X-Band Traveling Wave Maser Amplifier

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An X-band traveling wave maser amplifier (maser) has undergone preliminary tests in the laboratory. The masers are being developed for use in the 64-meter-diameter antenna Deep Space Stations to meet ground support requirements of the Viking 1975 flight project.

The maser has 53 dB net gain, with 43 MHz instantaneous 1-dB bandwidth at 8420 MHz. Mechanical tuning of the pump klystrons enables the maser to be tuned to 8600 MHz, with 43 MHz instantaneous 1-dB bandwidth at 45 dB net gain.

I. Introduction

An X-band traveling wave maser amplifier (maser) is being developed for operational use in the 64-meter-diameter antenna Deep Space Stations. The primary purpose of the maser is to meet ground support requirements of the Viking 1975 Project, which requires an instantaneous 1-dB bandwidth of 35 MHz covering the frequency band of 8400 to 8435 MHz.

A design goal of 35 MHz, 1-dB instantaneous bandwidth, and 8400 to 8435 MHz, with 45 ± 1 dB net gain, was established in November 1972 as the result of flight project and ground system requirements.

A maser has been designed and a preliminary test has been completed. Design criteria and preliminary test results are described in this article.

The test maser provides 53 dB gain, with an instantaneous 1-dB bandwidth of 43 MHz over the Viking 1975 frequency band. Mechanical tuning of the pump klystrons enables the maser to be tuned to 8600 MHz, with 43 MHz instantaneous 1-dB bandwidth at 45 dB net gain. The test results show that the gain/bandwidth design goal has been achieved, and indicate the possibility of future applications over a much wider frequency tuning range.

II. Maser Description

The assembled maser is shown in Fig. 1 (A) with the cover (B) removed. The slow wave structure (C) is machined from a solid piece of copper. The structure consists of two parallel comb sections, connected in series by sections. The signal is coupled from the input and output coaxial lines to the comb sections with loops that terminate near the base of each comb at the left-hand end. Pump frequency radiation enters the maser through an opening in the center of the flange at the left and is coupled to the ruby through shaped alumina dielectric strips, as shown in Fig. 2. The alumina strips improve the pump match into the ruby.

III. Maser Comb Design and Loading

A previous X-band maser (Ref. 1) was designed for a broad tuning range. The maser for Viking 1975 requires a larger gain/bandwidth product over the frequency range of 8400 to 8435 MHz. This requirement resulted in a new maser design for Viking 1975. The new design features a comb structure which provides (1) an increased fill factor, (2) improved isolator performance, and (3) improved slowing factor adjustment capability. It also features an improved technique for maintaining constant contact pressure between the ruby, alumina, and comb section finger surface.

The nonsymmetrical comb channel design, as shown in Fig. 3, together with optimized finger geometry, provides an improved fill factor over previous X-band masers (Ref. 1). The narrow channel width filled with ruby, combined with the finger geometry, maximizes orientation of the RF magnetic field in the direction of maximum transition probability. The larger channel filled with alumina provides larger regions of circular polarization for optimum isolator performance. Optimized fill factor and isolator performance result in higher net gain per unit length.

A beryllium copper strip with mounting screws on each side of the maser supplies pressure to pins which protrude through the maser sidewall (Fig. 3). The pins transfer pressure through the alumina strip, comb section, and ruby bar to insure consistent surface contact and sufficient pump heat conduction.

The 7.54-cm-length comb sections are loaded with ruby on the inner side of the comb and alumina (which supports the isolator material) on the outer side. This type of construction is similar to that of previous X-band masers.

The ruby bars, as in previous masers, are fabricated from "0-degree" Czochralski ruby with 0.05 to 0.07% Cr_2O_3. C-axis orientation is along the length of the comb. The alumina strip, as shown in Figs. 3 and 4, is constructed from two alumina bars glued together, with a 0.64-mm-width dimensional offset. The offset produces a step area on the top and bottom edges of the strip. The bottom step is used for isolator mounting, and the step at the top of the strip provides a coarse slowing adjustment. The ruby bar is bevel-shaped on one edge and provides a vernier slowing adjustment.

