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Waveguide Feeder System for the Goonhilly Satellite-Communication Earth Station*

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There are two features which distinguish the feeder arrangements at a satellite earth station from those used in conventional microwave line-of-sight links. The first is the importance of low loss in all waveguides and components and the second is the need for rotating joints. Losses are important in the receive direction because they contribute significantly to the overall system noise temperature while, in the transmit direction, not only do they waste expensive transmitter power but localized points of high loss can give rise to the formation of arcs when the power is applied. Rotating joints are required on the elevation axis of the aerial to permit waveguide connection between apparatus in the turntable cabin and on the dish.

In the installation at Goonhilly, three separate waveguide connections are required between the turntable cabin and the focus platform; one each for the Telstar and Relay transmitters operating at 6390 and 1725 Mc/s respectively, and one for the receiver feed, routed via the maser cabin on the back of the dish and operating at 4170 and 4080 Mc/s. Dominant-mode rectangular waveguide is used for these runs, and the components and installation practices used follow normal practice as far as possible.

MAIN WAVEGUIDE RUNS

Fig. 1 shows the layout of the main waveguide runs. Rectangular waveguide is used in sizes WG 8, 11 and 14 for the 1725, 4170 and 6390 Mc/s runs, respectively. Copper waveguide, using electrolytic copper, is employed to minimize the losses.

It can be seen from the sketch that a relatively large number of bends or corners are required on each waveguide run, including some

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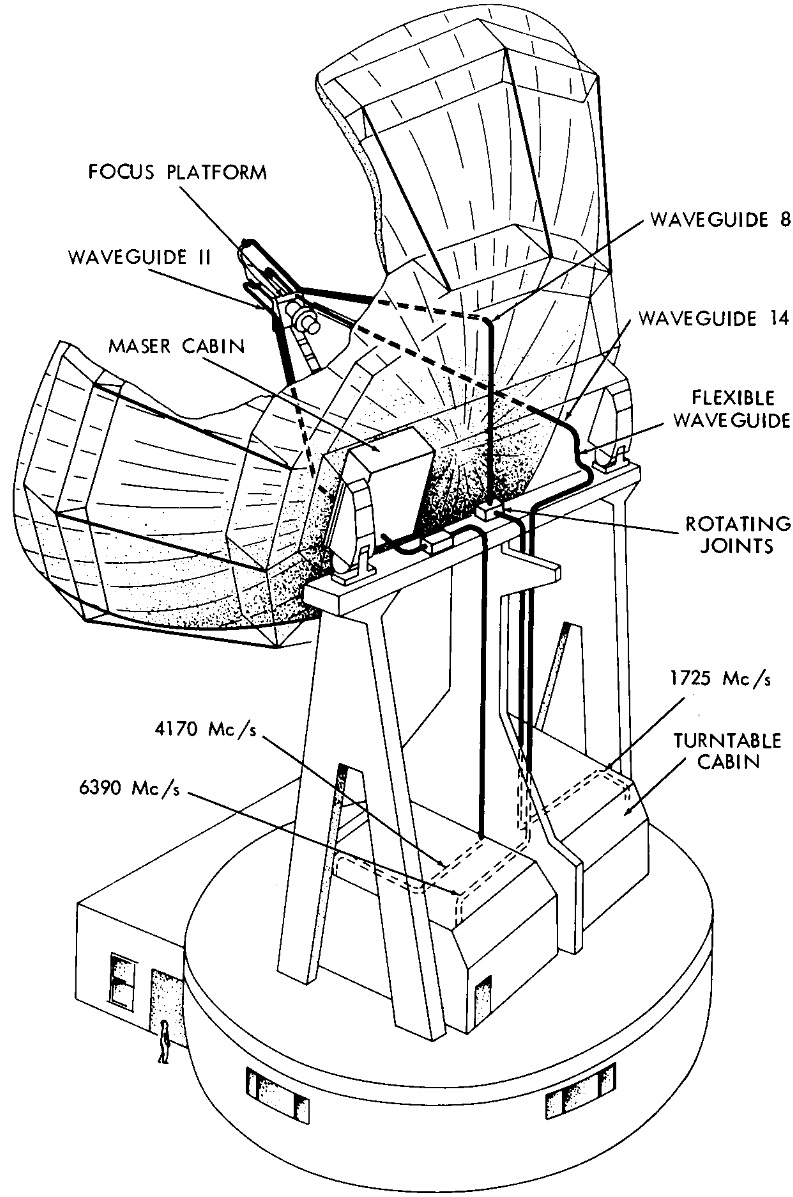

