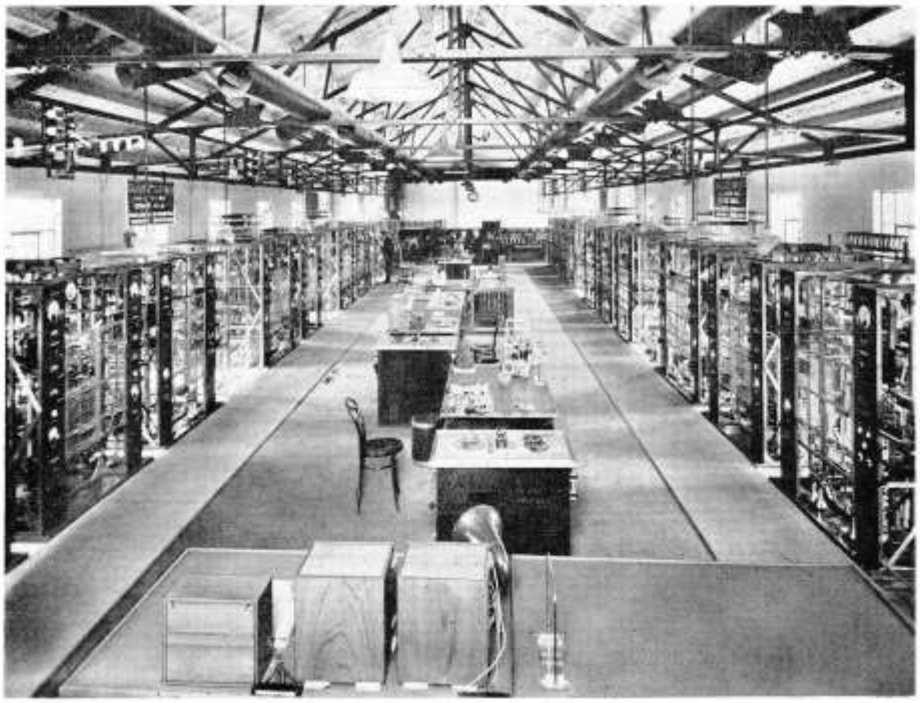
Points of view

IN THIS YEAR of 'Quality and Reliability', it is appropriate to reflect on equipments and systems that have proven these features for 40 years of operational service, namely, the original 'Swabs' and the 'Beam System'.

A new era in world-wide communications was started when Mr C. S. Franklin demonstrated the advantages of using 'short waves', compared with the 'long waves' of the Imperial Wireless Chain, then under construction but never completed. He proved that at these higher frequencies, 4 MHz to 20 MHz, aerials of considerably higher efficiency could be constructed at a relatively low cost and the bulk of the radiated power concentrated into a 'beam' in the desired direction. The increase in effective radiated power (e.r.p) was obtained by using Franklin 'uniform' arrays of stacked dipoles, known as 'beam' antennae.

The transmitters designed for feeding these 'beam' antennae were called 'short-wave beam', type SWB1, later editions of this series being known universally as 'Marconi Swab Transmitters' or just 'Swabs'. Because of the high-efficiency antennae and the increased e.r.p in the desired direction, the actual transmitter output required, about 11 kW, was only of the order of one-twentieth of that of the 'long-wave' transmitters. Thus considerable economies were effected in the cost of antennae, transmitters, power supplies and buildings, but the greatest advantage was operational, in that telegraph traffic could be handled at very much higher speeds.

In 1925 the Company, then Marconi's Wireless Telegraph Company Ltd, started to construct a series of two transmitting and two receiving stations for the GPO, as part of their programme to establish a chain of Empire short-wave wireless links. Two SWB1 transmitters were installed at Bodmin for communication with Canada and South Africa, and two at Grimsby for the Far East, Australia and Singapore, with reciprocal receiving stations at Bridgwater and Skegness.



The original SWB1 transmitters at Dorchester in 1928

At the same time the Company built two stations as a private venture, for setting up commercial links with North America. SWB1 transmitters were installed at Dorchester with the receiving station at Somerton. Later the same type of transmitters were installed at Ongar, with the receiving station at Brentwood, for commercial links with the Middle East. This enterprise was so highly successful that the Government of the day decided that such vital communication links must not be in the hands of a private company, so the stations were taken over by a new organization, Imperial and International Communications Company Ltd (later Cable and Wireless Limited). Could there be a greater tribute to the quality of the 'beam system'? Eventually the GPO took over all the beam stations, of which Bodmin, Dorchester, Ongar, Brentwood and Somerton are still in operation.

At the invitation of the Engineer-in-Charge, Mr H. Snell, a visit was made recently to Dorchester. The construction of this station started in 1925 and services were opened to North America in 1927, using two SWB1 transmitters. Two more were added later and the station was extended in 1928 by the addition of a new transmitter hall to accommodate eight SWB1's. The associated antennae were Franklin beam types which were arranged to fire either over the direct short route or the long route round the world to North America, for day and night operation.

The original transmitters used paraffin to cool the anodes of the CAT2 and CAT3 power valves, which were the first to use copper to glass seals. In 1958/59 these valves were changed to CAT9's and modifications made to use water for anode cooling. The transmitters are now encased in steel panelling and rendered safer by an extensive system of interlocks to comply with present-day standards. But although the outward appearance has changed considerably, on opening the doors the basic SWB1 is revealed. Closer inspection shows that the Franklin master oscillator and absorber type keying have been replaced by a crystal oscillator and HD61 keying unit.

The staff at Dorchester are justly proud of their SWB1's which are still operational after 40 years of continuous service. A remarkable proof of design reliability in theory and practice, and an example of the wealth of available experience on which Marconi engineers can draw.

Acknowledgement

The Editor wishes to thank the Director, External Communications Executive of the GPO, for permission to visit the Dorchester Radio Station, and the station staff for their co-operation.

Apollo Communications—The Installation on Ascension Island

K. U. BOLWELL, B.Sc, C.Eng, M.I.E.E

The Apollo-Ascension satellite communication ground station was set up to link Ascension Island with Andover Maine via the INTELSAT II synchronous satellite. The station was completed in 11 months from contract to handover. The article gives the background to the project and describes how the equipment was first assembled and tested in the UK then transported to site, installed, commissioned and handed over and its subsequent operations with the first INTELSAT II satellite.

1 APOLLO SUPPORT COMMUNICATIONS

FOR THE Apollo man-on-the-moon project, NASA decided to set up a network of spacecraft-tracking stations, so that the Apollo spacecraft would be in continuous radio contact with at least two stations during all the phases of its flight. These tracking stations would need reliable communications with the Apollo Mission Control Centre in Houston, Texas, USA, in order that telemetry, command, orbital data and the voice link could be centrally controlled. In the Mercury and Gemini projects this problem was met by the use of all forms of available circuit, including h.f, scatter, cable and microwave links, but the Apollo mission was more complex and new tracking stations were to be built, including ships to operate in mid ocean. In 1965, NASA approached the Communications Satellite Corporation (COMSAT) for communication links to be set up using synchronous satellites based on the proven Early Bird design, with capacity for a number of simultaneous transmissions. Hence the Apollo satellite-communications support programme came into being.

Two communications networks were to be established. The Pacific network would link two ships and Carnarvon (W. Australia) back to

Paumalu, Hawaii, while the Atlantic network would link two ships, Grand Canary Island and Ascension Island with Andover, Maine.

For each fixed site, a separate satellite communication ground station would be set up close to the tracking station. For the Ascension Island site, Cable and Wireless Ltd were asked to provide a ground station.

On 14th October 1965 The Marconi Company was awarded the contract with a completion time of 10 months.

2 REQUIREMENT FOR THE ASCENSION ISLAND STATION

The initial target for the Ascension Island station was for two-way communications to be established with Andover by 30th September, 1966, when COMSAT hoped to have both satellites (INTELSAT II) and the other stations operational.

The basic communications requirements were transmission in the 6 GHz band and reception in the 4 GHz band of frequency modulated carriers with information bandwidths of 28 kHz (seven telephone channels) and 56 kHz (14 telephone channels) respectively.

Power levels, antenna gain, receiver noise temperature and other parameters were specified to give an adequate traffic signal to noise ratio. Mechanical and servo-control performance was specified on the basis of acquiring and tracking the satellite under the worst wind conditions without significant degradation of communication performance. Baseband equipment was not included in the contract.

Emphasis was placed on reliable operation, for which vital equipment blocks were to be duplicated, with either parallel feed arrangements or manual changeover.

In November 1965 an extra COMSAT requirement was added involving the transmission or reception of a common network frequency for order wire speech and teletype channels.

It was required that the whole station had to be designed, built and tested in the UK before transportation to site. At the outset transport by air was assumed thereby imposing limits on the design, size and weight of individual packages. Later it was found necessary to use a charter vessel and at that time the target handover date was revised to 21st September 1966.

3 TECHNICAL DESCRIPTION

A simplified block diagram of the station equipment is shown in Fig. 1. This serves to indicate the complexity of the installation and to emphasize how much had to be accomplished within the limited time available.

3.1 PHYSICAL CONSTRUCTION

The Company was already engaged on a project for three transportable 40 ft ground stations for the UK Government and in view of the transportation limits it was natural to use similar design concepts for the Apollo project.

The antenna consists of a 15-ft high tripod gantry fixed into a concrete base and carrying at its apex a pivot mount, which provides the azimuth axis of motion. A large 'U' shaped fabrication fits on to the mount and has pivot points at the extremities of its arms. The 8-ft diameter centre hub of the reflector fits into the 'U' frame to form the elevation axis, the drive being provided by screw jacks with a differential gearbox. The reflector back structure is built out in sections from the centre hub and preformed aluminium-skinned reflector panels are fitted on to it.

The 42-ft diameter reflector is paraboloidal in shape with a focal length of 12 ft and a surface tolerance of 0.035 in r.m.s or better.

The Cassegrain sub reflector is a hyperboloid of 50-in diameter with a surface tolerance of 0.005 in r.m.s. It is supported on a tripod structure which picks up the back structure through the main reflector. The sub reflector is mounted on an axis inclined to that of the main reflector so that when rotated by a hydraulic motor, the antenna beam describes a conical pattern.

Two transmitter cabins are mounted on the rear of the back structure, one on each side of the centre hub. These are aligned with the cabin floor horizontal when the antenna is at its normal elevation angle of 76°. Access is via ladders pivoted from the wings of the azimuth platform, which is built out from the 'U' frame and used to support cooling equipment for the transmitters.