A range of slowing was achieved with the structure by using variable amounts of comb loading. Equivalent electrical lengths were measured over the range of 6.23 to 13.60 m. The slowing factor of the test maser was adjusted to yield the desired gain-bandwidth product over the 8400 to 8500 MHz band. The ratio of the slowing factor vs frequency of the test maser was measured with the results shown in Fig. 5. The equivalent electrical length is approximately 8 m.

IV. Isolator Performance

The isolator consists of 96 polycrystalline yttrium iron garnet (YIG) squares, each with dimensions of $0.635 \times 0.635 \times 0.0762$ mm. The squares are glued to the alumina strips, as shown in Figs. 3 and 4, on the bottom step. The isolators are positioned at a 45-deg angle to the finger surface, with one corner keyed in a locating slot cut in the alumina strip. The isolators are located in the optimized region of circular polarization, determined for this structure as defined by Chen and Tabor (Ref. 2). A reverse-to-forward loss ratio of 70 to 1, with the reverse loss greater than 200 dB and a forward loss of 3 dB, has been achieved. The minimum isolator forward loss occurred at the desired frequency location in the structure bandpass, as shown in Fig. 5. Previous X-band masers (Ref. 3), using strip-shaped isolators, achieved a reverse-to-forward loss ratio of 20 to 1. Isolator geometry and dimensional tolerances have been determined to place isolator resonance at the correct magnetic field strength in reference to ruby absorption. This results in maximized reverse loss at the correct frequency and bandwidth with tolerance to magnet field rotation. The isolator is capable of ± 4 deg rotation in the magnetic field without degradation to maser performance.

V. Maser Test Conditions

The test maser was cooled by submersion in liquid helium under controlled helium gas supply pressure. A Varian Electromagnet Model 3603 and Varian Field Regulated Power Supply Model V-FR2503 were used to supply a uniform-strength adjustable field. Field spreading was accomplished with two coils mounted to the bottom of the maser structure and connected in a figure eight manner, with one aiding and one bucking the main magnet field. Push-push pumping was performed by dual klystrons at different frequencies (as reported in Ref. 4).

VI. Pump Modulation

Preliminary tests were conducted to determine the effect of pump frequency modulation on the gain/bandwidth performance of the maser, using field spreading to obtain the desired bandwidth. In an early test, a 1-dB instantaneous bandwidth of 40 MHz centered at 8277 MHz, with 35 dB net gain (as shown in Fig. 6), was achieved without pump frequency modulation. A 1 dB instantaneous bandwidth of 38 MHz centered at 8277 MHz, with 46 dB net gain (Fig. 7), was obtained with pump frequency modulation at a 20-kHz rate and modulation amplitude adjusted for maximum maser gain. The pump level was adjusted for proper pump saturation for both tests. Tests indicate that an increase of approximately 10 dB in net gain at the same bandwidth can be realized by using pump modulation. Pump modulation was used on previous S-band and X-band masers operating in a uniform field (Ref. 5).

VII. Maser Performance

Gain vs frequency curves, with the maser tuned to 8420 MHz, 8500 MHz, and 8575 MHz, are shown in Figs. 8, 9, and 10, respectively. An instantaneous 1-dB bandwidth of 43 MHz is achieved at the center frequencies of 8420 MHz, with 53 dB net gain; 8500 MHz, with 46 dB net gain; and 8575 MHz, with 45 dB net gain. A net gain of 45 dB can be obtained at any frequency between 8400 and 8600 MHz, with an instantaneous 1-dB bandwidth of 40 MHz or greater, by mechanically tuning the two pump klystrons.

VIII. Conclusion

A new X-band maser has been designed to meet Viking 1975 requirements. The test results indicate that the requirements for gain/bandwidth have been met with a considerable margin. The structure shows a capability for operation up to 8600 MHz with appropriate accessory equipment. Minor adjustments will be made when the maser is installed in an operational closed-cycle refrigerator. Future tests will include gain stability, noise temperature, group delay, and match measurements.

Acknowledgment

The X-band maser described in this article is the product of a combined effort. The assistance of R. Clauss in providing his experience in maser design and R. Quinn in fabrication techniques is gratefully acknowledged. Thanks are also due to E. Wiebe for special test equipment and facilities support.