Fig. 1 — Main waveguide runs.

at special angles as at each end of the tetrapod legs. Fabricated corners of the simple mitred type are used in the WG_8 run. Typically, these give a measured VSWR of 0.995 at band centre (1725 Mc/s), the VSWR remaining greater than 0.99 over a bandwidth of ± 20 Mc/s. In the WG_{11} run, binomially-matched fabricated corners are used because the required bandwidth is greater—the beacon signal at 4080 Mc/s must be accommodated in addition to the communication signal at 4170 Mc/s. The VSWR of these corners is typically 0.995 at 4170 Mc/s and greater than 0.99 at 4080 Mc/s. In the WG_{14} run the compactness of the fabricated corner is of less importance than in the larger sizes and also the high power-density of the transmitted signal makes the use of fabricated corners inadvisable. Bends which are made by bending copper waveguide on a suitable mandrel are therefore used. The VSWR of such bends is typically 0.985 at 6390 Mc/s.

The use of large mean powers in waveguide systems is less common than the use of large peak powers. However, experience has shown that waveguide systems carrying large mean powers are subject to the formation of arcs at power levels of more than an order of magnitude below those which might be expected to give trouble from voltage breakdown. No adequate theory exists for this type of breakdown but it is known that one cause is localized over heating of lossy particles such as dust, swarf or shreds from rubber sealing rings. A consequence of the lack of an adequate theory of c.w. breakdown is that it is not possible to design a component with any assurance that it will not breakdown in service unless it has been tested at full power. Special precautions were taken during the installation of the waveguide runs to ensure that the interior surfaces of all waveguide and all components were kept scrupulously clean, particularly in the case of the WG_{14} installation where the power density is very high. The flange joints on the WG_8 runs were improved by using metallic gaskets.

The performance of the WG_{11} and WG_{14} runs were measured after installation with the following results. The WG_{11} between the maser cabin and the focus platform gave a VSWR of between 0.91 and 0.96 in the frequency range 4070–4185 Mc/s. The attenuation, calculated from VSWR measurements with a short-circuiting plate over the guide, was 0.262 db compared with the theoretical figure of 0.188 db for plain copper guide of the same length. The WG_{11} run between the turntable cabin and the rotating joint on the elevation axis gave a VSWR of between 0.89 and 0.98 over the frequency range 4060–4175 Mc/s and the attenuation was 0.67 db compared with a theoretical figure of 0.52 db. The WG_{14} run between the turntable cabin and the focus platform gave a VSWR of between 0.82 and 0.97 over the frequency range 6350–6430 Mc/s and the attenuation was 1.94 db as compared with a theoretical figure of 1.76 db.

ROTATING JOINTS

Rotating joints are required at the elevation axis of the aerial to permit the waveguide connections from the dish to be extended down to the joint, another polarizer and stepped transition convert the circularly polarized wave back to the normal TE_{01} wave in rectangular guide. The insertion loss of the complete rotating joint is 0.035 db at 4170 Mc/s and the VSWR is nearly constant at 0.95 over the range of angles of rotation which are used and over the frequency range 4080–4183 Mc/s. The rotating joint for the 1725 Mc/s waveguide run is similar in principle to that just described but uses waveguide turnstiles to convert from rectangular guide to circularly polarized waves in circular guide. This arrangement leads to a shorter axial length. Initially, some doubts were experienced about the bandwidth of this type of joint but the performance has proved to be adequate. At midband frequency, 1725 Mc/s, the VSWR is about 0.99 irrespective of angle of rotation while at ± 20 Mc/s the VSWR varies between 0.95 and 0.99 with angle of rotation.