The low-noise amplifiers and turn-round mixer are fitted on to the back structure above the platform. Hanging loops of cables, anchored

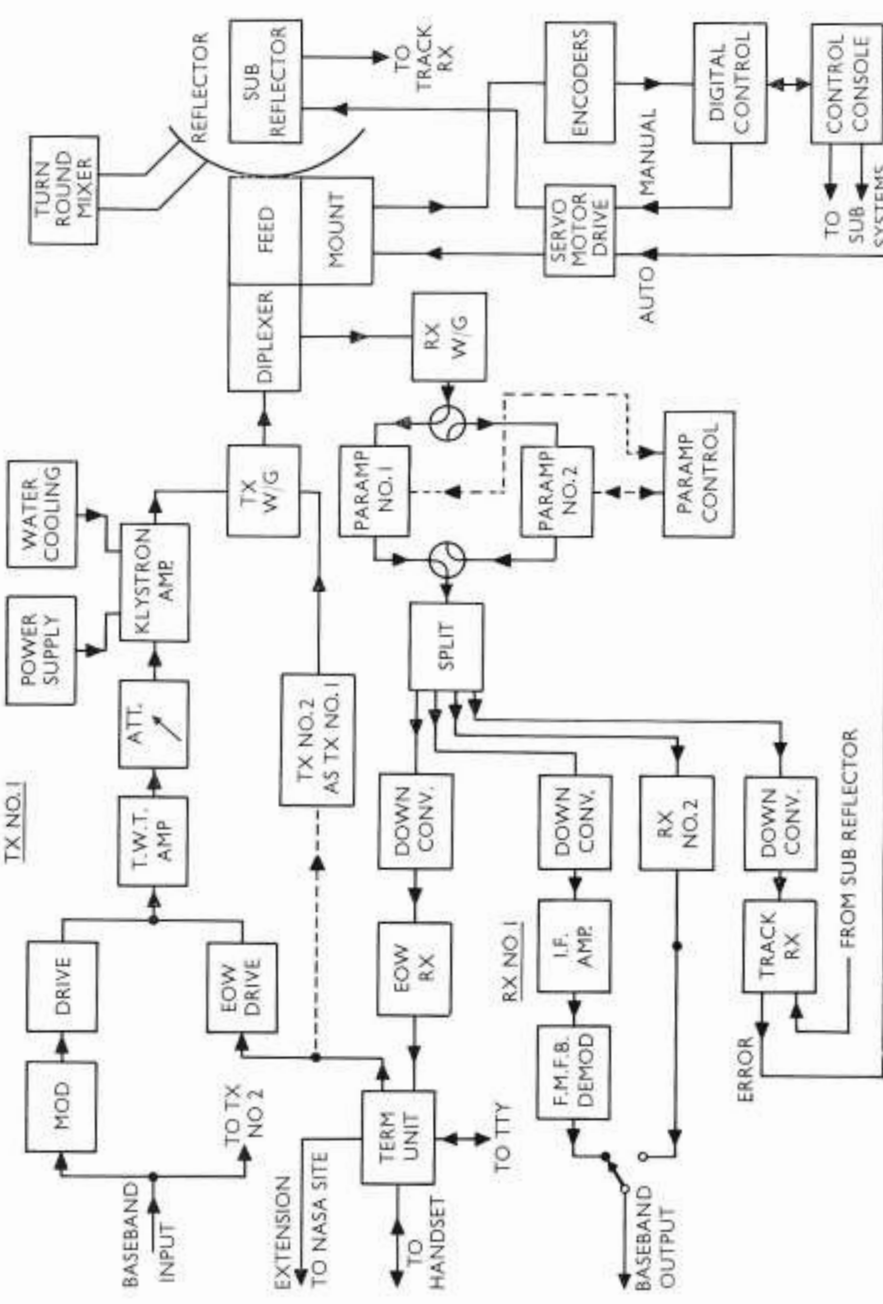


Fig.1. Block diagram of the Apollo ground station

at clamping points on the structure, are used to allow connections to cross the axes of motion.

Two power-supply cabins are fitted on the ground between the legs of the gantry. One contains the three racks of servo-motor drives in addition to the power supply for the transmitter.

Permanent buildings are used to house all other equipment including i.f and baseband communications equipment, the antenna control system and operational control console. Interconnections are made with durable multicore cable and connectors between termination plates at appropriate points.

3.2 ANTENNA SUB SYSTEM

The antenna is fully steerable with a range of movement nominally $+370°$ to $-370°$ in azimuth and $-2°$ to $+95°$ in elevation. Three sets of limits are imposed at the extremities of travel to protect the structure. The azimuth movement is only restricted by the arrangements for cable banding.

The antenna feed consists of a horn tapering into a 2-in circular waveguide with a vane for changing the angle of linear polarization and a diplexer for isolating transmit and receive paths.

The electrical design is such that the bandwidth is 150 MHz centred on 6 350 MHz for transmit and 4 120 MHz for receive, with a centre frequency gain of 53.5 dB referred to the transmitter dummy load and 52.7 dB referred to the low-noise amplifier input.

3.3 TRANSMITTER SUB SYSTEM

Two identical transmitters are supplied so that the description applies equally to both. The baseband multiplexed signal is fed in parallel into each 70 MHz frequency modulator, which is set up for a peak test-tone deviation of 103 kHz. The output signal is relayed to the transmitter drive contained in the r.f cabin on the structure, where it is up-converted to the working frequency of 6 325 MHz.

The order wire baseband signal is amplified and split into each e.o.w transmit drive, where it is phase modulated on to a carrier at approximately 49.3 MHz, which is then multiplied up to the final frequency of

6 315 MHz. The two carriers are combined and amplified in a t.w.t and fed to the power klystron input, through a motorized waveguide-vane attenuator.

The klystron is capable of producing an output power of 15 kW with a gain greater than 40 dB and a 1 dB bandwidth greater than 30 MHz. It has a permanent magnet mount which, together with all output waveguide components, is water cooled.

The transmitter output is connected through various power monitoring couplers, safety devices and a harmonic filter into a waveguide switch, which can either direct the output signal into the antenna feed, or into a dummy load in conjunction with another switch adjacent to the diplexer. The 18 kV e.h.t for the klystron is generated in the power supply cabin on the ground and supplied through the cable banding.

3.4 RECEIVER SUB SYSTEM

The receiver sub system is designed to handle four carriers, though in practice there are only three, a duplicate chain being used for the main communications.

A protection filter connects from the diplexer into the input of the duplicated parametric amplifier system. This comprises a two-stage parametric amplifier, which is cryogenically cooled to 15° K by a closed-cycle gaseous-helium refrigerator, and is followed by a tunnel-diode amplifier and branching network. The system noise temperature can be measured by built-in calibrated equipment and is typically 80° K with the antenna at zenith under clear weather conditions.

Each communications chain has its own down-converter, i.f amplifier and threshhold-extension frequency demodulator. This enables adequate telephone channel performance to be achieved with carrier to noise ratios as low as 4 dB. The e.o.w carrier is treated in a similar manner.

The tracking receiver consists of an a.f.c unit to lock on to the beacon carrier, and a tracking error detector to process the satellite-misalignment modulation, due to the conical-scan feed, into d.c error voltages.

3.5 ANTENNA CONTROL

The main modes of antenna control are manual and autotrack.

For autotrack, the servo loop is closed by the tracking receiver and integral control and velocity feedback are applied. For the manual position mode, digital control is used to compare the antenna position, from the 16-bit optical-shaft encoder against a position command, and derive an error to drive the servo. This system allows future extension to a computer mode. Manual velocity control is provided by the injection of voltages derived from a joystick.

An expanding square-search pattern (maximum size ± 0.5 degree) is provided for acquisition.

Independent three-phase thyristor drives are used for each 7 h.p d.c motor. There are two motors per axis driving through a differential and this allows the selection of:

'1 motor control'—one motor operates, the second is braked,

'2 motor control'—the second motor is slaved to the first by high loop gain velocity control,

or '2 motor bias'—the second motor becomes an independent velocity control and acts as a positive or negative bias to the speed of the first motor. This flexibility allows a wide range of antenna velocity.

3.6 OPERATIONAL CONTROL CONSOLE

The control console contains the essential control elements for operating the whole station from the operations room but does not necessarily duplicate those on nearby equipment racks. It contains panels for the transmitters, receivers, antenna control and servo metering. In addition it contains a standard oscillator, digital clock and oscilloscope which are used to generate and align an accurate time reference readout. A miscellaneous panel is used to provide access to the station intercommunication telephone system and the satellite network e.o.w. A joystick is provided on the table top.

4 RIVENHALL TRIALS

The site for the assembly and test of the station was at Rivenhall in Essex, where a 25-ft gantry and pivot mount were already erected. In March 1966 preparatory work began by laying concrete hard standing around the gantry, erecting two huts (one for an operations room, the other as an office) and putting up two marquee tents for stores

Fig.2. The site during construction with the antenna in course of erection

and staff premises. On 30th April the first major component, the 'U' frame, arrived and the construction began in earnest. Despite very bad weather the antenna was complete within two weeks and measurements of the polar diagrams began.

A system and acceptance test schedule was drawn up listing the tests to be performed starting on a sub-system basis and finishing with the complete operational station. This formed the basis for the trials with joint inspection by customer and contractor as the programme progressed.

The first tests, on the mechanical sub system, were completed on the 30th May 1966 and the last tests on 6th July. In between was a period of hectic activity which embraced all hours of the day and night.

The culmination occurred during the final week. On 2nd July 1966, using predicted data from the GPO station at Goonhilly as a guide, the Early Bird satellite was successfully acquired a number of times and tracking tests were performed. Continuous track was held for a period in excess of 12 hours, during which time the satellite beacon power varied by a considerable amount due to the change in traffic through the transponder.

In the early hours of 5th July, satellite loop-round tests were carried out, using Early Bird, for which special authorization from COMSAT was obtained. These tests consisted of plotting the input/output characteristic of the transponder, by varying the ground station transmitter power, recording the received carrier strength, and measuring the baseband noise power ratios (n.p.r) on a white noise test. Results were highly encouraging. The trials aroused a lot of public interest with a visit to Rivenhall of H.R.H The Duke of Edinburgh and an official Press Day.

5 PREPARATION ON ASCENSION ISLAND

In parallel with the Rivenhall trials preparations were being made on Ascension Island.

