Microwave Maser Development

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A traveling-wave maser operating at 15.3 GHz has been used to test the noise temperature contribution of various waveguide components. An assembled system, consisting of the maser, a directional coupler, a waveguide switch, a polarizer, and a feed horn, measured 23 K total system operating noise temperature. Previously measured X-band data are shown for comparison. The maser was installed on the 64-m antenna at the Goldstone DSCC. Maximum changes of 2.2 deg signal phase and 0.25 dB signal amplitude were observed during antenna motion tests for maser phase and gain stability. The excellent stability performance is attributed to the use of a superconducting maser magnet.

I. Introduction

Noise temperature tests of waveguide feed system components are described in this article. A traveling-wave maser, operating at 15.3 GHz was used in the measurement system. The maser and waveguide feed system has been installed on the 64-m antenna at the Goldstone DSCC. Initial performance has been measured to show the gain and phase stability of the 15.3-GHz maser on a moving antenna.

II. Noise Temperature Measurements

The 15.3-GHz traveling-wave maser (Refs. 1 and 2) was used on the roof of Building 238 at JPL to measure the noise temperature contribution of various waveguide antenna feed components. A similar test at 8448 MHz was reported in March 1970 (Ref. 3). Measured values of system noise temperature were used to determine individual component noise contributions. These values are listed in Table 1. At 8448 MHz the waveguide switch, the polarizer, and the feed horns were made of aluminum; waveguide bends and straight sections were made of copper. At 15.3 GHz all waveguide components tested were made of copper or silver; two feed horns were made of copper and one aluminum horn was measured. Table 1 shows values for components which can be measured by insertion into an operating system.

Table 2 shows the operating noise temperature of three configurations measured on the roof of Building 238. Minimum configurations consist of a feed horn connected directly to a maser and a follow-up receiver with power recording instrumentation. The final configuration (for 15.3 GHz) includes a waveguide switch, a directional coupler, and a polarizer; the components are in the same configuration that is used in the Cassegrain cone on the 64-m antenna at Goldstone DSCC.

The sky temperatures shown in Table 2 were obtained by subtracting the receiver, feed horn, and waveguide component noise temperature contributions from the total system operating noise temperatures. The final configuration at 15.3 GHz was measured at 15-min intervals during a time period beginning July 1 and ending July 12, 1971. The waveguide switch was automated and data were recorded on an almost continuous basis. Manual measurements interrupted the recording process on some occasions.

Roof-top air temperatures and humidity were recorded during the period of July 1 to 12. The absolute humidity varied from 7 gm/m^3 to 14 gm/m^3. The low and high temperatures recorded were 13.5 and 38°C, respectively. No attempt is made here to assign a particular noise contribution to the atmosphere at 15.3 GHz. Weather data were observed and recorded because the resulting changes in system noise temperature are a source of measurement error during component evaluation.

The receiver noise temperatures in Table 2 are the sum of calculated maser equivalent input noise temperatures (6.5 K at 8448 MHz; 8.6 K at 15.3 GHz) and the measured follow-up receiver contribution.

A comparative measurement using feed horns made of copper and of aluminum showed a 0.5 K higher noise contribution for the aluminum feed horn at 15.3 GHz. All feed horn values listed in Table 2 are estimates based on this measurement.

III. Measurement Technique and Accuracy

A large piece of microwave absorber was used as an ambient temperature termination for a feed horn. The system noise temperature data were obtained by covering the feed horn with the absorber and then removing the absorber, allowing the horn to "see" the cold sky; changes in total system noise power were recorded. A detailed description and analysis of noise temperature calibrations using ambient terminations have been published by C. T. Stelzried (Ref. 4).

Measurement errors introduced by mismatches (in the waveguide system) can be detected by using the microwave absorber as a sliding termination. A recording of total system power is made as the absorber is moved slowly away from the horn opening. At a distance of several signal frequency wavelengths the absorber still completely blocks the horn. Recorded power variations are due to mismatch and can be used to establish a limit on the mismatch error. The data recorded in Tables 1 and 2 contain no measurable error due to mismatch. The measurement system was able to resolve noise temperature variations of 0.05 K.

