The Post Office Satellite Communication System Ground Station at Goonhilly, Cornwall*

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The initial purpose of the Post Office satellite system earth station at Goonhilly Downs, Cornwall, is to obtain information on the performance of experimental communication satellite systems; such information will be of great importance to the designers of systems for commercial operation. To facilitate this dissemination the UK and USA Governments prepared and signed, in February 1961, a Memorandum of Understanding regarding collaboration between the British Post Office and the United States National Aeronautics and Space Administration (NASA) on the testing of experimental communication satellites to be launched by NASA. The first phase of the tests covered Projects Telstar and Relay, both active satellites.

The agreement with the United States covers full interchange of technical information, makes clear that the collaboration is for experimental tests only and is not concerned with commercial exploitation, and does not preclude the use of the Post Office experimental earth station for tests outside the cooperative projects outlined. Similar agreements between the United States and France, Federal Republic of Germany, Italy, and Brazil have since been approved.

The Goonhilly satellite system earth station has been planned and equipped, not only for participation in Projects Telstar and Relay and similar experimental projects, but also with a view to possible operational use at a later date.

The site of the Goonhilly radio station (Fig. 1) has been chosen to be particularly suitable for transatlantic communication in view of its westerly location; also, its southerly latitude is convenient for satellites in equatorial orbits. It is remote from the majority of microwave links in the United Kingdom, so that frequency-sharing with such links is

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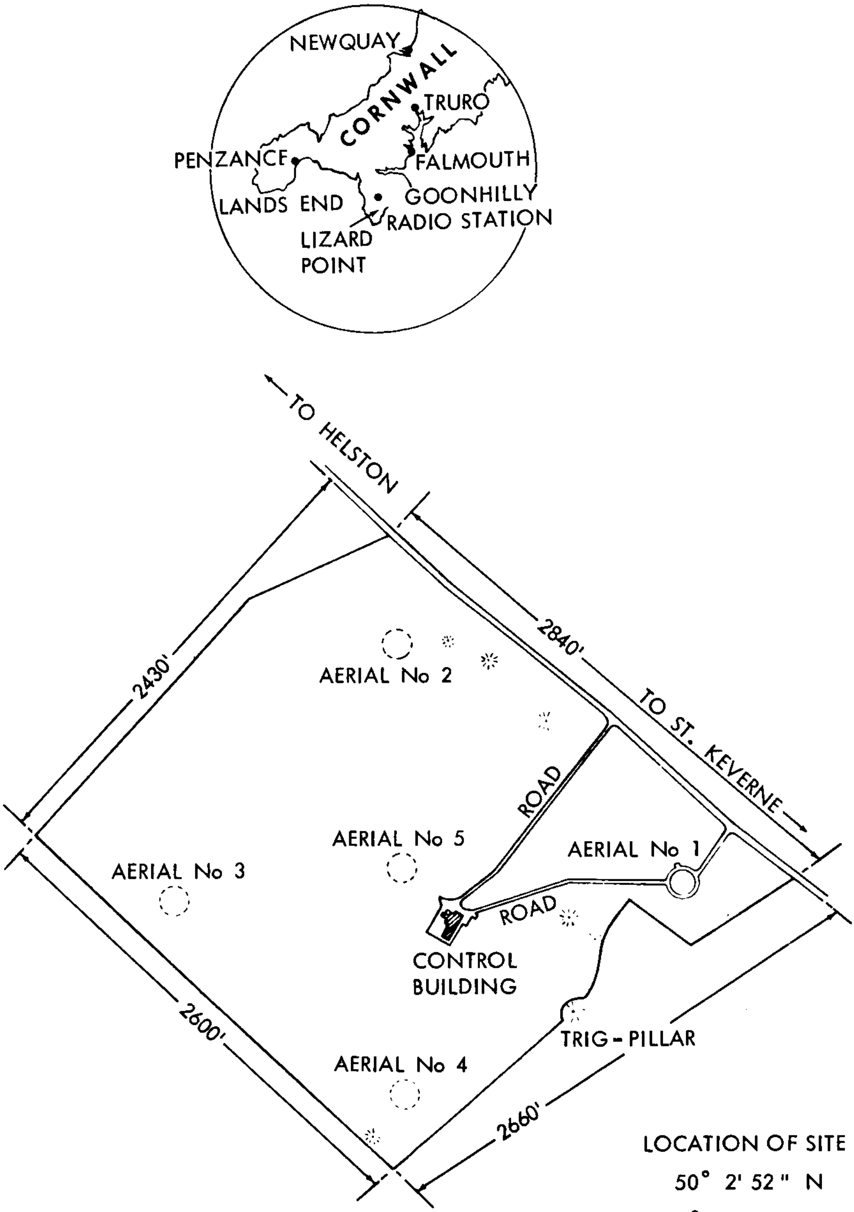


Fig. 1 — Simplified site plan, Goonhilly Radio Station.

facilitated. The horizon angles are predominantly negative with a maximum positive value of about 0.5°, so that satellite orbits involving low angles of elevation can be used. The main station building is located near the centre of the site; the aerial is close to one corner. However, the site is large enough to accommodate additional aerials for experimental purposes or for operational use in the future.

