Low-Noise Receivers: Microwave Maser Development

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An S-Band traveling-wave maser with a 2260- to 2400-MHz tuning capability has been built and installed on the 26-m antenna at the Venus Station of the Goldstone Deep Space Communications Complex. The Traveling-Wave Maser/Closed Cycle Refrigerator package was assembled within a limited time schedule and at low cost to meet the requirements of the Very Long Baseline Interferometry Validation Task. The maser uses a superconducting magnet with a field staggering coil for gain/bandwidth adjustment. The maser pump source is a Gunn effect oscillator with the capability of continuous tuning throughout the entire maser tuning range. The package was assembled from surplus components that have been used previously in the Deep Space Network in a variety of applications since 1967.

I. Introduction

The Traveling-Wave Maser (TWM) requirements for the Very Long Baseline Interferometry (VLBI) Validation Task include operation at a bandwidth of 40 MHz centered at 2290 MHz, with phase and group delay stability such that the VLBI measurement precision will not be degraded. Operation at 2388 MHz is required for planetary radar. Because the Venus Station (DSS 13) TWM did not meet the bandwidth requirement, a new package was assembled with previously used components and delivered at a procurement cost of $5300 and a 4-man-month labor effort.

II. Closed Cycle Refrigerator History

The Closed Cycle Refrigerator (CCR) is one of the early Block III prototype refrigerators which are now in use throughout the DSN. This particular CCR was built in January 1967 and installed at DSS 13 in March 1967. During 1973 the TWM/CCR was returned to JPL for modifications which included the installation of a cooled and shortened input transmission line and a superconducting magnet (Ref. 1). The system was then delivered to DSS 43 (Australia) to meet the special sensitivity and stability requirements of the Mariner Venus-Mercury missions (MVM'73). The refrigerator was used for MVM'73, in spite of its age, due to budgetary and schedule constraints.

Following the MVM'73 missions, the maser was returned to JPL to determine the cause of a refrigerator failure that occurred during the third Mariner Mercury encounter. By this time, the CCR had accumulated 60,000 h of run time. Cylinder wear in the region of the cryogenic seal on the #2 displacer had reached 0.38 mm. This wear results in ring leakage, which is aggravated by restriction in the regenerator pack. Replacement of the worn cylinder assembly and installation of new seals restored sufficient cooling capability to achieve maser operation. The reserve refrigeration capacity, however, was low and erratic. The use of a reserve capacity monitor was indispensable in this determination (Ref. 2).

Failure to achieve stable refrigeration capability has occurred on several occasions, both in the laboratory and in the field, as a direct result of drive unit replacement. It is believed that operation of a displacer assembly with a cryogenic seal in a badly worn cylinder can result in leakage when the edges of the seal contact the ridges at the ends of the cylinder wear. The leakage reduces regenerator efficiency. In some cases, excessive regenerator restriction has been noted. Such restriction increases the pressure differential across the seal and results in additional leakage and inefficiency.

To restore the refrigerator to "like new" condition, the following major repairs were effected: (1) The weld holding the cylinder was cut, the heat stations were unsoldered, and the worn cylinder was replaced. (2) The displacer and drive unit assembly were overhauled (all seals and worn parts were replaced). (3) The lead sphere regenerator pack in the second stage displacer was replaced, and the bronze screen pack in the first stage displacer was flushed with freon 11 to remove accumulated lead dust. (4) Both charcoal traps in the J-T circuit were cut out and replaced.

Following reassembly, a complete checkout of the CCR was made, and normal refrigeration capacity was achieved.

The cylinder and charcoal trap replacement is not currently within the scope of normal field maintenance. It is expected that the above-described rebuilding procedure can be used at the DSN Maintenance Depot to extend the life of worn CCRs at a small fraction of the CCR replacement cost.

III. Maser and Superconducting Magnet Assembly Modifications

The TWM used for this system (a tunable R&D type) was originally built in 1967 and used in the ultracone at DSS 14 (Ref. 3). It was returned to JPL in 1974. During inspection of the maser, several of the single crystal YIG disks on the isolator strips were found to be loose. Improved cutting and gluing techniques were used to fabricate new isolator strips. The TWM input coaxial line was modified to permit its use with the cooled and shortened input transmission line.

The comb structure body was machined to provide a mounting location for a magnetic field staggering coil. The field staggering coil covers half the maser's amplifying length and is used to increase maser bandwidth. The best gain/bandwidth tradeoff was achieved by using a current in opposition to that of the superconducting magnet, subjecting half the maser to an adjustable bucking field. This serves to magnetically separate the maser into two halves in much the same manner as the figure-eight field shaping coil that was developed previously for an X-band maser (Ref. 4). The field staggering capability is used primarily at the 2290-MHz center frequency, where the 40-MHz bandwidth is required and the maximum gain/bandwidth product is available.

