Beam-Swinging Facilities for the Goonhilly Satellite-Communication Aerial*

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The mode of satellite tracking adopted at the Goonhilly earth station is to steer the aerial primarily by means of predicted data computed from the satellite orbital parameters and to superimpose, during the passage of the satellite, corrections to remove any prediction errors or aberrations due the transmission path. Predictions have proved to be highly accurate for satellites having a high mass to projected area ratio orbiting at altitudes at which air drag is very small; hence the corrections are small and infrequent.

SYSTEM DESIGN

Aberrations in the predicted steering data are likely to be greatest during the acquisition phase when the aerial elevation is near zero and when, in consequence, tropospheric ray bending is greatest. It was assessed initially that a beam swing of 1° in all directions from the boresight axis would adequately meet the most extreme condition, i.e. at the time of the earliest satellite passes and prior to refinement of the orbital parameters. Provision was therefore made in the original design for a swing of 1° but experience proved this to be in excess of requirement and it was subsequently reduced to ½°. The corresponding shift in the position of the feed unit in the focal plane of an 85-ft focal-plane paraboloid is 3 in.

A beam deviation of ½° is equivalent to 2½ beamwidths (3 db) at the frequency 4080 Mc/s, at which tracking of the Telstar and Relay satellites is performed. At this deviation a degradation in aerial gain of about 2 db is incurred and some beam distortion is present in the form of a coma lobe on the boresight-axis side of the beam. It was envisaged, therefore, that corrections to the predicted steering data

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would be needed, at least in the initial phase of a satellite pass, to ensure that large beam offsets were removed.

The feed-shift mechanism at the aerial focus, by which the beam is offset from the axis, is controlled through a hydroelectric servo system from a console in a control room about ¼ mile from the aerial. This form of control has the advantages, as compared with an all-electric system, of lower weight at the focus, a safer stalling condition, and the removal of most of the moving parts requiring maintenance to positions where they are more easily reached.

After approximate acquisition, the deviations of the satellite from the predicted course are followed by means of a conventional radar mode of tracking. No satisfactory adaptation of the static-split feed (monopulse) system is obvious when diplexed signals with circular polarization are utilized in a focal-plane dish. A conical-scan feed system is therefore used. The requirements, however, are notably different from those common to radar applications in which pulsed signals are generally received from a target whose course is likely to be erratic and evasive. In contrast, the course of a satellite is closely predictable and smooth and the target is a cw beacon on the satellite itself. A slow-speed scan in which the beam rotates about a point 1 db or less from the peak is therefore adequate. A slow speed is essential also to minimize the centrifugal forces encountered in spinning a heavy diplexed feed. The scanning speed is adjustable to avoid synchronism or harmonic relationship with the ripples in the aerial-radiation pattern of a spin-stabilized satellite.

The optimum offset of the rotating beam about the boresight axis depends on the sensitivity of the display equipment and on the allowable loss from the peak gain of the aerial. The latter is of particular importance when, as in Project Telstar, the ground transmit frequency in the diplexed signal is higher than the receive frequency. The trans-

TABLE I — EFFECT OF FEED OFFSET IN AN 85-FT FOCAL-PLANE PARABOLOID

Beam Offset (Degrees)	Feed Offset (in.)	Beacon Signal Loss (db)	Transmit Loss	
			Telstar (db)	Relay (db)
0.061	0.36	1.0	2.5	0.25
0.041	0.24	0.5	1.25	0.12
0.027	0.16	0.25	0.62	0.06

mit beam is then narrower and, for a given offset, introduces a greater loss into the transmit path than in the receive path. For the aperture illumination employed, Table I shows the approximate losses in the transmit and receive paths as the offset is varied. The transmitter frequency for Telstar is nearly 6390 Mc/s and that for Relay 1725 Mc/s. The beacon frequency is the same for both projects: 4080 Mc/s.

The system was provided initially with a conical-scan radius for a 1 db loss in the beacon signal. It was found, however, that the sensitivity of the equipment was sufficient to allow the radius to be reduced to the ¼ db point. The transmit loss and signal modulation at the conical-scan frequency were reduced by this means, especially with respect to the Telstar satellite.