The present equipment for participation in Projects Relay and Telstar includes the following facilities:

An 85-ft diameter paraboloidal-reflector dish aerial with full steerability over the hemisphere above the horizontal plane;

Means for steering the aerial automatically from predicted orbital data;

A 10 kW transmitter operating at 1,725 Mc/s for Project Relay;

A 5 kW transmitter operating at 6,390 Mc/s for Project Telstar;

Low-noise receiving equipment for the 4,170 Mc/s communication and 4,080 Mc/s beacon signals transmitted by the Telstar and Relay satellites;

Terminal equipment for transmission and reception of multi-channel telephone, telegraph and television signals;

Video and multi-channel telephone and telegraph links to the trunk network; and

Support communications, including teleprinter and voice circuits to the USA, for the transmission of data and other information concerning the tests.

THE STEERABLE AERIAL

The steerable dish aerial (Fig. 2) is designed for operation up to at least 8,000 Mc/s, at which frequency the beamwidth is only about 0.1°. Since the satellites move rapidly across the sky, the aerial is required to track a rapidly moving satellite to within a few minutes of arc. The aerial as a whole rotates on a turntable to provide changes in azimuth, and the dish is rotated about a horizontal axis for elevation changes. In addition, small variations (up to a degree of beam direction are possible by remotely-controlled movements of the feed at the focus of the dish. The feed for the dish is in the plane of the aperture, an arrangement which, with appropriate feed design, reduces the levels of the minor lobes of the radiation diagram. This is of great importance since, unless the minor lobes are very small, noise can be picked up from the terrain surrounding the aerial which would significantly

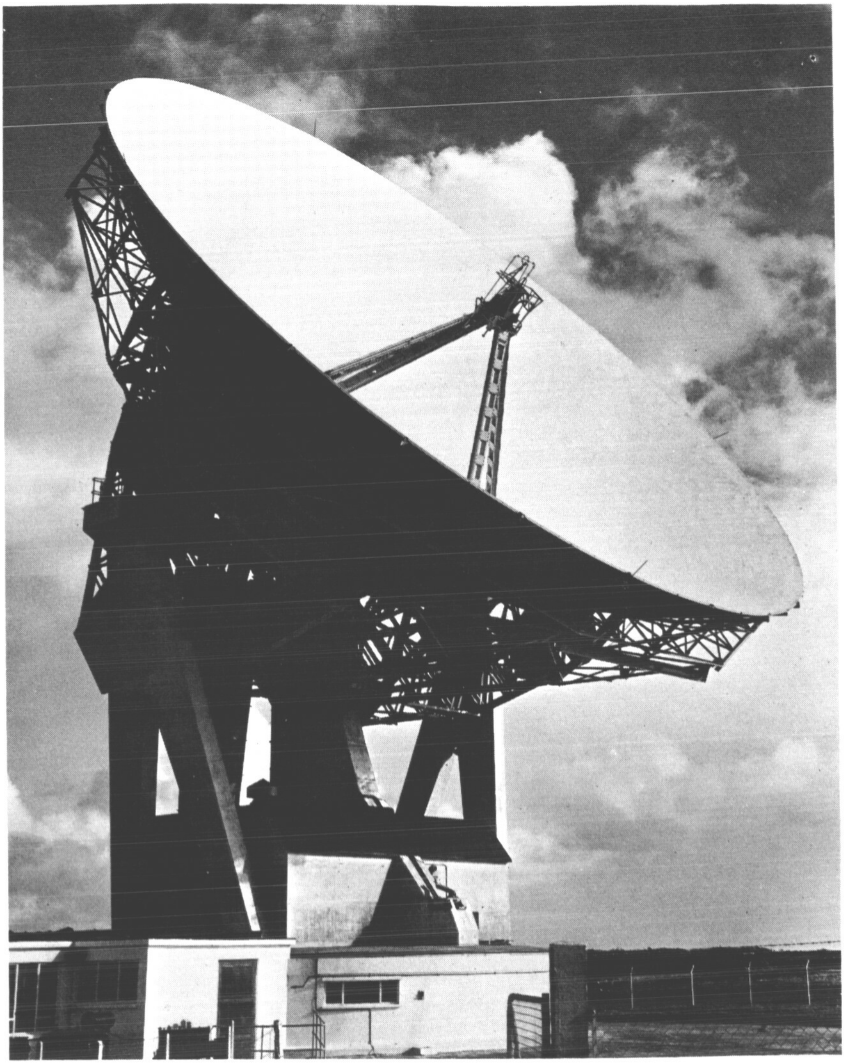


Fig. 2 — The steerable antenna.

degrade the signal-to-noise ratio of the very weak signals received from a satellite.

Since the aerial is not protected by a radome, stability under high wind conditions is achieved by a heavy, sturdy construction using reinforced concrete supporting members, and powerful driving motors. The weight of the movable part of the aerial structure is some 870 tons, and the structure is designed to operate in wind velocities up to 65 mph.