Waveguide component noise temperature contributions listed in Table 1 are accurate to ± 0.2 K. Atmospheric changes during the time length required for the measurement, together with system resolution, determine the measurement accuracy. A ± 0.05 K accuracy results from many rapid measurements of horn covering material.

The absolute accuracy of the total system noise temperature measurement is limited to $\pm 1\%$ by the precision attenuator used for power ratio measurements. The receiver and feed horn values shown in Table 2 are calculated values based on measurements which introduce an uncertainty of ± 1 K. The sky, receiver, and feed horn values should be considered best estimates.

IV. Maser Gain and Phase Stability

A comparison of gain and phase stability recorded for the X-band maser and the 15.3-GHz maser is of particular interest. The X-band maser uses an external ambient-temperature 5000-G permanent magnet. The 15.3-GHz maser uses an internal 4.5 K 7500-G superconducting magnet. The difference in the stability of the two masers is a result of the different maser magnets used.

Use of the superconducting magnet has reduced, by more than half, gain and phase changes caused by relative motion between the maser and the magnet. Signal frequency phase changes caused by changing the alignment of the maser magnet with respect to the Earth's magnetic field (during antenna motion) have been reduced below the level of detection.

A Hewlett-Packard network analyzer has been used on the 64-m antenna to compare the phase of a signal passing through a reference path to the phase of a portion of the same signal amplified by the maser. Figure 1 shows the signal phase change which occurred in the X-band maser and in the 15.3 GHz maser measurement systems. The antenna was rotated 360 deg in azimuth with the elevation angle constant at 88 deg.

The X-band test began at an azimuth of 270 deg; the antenna rotation rate was 0.25 deg/s in the direction of decreasing azimuth. The 28-deg phase change (Fig. 1) is caused by a 0.9-G change within the permanent magnet air-gap. This magnetic field change occurs because the horizontal component of the Earth's magnetic field (0.25 G) alternately aids or opposes the permanent magnet during antenna rotation. The 1.8-to-1 ratio of field in the gap versus external field change is caused by the configuration of high and low permeability materials used in the permanent magnet. Antenna motion in both azimuth and elevation can cause phase changes of up to 45 deg in a maser with a permanent magnet.

The 15.3-GHz test began at an azimuth of 170 deg; rotation was in the direction of decreasing azimuth. Figure 1 shows a peak-to-peak phase change of 0.7 deg. Changes in antenna elevation (from zenith to the horizon) caused a maximum phase change of 2.2 deg through the 15.3-GHz maser.

Changes in maser gain with antenna motion are shown in Fig. 2. The two masers were switched to reference terminations; changes in system noise temperature due to antenna motion near the horizon did not affect the recorded data. The maximum gain change observed for the 15.3-GHz maser was 0.25 dB.

V. Conclusion

Construction and evaluation techniques previously used at X-band have been used to build and test a very low noise 15.3-GHz maser receiving system. A comparison of the new maser with a previously installed X-band maser (on the 64-m antenna) shows a large improvement in gain and phase stability. The improvement in maser stability is the direct result of the use of a superconducting magnet.

References

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Table 1. Component noise temperature contributions

Component	Noise temperature contribution, K	
	8448 MHz	15.3 GHz
Horn cover, 0.0025-cm thick Kapton	–	0.15
Horn cover, 0.008-cm thick Kapton	–	0.3
Horn cover, 0.013-cm thick Kapton	0.2	–
Horn cover, 0.008-cm thick Mylar	0.2	–
Waveguide rotary joint, TE_{11}	–	0.6(3)
Waveguide vacuum window	–	0.7
Linear to CP polarizer	0.9(2)	1.3(3)
Straight waveguide, 10-cm long	0.6(1)	1.4(1)
Waveguide switch, straight through	1.3(2)	1.3(3)
Waveguide switch, side arm and 90 deg bend	2.0(4)	3.2(5)
Directional coupler, 30 dB	–	2.0(3)

(1)Calculated value based on insertion loss of copper waveguide is shown for comparison.
(2)Material, aluminum.
(3)Material, copper.
(4)Switch material, aluminum; bend material, copper.
(5)Switch material, copper; bend material, silver.