DESCRIPTION OF EQUIPMENT

Beam-Swinging Mechanism

The general arrangement of the beam-swinging mechanism is shown in Fig. 1. The tube marked "Aerial Feed Unit" points towards the apex of the dish and in its central position its aperture is at the focus. The frame, shown as cut away, is mounted on a platform situated about 2-ft outside the focal plane. Two motions of the feed are provided; one is the major beam-swing motion in which the feed aperture can move to any position within a circle originally of 6 in. radius but later limited to 3 in.; the other is the conical-scan motion in which the feed moves circularly with a radius (in the final modification) of 0.16 in. about an axis fixed by the beam-swing motion. The radius of the conical-scan motion is modified simply by changing an eccentric in the motor drive.

The beam-swing motion pivots about gimbals at the rear and is effected by two hydraulic pistons mounted orthogonally in the plane of the main frame. The gimbals have an internal clearance sufficient to allow the waveguide components to be withdrawn through them, without dismantling the main structure. The rear section of the waveguide is flexible to allow movement of the feed relative to the external fixed feeder. The hydraulic pistons are controlled by servo-operated oil valves fed at 800 lb/in.^{2} by a pipe line from a hydraulic pump mounted on the roof of the cabin on the azimuth turntable of the aerial.

The gimbals for the conical-scan motion are placed midway on the feed support tube, the far end of which is given a circular motion by a motor mounted outside the beam-swing gimbals. The central dis-