Ascension is an extinct volcano, 7½ miles long, mostly covered with

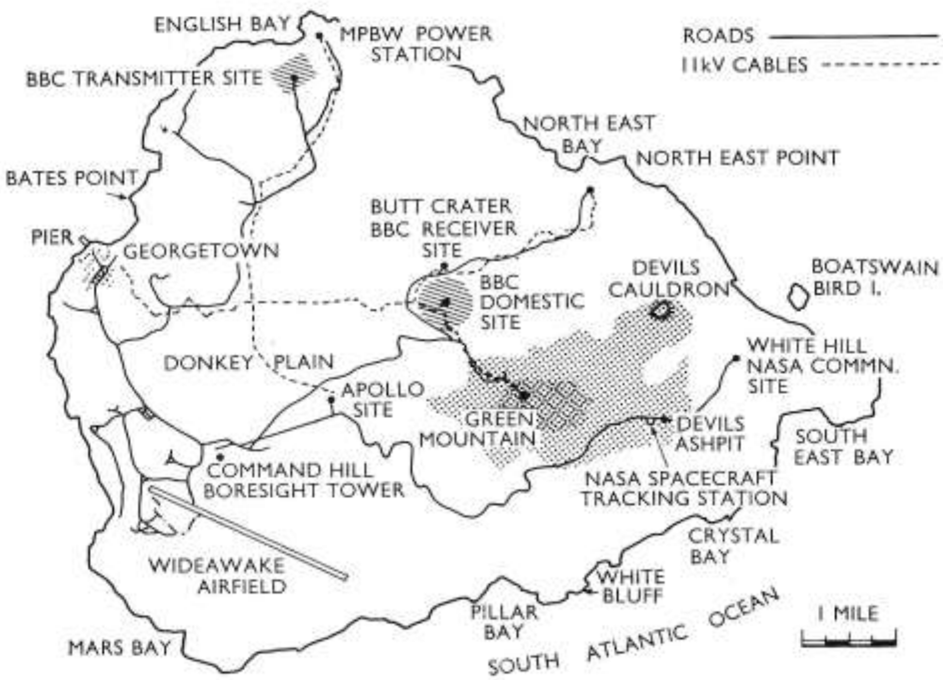


Fig.3. Map of Ascension Island

volcanic clinker, rock and scrub vegetation. Fig.2 shows the site during construction with the antenna in course of erection.

Because of its geographical position in the middle of the south Atlantic Ocean Ascension has been a relay station for cable telegraphy since 1899, is now a centre for a variety of communications and navigational aids and is associated with the American Atlantic missile range. A map is shown in Fig.3.

NASA chose Devil's Ashpit, towards the eastern end of the island, as the site of its spacecraft tracking station, Cable and Wireless Ltd choosing Donkey Plain in the centre of the island as the site for their communications station. The site is flat and clear but screened on all sides by hills giving natural protection from radio interference from the other installations, which tend to be situated around the coastline. It is conveniently located, roughly equidistant between Georgetown and Devil's Ashpit off the linking road.

The provision of buildings, civil works and power was not part of the contract—Cable and Wireless Ltd undertook this task themselves. Two advance planning visits were paid to the island and as a result plans were agreed for the site arrangements and gantry foundations. A plan of the site is shown in Fig.4.

The main power supply is brought over land on a 11 kV line from the new power station at English Bay, with a local 250 kW standby diesel generating set. Providing an adequate electrical earth on the station presented a problem due to the high resistivity of the bedrock and the long power line. This was solved by using large quantities of copper sheets, connected together, and buried below the volcanic clinker at bedrock level.

The Deputy Site Engineer, fresh from the bustle of activity of the Rivenhall trials, left Gatwick on 4th July for Ascension Island. His first task was to check the civil works and in particular the concrete footings for the gantry. Then followed a period of preparation for the main installation party; making arrangements for the use of cranes and labour, checking the equipment that had already arrived by boat, including the gantry and pivot mount, checking tools, and generally ensuring that the preliminaries to installation were complete.

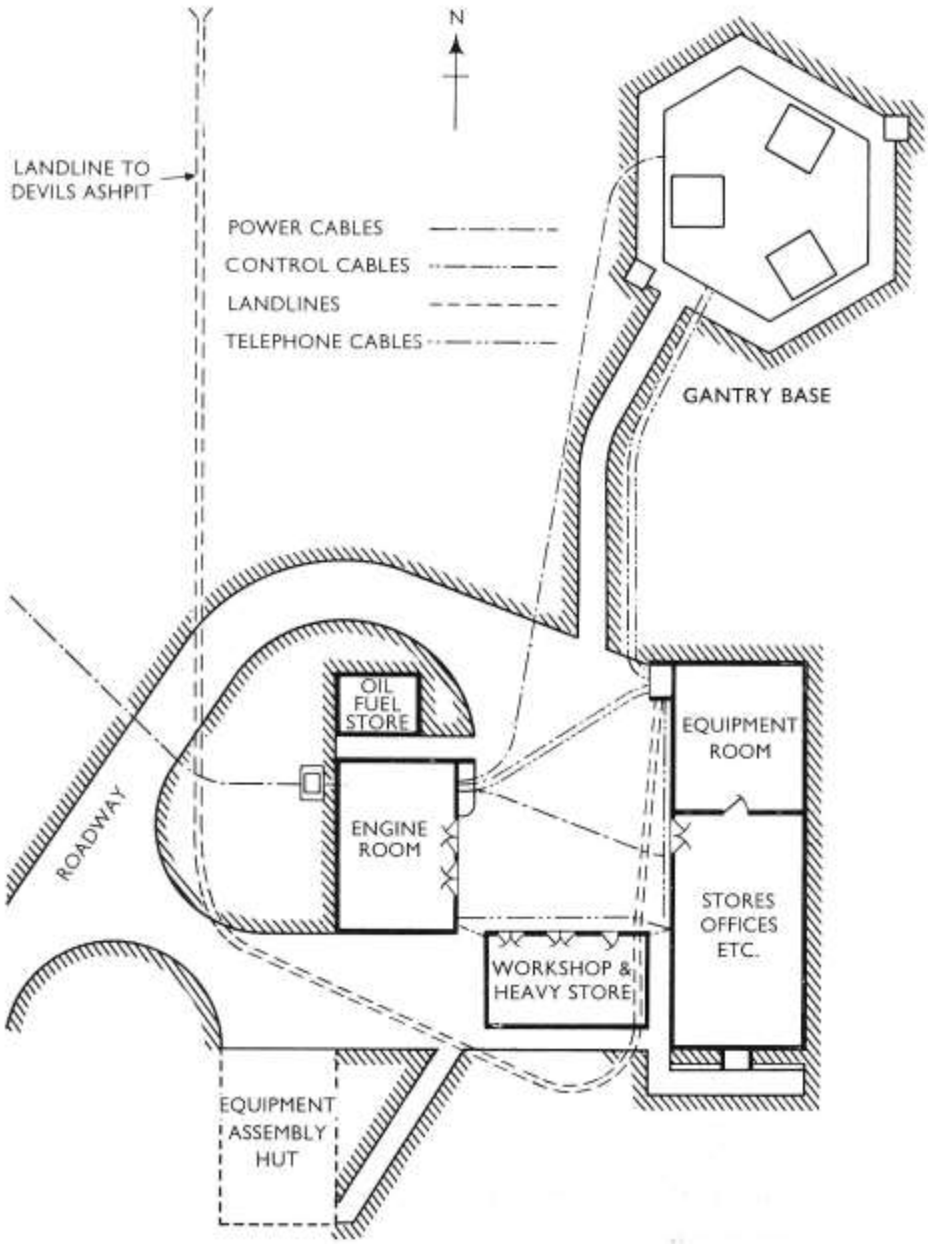


Fig.4. Plan of the Apollo site

6 TRANSPORTATION

Dismantling at Rivenhall commenced at lunchtime on Thursday, 6th July, and by Tuesday morning 11th July the last item, the 'U' frame, was removed from the structure. In the meantime the cabins, platforms, reflector, back structure and other parts had all been taken down against a programmed schedule and despatched to another area for cleaning, painting and packing.

At the same time a similar exercise was taking place on the electronic equipment with workmen carrying out the many odd jobs that had accumulated during the hectic testing phase prior to packing. The inter-site cables were disconnected, sorted and carefully coiled in a logical sequence for packing, whilst in another area the test equipment, spares and installation equipment were being assembled and packed.

On Wednesday, 20th July 1966 the 'MV Flut', on private charter to Cable and Wireless Ltd, docked at Felixstowe. Loading of the equipment began immediately and continued until all the 40 tons of equipment had been handled.

'MV Flut' sailed on the evening tide on 22nd July, three days earlier than anticipated, bound non-stop for Ascension Island on her maiden voyage. On 4th August she anchored off Georgetown and the task of unloading began. Because of the high rise and fall in the tide and large Atlantic swell, boats cannot dock alongside the jetty. The practice is to discharge cargo onto large, flat, tank pontoons using the ship's own crane. The pontoons are then towed to the jetty for unloading by the jetty crane. This method was used for the Apollo equipment but with some anxious moments, for the German crew had little experience of using the ship's crane, especially in that sort of situation. However, all went well and the equipment landed safely. A fleet of lorries waited to take the equipment to site where a handling bay had been set up to sort the cases into the right order for unpacking or storage.

The construction party of eight mechanical engineers and riggers had arrived on Ascension on 26th July. By the 29th July the gantry had been erected and the pivot mount fitted on top, ready for the arrival of the main equipment.

Travelling by charter aircraft the main installation party of 17 men

Fig.5. The completed antenna shown in its operational attitude with the transmitter cabins horizontal under the reflector and the power-supply cabins under the gantry legs

Fig.6. Equipment cabinets in the operations room

(including the Site Engineer) arrived at Wideawake Airfield at 13.55 on 5th August 1966 to learn that the last item of cargo had been landed only 15 minutes previously. At 18.00 that evening 'MV Flut' sailed from Georgetown after a stay of only 25 hours, and her part in the project was over.

7 INSTALLATION

The programme allowed just over six weeks to handover, with nominally three weeks for the construction and installation and three weeks for the commissioning. During this time a two-way telex circuit was set up from Ascension to Cable and Wireless Ltd, London, and the Project Manager in Chelmsford to provide the site team with help and advice as required.

The whole party, engineers, riggers, wiremen, hired labourers from St Helena and Cable and Wireless Ltd personnel enthusiastically set about the immediate task of unpacking, sorting, storing and installing. Activity could take place in a number of areas at the same time and full use was made of this fact with all personnel joining in to create the station, their normal special expertise forgotten for the time being.

The first fortnight was one of remarkable progress. True the antenna had been built before, but not in the same sequence, site conditions or with such a small team. An 80-ft mobile crane with driver was borrowed from the USAF base on the island and this proved invaluable for the task. By 11th August the 'U' frame, hub and back frame had been fitted and the reflector petals were being dropped into place. By 15th August the two transmitter cabins were being hung. Two days later the whole mechanical structure was complete and the crane was returned. Fig.5 shows the completed antenna structure.

At the same time the operations room was being fitted with the control console and cabinets of equipment. Minor modifications had to be made to cabling arrangements but by 15th August the installation was complete, including the connection of mains power, and several cabinets were being individually checked. Fig.6 shows the equipment cabinets in the operations room.

The laying of the underground inter-site cables between the operations room and the gantry proved a difficult task. A concrete cable duct had been made about 2 ft below the surface, but because of the loose clinker through which it had been cut the slightest movement in the vicinity caused the duct to fill. In consequence, cables were spread out some distance away and laid very carefully with continuous cleaning operations until the job was completed and the duct could be covered.

