# S-Band Ultralow-Noise Traveling-Wave Maser

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*Two S-band traveling-wave maser (TWM) systems with effective input noise temperatures of 2.0 K at 2295 MHz have been supplied to the Deep Space Network. These TWMs are used on the 64-m antennas at Deep Space Stations 43 and 63 to meet the requirements of the Voyager and Pioneer projects. The TWMs use shortened and cooled signal input transmission lines to reduce noise and are equipped with superconducting magnets and solid-state pump sources to provide improved stability performance.*

## I. Introduction

The Voyager and Pioneer projects have increased requirements for traveling-wave maser (TWM) sensitivity and stability at S-band. Two TWM systems have been built in response to these requirements and installed at Deep Space Stations (DSSs) 43 and 63. Interchangeability with existing Block III TWMs was required. The TWMs have shortened and cooled input transmission lines that reduce the noise temperature as compared to previous operational systems (Ref. 1). Superconducting magnets and solid-state pumps are used to improve TWM gain, phase, and group delay stability. Previously reported research and development (R&D) TWMs (Ref. 2) used the shortened input transmission lines; they were described in detail and will not be covered here. The TWMs provide 45 dB net gain with a 3-dB bandwidth from 2265 to 2305 MHz. Optimum noise performance is achieved at 2295 MHz. An effective input noise temperature of 2.0 K and an overall system temperature of 8.0 K were measured during the evaluation of these systems using a low-noise horn looking at cold sky. The new S-band TWMs are identified Block IV TWMs.

## II. Maser Description

The Block IV TWM assembly shown in Fig. 1 is supported by a new frame that is similar to X-band TWMs implemented into the DSN this year. The Block IV TWM package design is smaller in volume and weight, approximately 80 kg, and enables the maser to be shipped at lower cost. Previous TWMs (Ref. 1) utilized a much larger frame and included support equipment on the same frame. The Block IV TWM package enables the refrigerator-maser assembly and pump assembly to be separated from the support equipment, thereby simplifying removal and maintenance procedures. The Block IV TWM assembly is similar in function to a previous R&D model TWM (Ref. 2). The Block IV TWM uses a similar shortened and cooled signal input transmission line that reduces its noise contribution to only 0.4 K; previous Block III TWMs (Ref. 1) used input signal transmission lines that contributed 2.1 K. The Block IV TWMs are equipped with superconducting magnets and solid-state pump sources to provide improved stability performance. The use of solid-state pump sources will also increase reliability over previous klystron tube pump sources used on Block III type TWMs.

## III. Structure Detail

The Block IV TWMs use modified Block III TWM comb structures returned from the DSN for conversion. The converted comb structures are similar to Block III units as reported in Ref. 2 with the exception of modifications described here. A large slowing factor was used on the original Block III TWM comb structures and, because of high resulting gain, magnetic field distortion was necessary to reduce gain to the specified value. During this conversion, the electrical length was reduced from 40 meters to around 35 meters. The reduced electrical length was achieved by grinding a bevel on the ruby top edge on the surface contacting the comb. The structure lid-to-comb-finger top clearance was decreased to further reduce the slowing and shift the maser bandpass lower in frequency to compensate for the upward shift caused by ruby shaping. Reduced slowing, used mainly to obtain the proper gain without magnetic field distortion, results in reduced structure loss and reduces the TWM noise temperature. The desired bandwidth is obtained by use of two field spreading coils attached to the TWM structure. The coils create two magnetic field strength levels within the maser structure and result in a stagger-tuned bandpass. The coils are movable along the length of the maser comb structure and are used to equalize the gain of the lower and higher frequency sections of the maser. Separation of the coils reduces the overall net gain and increases the maser bandwidth by producing a third intermediate, magnetic field region. A soft iron shim is used under one of the coils to reduce the amount of field spreading current required.

## IV. Solid State Pump

The solid-state pump assembly uses a Gunn-effect oscillator (for the pump frequency source), a modulator, and protective circuitry similar to a previous solid-state pump source (Ref. 3). A commercially available overvoltage protect circuit and variable attenuator are used with the Block IV pump source assembly shown in Fig. 2. The overvoltage protector prevents damage to the Gunn-effect oscillator caused by excessive power supply output voltage due to improper adjustment, improper connection, or failure of the power supply. The variable attenuator is used to reduce the pump power to a level that saturates the TWM without subjecting the cryogenic system to excessive heat loads. The Gunn-effect oscillator provides up to 200 mw of power electronically tunable from 12.6 to 12.9 GHz. The modulator can be adjusted to sweep the pump frequency across any portion of this range at a 100-KHz rate.