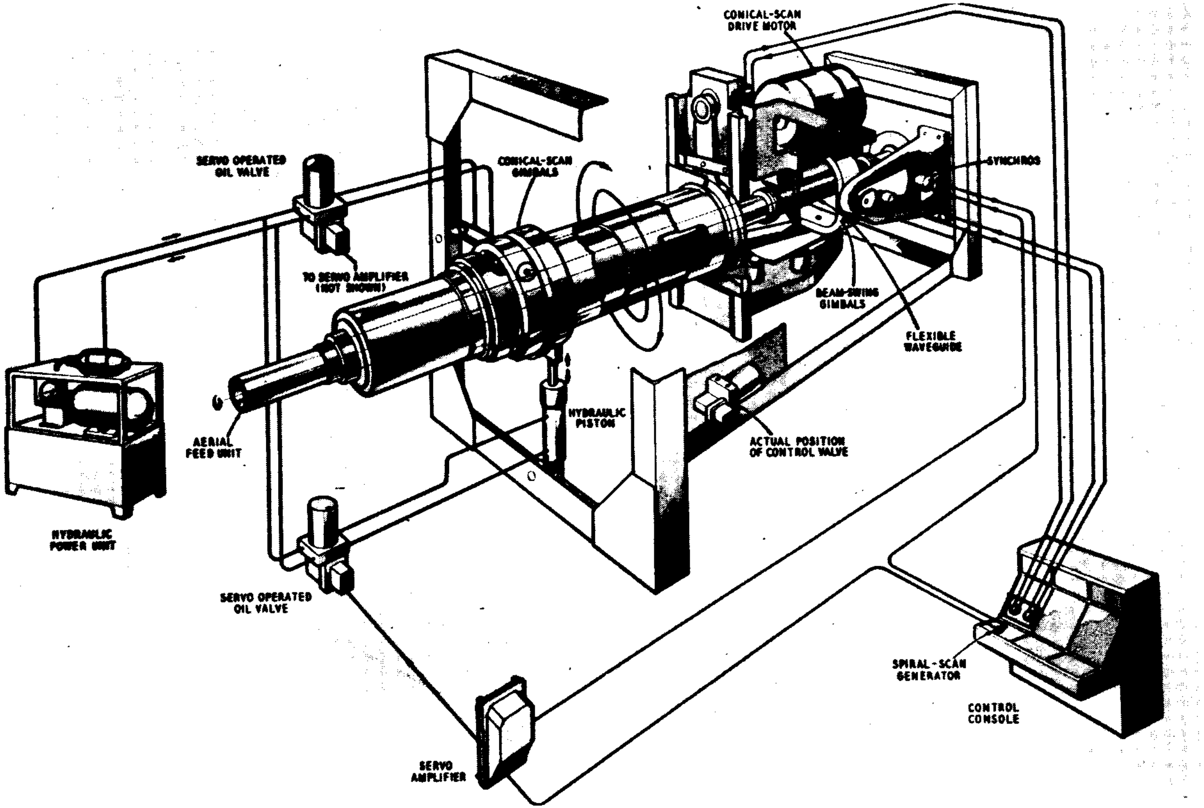

Fig. 1 — Schematic of the waveguide feed system.

position of the conical-scan gimbals results in this part of the mechanism being sensibly in mechanical balance. Counter balance collars are placed on the support tube fore and aft of the gimbals to balance completely particular feed assemblies. The conical-scan drive motor is fed from a small dc control set, originally of the Ward-Leonard type but which is shortly to be changed to the silicon-controlled rectifier type to minimize space, weight and the need of maintenance. The control set is mounted in one of the cabins behind the dish and allows the scanning speed to be regulated between ½ and 5 cps by remote control.

The whole assembly is designed for minimum maintenance and to withstand the weather conditions encountered on Goonhilly Downs. The weight of the mechanism, exclusive of the external waveguide feeders, is about 900 lb.

Conical-scan Control and Display

A cathode ray tube display is associated with the conical-scan system to indicate the divergence of the satellite from the scanning axis in direction and angular magnitude up to 8 ft. When the direction of the incoming beacon is off the axis of the conical scan by a small amount the output of the beacon receiver is modulated at the scan frequency. The depth of modulation increases as the deviation off axis increases and determines the length of a radial trace on the cathode ray tube. The direction in which the satellite is off axis determines the phase of the modulation and hence the angular position of the trace. Erroneous indications of direction due to the modulation of the beacon by the satellite spin are readily eliminated by adjusting the conical-scan speed to be non-synchronous with the spin-stabilization speed. A block diagram of the equipment is shown in Fig. 2.

A 50 cps magslip link relays the rotary motion of the feed to the control console where a resolver is driven to provide the phase reference for the incoming beacon signal. The 2-phase output of the resolver is fed directly to the magnetic deflection coils of the cathode ray tube and the input of the resolver is derived from the beacon signal in the following way. The modulated dc output of the beacon receiver is detected, amplified and fed to a modulator which is so biased that only the positive tips of the input ac wave produce an output. The carrier source to the modulator is a 1.5 kc/s pulse generator in which the pulse width is small. The pulsed output of the modulator is fed to the input of the synchro resolver through a drive amplifier. The necessity for pulsed modulation is twofold; firstly adequate