References

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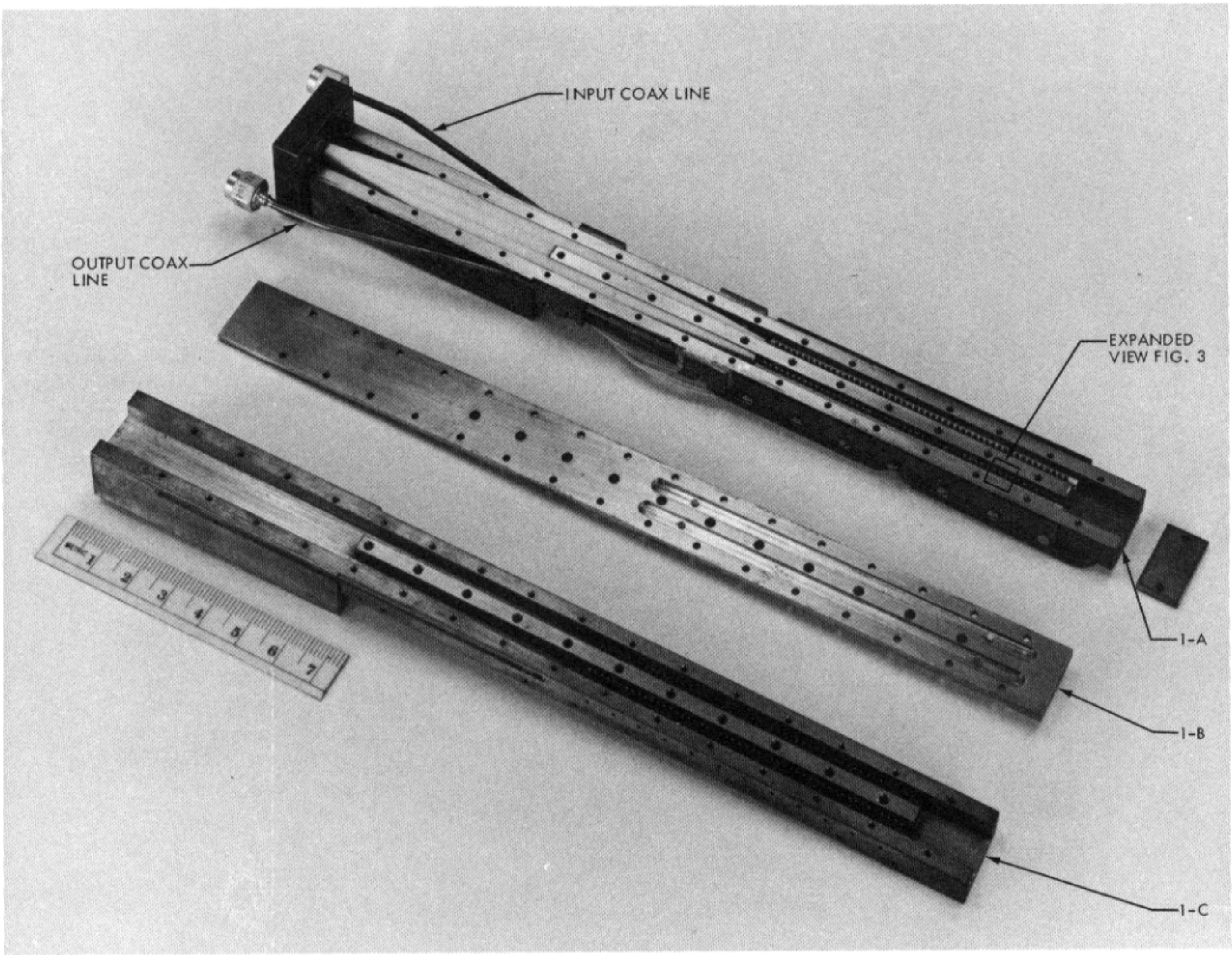