Table 2. System operating noise temperature contributions

System or part of system	Noise temperature, K		
	8448 MHz	15.3 GHz	
	Minimum configuration	Minimum configuration	Final configuration[a]
Total system operating noise temperature, T_{op}			
Minimum	–	–	21.5
Maximum	–	–	26.0
Nominal	13.1	18.5	23.0
Sky (includes atmosphere and background)			
Minimum	–	–	6.4
Maximum	–	–	10.9
Nominal	4.3	8.1	7.9
Receiver (maser + follow-up contribution)	7.2	8.7	8.7
Feed horn	1.6	1.7	1.7
Waveguide components (switch, coupler, polarizer and horn cover)	–	–	4.7

[a]Waveguide system identical to cone configuration installed on 64-m antenna.

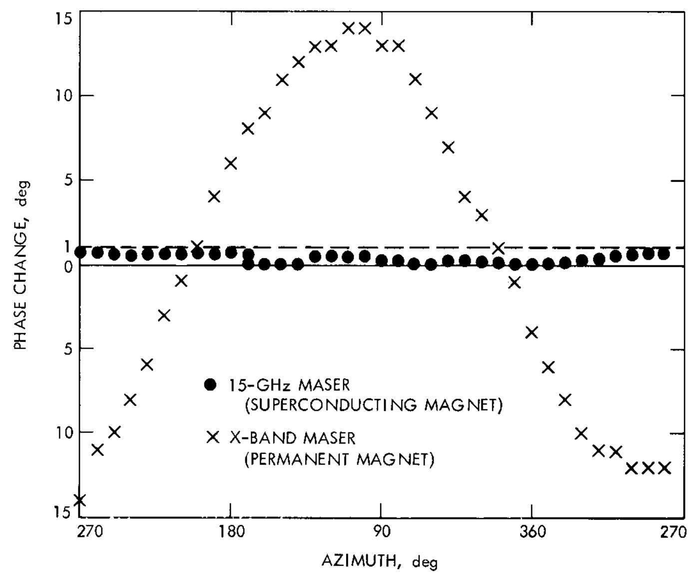

Fig. 1. Maser phase stability, antenna moving in azimuth

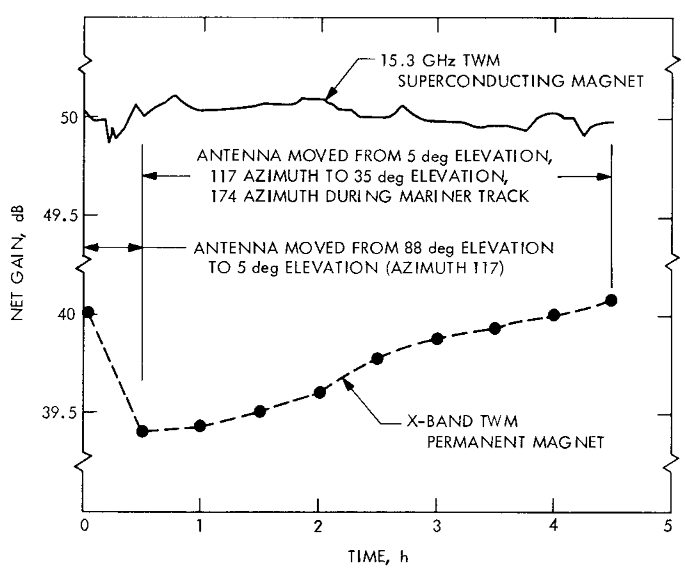

Fig. 2. Maser gain stability, antenna moving in elevation and azimuth