IV. Pump Source

The maser pump source is a Varian model VSU-9012Y varactor-tuned, Gunn-effect oscillator which is electronically tunable across the entire tuning range of the maser (Ref. 5). A 100-kHz oscillator is a part of the pump control/protective circuitry; it amplitude-modulates the varactor tuning bias voltage, thereby frequency-modulating the pump. The circuitry provides remote control for narrowband pumping of the maser at any single frequency within the maser tuning range and also across the wider bandwidth, as required by the VLBI Validation Task.

V. Performance

This maser uses a comb design intended for operation over a wide frequency range; it does not have the same gain/bandwidth capability that is achieved by the newer Block III maser used in the Deep Space Network. The magnetic field staggering necessary to achieve the 2270- to 2310-MHz bandwidth reduces the maser gain to 25 dB. A low-noise Avantec model AM2402N transistor amplifier is used in series with the maser to achieve an overall package gain of 40 dB. The transistor amplifier's operating voltage is supplied by the Gunn-effect diode bias power supply. A bandpass filter is used behind the transistor amplifier to prevent wideband noise from entering the image response of the receiver following the maser package. The transistor amplifier contributes 2 K to the maser input noise temperature in the wide bandwidth mode of operation.

Operating characteristics of the tunable maser (with relatively narrow bandwidth) have been described previously (Ref. 3). The maser performance between 2270 and 2310 MHz is described here. The equivalent input noise temperature across the 40-MHz instantaneous bandwidth is between 4 and 5 K (including the transistor amplifier contribution). The amplitude response (flat within 1 dB) and the phase shift, as a function of frequency, are shown in Fig. 1. The outputs of a Hewlett-Packard network analyzer were recorded with the maser bypassed to produce reference lines. The difference in the slope of the phase reference recording and the phase response of the maser is used to determine the group delay time through the entire maser package.

Figure 1 shows that the delay time through the maser is 114×10^{-9} s at 2270 MHz, 106×10^{-9} s at 2290 MHz, and

111×10^{-9} s at 2310 MHz. The dispersive characteristics of the maser can be observed more easily, with improved resolution, by using a delay line in the reference path of the network analyzer measurement system. Figure 2 is a recording of the phase and amplitude as a function frequency with improved phase resolution. Recordings were made at refrigerator temperatures of 4.41 and 4.55 K. Increasing the CCR temperature by 0.14 K reduced the phase slope between 2270 and 2310 MHz by 14 deg. The corresponding 0.97×10^{-9} s delay time change and the 2.8-dB gain change are 10 times larger than would be experienced during tracking operations on a moving antenna.

References

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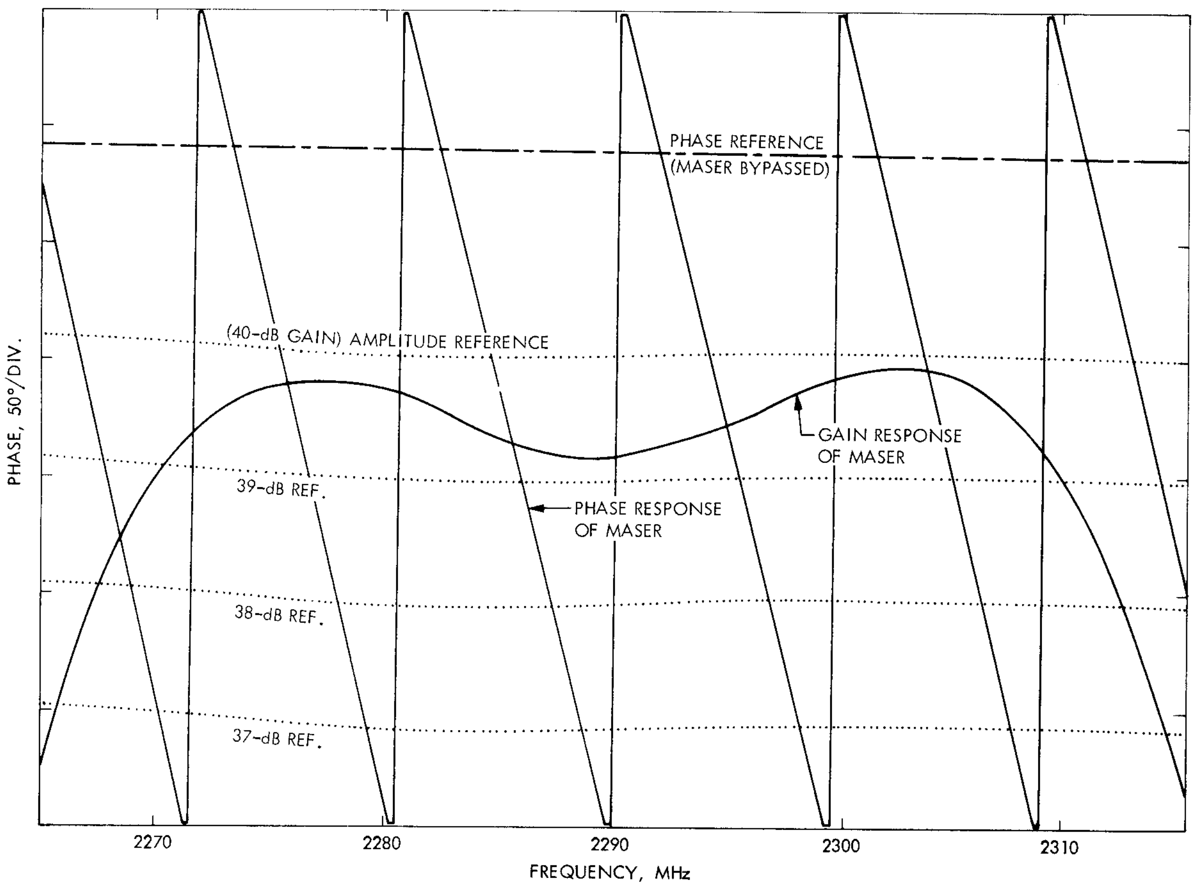