Fig. 1. Assembled X-band maser and slow wave structure

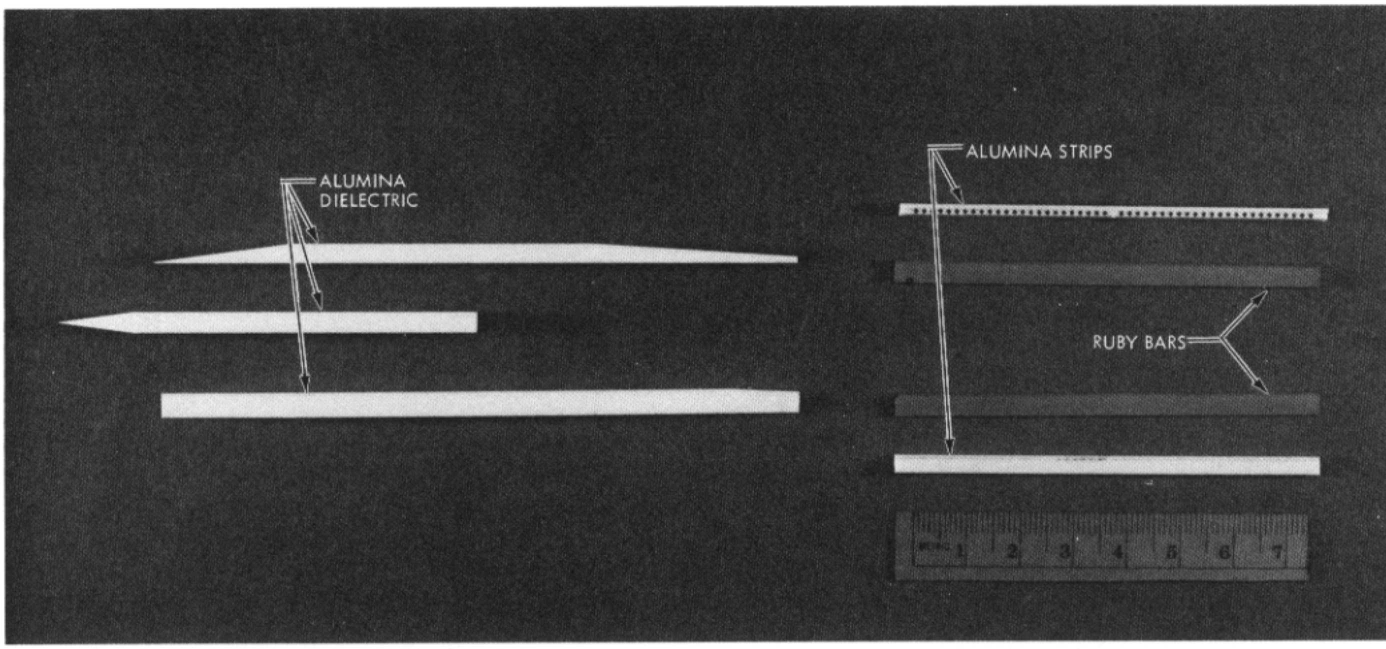

Fig. 2. Shaped alumina dielectric bars with ruby bars and alumina strips

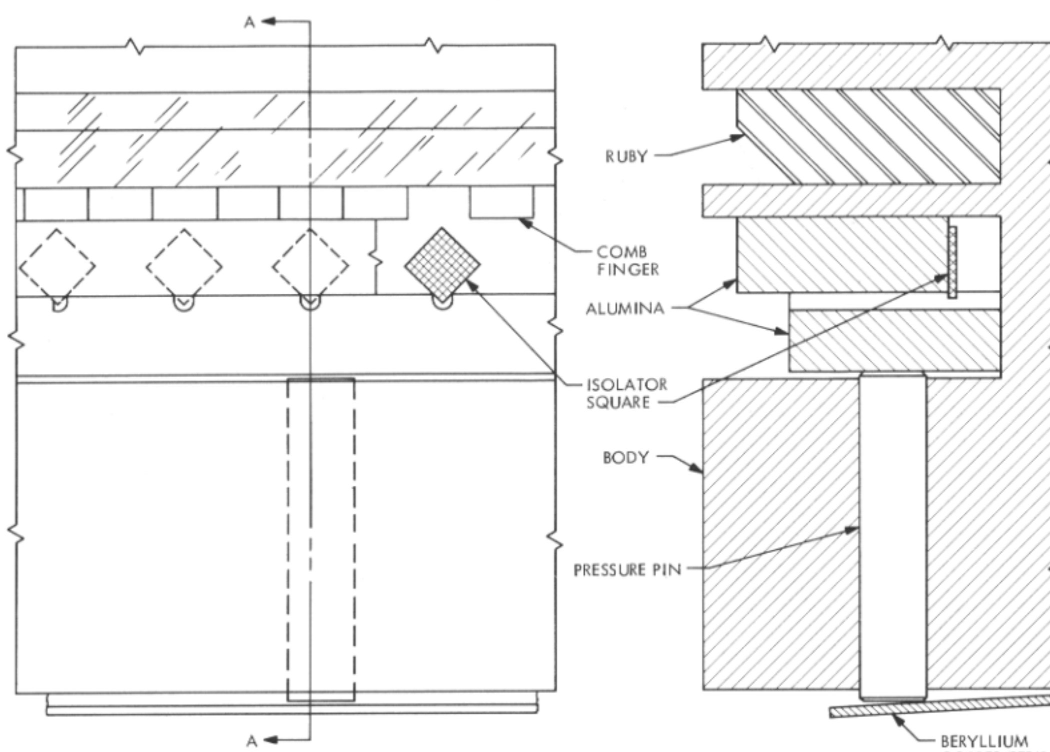

Fig. 3. Comb structure loading and isolator location