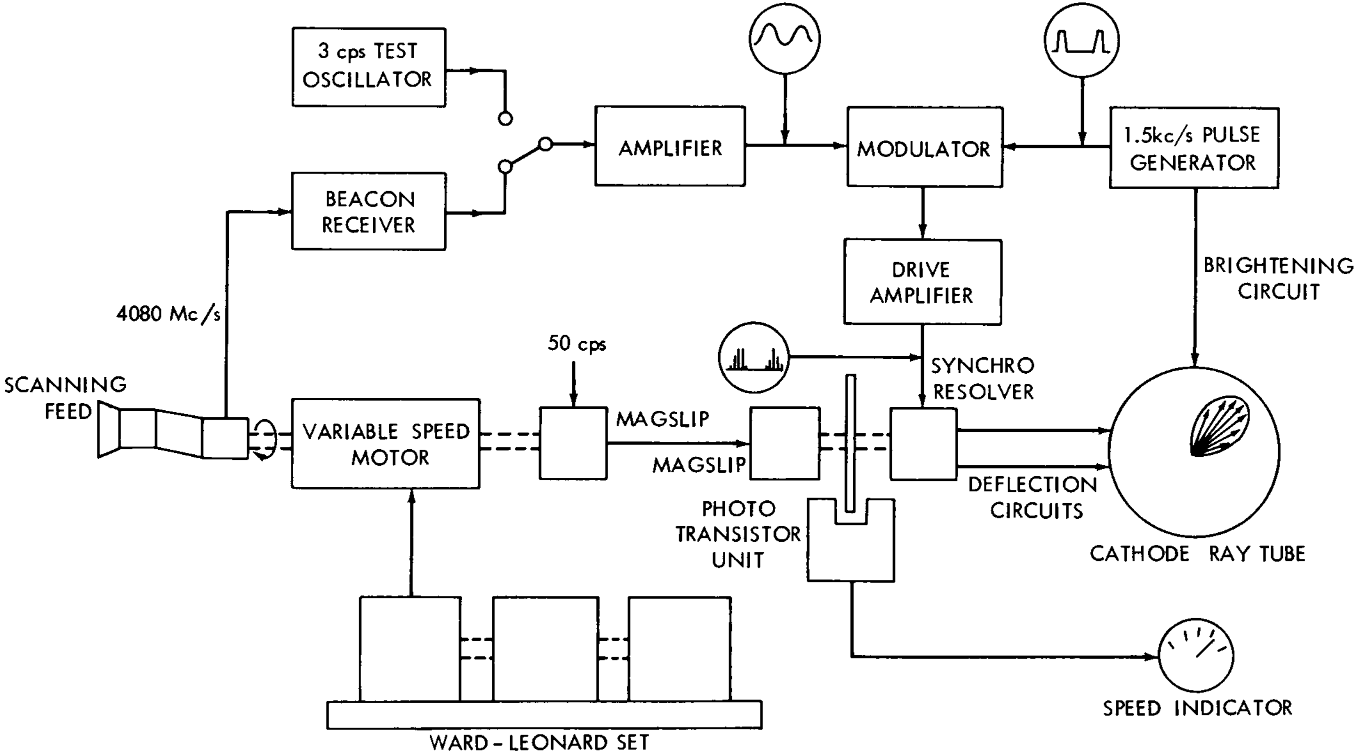

Fig. 2 — The Goonhilly aerial, conical-scan control and display.

transmission through the resolver cannot be obtained at the low conical-scan frequency in use, so translation to a higher frequency is necessary; secondly, it affords a simple means of deriving a radial trace on the cathode ray tube without dc restoration when the input is alternating current. The tips of the forward pulses are brightened to improve the presentation and to blank the small backward pulses. The result is a lobe as shown in the sketch in Fig. 2.

A 3 cps test oscillator is provided in the unit to stimulate the output of the beacon receiver when the equipment is non-operational. The magslip-resolver link is also used to provide an indication of the conical-scan speed. A perforated disc mounted on the coupling between the magslip and the resolver modulates a light beam focussed on a photo-transistor. The output of the transistor is measured on a meter in terms of the conical-scan speed.

Beam-position Control and Display

The beam-positioning equipment is shown diagrammatically in Fig. 3. The angular offset of the satellite relative to the aerial boresight axis is displayed on two meters calibrated respectively in terms of angular deviation in azimuth and elevation up to 30 ft each side of the central position. The meter display is derived from aerial feed-position indicators (linear transformers) mounted orthogonally on the beam-swing gimbals. The outputs of the transformers are rectified and fed to the relevant centre-zero meter.

Indication that the satellite is acquired is shown on 3 lamps triggered at predetermined stages of acquisition by the depth of modulation imposed on the beacon signal by the conically scanned beam. Indication of complete acquisition is extended to other lamps at points in the earth station where the information is required.