WAVEGUIDE FOR RECEIVER INPUT

The losses which occur between the primary feed at the focus of the dish and the input port of the maser are of particular importance because they contribute significantly to the overall system noise temperature. Unfortunately, a large number of waveguide components is required in this part of the system in addition to the plain waveguide, and this increases the difficulty in making the total loss small. The path between the primary feed and the maser includes the broad-band polarizer and diplexer (described elsewhere), flexible waveguide to permit the feed to be moved, some 31 ft of waveguide between the diplexer and the maser cabin, and the rather complex assembly of components within the maser cabin which is illustrated in Fig. 2. The assembly in the maser cabin is required to provide the desired test facilities and to provide an alternate path for the beacon signal which lies outside the pass band of the maser.

Of the components in the maser cabin, the filter which separates the beacon signal from the communication signal could have the greatest potential for introducing loss in the communication channel. However

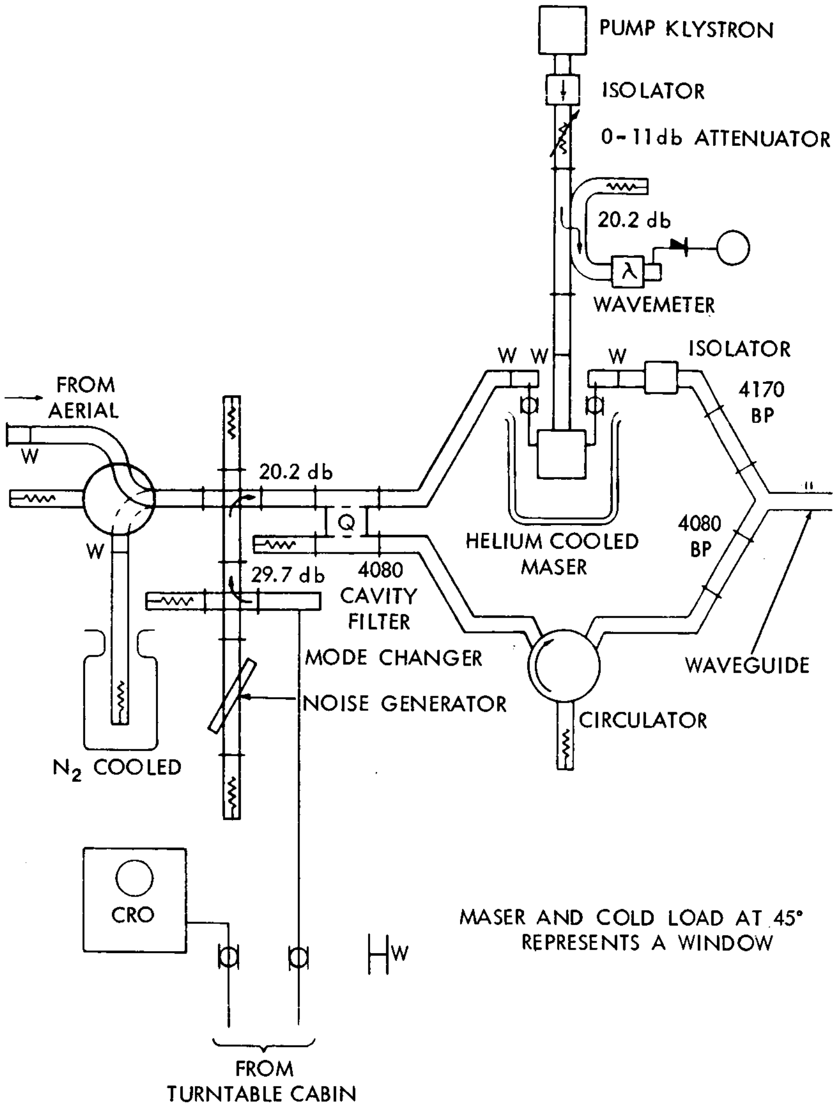

Fig. 2 — Schematic of equipment in aerial cabin.

by employing a resonant cavity coupler for the beacon channel this loss is only 0.033 db at 4170 Mc/s, and the loss in the beacon path is 1.3 db at 4080 Mc/s. The coupling loss between the beacon guide and communication channel output is 33 db so the extra contribution to system noise is negligible.