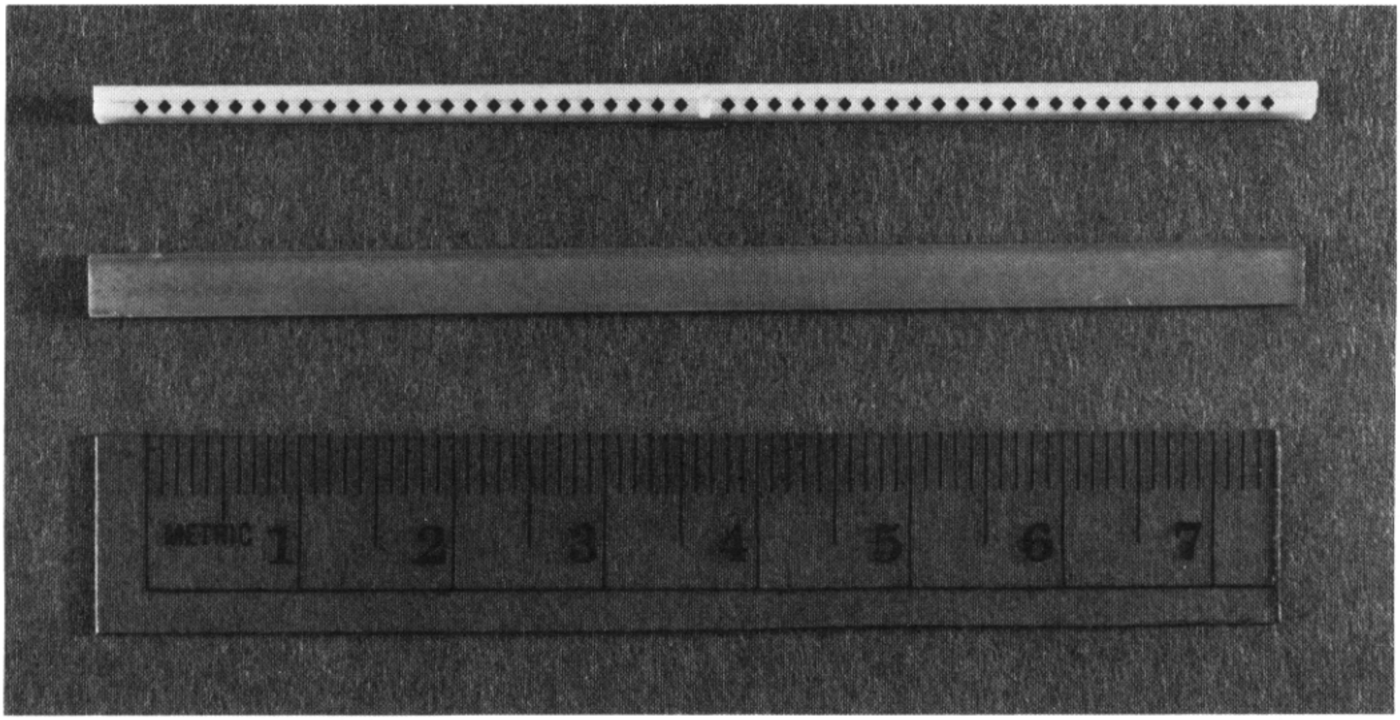

Fig. 4. Alumina strip with mounted isolator squares and ruby bar

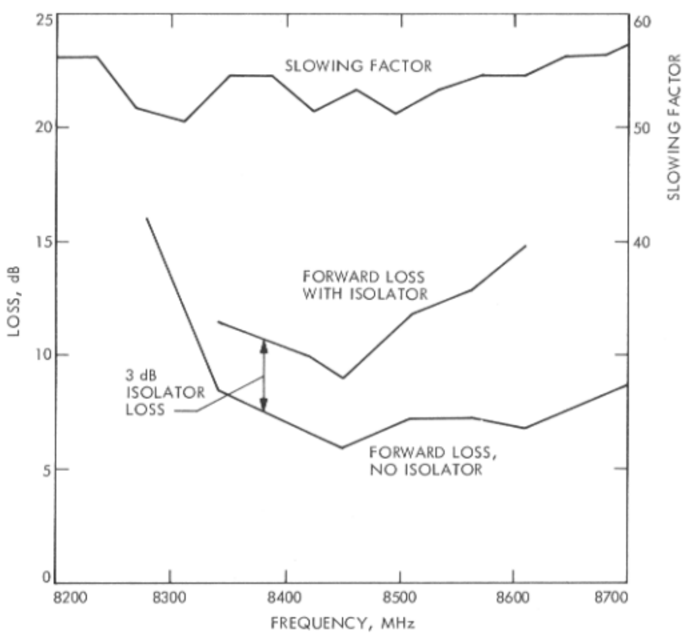

Fig. 5. Maser forward loss and slowing factor vs frequency

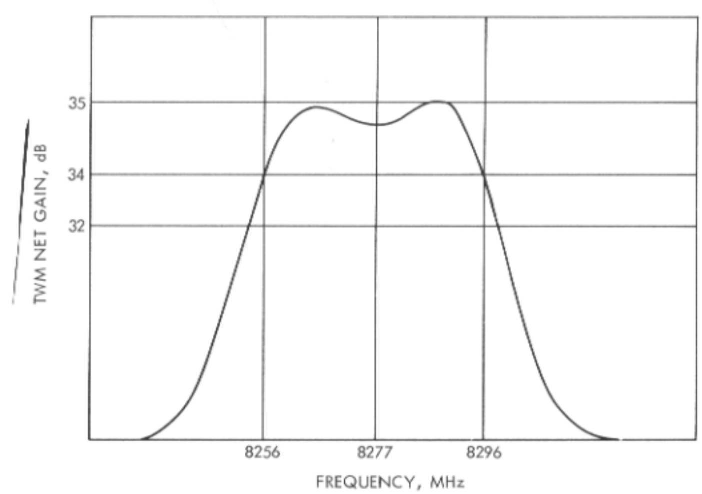