Control Console

A two-position console, part of a suite of six used for experiment control, houses the conical-scan and beam-position presentation units. A photograph of the two positions is shown in Fig. 4. The conical-scan display cathode ray tube is under the hood on the left hand position. Test facilities for the conical-scan unit, the scan speed indicator and beacon output meter are placed immediately above the hood. The aerial position is displayed digitally on the top panel. The hand control for positioning the aerial beam is on the desk below the cathode ray tube. The original version of this control incorporated a spiral-scan generator for wide-angle search but the high accuracy of the

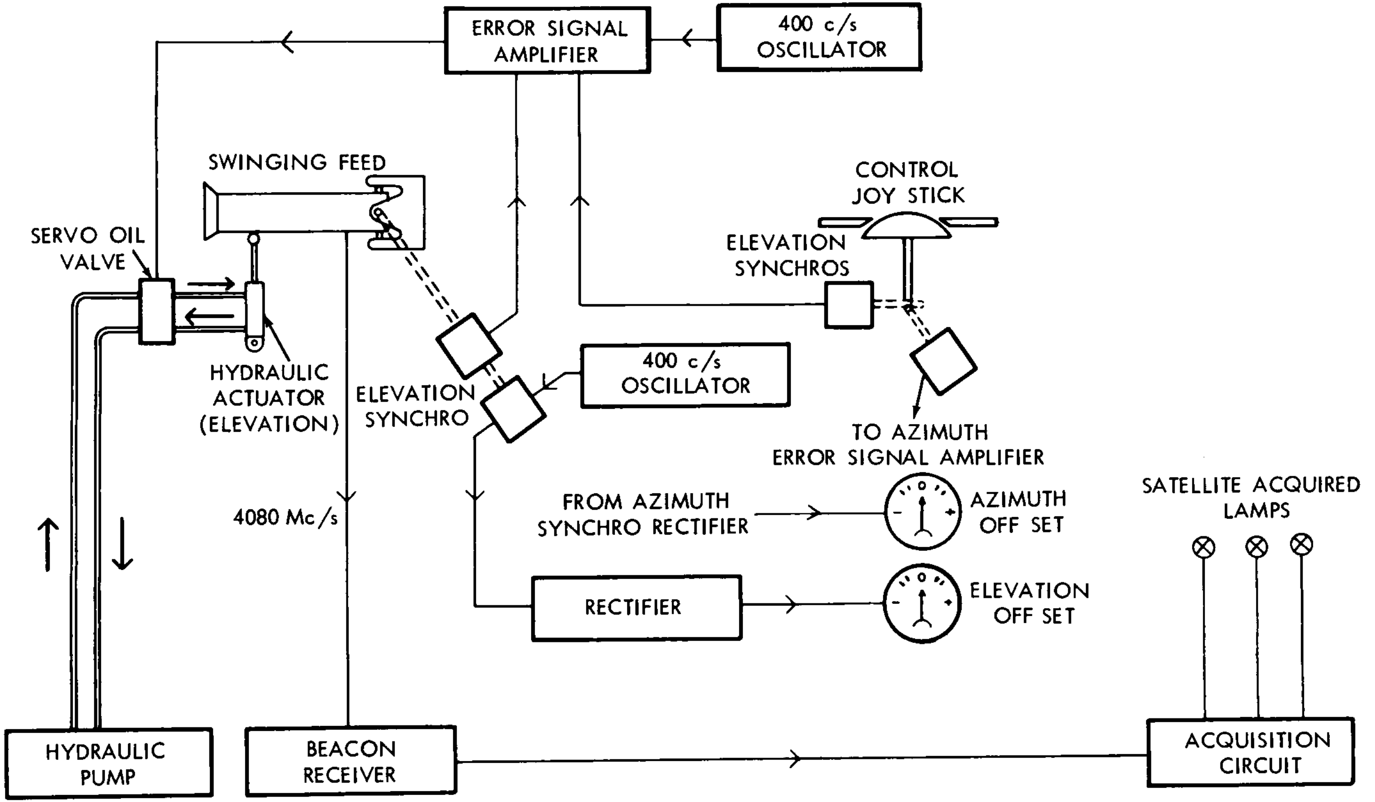

Fig. 3 — The Goonhilly aerial, beam-position control and display.

