The Helium System of the Maser Installation at the Goonhilly Satellite-Communication Earth Station*

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A travelling-wave solid-state maser amplifier is used to provide the first stage of amplification in the receiving system at the communication-satellite earth-station at Goonhilly Downs. While the maser itself was built by an industrial research laboratory, the auxiliary supplies and equipment essential for the operation of the maser were designed and built by staff of the Post Office Research Station. A major part of this auxiliary equipment consists of apparatus for handling the helium refrigerant.

GENERAL DESCRIPTION

The maser is a microwave amplifier in which the amplification takes place in a single crystal of "pink" ruby-crystalline alumina containing a small percentage of chromium. Microwave power, at a frequency of about 30 Gc/s, is injected into the crystal and temporarily disturbs the thermal equilibrium of outer electrons in the chromium ions in the crystal. Some of the energy stored in this way is available to amplify a low-level signal at a frequency of 4.17 Gc/s. The particular frequencies involved are determined by an applied steady magnetic field. The particular property of the amplifier which makes it so important for use in satellite communication is its ability to amplify extremely weak radio signals whilst introducing a negligible amount of additional background noise. A disadvantage is that it will only operate at very low temperatures. The present equipment requires a temperature lower than 2°K (i.e. −271°C) and the only possible method of obtaining such a low temperature is to immerse the amplifier in liquid helium. This normally boils at 4.2°K, but the lower temperature required for the maser can be produced by causing the

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helium to boil at a reduced pressure. A large vacuum pump must therefore be incorporated into the apparatus.

If the maser and all the associated equipment could have been mounted in close proximity, the installation would have been relatively straightforward. However, to make use of the unique low-noise properties of the maser, it was essential that it should be mounted as near as possible to the focus of the 85-ft. parabolic reflector, whilst the remainder of the equipment had to be mounted in the rotating cabin or at ground level.

It was not practicable to mount the maser actually at the focus because of its weight and because there was already a considerable amount of aerial-feed equipment at the focus. The maser was therefore

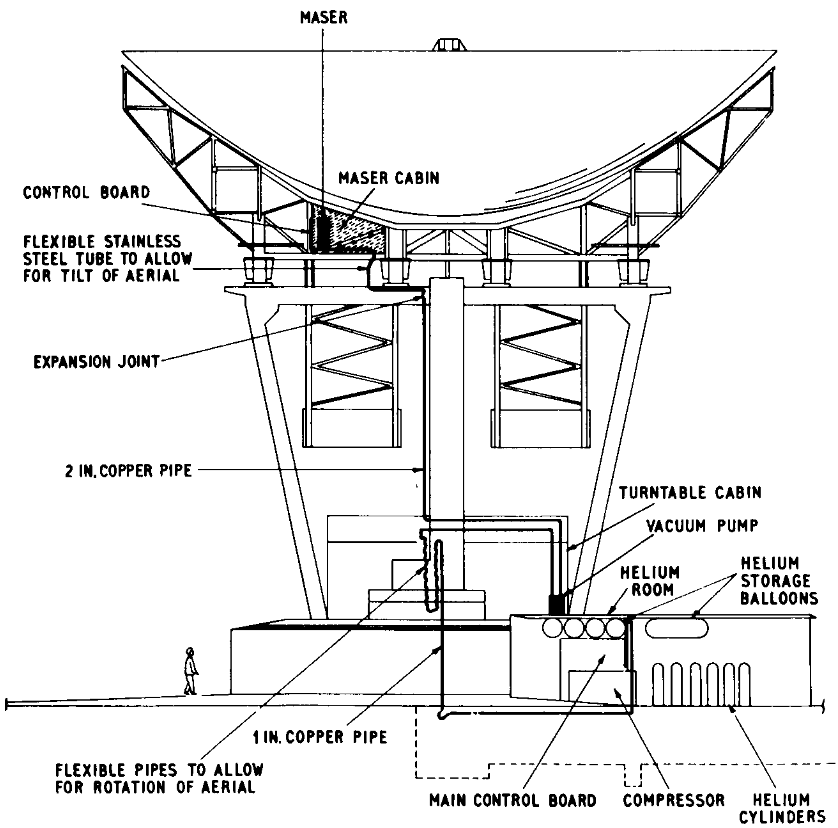

Fig. 1 — Position of the maser and helium equipment on the Goonhilly aerial.

housed in a cabin constructed on the back of the parabolic reflector, and connected by waveguide to the feed equipment at the focus.