Fig. 6. Maser gain vs frequency without pump frequency modulation

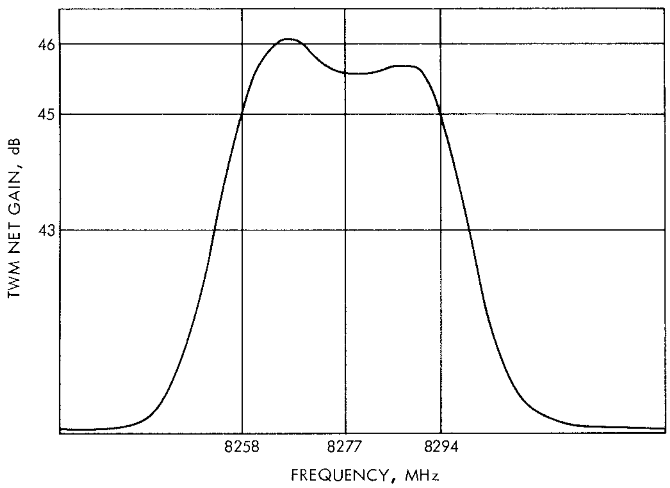

Fig. 7. Maser gain vs frequency with pump frequency modulation

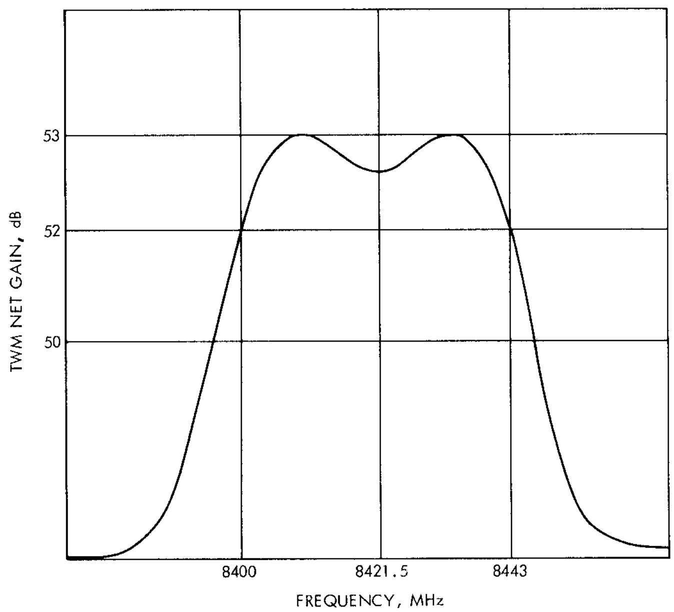