The aerial is automatically steered, using predicted orbital information derived from the NASA worldwide network of Minitrack stations, one of which is operated by the Department of Scientific and Industrial Research at Winkfield, near Slough. This data is received in digital form over a teleprinter circuit from NASA Space Flight Center, USA; it has to be processed in an electronic computer at Goonhilly to give the aerial steering instructions in an appropriate form. To correct for small errors in prediction and errors arising from other causes, the aforementioned manually or automatically controlled aerial beam swinging facility is used. In this operation, the 4,080 Mc/s beacon signal transmitted by the satellite causes the aerial beam to "scan" circularly over a few minutes of arc. Information is thereby derived which enables the appropriate corrections to be applied, initially on a manual basis and later automatically on a "lock-on" basis. A spiral scan of up to 1° is available, if required, to aid in satellite beacon acquisition, but in practice has not been found necessary.

Immediately behind the reflector dish there are two apparatus cabins; one of these accommodates the travelling wave maser amplifier operating at 4,170 Mc/s. The necessary low temperatures for this device are obtained by using liquid helium and liquid nitrogen; evaporated helium is recovered, stored, and compressed by equipment housed in a cabin on the horizontal turntable.

A cabinet behind the reflector also accommodates filters for separating the satellite beacon signal from the satellite communication signal, so that the latter may be amplified separately in the maser. Means for determining the system noise temperature are also provided. Waveguide assemblies with rotary and flexible joints connect the feed at the focus of the reflector with equipment in the cabins at the back of the reflector and on the aerial turntable.

On the horizontal turntable is an apparatus room accommodating the high power stages of the Telstar and Relay transmitters, the low power drive equipment for the transmitters and equipment for translating signals to and from radio frequency and an intermediate frequency of 70 Mc/s.

A cylindrical enclosure in the middle of the apparatus room accommodates the loops of flexible cable used to make connection between the equipment in the moving apparatus room and fixed equipment in the main control building and elsewhere. Rotation of the turntable around the vertical axis is restricted to ±250°, so that cable loops rather than slip rings can be used. Beneath the horizontal turntable and beyond it there is a chamber and tunnel for the interconnecting cables.

MAIN CONTROL BUILDING

In the main buildings (Figs. 3 and 4) from which all experiments are controlled, the principal rooms contain the following:

Control and experimental apparatus;
Telegraph equipment;
Computer and data processing equipment;
Aerial steering equipment and precise time and frequency standards;
Aerial steering console; and
Auxiliary test apparatus, including telecine and television equipment.

Control and Experimental Apparatus Room

A console is provided for the experiment control (Fig. 5) enabling the availability of the transmitting, receiving, and test equipment and the aerial to be determined at all times, together with voice communication facilities to the operating staff concerned. A similar console is

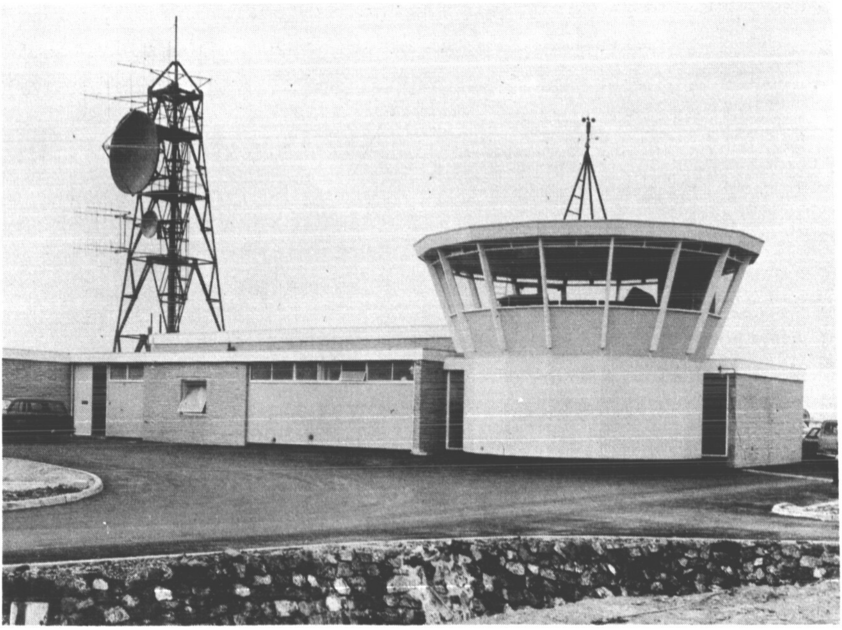
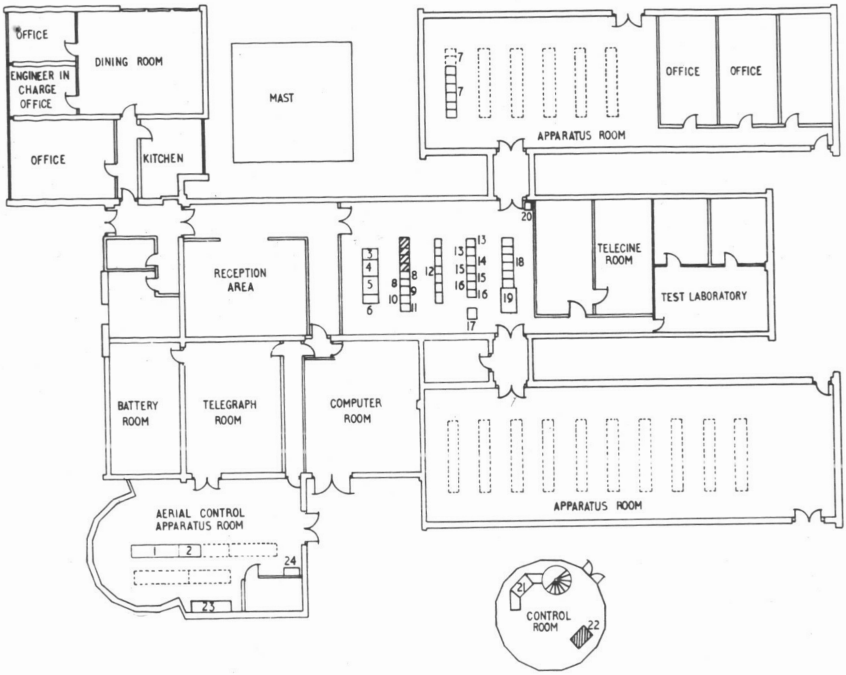