Thus the complete installation consists of the helium control equipment associated with the maser, a vacuum line along and down the aerial structure to the vacuum pump, together with the equipment for controlling the flow of helium gas from the vacuum pump and storing this helium for return to the liquefaction plant. The location of the various items is indicated diagrammatically in Fig. 1.

During operation, the axis of the aerial may be tilted between horizontal and 10° beyond vertical, and consequently all the equipment in the maser cabin, including the klystron and magnet power supplies, a small oscilloscope, a nitrogen-cooled reference load and the maser itself, must operate satisfactorily when tilted by 100°. To prevent refrigerant from spilling from the maser as the aerial tilts, it was mounted at an angle of 45° to the axis of the aerial, so that the maser axis is never more than 55° from vertical. However, access to the aerial cabin to fill the maser with refrigerant is only possible when the aerial axis is horizontal, so that the maser must be capable of being tilted in its cradle from the normal operating position through 45° to the vertical position for filling. The helium-gas handling system must also provide for the maser to be tilted inside the cabin, and, when the aerial is in use, for the cabin to tilt with respect to the ground without restricting the flow of helium gas. Sections of corrugated stainless-steel tube are used to provide this flexibility.

Special quick-release waveguide flanges were designed to permit the maser to be tilted through 45° into the filling position, as shown in Fig. 2.

LIQUID HELIUM AND LIQUID NITROGEN

Liquefied gases are usually contained in metal "dewar" vessels, which are spherical flasks with a double wall, the space between the walls being evacuated to provide thermal insulation. The latent heat of helium is so low that this form of thermal insulation is inadequate. The maser is therefore mounted inside a double vacuum-insulated dewar, with the outer vessel containing liquid nitrogen. Equipment was provided for re-evacuating the insulating spaces in the maser dewar when necessary.

Double dewars must also be used for transporting and storing liquid helium. All supplies of liquid nitrogen and liquid helium are despatched by rail from a liquefaction plant in London to Cornwall two or three times a week.

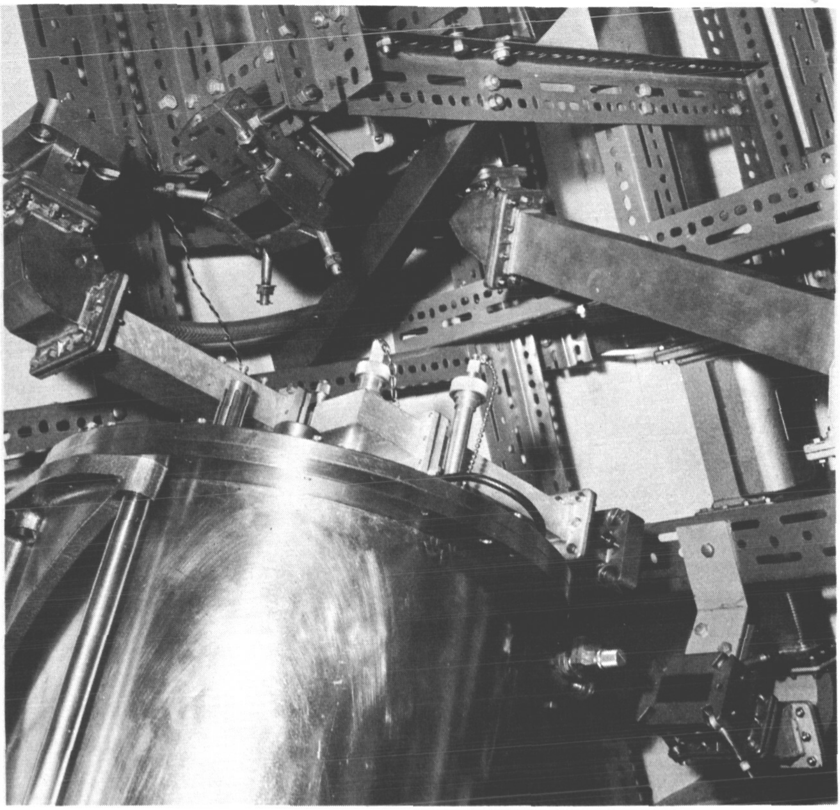

Fig. 2 — The top of the maser tilted to show the quick release flanges.