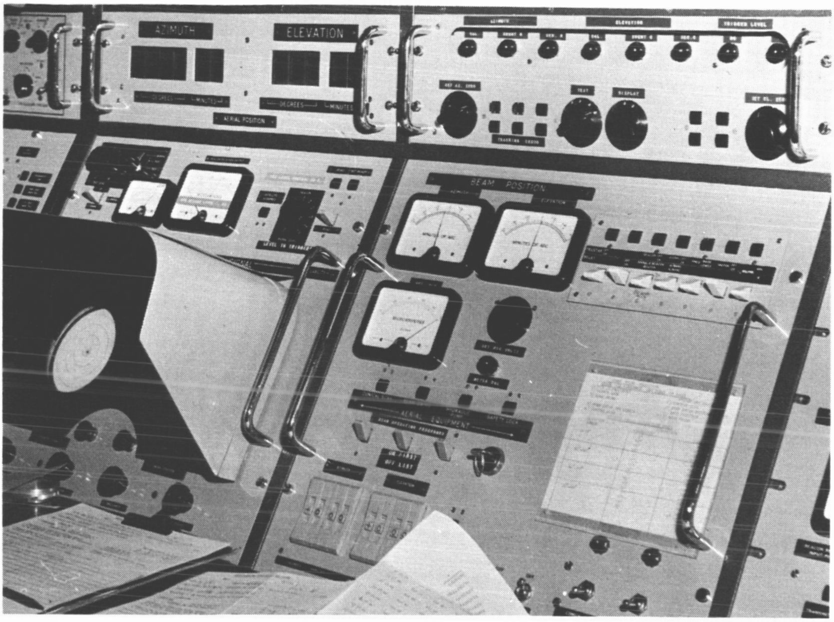

Fig. 4 — The beam-swinging console.

predicted data supplied by the GSFC made the provision superfluous and it has been replaced by a "finger-tip" ball-type control.

The right-hand bay of the console houses the beam-position unit and the satellite acquisition circuits. The digital switches, by which the corrections to be applied to the predicted course of the aerial are signalled to the aerial controller, are situated at the bottom left hand corner of the panel.

The operational procedure is:

1. The functioning of the presentation units and the scanning mechanism is checked before each satellite pass in conjunction with the Leswidden test station about 22 miles away.
2. The conical-scan motion is applied at the commencement of the pass and the radial display reveals any offset of the satellite from the aerial beam.
3. The hand control is used to steer the beam exactly on to the course of the satellite.
4. If the divergence of the beam from the boresight axis of the aerial, as displayed on the beam-position meters, is more than about 4 ft (one-third beamwidth) then azimuth and/or elevation

corrections to the predicted course of the aerial are demanded of the aerial controller to restore the beam to its on-axis position. As the corrections take effect the hand control is adjusted to follow the satellite to its on-axis bearing. This process is repeated as required during the period of the pass.

OPERATIONAL EXPERIENCE AND CONCLUSIONS

Experience in Project Telstar showed that the tracking facilities, as originally provided, with an extensive beam-swing capability and automatic spiral-scan facility, were more than adequate. These features have now been modified. It had been expected that acquisition would not be possible until the aerial elevation was about 5° to 7½° but, in a very large proportion of the passes the satellite has been sighted while the aerial was waiting at zero elevation, i.e., when the satellite was yet below the horizon. Only very occasionally has acquisition been delayed until the elevation has reached 2°. This fact, and the accuracy of subsequent tracking, reflects very favourably the high accuracy of the predicted data obtained from the Goddard Space Flight Center. After superimposing standard corrections on the predicted steering data to account for tropospheric refraction at low elevations the remaining corrections necessary during the period of a pass have generally totalled no more than 5 ft. Corrections in azimuth have been a little larger, totalling up to 10 ft. Adjustments in tracking by the beam-swing equipment and by overriding the predicted data have, so far, been applied manually. Equipment to track the beam-swinging mechanism automatically has now been developed; further development to provide auto-track facilities for correcting the predicted data from the conical-scan equipment is in hand.