Fig. 3 — External view of the control building.



ITEM	DESCRIPTION
1	AERIAL No.1 CONTROL EQUIPMENT
2	AERIAL No.2 CONTROL EQUIPMENT
3	CONTROLLER'S CONSOLE
4	CIRCUIT SWITCHING CONSOLE
5	BEAM SWINGING EQUIPMENT
6	TX AND RX SUPERVISORY CONSOLE
7	INLAND MICROWAVE LINK EQUIPMENT
8	TIME EQUIPMENT
9	EQUIPMENT RACK FOR CIRCUIT SWITCHING CONSOLE
10	MISC. APPARATUS RACK
11	D.P.U. RECEIVERS
12	BASEBAND AND I.F. EQUIPMENT
13	RECORDERS
14	WHITE NOISE TEST EQUIPMENT
15	MISC. TEST EQUIPMENT
16	T.V. TEST EQUIPMENT
17	CABLE TERMINATING RACK
18	CARRIER AND TRANSMISSION EQUIPMENT
19	DISTRIBUTION FRAME
20	VOLTAGE REGULATOR FOR ITEM 18
21	CONTROL CONSOLE AERIAL No.1
22	CONTROL CONSOLE AERIAL No.2 (PROPOSED)
23	CABLE TERMINATIONS AERIAL No.2
24	MISC. APPARATUS RACK

Fig. 4 — Simplified floor plan of the control building.

provided for aerial steering purposes, the latter including visual presentation on cathode ray tubes of the incoming wave direction from the satellite. The equipment in this room includes:

Baseband and intermediate frequency equipment forming part of the transmitting and receiving communication system;

Fig. 5 — The control console suite.

Receivers for the "off-the-air" reception of television broadcast signals;
Test equipment;
Magnetic tape and other recorders;
Satellite beacon signal receivers; and
Video and multi-channel telephony terminals.

Telegraph Room

Separate teleprinters are provided for:
Operational traffic with, and reception of orbital prediction data from, the Goddard Space Flight Center, Greenbelt, Maryland;
Communication with the satellite ground station at Andover, Maine, on a private wire basis;
Telex facilities;
The receipt of local meteorological information (to enable aerial safety precautions to be taken if necessary).

Computer Room

The principal item in this air conditioned room (Fig. 6) is a National-Elliott Type 803 electronic computer. As noted earlier, orbital data is received in digital form from the USA; this data provides predicted

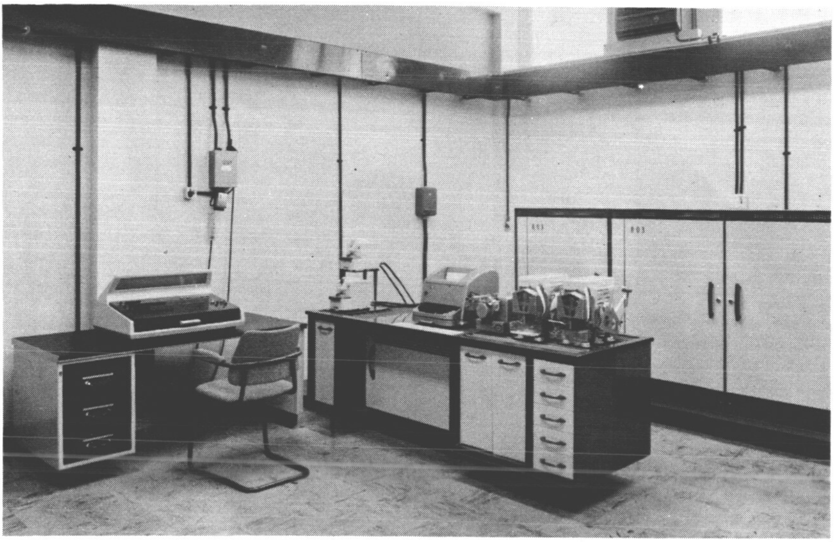


Fig. 6 — The computer room.