Fig. 8. Maser gain vs frequency at frequency band required for Viking 1975

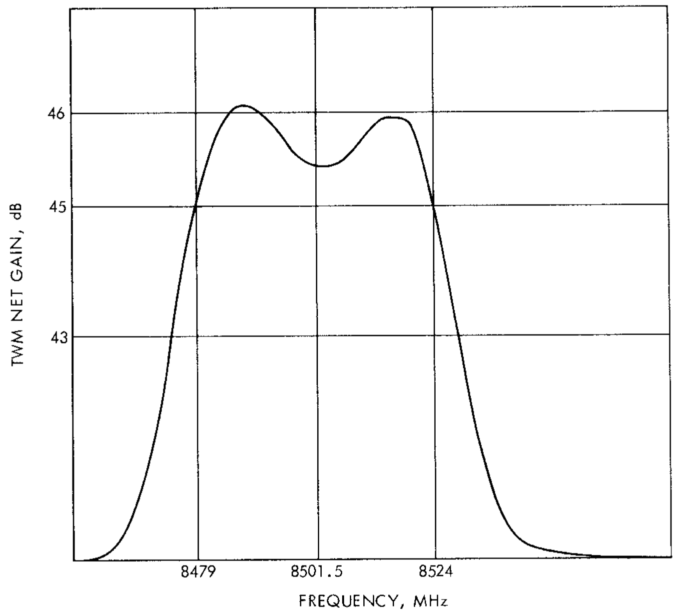

Fig. 9. Maser gain vs frequency at mid-structure tuning range

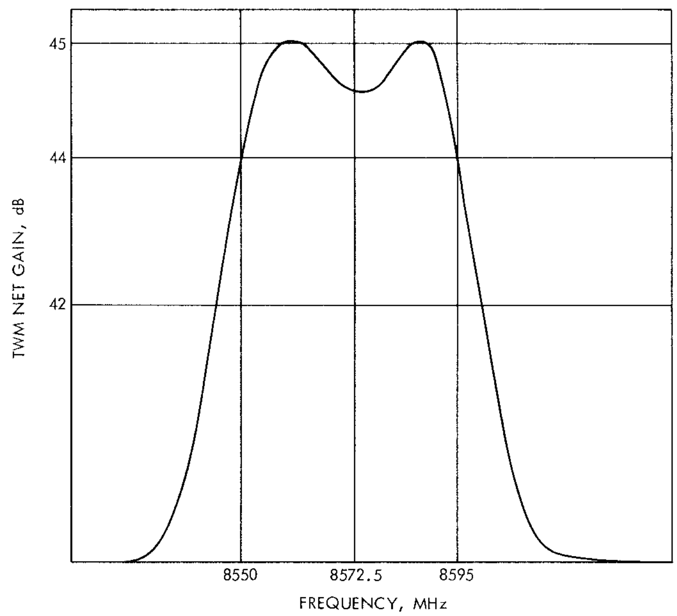

Fig. 10. Maser gain vs frequency at upper end of structure tuning range