The filter pair which combines the communication and beacon signals at the output of the maser and a similar pair which is fitted in the turntable cabin and feeds the two receivers, are of straightforward design and use apparatus in the turntable cabin. A separate joint is required for each frequency band but the basic principle of them all is the same. This is that the TE_{01}-mode wave in rectangular guide is converted to a circularly polarized (or rotating) TE_{11}-mode wave in circular guide. The joint itself is in the circular guide and uses a simple choked flange, the rubbing contact occurring at the high-impedance junction between the two quarter-wave sections of the choke. After the joint, the wave is converted back again to the dominant mode in rectangular guide. This class of rotating joint was chosen for economy in design effort as some of the components used in it are also required for other purposes.

The 6390 Mc/s version of the rotating joint was not completed in time for the initial installation at Goonhilly and a length of flexible (twistable) rectangular waveguide was installed instead. This was arranged so that it is straight when the aerial elevation is 45°, the maximum bending thus being ±45°. This arrangement has proved so successful that it is doubtful whether it is worthwhile replacing it with the more complex rotating joint.

Fig. 3 shows a sketch of the 4170 Mc/s rotating joint. To minimize the axial length of the unit, a binomially corrected stepped transition is used to convert the TE_{01} wave in rectangular guide to a TE_{11} wave in circular guide. A constant guide-width is maintained throughout the intermediate rectangular steps of the transition to simplify the problem of obtaining a theoretical starting point for the design. The final dimensions are, however, obtained by experimental modifications of the inital design. In its final form the transition has a VSWR in excess of 0.98 from 4070 Mc/s to greater than 4300 Mc/s, the figure for 4170 Mc/s being about 0.99. The TE_{11} wave in the circular guide is converted to a circularly polarized wave by the finline polarizer. This contains a copper fin inserted into circular guide at an angle of 45° to the plane of polarization of the linearly polarized incident TE_{11} wave, and retards the phase of the resolved component of the incident wave which is parallel to the fin by 90° with respect to the component which is at right angles to the fin. The circularly polarized wave which emerges has the necessary circular symmetry to permit the joint to be rotated without introducing variations in its transmission properties. The joint itself is of the simple choke-flange type with a rubbing contact at the current null in the choke. Time did not permit the

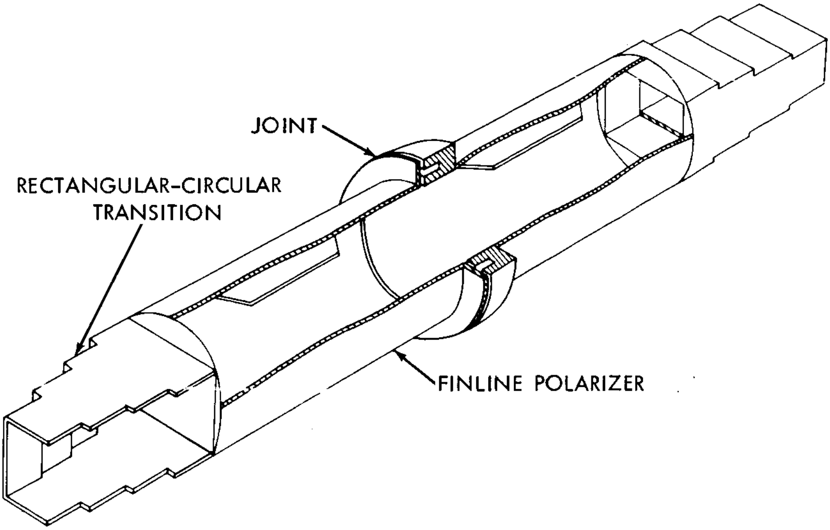

Fig. 3 — Rotating joint.