X, Y, Z versus time coordinates at one-minute intervals and is recorded on punched tape. The computer processes the data to provide aerial steering instructions also in punched-tape form, the output information for each one-second interval including time, azimuth bearing, rate of change of azimuth, elevation, rate of change of elevation and the slant range to the satellite. The computer programme also makes allowance for changes of apparent satellite bearing due to atmospheric refraction. Telegraph-type tape readers and data recording equipment are provided for processing the received orbital data and for the preparation of the aerial steering tapes.

The manner in which instructions from the computer are passed into the aerial steering equipment is a punched paper tape (Fig. 7). This tape is "read" by the equipment one second in advance, one second at a time, the tape reading equipment positioning the tape for each reading operation from the single "cycle start" hole marking the commencement of each sequence. The time to which the start of each sequence refers is punched into the tape as hours, minutes and seconds in a code which can be read by inspection. This is followed by instructions, in binary code, defining the azimuth and elevation instructions required at that time.

With the exception of a short portion of tape giving a tape identification number, also in a simple code which can be read by inspection,

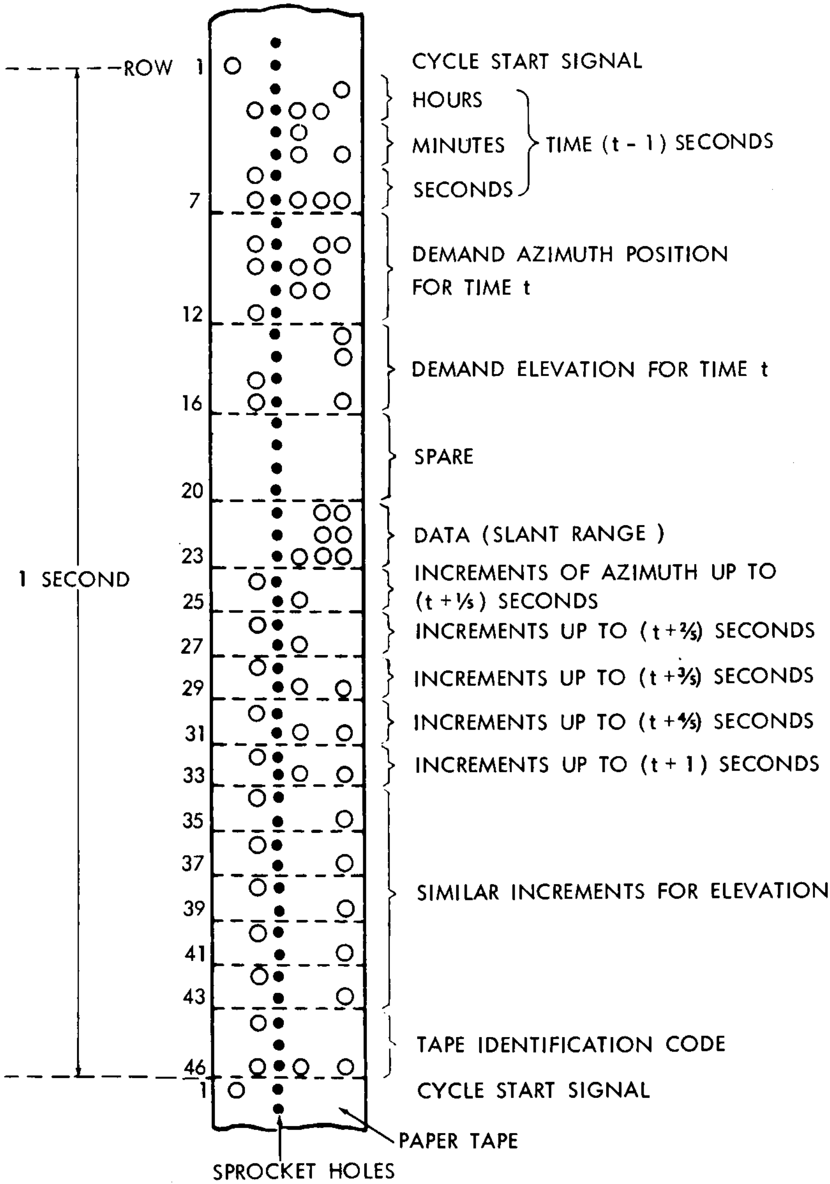


Fig. 7 — A section of control tape.

the remainder of the one second sequence contains a series of increments to the initial demanded aerial directions which enables the equipment to keep the driving motors running at the correct rates for the next demanded position to be reached with minimum error.

Aerial Steering Apparatus Room

The apparatus in this room enables a comparison to be made between the aerial steering input data in digital form and digital signals derived from read-out units on the aerial azimuth and elevation drives, thus enabling the servo feedback loops to be completed.

A temperature controlled annex to this room accommodates quartz-crystal timing oscillators of high accuracy which, in conjunction with time signal radio-receivers, provide a precise time source adjustable to Universal Time 2.