The power-supply cabins were positioned under the gantry and cabling to them and to the gantry junction boxes began. As the antenna was completed, the azimuth and elevation cable bands were fitted and made up. Fig.7 shows power supply cabin No. 1 with the servomotor drive equipment and Fig.8 shows the station control console with some of the teleprinter equipment.

The boresight tower installation, on Command Hill about a mile away, was another scene of activity as the beacon simulator with its dish aerial was installed and commissioned.

Gradually all the individual activities were brought together and with the fitting of all the smaller pieces of equipment the station as a whole

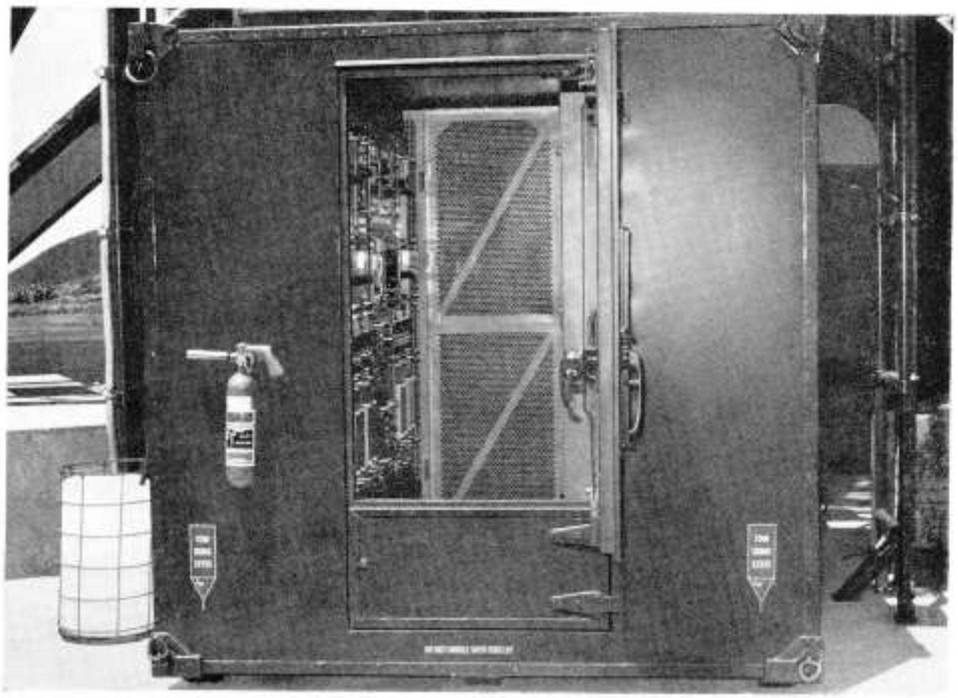


Fig.7. Power supply cabin No. 1, showing the servo equipment through the door

took shape. On 23rd August the construction and installation of both mechanical and electrical items were complete, the antenna was turned in azimuth under power for the first time, and pumping down to temperature of the parametric amplifier cryogenic systems began.

8 COMMISSIONING

With the completion of the installation phase the riggers left site and the system and acceptance test schedule commenced. The site tests were basically the same as those at Rivenhall but with emphasis placed on demonstration of overall performance. Again engineers from contractor and customer worked together to carry out the tests.

The first section of tests was concerned with the cabling and connectors, which proved to be straightforward, as considerable work had been done in this area at Rivenhall.

The next section concerned the antenna mechanics. Many tests and checks had been carried out as the antenna was constructed. Now it was necessary to record these formally and perform other tests to show that the antenna worked to specification. Such tests involved checking the ranges of movement of the main axes, safety limits, brakes, gearboxes, Cassegrain sub-reflector mounting and drive mechanism and the profile of the main reflector.

The third section involved the aerial feed, the measurement of v.s.w.r and loss of the waveguide runs and the alignment of the boresight telescope.

The fourth series concerned the transmitter sub system with tests on the modulators, transmitter drives (communications and e.o.w) and power amplifiers, leading to overall operation both from the local control panel and from the console. Tests included the measurement of waveguide nitrogen pressure, radiation leakage levels, and performance of the power klystrons with both communication and order wire carriers.

Fig.8. The station control console with some of the teleprinter equipment

The next section dealt with the parametric amplifier and cryogenic cooling. Each amplifier was pumped down to temperature and measurements made of system gain and bandwidth.

The sixth section covered the communications receiver and was mainly concerned with setting up the frequency feedback demodulators and checking their performance with injected signals.

The tracking receiver and its peripherals were the subject of the seventh section. The tracking receiver was first tested on its own and then integrated with the antenna and acquisition, alignment and beamwidth tests performed using the boresight beacon.

Section eight, manual and closed-loop servos, covered checks on the antenna control equipment. Initial tests were aimed at establishing the electro-mechanical characteristics of the structure and the operation of the encoder and limits. Checks on the various motor modes of motion followed and the manual command of antenna position. Operation in the auto-track mode was then tested using the beacon simulator and tracking receiver.

Most of the above tests were completed by 7th September, when attention was concentrated on the complete operation of the station. Section nine of the test schedule contained overall system tests. The most important of these were overall performance through the transmitter, turn-round mixer and receiver, measuring frequency response, n.p.r and spurious outputs. Other overall checks covered telephone intercommunications, interference, system noise temperature and low elevation limit. Performance was satisfactory on all counts.

On 7th September 1966 an attempt was made to acquire and track Early Bird. The beacon frequencies of INTELSAT II and Early Bird are different, so this necessitated a change of frequency for the tracking receiver, as at Rivenhall. At 09.30 lock-on was achieved and held solid whilst Early Bird was not passing traffic. Later that day with traffic present the lock-on was marginal. It should be explained that the antenna polar diagrams of Early Bird are orientated towards the Northern hemisphere with quite a loss below the equator, i.e towards Ascension Island, but that the patterns are not constant with frequency. As a result of this success, permission was requested from COMSAT for communication trials and 08.00 to 09.00 on the 17th September was allocated. During the hour, tests were made on tracking, e.r.p. receive level, and n.p.r. The results compared favourably with those obtained at Rivenhall, although the path loss was greater by 4.2 dB for communications and 4.5 dB for the beacon. These tests provided a fitting climax to the commissioning of the station, especially in the absence of INTELSAT II.

9 HANDOVER

On 19th September 1966 two days in advance of the planned target date, the Apollo Ascension Satellite Communications Earth Station was handed over to the customer. It was complete apart from the order wire receiver, which arrived later. This, together with a number of minor observations, was left for the Site Engineer and some assistants to clear while the installation party departed.

The main task for the remaining engineers was to train customers' staff on site in the operation and maintenance of the station. Due to the late launching of the satellite, the traffic requirement for 30th September had receded and the extra time was put to good use.

10 OPERATION

On 23rd October 1966 the order wire receiver arrived and was installed.

On 26th October NASA launched its first INTELSAT II satellite, intended for the Pacific Ocean position. However, a fault occurred and the satellite did not achieve the correct orbit, being left in a highly elliptical transfer orbit (220 × 23 000 miles) of approximately a 12-hour period. Predicted data was sent to Ascension by COMSAT with a request that network tests commence with the rogue satellite as soon as possible.

On 10th November 1966 at 13.10 the station locked on to the satellite beacon. First attempts to contact Andover on the order wire failed although loop-round tests via the satellite were successful. The Andover station then came through on the communications carrier and a speech circuit was established on channel 1. Later, communications were also established via the order wire. Lock was lost about 18.30 that day when the satellite had moved out of sight, but contact was established the next day and faultless teletype messages passed.

The Canary Island station also transmitted on the order wire that day, but two-way contact was not established due to malfunction of their receiver.

There followed a period of inter-station testing with Andover via the rogue satellite, when the characteristics of the station were measured.

The last Marconi engineer left on 18th December after a period of three months' maintenance and staff training, leaving the station in the capable hands of its operators to play its rôle in the NASA man-on-the-moon project.

Acknowledgement

The author wishes to acknowledge the combined team effort which made the project a success and to thank the Engineer-in-Chief of Cable and Wireless Ltd for permission to publish this article.

KEITH U. BOLWELL was educated at Sir Joseph Williamson's Mathematical School, Rochester and King's College, London. He entered The Marconi Company as a graduate apprentice in 1954, and joined the Communications Research Group in 1956. He was appointed Chief of Information Processing Group on the creation of Space Communications Division in 1965 and took part in the Apollo-Ascension Project, initially as Deputy Project Manager, responsible for technical matters, and later as Manager.

A 100 kW L.F Linear Amplifier 40 kHz—160 kHz

C. E. BROWN, B.Sc(Eng), C.Eng, M.I.E.E
A. T. CURTIS

Communication in the frequency range of 40 to 160 kHz offers a number of advantages over communication at other frequencies, but the number of channels which can be used is limited by the available spectrum and antenna characteristics. After discussing the features associated with the greater use of the l.f spectrum, a description is given of a high-power linear amplifier of compact design for multi-channel operation, made possible by the full use of modern techniques.

1 INTRODUCTION

IT IS A well-known characteristic of low-frequency propagation in the 40 to 160 kHz band that, relative to frequencies in the h.f band, both ground-wave attenuation and ionospheric reflection are lower. The combination of these two effects means that deep and rapid fading is practically non existent and slow fading predictable and less severe. Another important feature of the use of low frequencies is that reception is less affected by ionospheric storms, even in the polar regions.

These characteristics enable low frequencies to be used as a reliable medium for long-range communication circuits, in which multi-channel operation is desirable for their full exploitation. Unfortunately the bandwidth is limited both by the available spectrum and by the antenna characteristics. Consequently for multi-channel circuits, the channels must be closely spaced and have narrow bandwidth, which in turn means a high order of frequency stability.

A drive unit with channels having these features has been described previously[1]. This drive provides a number of services, for some of which subsequent amplification must be linear, so the high-power amplifier must be linear. Another useful feature of the final stage being linear is that valves operating in or near class A condition provide some damping on the antenna circuit, thereby reducing the effective Q factor and increasing the bandwidth.

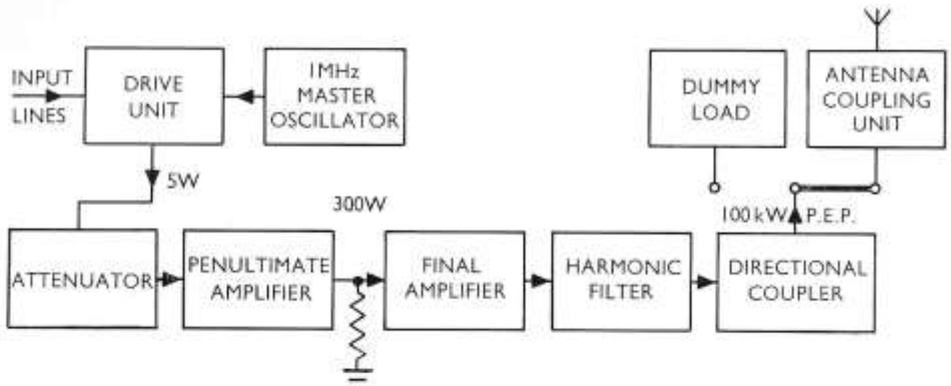


Fig.1. Block diagram of radio-frequency circuits

It is neither practical nor economic to make high-efficiency antennae for l.f operation, neither is it possible to obtain any appreciable gain in a desired direction by concentrating the power in a beam. Therefore the output power of an l.f amplifier for communications must be considerably greater than its h.f counterpart. For these reasons, combined with economic considerations, the power output of the amplifier has been specified at 100 kW p.e.p.