Fig. 1. Gain and phase response of maser

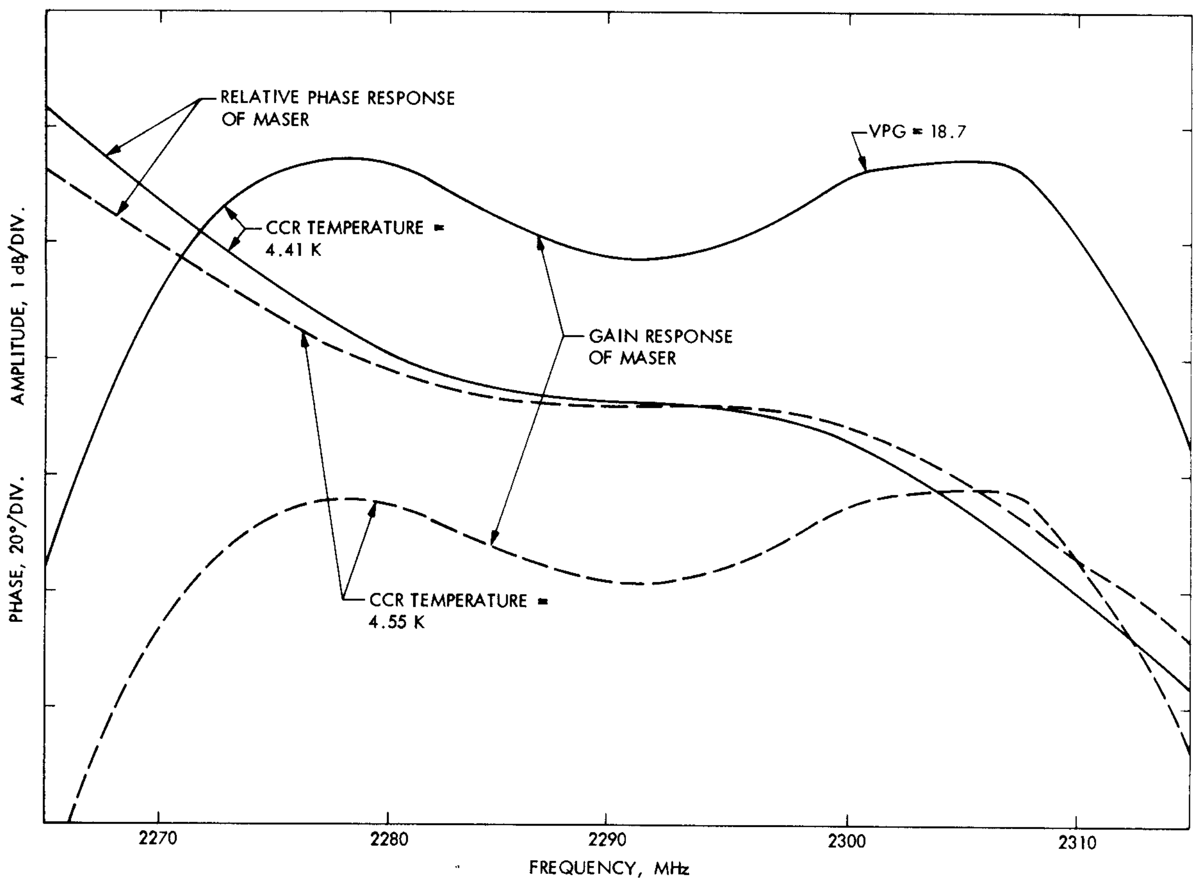

Fig. 2. Gain and relative phase response of maser at two different CCR temperatures