Steering tapes are received from the computer room for application to the input of the aerial steering apparatus, initiation of aerial movement being dependent upon synchronism between time as recorded on the tape and as generated by the precise time source.

Aerial Steering Console Room (Control Tower)

The aerial steering console room in the Control Tower (Fig. 8) has been designed and placed to give uninterrupted visibility over the

Fig. 8 — The aerial steering position in the control tower.

whole site. Though every precaution has been taken to ensure safety of personnel, by the provision of mechanical and electrical interlocks, it has been considered desirable that those controlling the movement of the aerial should have full visual surveillance. The aerial is floodlit at night.

Though aerial steering is fully automatic, it has been arranged that the mechanical and electrical conditions of the aerial are displayed to an operator who can observe fault conditions, apply corrections and override the automatic system should any abnormality occur.

POWER SUPPLIES

The power supply for Goonhilly radio station is obtained at 11 kV from an electricity substation four miles distant, together with an alternative supply from Helston, eight miles distant. Both supplies are via overhead lines, except for a distance of some 400 yards on site, which is via underground cable. Changeover facilities are provided to enable the second supply to be used in the event of failure of the first. The present supply capacity is 450 kVA; this will ultimately be increased to 800 kVA.

The supply terminates at three transformers. At the aerial site a 250 kVA transformer supplies power for driving motors and a 100 kVA transformer supplies power for electronic equipment, etc. The third transformer, at the control building, is of 100 kVA to provide power for the whole building.

Because of the very small risk of failure of both electricity supplies simultaneously, and because of the large amount of power required, no local standby power is provided except that derived from a 50 V battery to operate emergency lighting, clocks and telephones.

SYSTEM CHECKING FACILITIES

It is necessary to be able to check periodically the mechanical alignment of the aerial, the electrical bearing of the aerial beam, and the performance of the transmitting and receiving equipment—independently of a satellite. For these purposes the aerial is fitted with a boresight telescope for ranging on local and distant points of accurately known bearing. In addition, there has been installed at Leswidden, some 21 miles away, apparatus capable of simulating the Telstar and Relay satellites, thus enabling comprehensive overall system tests including tests of the aerial gain and radiation diagram to be made. Measurements of the aerial tracking charateristics are made using the radio star Cassiopeia A.

TRANSMISSION EQUIPMENT

The radio transmission equipment at a satellite system earth station differs markedly from that used in conventional radio-relay systems, for the following reasons:

1. the need for high-power earth station transmitters—with outputs of kilowatts instead of a few watts,
2. the very small signal power, of the order of micro-microwatts, received from satellites, and the resulting low signal-to-noise ratio in the intermediate-frequency passband of the ground station receiver,
3. the use of circularly polarized waves, as compared with linear polarization in most radio-relay systems,
4. the presence of Doppler frequency shifts on the received signals due to the motion of the satellite relative to the earth stations.

The earth station transmission equipment, shown in block schematic form (Fig. 9), enables signals to be transmitted in a 5 Mc/s baseband. Such a baseband could accommodate several hundreds of telephony channels or a television signal of up to 625-line definition or high-speed data transmissions. Multi-channel telegraphy and facsimile signals could alternatively be transmitted in the telephony channels.

The baseband input signals are applied to a 70 Mc/s frequency modulator, the wide-deviation output of which is then passed to up-conversion equipment (for translation to the desired radio frequency), a low-power driver stage and a high-power transmitting amplifier. As the ground-station transmitter frequencies for Telstar and Relay are very different, being 6,390 and 1,725 Mc/s respectively, separate up-conversion, driver and high-power equipment are provided for the two projects. The Telstar high-power transmitter uses a 5 kW travelling-wave tube developed specially by the Services Electronics Research Laboratory, while that for Relay uses an Eimac 10 kW multi-cavity klystron amplifier.

Signals received from a satellite include a c.w. beacon emission on 4,080 Mc/s for tracking purposes, as well as a communications signal on or near 4,170 Mc/s. In view of the limited bandwidth of the maser used as a low-noise first-stage amplifier in the receiver, only the communications signal is amplified in the maser though both signals are amplified in a second-stage comprising a low-noise travelling wave