Low-frequency transmission systems having a high order of frequency stability offer several advantages over other systems, particularly in the field of navigation. In the form of radio beacons they provide a very accurate means of long-range position determination, which is available throughout 24 hours of every day. This is an extremely important feature for modern air and marine navigation, both civil and military, especially in the polar regions, where severe ionospheric disturbances make h.f systems unreliable. Another important advantage is that communication can be established with submerged submarines from remote land stations.

2 GENERAL CONSIDERATIONS

There are a number of interesting features in the design of a 100 kW p.e.p linear amplifier for a low-frequency transmission system, the radio-frequency stages of which are shown in Fig.1.

It will be seen that only two amplifier stages are used to raise the power level to 100 kW from the drive power of 5 W, a gain of 43 dB, including the loss introduced by the attenuator for adjusting the output power. This has been made possible by the use of a high-gain pentode valve for the penultimate stage and a pair of high-gain tetrode valves in the final stage. Furthermore, adequate gain and power output are obtained without grid current in either stage, thus avoiding the debasement of linearity associated with positive grid excursion. As the final stage is in a grounded-cathode arrangement, it is necessary to provide an output load for the penultimate stage, in order to operate the pentode on its optimum load line for linearity.

The main source of non-linearity is the curvature of the valve characteristics in the final stage. The linearity performance is improved by the application of radio-frequency feedback over this stage to a figure well within the specified −35 dB level for intermodulation products. Even with feedback the effective gain of this stage is 25 dB. Feedback also reduces the harmonic content produced in the stage, but a second harmonic filter is included to ensure compliance with international regulations.

For amplifiers in this application rapid frequency changing is not an operational feature, so they are designed for fixed frequency only, but a complete frequency change can be made in only 30 minutes. Thus the variable tuning elements need not be the very large capacitors or inductors which would be required for continuously-variable coverage at these frequencies. The use of a relatively small variable capacitor for tuning has obvious advantages, both constructional and economic, but there is one disadvantage. The proportional frequency change covered by the tuning capacitor means a very flat frequency response, particularly at the lower frequencies. This has been overcome by the use of a phase discriminator which gives a much clearer indication of tune. The addition of the discriminator is advantageous in itself, for it enables tuning adjustments to be made with feedback on, an unusual but useful feature.

The amplifier output is fed into a 50-ohm coaxial cable fitted with a directional coupler, which provides indications of forward power and reflection coefficient. The coupler also contains trip facilities, should the v.s.w.r exceed a predetermined value.

The impedance characteristics of the various antennae used in this frequency band cover a wide range, so a matching unit is necessary between antenna and feeder, which can only be correctly set up on site to suit a specific antenna and frequency. Therefore an external 50-ohm dummy load is provided to check the amplifier performance without a matching unit and antenna, both in the factory and on site.

3 FREQUENCY STABILITY

It will be seen from Fig.1 that all frequencies radiated are derived from a 1 MHz master source, thus the stability of the output frequencies is the same as the source. A number of master oscillators are available, the choice of which depends on the type of service required, the cost increasing as the required stability increases. For standard time signals and accurate information for navigation, short term stabilities of the order of 1 part in 10^{11} (.0000004 Hz in 40 kHz) are obtainable, such as those based on the rubidium gas cell or the ceasium beam. For general purposes less expensive oscillators are suitable with a stability of the order of 1 in 10^{8} per month (.0004 Hz in 40 kHz).

4 THE PENULTIMATE STAGE

The output from the drive is fed through a 75-ohm coaxial cable, adjustable attenuator and ferrite transformer, directly on to the grid of the pentode valve. When drive is not required, such as when setting the static feed of the valves, the drive is switched to a dummy load in front of the attenuator. This switching function is performed by a relay, controlled by push buttons on the front panel. The 75-ohm cable also carries a d.c interlock command signal, which causes the drive to be removed if the actual drive setting is readjusted after initially setting up the system. This prevents the amplifier from being overdriven by maladjustment when the drive equipment is remote from the power amplifier.

The anode circuit is in the form of a π network with a variable capacitor at the anode for tuning and a number of fixed capacitors at the output for loading. The h.t supply is fed via an r.f choke into a point of low r.f potential along the inductor, thereby reducing the amount of decoupling required and allowing the use of physically small decoupling capacitors. A d.c blocking capacitor is fitted in series with the inductor at the output end to remove the d.c from the loading capacitors, allowing a more compact loading arrangement. The loading capacitors are monolithic, high-temperature, high-current ceramic types. As the output is terminated in a load resistor of fixed value, the capacitance value for any frequency can be preset from charts, leaving the anode variable capacitor as the only element requiring adjustment during the tuning process. Due to the small frequency range covered by the variable capacitor, the tuning response is very flat, so a phase discriminator is fitted as a tuning indicator.

The linearity of this stage is good, but has been improved by the use of 3 dB of r.f feedback. The feedback voltage, which is obtained from a capacitance potentiometer between anode and earth is fed into the earthy end of the input transformer where the phase is correct for negative feedback.

The 1 500 watt pentode valve and associated circuitry are forced-air-cooled by a separate blower contained within the penultimate stage assembly. Loss of air flow in the stage and excessive pressure drop across the inlet air filter are monitored by switches, the operation of which remove the power from the amplifier before the equipment suffers damage.

5 THE FINAL STAGE

The input circuit consists of a wideband ferrite transformer, the primary being connected in parallel with the load resistor of the penultimate stage. The secondary is provided with a number of tapping points, which can be preset to give the same cathode current to each of the two valves by providing the appropriate grid voltage.

As in the previous stage, the anode circuit is a π network for matching the anode impedance to the output impedance, with allowance for a mismatch of 2 : 1 v.s.w.r on the 50-ohm feeder. The main inductor is interesting in that it is made of 1-in diameter copper tube, thereby departing from the conventional use of litz-wire conductors for these frequencies. Fig.2. There are a number of advantages in the use of copper tube; construction and tapping points are simplified, rigidity is much

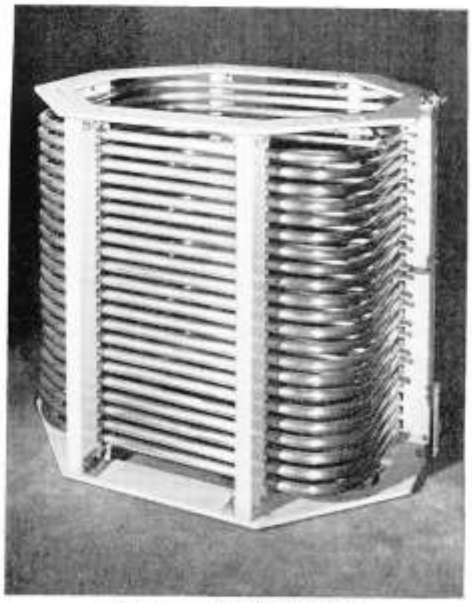


Fig.2. Final stage inductor

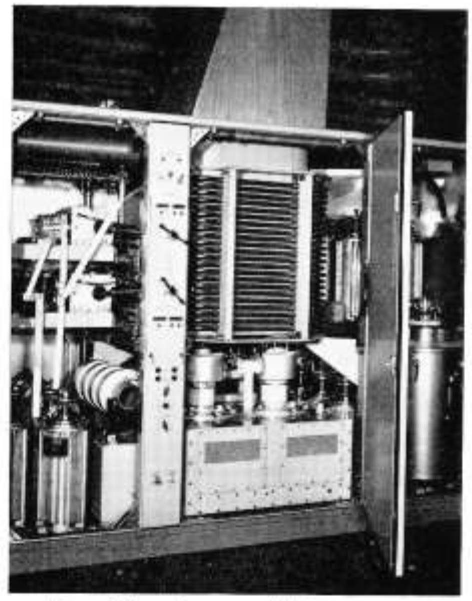


Fig.3. R.F enclosure with doors open

better (an important feature in the reduction of phase modulation), the cost is considerably reduced and the slight increase in loss increases the bandwidth. The copper tube is mounted on a fibreglass comb frame, the whole inductor being fitted around the main air duct to save space. This is shown in Fig.3, which is a view of the r.f amplifiers with the doors open. The penultimate stage is in the compartment underneath the final stage valves.

The anode tuning capacitance consists of a number of oil-immersed mica capacitors, which are linked in circuit as required, in parallel with a motor-driven nitrogen-filled variable capacitor. The loading capacitance is made up of a number of oil-immersed mica capacitors in parallel with banks of ceramic capacitors for fine loading. The switching of these capacitors is controlled from the front panel and can be operated with the transmitter on power. This stage also has a tuning indicator based on information derived from a phase discriminator.

Radio-frequency feedback is an important feature of this stage for linearity improvement. The basic circuit is shown in Fig.4. A sample of the anode r.f voltage, derived from a capacitance potentiometer between anode and earth, is fed into the earthy end of the input transformer secondary, where it is in the correct phase for negative feedback. Feedback of 12 dB is applied, giving an improvement in intermodulation product in excess of this level, due to some upgrading of the input. With this amount of feedback, disturbing transient conditions are liable to be set up if the d.c supplies are applied with feedback on, so feedback is applied after the power supplies by means of an r.f vacuum switch. This switch is interlocked with another in the input attenuator, which increases the input level as feedback is applied, thereby maintaining the same power output with feedback on or off.

The inherently large input capacitance of high-power tetrodes effectively changes the phase in the feedback loop from the required antiphase condition. This difficulty has been overcome by tuning out this capacitance with a shunt r.f choke. The Q factor of the input circuit is relatively low, due to the reflected load of the penultimate stage, so the tuning is not at all critical.