## V. Superconducting Magnet

The superconducting magnet (SCM) provides a uniform field near 0.25 tesla as required for S-band maser operation. The SCM is similar to a previously reported SCM (Ref. 4). The magnet operates in a persistent mode in the vacuum environment of the closed cycle refrigerator (CCR) at the 4.5 K temperature. The circuit consists of a pair of superconducting magnet coils, a superconducting switch (S-C switch) and a resistive shunt circuit. The SCM coils and the S-C switch are constructed of superconducting wire of copper-clad niobium-titanium (NbTi), coated with Formvar insulation. The SCM coils and S-C switch are constructed from one continuous piece of superconducting wire with a zero-resistance superconducting welded junction at a heat sink attached to the 4.5 K heat station of the CCR. The S-C switch is a portion of the superconducting wire (with the Formvar and copper removed) inside a small radiation shield, where it is exposed to radiation from a light bulb to heat the wire. The resistive shunt circuit is constructed of brass rod and a specific length of a stainless steel screw. The shunt circuit is connected at one end to the superconducting wire welded junction and the other end (stainless steel screw) to a ground point on the SCM base flange. The shunt circuit is in parallel with the SCM coils and S-C switch circuit. The entire circuit operates at a temperature of 4.5 K, and is mounted on the CCR at the same heat station as the maser structure.

## VI. Support Equipment and Instrumentation

The following new assemblies were replaced or incorporated in the Block IV maser instrumentation: (1) replacement of the calibration assembly, (2) new maser monitor assembly, (3) new superconducting magnet control assembly, (4) replaced klystron power supply with the pump control assembly, (5) new magnet charging supply, and (6) new junction boxes for maser and monitor equipment.

The TWM assembly is mounted on a common base plate with the support equipment rack and is shown in Figs. 3 and 4. The support equipment rack provides calibration signal injection points for gain, noise temperature, and signal path length calibration of the TWM. A switch is provided to connect a calibration signal to a pre- or post-TWM injection point for gain calibration of the TWM. A post-TWM directional coupler is provided for output signal connection to the monitor receiver. The monitor receiver remains unchanged and provides the same visual bandpass indication as used with previous Block III masers.

New operating controls and indicators for the Block IV TWM are provided by the maser monitor assembly, which is located on the support rack assembly (Fig. 4); and the superconducting magnet control assembly (Fig. 5) and the magnet charging supply, which are located in the control room cabinets. These assemblies are used in conjunction with the monitor receiver instrumentation to charge the superconducting magnet to the correct field strength for maser operation. The maser monitor assembly contains a field strength meter and a bridge amplifier that amplifies the current unbalance that exists in a magnetic field sensitive resistance bridge located on the maser amplifier body within the superconducting magnet. The bridge amplifier output is adjusted to provide zero deflection on the superconducting magnet control field strength meter with no magnetic field. It is adjusted for one-half scale deflection at the operating magnetic field strength of 0.25 tesla. The field strength meter provides the operator an indication of magnet charging rate. The magnet unlock control applies power to the S-C switch heater (light bulb) in the SCM assembly. This control is interlocked with the magnet charging power supply to prevent accidental unlocking of the SCM and its discharge to zero field.

The maser pump control, shown in Fig. 6, provides the tune, modulate, and Gunn bias voltages for the solid-state pump source used with the Block IV TWM. The pump control is all solid-state and is expected to greatly reduce power supply failures associated with the previously used klystron power supplies.

## VII. Performance

The following performance requirements were established for the Block IV TWM:

(1) Gain and bandwith: 45 ± 1 dB at maximum between 2270 and 2300 MHz with −1 dB bandwidth of 30 MHz minimum and −3 dB bandwidth of 40 MHz minimum.

(2) Gain stability: stationary short term ±0.03 dB for 10 seconds any position, and long term ±0.5 dB for 12 hours any position.

(3) Effective noise temperature: 2.5 K ± 1.0 K, 2285 to 2300 MHz and 2.5 K + 2.0, −1.0 K, 2270 to 2285 MHz.

The gain and bandwidth were measured prior to shipment and the above specifications were met. The noise temperature was measured using a horn and ambient temperature load (microwave absorber). The TWMs effective temperatures were 2.0 K at 2300 MHz, 2.5 K at 2285 MHz, and 4.0 K at 2270 MHz. The gain stability and system noise temperature (includes feed horn, maser, and receiver noise temperature contributions) as reported by DSS 43 and 63 are listed in Table 1.

The Block IV TWMs have met or exceeded all the performance goals established. A third unit is to be installed at DSS 14 in the near future and one additional unit at each 64-m station will bring the total number of Block IV TWMs in the DSN to 6.