The temperature of liquid helium is lower than the freezing point of both oxygen and nitrogen, and it is necessary to take precautions to prevent air from freezing inside the neck of the dewar vessels. A non-return valve must therefore be fitted to the dewars, allowing helium gas to boil away from the liquid, but preventing air from entering.

COOLING THE MASER

The maser is mounted in its tipping cradle on one wall of the maser cabin, as shown in Fig. 3. Above it on the wall is a control panel that enables the flow of helium gas to be regulated, and the pressure in the maser to be measured. A flexible stainless-steel tube connects the maser to the control panel. Electrical monitoring equipment is also

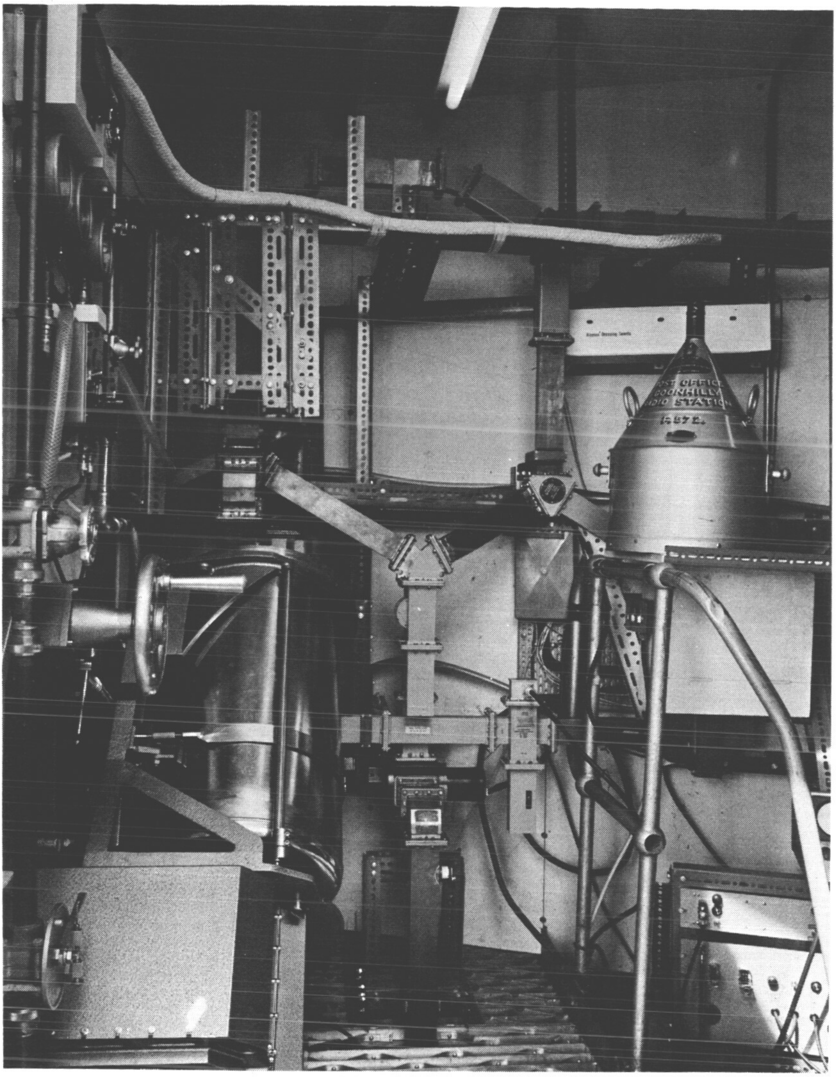

Fig. 3 — The maser in the operating position showing the 12 litre dewar.

mounted on this panel, indicating the output of the klystron oscillator and the level of helium in the maser.