The air supply for cooling the valves in the final stage is also used to cool other items in the enclosure. On entering the power cabinet via air filters, it passes over the main h.t silicon-rectifier banks then over and around the transformer. By this means it has been possible to reduce the size of the transformer, for the flow of air is considerable. From the power cabinet the air passes over various r.f components before entering the valves, after which it is exhausted to atmosphere via the top of

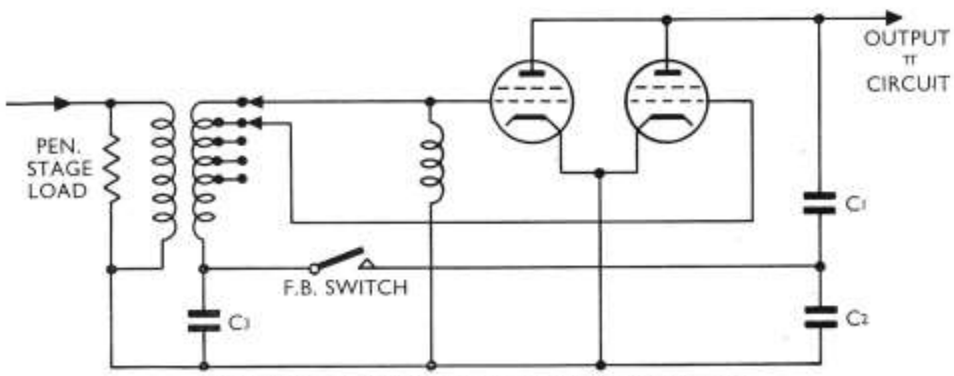


Fig.4. Basic circuit for r.f feedback (patent applied for)

the amplifier. Adequate air monitoring is provided which takes executive action before damage can be caused to the valves or other equipment.

6 TUNING DISCRIMINATORS

The use of feedback in both amplifier stages prevents the use of normal indications of tune when feedback is on. In addition the circuits have very flat tuning responses, especially at the lower frequencies. Phase discriminators are fitted in both stages to overcome these difficulties by providing an accurate indication of tune position. The two discriminators are identical, the difference in stage voltages being covered by adjustment of the pick-up capacitance probes. These probes deliver samples of anode and grid r.f voltages to the discriminators, where they are applied to a wideband ferrite transformer and vectorially added to produce an incremental error voltage. This voltage is proportional to the phase difference between the anode and grid voltage. The error voltage is applied to a centre-zero meter, giving an indication of tune position, accurate to within $5°$. The detector circuits are linearized in order to maintain an accurate 'on tune' indication at various power levels.

7 DIRECTIONAL COUPLER

Power output is measured by means of a directional coupler, the design of which is based on the proven technique used for higher frequencies, giving meter indications of forward power and reflection coefficient. In addition the amplified output is fed into a control unit for protection of the output circuit if the v.s.w.r exceeds 2.3 : 1. If this value is exceeded, the three-shot sequence of h.t restoration is initiated and lock-out occurs if the fault is maintained.

Although the directional coupler is an integral part of the amplifier, it is a discrete component and may be used separately. In the 40 kHz to 160 kHz frequency range the coupling factor is -50 ± 2 dB and directivity better than -45 dB.

8 CONTROL CIRCUITS

Control of the amplifier is effected by using a combination of heavy-duty relays, operating a.c contractors, high-speed light-duty relays for low-level switching and interface isolation, and thermal relays for filament heating delay and air-hold facilities.

Hybrid-trip circuits are used for amplifier protection, giving both a visual indication and lockout in cases of more severe faults. They consist of solid-state switches for performing voltage-sensing, logic functions, drive high-speed hermetically-sealed relays and may be divided into two groups. The first group, giving screen overload, cathode overload and v.s.w.r protection, initiates a three-shot cycle of h.t restoration for fault conditions. The timing circuit producing the 'h.t off' time is solid-state, while the number of h.t restorations are counted by a thermal relay, which operates after the final count to place the amplifier in the lockout condition. The second group provides h.t over-current, harmonic-rejector circuit and valve over-dissipation protection. Each trip circuit places the amplifier in a lockout condition immediately a fault is sensed and is individually protected against surges by a series-resistor zener-diode circuit and 'L' section low-pass filter where necessary. These filters, together with decoupling capacitors, remove the possibility of circuit malfunction due to r.f pick up in the wiring.

The protection circuit for valve over dissipation incorporates a precision thermistor for temperature sensing, situated directly in the output air duct. A further two thermistors in the control unit provide rationalization of this sensed temperature for wide variations in environmental temperature.

The main d.c power is applied in a step-start mode to reduce switch-on surges and so eliminate pseudo trips on starting. The delay time for the step-start sequence is achieved electronically with simple solid-state timing circuits.

The mains supply is controlled by a built-in automatic-voltage regulator with a solid-state control unit and a variable transformer, which drives a 'buck and boost' transformer in series with the supply line. The three-phase voltages are controlled individually to within $\pm 1\%$ for incoming variation of $\pm 6\%$. This has the effect of reducing the ripple on rectified supplies by reducing phase-voltage unbalance, allowing the use of smaller smoothing components. Protection is provided against mains failure of up to three seconds duration, so that the amplifier returns to its fully operational condition immediately after a failure.

Extended control is provided with similar facilities to the local con-

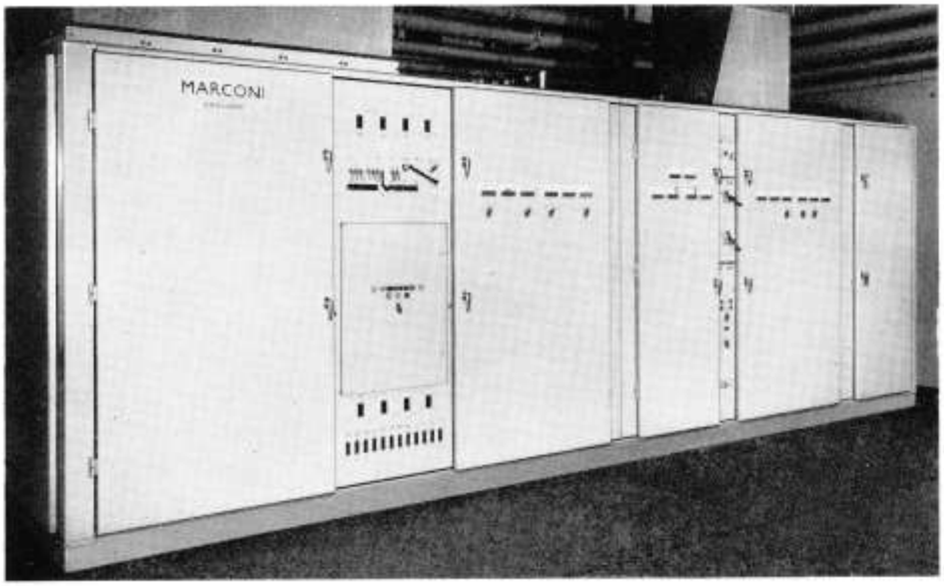


Fig.5. The complete 100 kW amplifier

trol, together with bell, visual lockout alarms and indications of forward power and reflection coefficient.

9 ANTENNA TUNING

In the frequency range of 40 kHz to 160 kHz, several types of antenna may be used, such as a top capacitance-loaded delta array, umbrella array or a 'T' arrangement. The antenna tuning unit has to be capable of matching the impedance of any selected antenna to the 50-ohm feeder, within the limiting 2 : 1 v.s.w.r condition. For this purpose it contains inductors and capacitors which can be linked into any configuration which may be required. This unit can be tuned automatically.

Normally this tuning unit is situated at the base of the antenna and provided with an enclosure for personnel and weather protection as very high r.f voltages are developed, often 100 kV across the matching inductor.

10 PHYSICAL ARRANGEMENT

The complete equipment is housed in two adjacent cabinets, each 10-ft long, 4-ft deep and 7-ft high, covering a total floor area of 80 sq ft. All units are completely accessible from the front, so no back access is required. The combination of these two features means that space required for accommodation is considerably less than with previous l.f equipments of similar power. The only external item of the amplifier is the blower, which can be a weatherproof type for mounting outside the main building. Fig.5 shows the two cabinets which comprise the amplifier. Each is mounted on a rigid steel-framed base with facilities for transportation, thereby reducing the amount of dismantling required before despatch and simplifying installation, both of which are time consuming and costly operations.

The left-hand cabinet contains the power supplies including the main h.t rectifier, transformer and automatic voltage regulator. Silicon rectifiers are employed throughout and where possible use has been made of silicon avalanche diodes, which require less protection. All power controls are on the central panel with meter indications on the right. Provision is made for incoming cables to enter from either overhead or underfloor ducting, with the air supply entering the top of the cabinet via readily removable filters.

The right-hand cabinet houses all items of the radio-frequency section with the exception of the antenna matching unit which must be near the antenna. Within this cabinet there is a movable deck carrying the two amplifier stages and associated circuitry. This facilitates construction, simplifies valve changing and adds to the compactness of the overall design. All r.f controls and meter indications are mounted on the front, in the layout of which considerable attention has been paid to ergonomics and general appearance. The outlet of the air system is at the top of this cabinet.

11 CONCLUSION

Although the long-range advantages of low-frequency propagation have been realized for many years, little attention was given to it largely because of the limited channel capacity and the high cost of equipment per channel. Recently there has been a resurgence of interest in this field, due to the facilities offered which are not possible with propagation in other frequency bands, particularly for navigation. By the use of modern techniques a compact low-frequency equipment has been developed which makes multi-channel operation practical, thereby enabling better use to be made of this valuable frequency spectrum.

Reference

1 R. E. J. GERARD: 'A Low-Frequency High-Stability Telegraph Drive', *Point to Point Telecommunications*, Vol. 11, No. 2 (April 1967).

C. E. BROWN was born in Essex in 1924. He joined the Test Department of The Marconi Company in 1941 and after graduating from London University in 1950 entered the Airborne Group developing automatic direction finders. Transferring to Transmitter Development in 1956 he was concerned with the development of f.m and t.v transmitters. In 1964 he became a member of the Communications group working on h.f transmitters. He is the engineer responsible for the design of the 100kW low-frequency amplifier described in this issue. His interests are motor racing and gardening.

A. T. CURTIS was born in Haslemere in Surrey in 1941 and educated at the Xaverian Associations Clapham College in London. Subsequently, while employed by a London company engaged in t.v transmission, his education was continued at the Borough Polytechnic. He joined The Marconi Company in June 1965 in the High Power Communications Department where he assisted in the design and development of the low-frequency, high power amplifier. His hobbies include Karate and swimming.

Scatter Links in Tandem

G. C. RIDER, B.Sc, and D. S. PALMER, M.A, F.F.A

The correlation between transmission loss over successive links in a communications circuit is a very important planning parameter.

Measurements are presented of the cross-correlation between the signals on two contiguous over the horizon links on 186.25 MHz. Cross correlations of daily and hourly means are given and the interesting forms shown by the hourly-lag correlograms are discussed with reference to meteorology.

1 GENERAL PICTURE

THE BASIC physical model on which prediction of tropospheric scatter signals is based depends upon a division of the signal variations into two classes. The fast fading, having periods measured in seconds, is considered to be due to interference between the vectors which are random in phase, contributed by individual scattering or reflecting sources. This fading has a Rayleigh-type amplitude distribution, is uncorrelated over quite small intervals of space, time or frequency, and can be dealt with by diversity techniques.