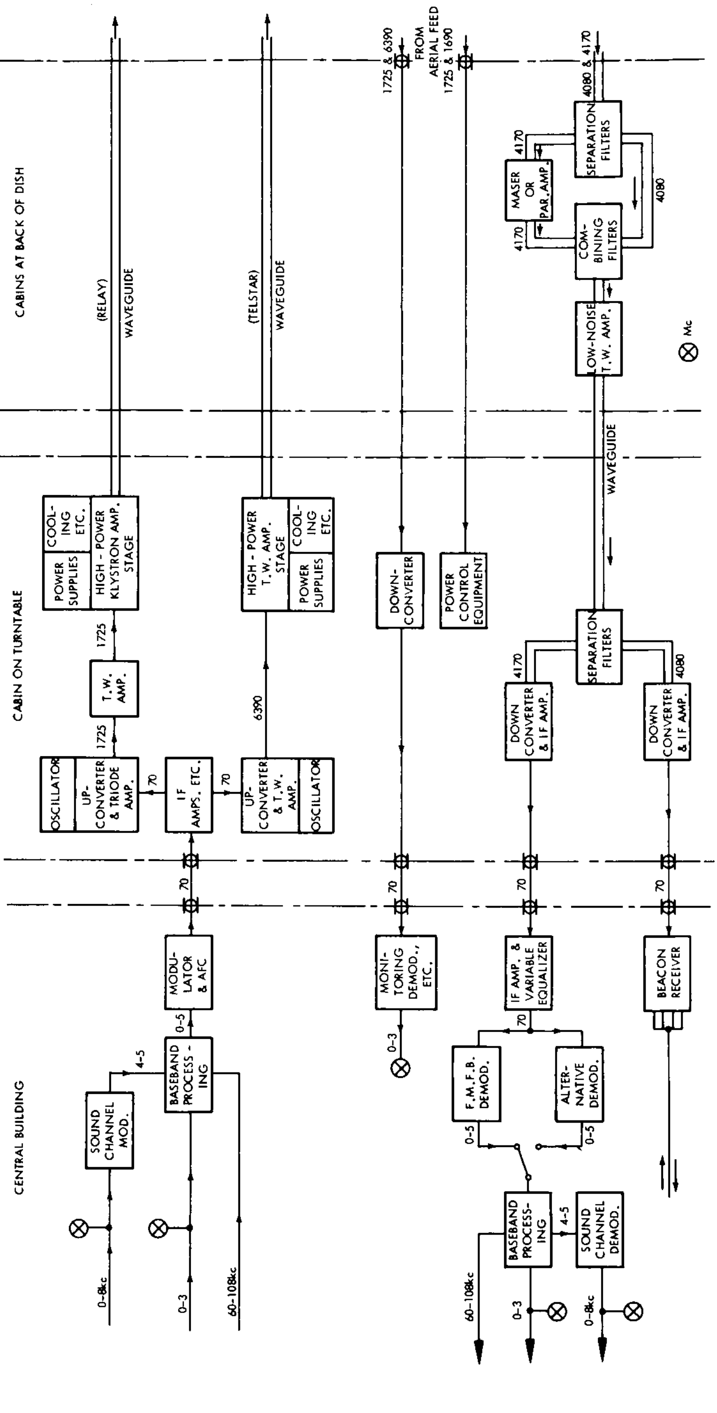


Fig. 9 — Simplified block schematic of the transmitters and receivers.

valve. The beacon signal is selected by a waveguide filter and, after frequency-changing, is applied to a narrow-band beacon receiver.

The communications signal is frequency-changed in a down-converter to an IF of 70 Mc/s and is then applied to one of three FM demodulators. One demodulator is of the conventional limited/discriminator type and is suitable for use only when the received signal-level is relatively high. The second demodulator is of the frequency modulation negative feedback type; it is particularly suitable for multichannel telephony. The third demodulator comprises a tuned circuit which instantaneously follows the frequency of maximum signal energy, the bandwidth being automatically adjusted according to the received signal level. The second and third demodulators reduce the effective noise bandwidth and thus enable relatively weak signals to be satisfactorily received.

TESTS AND TESTING EQUIPMENT

Although objective tests (i.e. measurements of the transmission characteristics between earth station "baseband input" and "baseband output" via the satellite) can provide information on which the suitability of the system for any form of signal transmission can be assessed, it is nevertheless of value also to make subjective assessments. To this end facilities have been provided so that either one-way television pictures or two-way telephony signals can be transmitted for demonstration purposes.

One-way transmission tests via a satellite are carried out either between pairs of similarly equipped earth stations or "in loop". In the latter arrangement, the signals transmitted from a given earth station are received back at the same station.

Under two-way transmission conditions both of a cooperating pair of earth stations energize the same satellite at slightly different frequencies. For two-way telephony transmission the Relay satellite includes two separate receivers operating on slightly different frequencies, but in the Telstar satellite there is only a single wideband receiver. When working on a two-way basis via the Telstar satellite the transmitter powers of the cooperating earth stations must be continuously adjusted so that the signal levels at the distances of the respective earth stations from the satellite.

Many items of test equipment have been provided for the objective tests. These permit the measurement of insertion-gain stability, selective fading, noise levels, television signal transmission characteristics,