Figure 4 shows dewars of liquid helium and liquid nitrogen being lifted by a hydraulically-operated platform to the portal beam of the aerial, from which they can be carried to the maser cabin. Here, the liquid-nitrogen dewar is connected to an insulated transfer tube

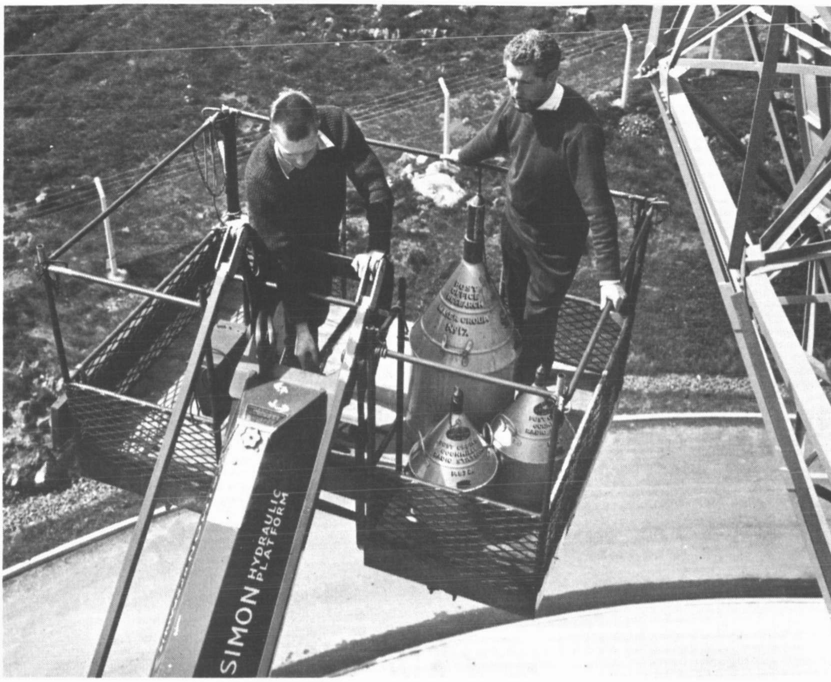

Fig. 4 — Dewars of liquid helium and liquid nitrogen being lifted to the maser cabin.

permanently installed in the cabin. Compressed nitrogen from a cylinder is used to force the liquid nitrogen along the thermally-insulated tube into the outer part of the maser dewar.

When the outer vessel of the maser dewar is full of liquid nitrogen, the inner vessel is filled with liquid helium. The helium-storage dewar is placed on a hydraulically-operated lift-platform beside the maser dewar, and a transfer tube is inserted into the two dewars. This transfer tube, which can be seen in Fig. 5, has a vacuum-insulated double wall, to prevent the boiling of helium inside the transfer tube due to heat entering through the walls. A bladder attached to the helium-storage dewar is used to start the helium transfer. A gentle squeezing action agitates the liquid in this dewar, causing increased evaporation. The gas pressure so produced forces the liquid helium through the transfer tube. As the level of the helium rises in the maser dewar, the storage dewar and transfer tube are raised to keep the outlet of the transfer tube above the liquid surface in the maser dewar.

Fig. 5 — Helium transfer into the maser.

Great care must be exercised during the transfer to prevent air or water entering the dewars. When the dewar containing the maser is full, the transfer tube is rapidly removed and the entry port sealed. During the helium transfer, a considerable amount of liquid is evaporated in cooling the structure to 4.2°K. The helium gas so evolved passes along the flexible tube to the control panel, and thence into the helium collection system.

Immediately the maser dewar has been filled and the filling port sealed, the pressure must be reduced to a few torr (mm Hg) in order to lower the helium temperature from 4.2°K. The rate of change in the pressure must be controlled carefully in order to prevent the risk of damage to the maser. A special adjustable throttle valve was designed to control the rate of change of pressure during the initial stage of pump-down.

The version of the maser installed initially was built into a relatively small commercial helium dewar. More recently, a new dewar has been installed to give an extended maser operating life. This dewar (Fig. 3) holds approximately 12 litres of liquid helium.

The operating procedures devised for the small dewar have proved quite adequate for the new installation. The principal change has been an increase in the time needed to fill the dewar because of the greater volume of liquid, and the increased mass of metal to be cooled. Operationally the increased helium capacity has enabled several successive TELSTAR and RELAY passes to be used without refilling the maser. It has also been possible to carry out the maser filling some hours in advance of a satellite experiment, when this has been desirable.