The slower signal variations, due to changes in the intensity of the scattering mechanism or in its polar diagram, or to changes in scattering angle caused by ray bending effects, are considered to be related to weather and climate. These variations are usually shown in plots and distributions of hourly, daily or monthly mean signal and some success has been achieved in correlating these signals,[1,2] more especially the monthly means, with surface refractive index, so that the prediction methods currently used often employ this conveniently available parameter in order to estimate signal variation.[3,4]

Little is known about the correlation functions of these slower-signal variations, and the results of some cross-correlation measurements made on two 'over the horizon' paths in tandem are now presented. This is important for the design of multi-hop systems, since the necessity to assume a high correlation, with its implication that the worst

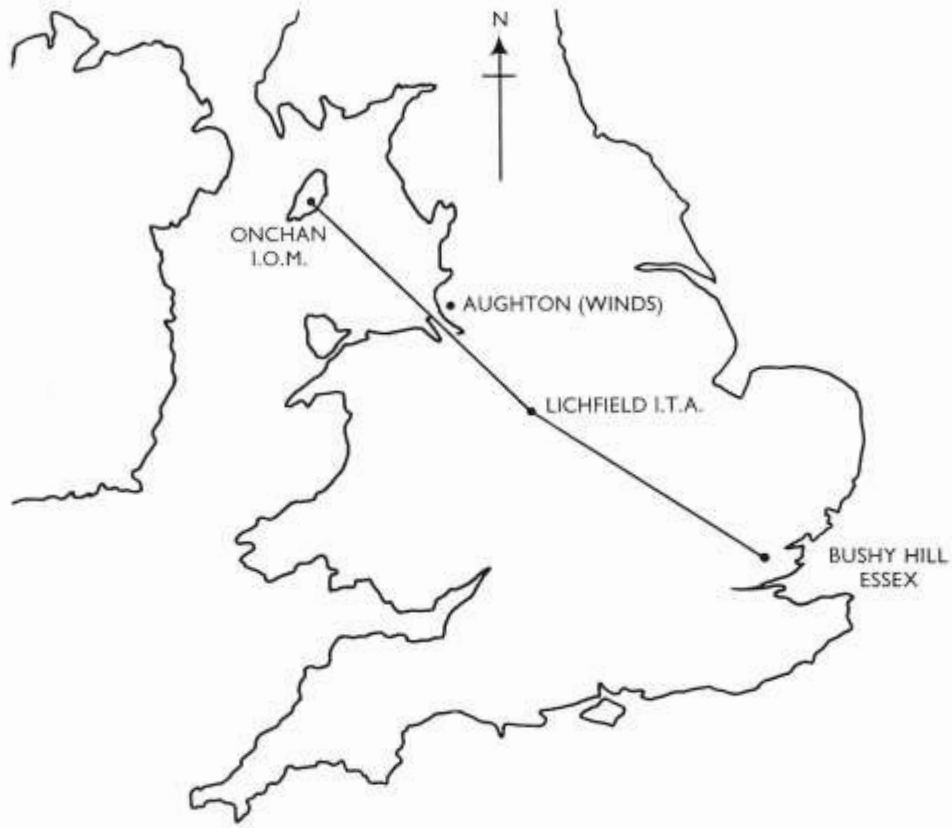


Fig.1. Map of propagation paths

days or hours may be coincident on the various component links in the system, has to be paid for with reserve system gain.

2 PROPAGATION PATHS

Figure 1 shows the paths which were used. The ITA Lichfield transmitter was used for both paths radiating on 186.25 MHz; and standard survey type receivers and recorders[5] were installed at Onchan, Isle of Man and at Bushy Hill in Essex. The two paths are almost co-linear in a NW-SE direction, as is Aughton, the upper air sounding station, from which meteorological observations have been used.

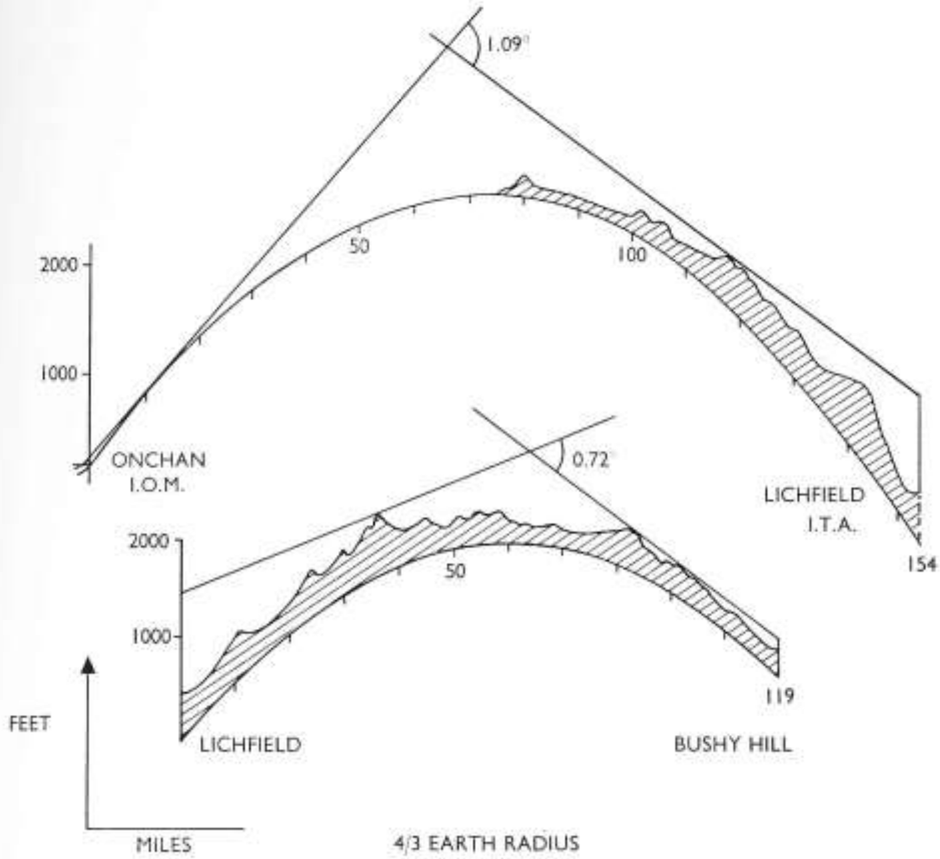


Fig.2. Propagation path profiles

Figure 2 shows the path profiles, drawn with 4/3 earth radius to allow for standard refraction. The longer path of 154 miles, half over the Irish Sea, has a scatter angle of 1.09°, and the shorter path of 119 miles a scatter angle of 0.72°. In each case the signal was well in the scatter region. The transmitter radiated for 14 hours each day from about 10 a.m. until midnight, and 61 days of satisfactory simultaneous recording were available for analysis through March, April and May of 1964. At least a year of recording would clearly be desirable, but it will be shown that the available sample of days is by no means atypical of a full year.

3 WEATHER TYPES

The classification of weather types suggested by Gold[6] has been used, taken in a simplified form from Bilham's book 'The Climate of the British Isles'.[7] Seven basic weather types are shown in Table 1.

TABLE I
WEATHER TYPES

		A	B	C	D	E	F	G
MEASURED DAYS								
MARCH-MAY	%	26	15	0	13	19	11	16
EXPECTED — BILHAM								
MARCH-MAY	%	24	12	7	11	11	16	19
YEAR	%	31	14	7	7	11	14	16

A Warm westerly (SW)
B Cold westerly (NW)
C Northerly
D North easterly
E South easterly
F Anticyclonic
G Cyclonic

Type A has low pressure to N or NW and high pressure to the S or SE resulting in a general airflow from the Atlantic with a southerly component. (Although the definitions are in terms of the pressure pattern distribution, the table is marked for ease of reference in terms of the dominant wind directions.) Type B has low pressure to the NE and high to the S or SW giving an airflow generally N of W. Type C has low to the east and high to the west giving north winds. Type D has low to the SE and high to the NW giving E to NE winds. This is a complete reversal of the more normal distribution of type A. Type E has low to the west and high to the E or NE giving S or SE winds. Type F shows an anticyclone or belt of high pressure covering the British Isles, and type G a depression centred over the country, or so situated that the associated rain-belts covered the propagation path during the day. The daily classification during observation was made from the 1800 hours chart in the weather report, with the first line of Table 1 showing the constituents of the weather in the recording period. Bilham also conveniently shows an average breakdown of the weather for the same months, and for the average year, so it may be seen that the period of recording is fairly typical of a year. It would of course be simple to relate the recorded data to a 'typical year' but the poor meteorological correlation reported below and the fact that the hours from midnight to midmorning are missing for each day, indicate that this is not justified.

4 THE ANALYSIS

At each receiving terminal the signal was recorded on chart paper, regularly calibrated with a reliable signal generator, and the hourly mean signal levels extracted by eye and punched on to cards for computer analysis. In addition to a straightforward cross-correlation of the Onchan and Bushy Hill hourly and daily mean signals, lag correlations have been computed for one and two hours time displacement in each direction. Due to the 10-hour gap each day it would be meaningless to have done this with the complete set of data throughout the recording period, it has therefore been done on a daily basis, producing a five point lag correlogram for each day.

5 PRESENTATION OF RESULTS—CORRELOGRAM SIGNATURES

Figure 3 summarizes the lag correlation results. After the 14-hourly signal levels at one station have been displaced in time by two hours relative to the other, only 12 pairs of values remain and the actual values of the correlation coefficient mean little. It is of interest however, to observe the values of time displacement which give the best correlation, and a correlogram was drawn for each day plotting the correlation coefficient against the time lag or lead. By taking account of magnitude only to observe if a point is higher or lower than its neighbour, it may be seen that eight shapes of correlogram, or signatures, are possible.

Thus, for example, the top signature shows the cross-correlation coefficient increasing smoothly as the Onchan signal is delayed from two hours lead to two hours lag relative to the Bushy Hill signal.

BUSHY LATE	ONCHAN LATE	NO OF DAYS OBSERVED	RANDOM
		13	3.8
		13	11.4
		5	11.4
		0	3.8
		2	3.8
		3	11.4
		7	11.4
		13	3.8

Fig.3. Correlogram signatures

This effect, of the greatest value in correlation when Onchan is delayed, might be produced by a change in the properties of the air mass moving with a component in the direction from Bushy Hill to Onchan, that is toward the north west. The second signature may have a peak in one of three positions.

The right hand columns in Fig.3 show the incidence of each class compared with what might be expected by chance. Only for the first two and the last may any claim to statistical significance be made, and the remainder are not considered further.

6 WEATHER CORRELATION FOR SIGNATURES

It is of interest to see if the weather classification, which has already been used to show the observing sample to be reasonably typical, substantiates the simple explanation hazarded above for the signature form.

In Table II the signatures are sub-divided according to the value of lag or lead showing the greatest correlation coefficient, and according to the weather type appropriate to the day.