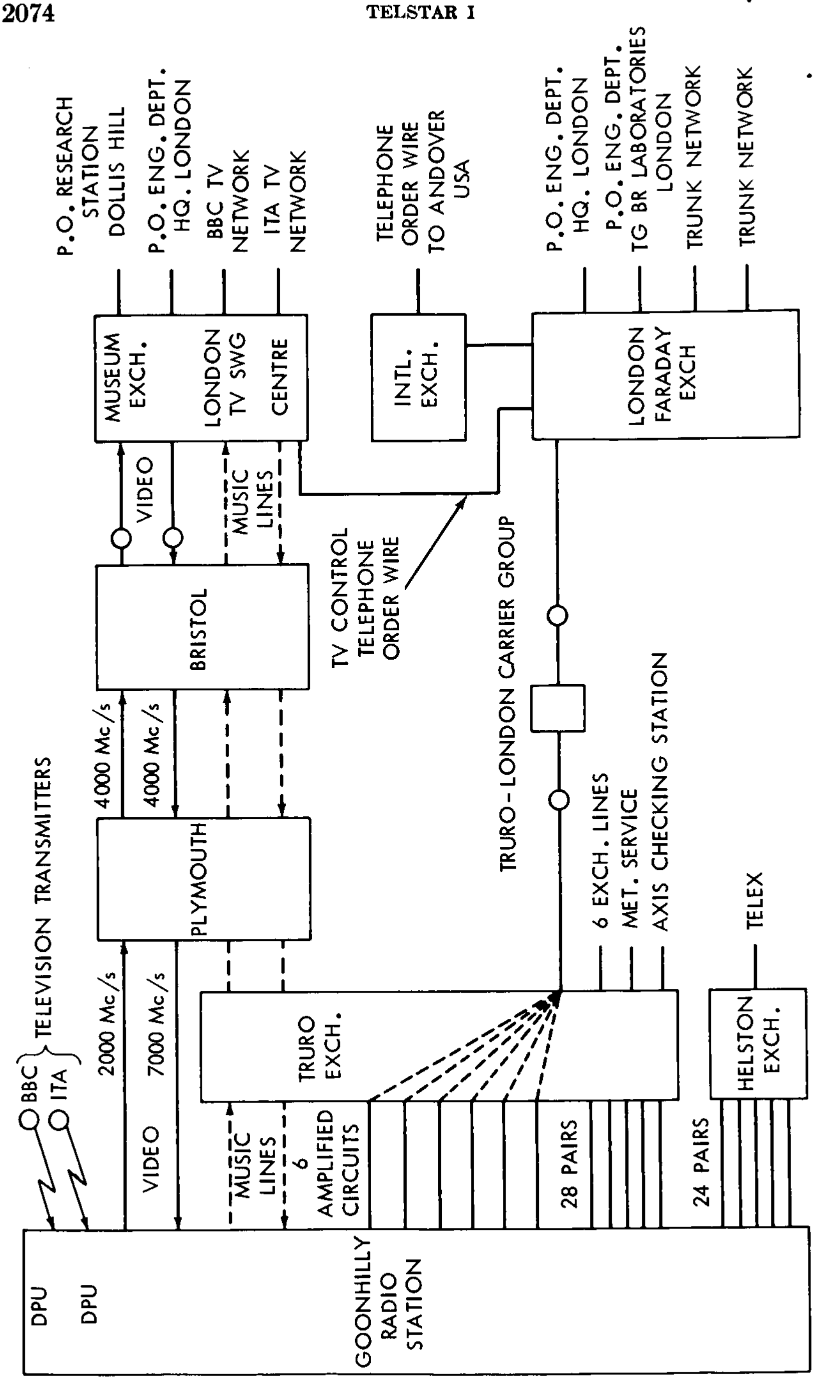


Fig. 10 — Block diagram of the video, telephone (including telephoto) support communications for tests and demonstrations.

telephone and telegraph signal transmission characteristics, received carrier power levels, Doppler frequency shifts and receiving system noise-temperatures, etc. For multi-channel telephony tests, white-noise signals simulating up to 600 telephone channels are available.

In the case of subjective telephony tests baseband equipment has been provided so that twelve two-way circuits assembled in the ranges 12-60 or 60-108 kc/s may be set up. For subjective tests of television transmission, telecine equipment and high-grade picture monitors, suitable for 405, 525, and 625-line standards have been provided.

For telephony demonstrations the audio circuits are connected to the Post Office trunk telephone network. The audio circuits are also available for carrying out telegraphy, facsimile and data transmission tests via the Post Office Telegraph Branch Laboratories in London. In the case of television demonstrations, the video circuit is connected to the Post Office television distribution network, use being made when necessary of line-standards conversion equipment provided by the broadcasting organizations. The comprehensive network of inland communications is provided for such demonstrations and tests (Fig. 10).

CONCLUSION

The station will undoubtedly play a useful part in the acquisition of the information and experience needed for the design and construction of successful operational satellite communication systems. It is of interest to note that the whole of the equipment and facilities provided, including the large steerable aerial, are of British design and manufacture, with the exception of the Eimac klystron used in the Project Relay transmitter.

ACKNOWLEDGMENTS

The thanks of the authors are due to their colleagues in the Post Office who contributed to the planning, design, and provision of the Goonhilly satellite communication radio station, and in particular to the staff of the SW Region of the Post Office for their help in the installation phase.

Tribute is also due to the British Telecommunications Industry for its part in providing much of the electronic equipment, to the Services Electronics Research Laboratory for the development of the 5 kW travelling wave tube, and to Husband & Co. and associated contractors for the design and construction of the large steerable aerial. Special

mention should be made of the contractors' staff who worked long hours on the aerial construction, often under extremely adverse weather conditions.

The permission of the Engineer-in-Chief of the Post Office to make use of information contained in this article is gratefully acknowledged.