THE MAIN VACUUM LINE

As already mentioned, the nearest position to the maser which could be used for the vacuum pump was in the turntable cabin. The main vacuum line between the maser cabin and the pump therefore had to be about 80 ft. in length. Two-inch diameter copper pipe was used, with joints and bends assembled from commercial fittings, silver soldered into position. The pipeline was constructed in sections on the ground and these sections were joined by vacuum flanges sealed with rubber rings and bolted together by stainless-steel bolts.

A great deal of care was taken in assembling the system, to eliminate possible sources of contamination or leakage. Apart from directly reducing the purity of the recovered helium, any volatile contamination in the pipeline would increase the background pressure in the system, making subsequent detection of possible leaks much more difficult. The success of the whole installation depends upon the quality of the silver-soldered joints and upon the cleanliness of the system, and elaborate cleaning and leak testing procedures were devised and followed during the installation.

The 2-in. pipe is supported by a series of brackets fixed to the waveguide ladder which runs alongside the vertical centre member of the concrete aerial structure. The weight of the pipe is taken on a special flange located near the base of the ladder and a flexible stainless-steel section near the top permits small residual movements.

THE VACUUM PUMP

In order to handle large quantities of helium, a vacuum pump of large capacity is needed. The rate at which helium gas would be evolved could not be known in advance, as it depends upon the constructional details of the maser structure. A large margin of safety was therefore desirable when specifying the required pump performance. A pump with a capacity of 36 cubic ft/min. was fitted; this was the largest available air-cooled vacuum pump, air cooling being very desirable to avoid the necessity for an additional water-circulation system on the aerial.

A remotely controlled valve is used to provide a low impedance path round the pump while the maser is being filled.

THE HELIUM RECOVERY APPARATUS

The output from the vacuum pump cannot be exhausted to the atmosphere in the usual way, but must be piped away for recovery. Accordingly, a 1 in. diameter copper pipe is connected to the output of the pump to carry the helium over the transmitting equipment to the rotating joint at the centre of the turntable cabin. To carry the helium through this rotating joint four 17 ft. lengths of nylon-reinforced PVC tube are used, hanging as U-loops, connected in parallel. As the aerial rotates, the loops wind round a central pylon, permitting a movement of $\pm 250°$ from the central position. From the bottom of the central pylon the copper pipe goes through underground ducts to the helium room, which is part of the building housing the aerial control gear.

The total length of the 1 in. pipe is about 120 ft. and the same care over cleanliness was observed in its fabrication as for the 2 in. vacuum section.

The helium room (Fig. 6) contains a large control panel to handle the helium gas which is now at atmospheric pressure. This panel is fitted with over 20 vacuum-type valves to interconnect the pipe which brings the helium gas from the vacuum pump, the temporary gas store, and the compressor. A flowmeter is included, to monitor the rate of evolution of helium gas from the maser.

Fig. 6 — The helium collection room.

The helium store consists of rubberized-canvas balloons suspended beneath the ceiling, each balloon holding up to 17 ft of helium. The initial installation of six balloons has been increased to 16, to give adequate storage for extended periods of maser operation.

For return to the liquefaction plant, the contents of the balloons must be compressed into steel cylinders. A modified commercial air compressor is used to compress the helium to 1,000 lb/in.^{2} Additional facilities are required to collect gas released from the sump and the starting bypass valve, which are normally open to the atmosphere in an ordinary air compressor. Helium, which is a monatomic gas, becomes hotter than diatomic oxygen or nitrogen during compression. To avoid damaging the compressor by over-heating, it must not be used for more than 10-15 minutes at any one time when compressing helium. The full cylinders are returned by rail to the liquefaction plant in London, for the cycle to begin again.

Also visible in Fig. 6 is the continuous chart recorder, connected to the resistance thermometers in the maser dewar. A continuous indication of helium level is thus always available.

CONCLUSION

The helium system at Goonhilly was commissioned on 25th June, 1962, having been completely designed and constructed in four months. The general features of the system have proved satisfactory in operation, requiring little modification to the original conception, although a number of changes have been introduced to simplify the filling of the maser with liquid helium.

The great care taken in construction and operation of the helium system has been justified by the high level of purity attained for the returned gas.