TABLE II

CORRELATION BETWEEN CORRELOGRAM SIGNATURES AND WEATHER

WEATHER TYPE	A SW	B NW	C N	D NE	E SE	F HIGH	G LOW
LAG FOR							
ρ MAX							
BUSHY HILL LATE							
2 HRS	4	1	—	4	1	2	4
1	3	—	—	—	3	1	1
ZERO LAG 0	1	1	—	1	2	—	—
1	1	3	—	1	2	—	—
2 HRS	7	2	—	1	3	3	1
ONCHAN LATE							

Weather type B, predominantly north westerly winds might be expected to give a peak in the correlogram when the Bushy Hill signal is lagging. Bushy Hill being to the SE, and conversely Group E should fall chiefly in the Onchan lagging squares. There is no trace of either effect in the table though the data is certainly sparse for such detailed analysis.

A comparison of the first and last signatures in Fig.3, i.e those smoothly rising to one end or the other, with the wind direction at Aughton at a height of 900 and 1 500 metres, showed an equal absence of correlation.

The histograms in Fig.4 present the magnitudes of some of the correlation coefficients forming the correlograms discussed above. The histogram (a) shows the number of days on which the indicated cross correlation coefficients (zero lag) were obtained and histogram (b)

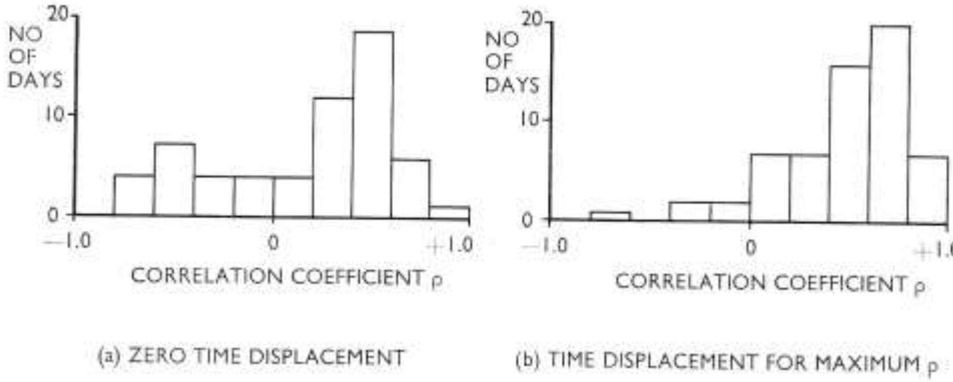


Fig.4. Histogram of day by day hourly correlations

shows the distribution of the maximum value of ρ obtained each day, for whatever time lag it occurred. It is noticeable that markedly higher correlations are obtained when the appropriate time lag is used, though the simple weather approach outlined has not been able to account for this.

Fortunately though this is not the significant case for link planning and Fig.5 shows the straight correlation of daily mean values throughout the test period, with no time displacement. The positive correlation, the value computed is $+0.30$, appears to be caused by longer period trends followed by both signals; the daily variation about these trends is almost random.

Finally, much the same can be said about the cross correlation of the hourly mean values throughout the test period, the value $+0.33$ is substantially the same as for the daily means, and this figure, quite low when we remember that a value of 1.0 is often used in planning, is the most valuable outcome of the tests.

7 CORRELATION WITH SURFACE REFRACTIVE INDEX

In connection with the longer period trends, an attempt was made to correlate the monthly-median signals with the monthly-median surface refractive-index of the atmosphere at Cardington for the Bushy Hill recordings, since Cardington is approximately midway between Lichfield and Bushy Hill. No sign of correlation was seen in the points for seven months of data tested. This is in marked distinction to the good correlation obtained on the Bromley-Catterick circuit; a path tested earlier on 900 MHz with low aerials of much higher gain.[2]

8 CONCLUSIONS

Two points of considerable significance for the planning of links emerge from the work described. Firstly, there is the absence of a correlation between monthly-median signal and surface refractive index. This is important and rather disturbing, but is not new for test circuits of this nature.

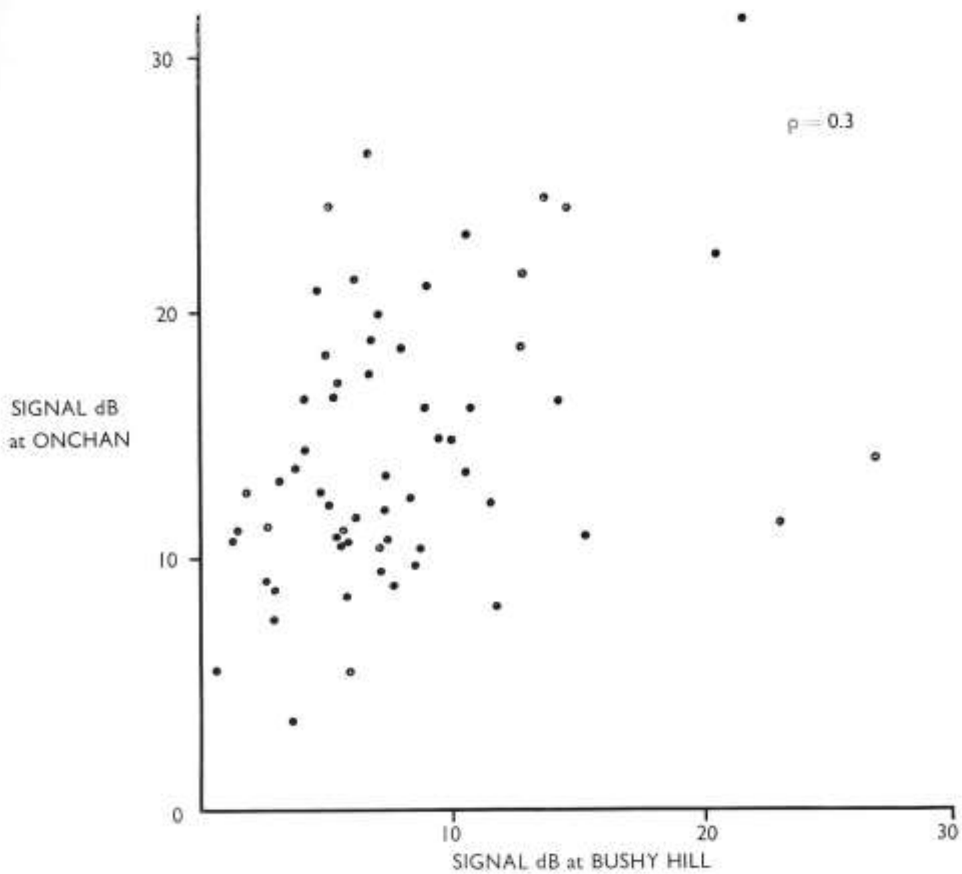


Fig.5. Scatter plot of daily mean signal strengths

Secondly, there is the low correlation between hourly mean signals on the links in tandem. This of course may not be typical of systems in other geographical and climatic regions, since it is well known that British weather changes quickly in both space and time. However, Gough has shown[8] that the limiting condition for a scatter system endeavouring to meet C.C.I.R specifications is likely to be critically dependent on an assumption about this cross correlation. The effect of the correlation found in these tests, in so far as it may be taken as typical, is to significantly relax this criterion.

Acknowledgements

Thanks are due to the Independent Television Authority for providing the transmissions and particularly for permission to use data recorded for their purposes on the Lichfield-Onchan path.

Thanks also to the Director of Research, The Marconi Company, for permission to publish.

References

1 B. R. Bean and B. A. Cahoon: 'Correlation of Monthly Median Transmission Loss and Refractive Index Profile Characteristics', *Journal of Research N.B.S.* Vol. 65D, No. 1, p. 6·, Jan.-Feb. 1961.

2 G. C. Rider: 'Median Signal Level Prediction for Tropospheric Scatter', *Marconi Review*, Vol. 25, No. 146, p. 203, 3rd Quarter 1962.

3 'Transmission Loss Predictions for Tropospheric Communications Circuits', N.B.S. Technical Note No. 101.

4 L. P. Yeh: 'Simple Methods of Designing Tropospheric Circuits', Trans. I.R.E, CS-8, No. 3, p. 193, Sept. 1960.

5 G. A. Isted: 'Field-Strength Surveys of V.H.F. and U.H.F. Broadcast and Television Service Areas', *Marconi Review*, Vol. 26, No. 149, p. 93, Second Quarter 1963.

6 E. Gold: 'Aids to Forecasting', *Geographical Memoir*, No. 16 (H.M.S.O).

7 E. G. Bilham: 'The Climate of the British Isles' (Macmillan, 1938).

8 M. W. Gough: 'The Assessment of Troposcatter Radio Relay Systems in Terms of C.C.I.R (Geneva, 1963) Recommendations', *Marconi Review*, Vol. 29, No. 160, p. 31, First Quarter 1966.

G. C. RIDER was born in Bournemouth in 1919 and educated at the Bournemouth School and King's College, London, where he took a general honours degree in mathematics and physics.

Commissioned in the Royal Artillery, he served throughout the war in heavy anti-aircraft and in the Indian Army, joining The Marconi Company in 1951 after a short period teaching physics.

Since then he has been with the Radio Wave Propagation Group where he leads the Tropospheric Propagation Section and has carried out extensive tests on microwave propagation and on u.h.f tropospheric scatter. Additional current interests are radio meteorology and radar ornithology.

D. S. PALMER was born in Dumfries in 1915 and educated at the Edinburgh Academy and Cambridge (M.A Maths, (1937) and History, (1938)). He has been with the R.N Scientific Service (statistical work), and the Scottish Provident Institution (Fellow of the Faculty of Acuaries, 1949). Since 1951 he has been at the Marconi Company's Research Laboratories and is at present a specialist concerned particularly with stochastic processes, reliability and theoretical statistics.

Designed by London Typographical Designers Limited. This journal is set in 8 pt. and 12 pt. Linotype Pilgrim and is printed in Great Britain by The Shenval Press, London, Hertford and Harlow

Page Index - Volume Eleven

Marconi H4000

transistorized 100W h.f s.s.b transmitter/receiver

suitable for speech, c.w and telegraph signals.

- ✳ transistorized, apart from high level transmitting stages
- ✳ 6 radio channels 1.6 to 15 MHz, upper or lower sideband as nominated
- ✳ 100W p.e.p transmitter power: 500W amplifier available
- ✳ s.s.b or compatible a.m
- ✳ mobile or static operation
- ✳ suitable for operation in all parts of the world
- ✳ low power consumption
- ✳ versions for mains or battery operation
- ✳ compact width $10\frac{3}{4}$ in. *273 mm*
  height 7 in. *178 mm*
  depth $13\frac{3}{4}$ in. *350 mm*
  weight (a.c version) 25 lb. *11.4kg;* (d.c version) 22 lb. *10kg*

Marconi telecommunications systems

The Marconi Company Limited, Radio Communications Division, Chelmsford, Essex, England. LTD/H601