investigation of more sophisticated joints but present indications are that the simple type is quite adequate. Following the joint, another polarizer and stepped transition convert the circularly polarized wave back to the normal TE_{01} wave in rectangular guide. The insertion loss of the complete rotating joint is 0.035 db at 4170 Mc/s and the VSWR is nearly constant at 0.95 over the range of angles of rotation which are used and over the frequency range 4080–4183 Mc/s. The rotating joint for the 1725 Mc/s waveguide run is similar in principle to that just described but uses waveguide turnstiles to convert from rectangular guide to circularly polarized waves in circular guide. This arrangement leads to a shorter axial length. Initially, some doubts were experienced about the bandwidth of this type of joint but the performance has proved to be adequate. At mid-band frequency, 1725 Mc/s, the VSWR is about 0.99 irrespective of angle of rotation while at ± 20 Mc/s the VSWR varies between 0.95 and 0.99 with angle of rotation.

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The filter pair which combines the communication and beacon signals at the output of the maser and a similar pair which is fitted in the turntable cabin and feeds the two receivers, are of straightforward design and use three quarter-wave-coupled triple-post cavities. The isolator which follows the maser and the circulator in the maser by-pass are provided to ensure that the filters, which are designed on an insertion loss basis, are correctly terminated and so give their design performance.

In view of the importance of knowing the very small losses introduced by individual components an experimental equipment for measuring very small losses has been developed. An analysis of the loss figures for the pre-maser waveguide components is given in Table 1.

It can readily be shown that a matched network of loss L (input/output power ratio) at a temperature T_0, inserted between an aerial of noise temperature T_a and a low-noise receiver (e.g. a maser) at a temperature T_r, increases the effective aerial temperature by $T_0(L - 1)$. Thus the total effective noise temperature of the system referred to the aerial is

$$T_a + T_0(L - 1) + LT_r.$$

By inserting the figures of Table I this becomes

$$(T_a + 42 + 1.14\ T_r)\,^\circ\mathrm{K},$$

or referred to the maser input,

$$(0.87\ T_a + 37 + T_r)\,^\circ\text{K}.$$

As the system noise temperature measured at the maser input, with the aerial pointing at zenith, is 56°K and the effective maser noise temperature is of the order of 13°K, the component of the noise temperature due to the waveguide losses cannot differ very much from the estimated figure of 37°K. While this figure is large, it can be seen from the Table that there is not much scope for a substantial reduction unless the first-stage amplifier can be placed nearer the feed. The largest single component is the waveguide run between the diplexer and the maser cabin. Consideration is being given to using oversized rectangular and even circular guide, for the straight portion of the run down the tetrapod leg, but the maximum saving would only be some 7°K. Cooling of the waveguide run has been investigated, but it is not considered worth-while.

TABLE 1 — ANALYSIS OF LOSSES IN PRE-MASER WAVEGUIDE COMPONENTS

Component	Loss (db)
Diplexer (incl. polarizer)	0.100
Connecting section (incl twist and 1 corner	0.074
External WG_{11} (incl. flexible section and 2 corners)	0.232
Internal WG_{11} (incl. 1 window and 2 corners)	0.021
Waveguide switch	0.028
Directional coupler	0.048
Internal WG_{11} (incl. 5 corners	0.047
Beacon separation filter	0.033
Total	0.583

CONCLUSIONS

The special features of the waveguide installation on the aerial at Goonhilly have been outlined and performance data have been given. The installation and all its components have functioned successfully in the manner expected. The most significant feature is the relatively large contribution which the waveguide installation between the primary feed and the maser makes to the system noise temperature. This is not due to any one cause but arises partly from the distance involved and partly from the necessary complexity of the arrangements. While it can be expected that further work will lead to a reduction in the losses in this part of the system, it seems unlikely that any very large reduction will prove possible unless the first-stage amplifier can be placed nearer the feed.