# References


1. Trowbridge, D., "Block III Implementation Program" in *The Deep Space Network Progress Report*. Technical Report 32-1526, Vol. XVIII, pp. 130-135, Jet Propulsion Laboratory, Pasadena, Calif., Dec. 15, 1973.

2. Clauss, R., and E. Wiebe, "Low Noise Receivers: Microwave Maser Development" in *The Deep Space Network Progress Report*. Technical Report 32-1526, Vol. XIX, pp. 93-96, Jet Propulsion Laboratory, Pasadena, Calif., Feb. 15, 1974.

3. Quinn, R., "Low Noise Receivers: Microwave Development" in *The Deep Space Network Progress Report*. Technical Report 32-1526, Vol. XIV, pp. 46-49, Jet Propulsion Laboratory, Pasadena, Calif., April 15, 1973.

4. Berwin, R., E. Wiebe, and P. Dachel, "Superconducting Magnet for a Ku-Band Maser" in *The Deep Space Network Progress Report*. Technical Report 32-1526, Vol. V, pp. 109-114, Jet Propulsion Laboratory, Pasadena, Calif., Oct. 15, 1971.

**Table 1. TWM performance**

| Parameter | DSS 43 | | DSS 63 | |
|---|---|---|---|---|
| Gain stability | | | | |
| short term | 0.04 dB p-p | | <0.05 dB p-p | |
| long term | 0.33 dB p-p | | 0.05 dB p-p | |
| System noise temperature at: | RCVR 1 | RCVR 2 | Monitor RCVR | RCVR 3 |
| 2265 MHz | 19.8 | 19.8 | – | – |
| 2270 MHz | – | | 19.91 | – |
| 2275 MHz | 17.3 | 17.4 | – | 18.49 |
| 2285 MHz | 16.3 | 16.3 | 18.16 | 16.78 |
| 2295 MHz | 15.8 | 15.8 | – | 16.67 |
| 2300 MHz | – | | 18.71 | – |
| 2305 MHz | 16.3 | 16.3 | – | – |

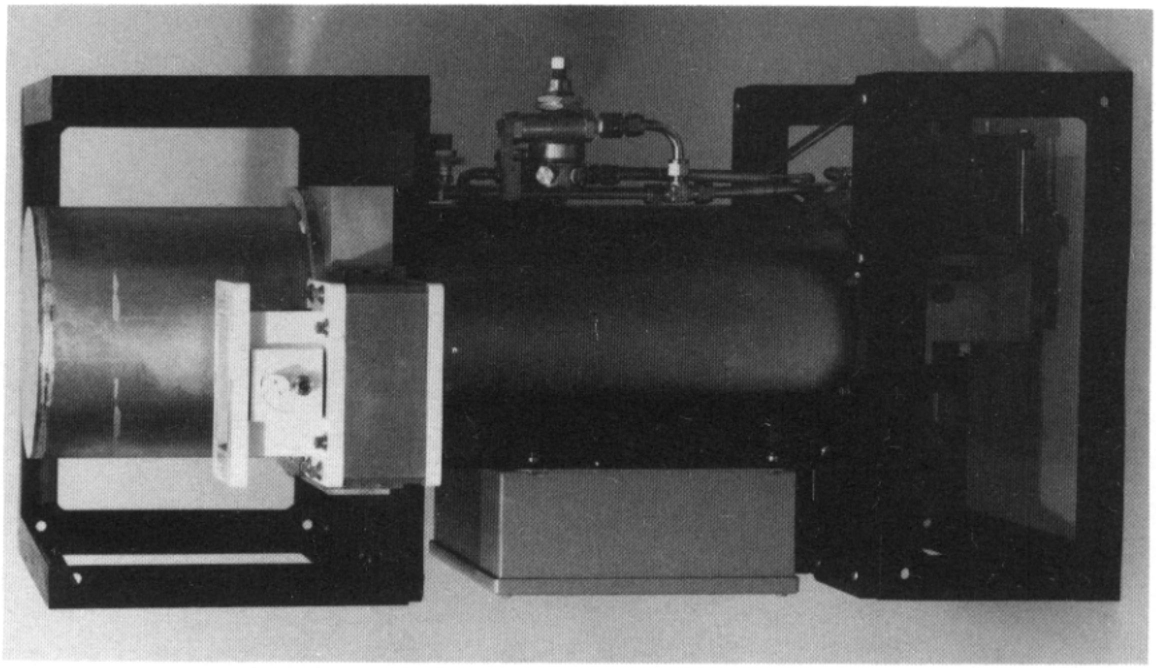

Fig. 1. Block IV traveling-wave maser (TWM) assembly

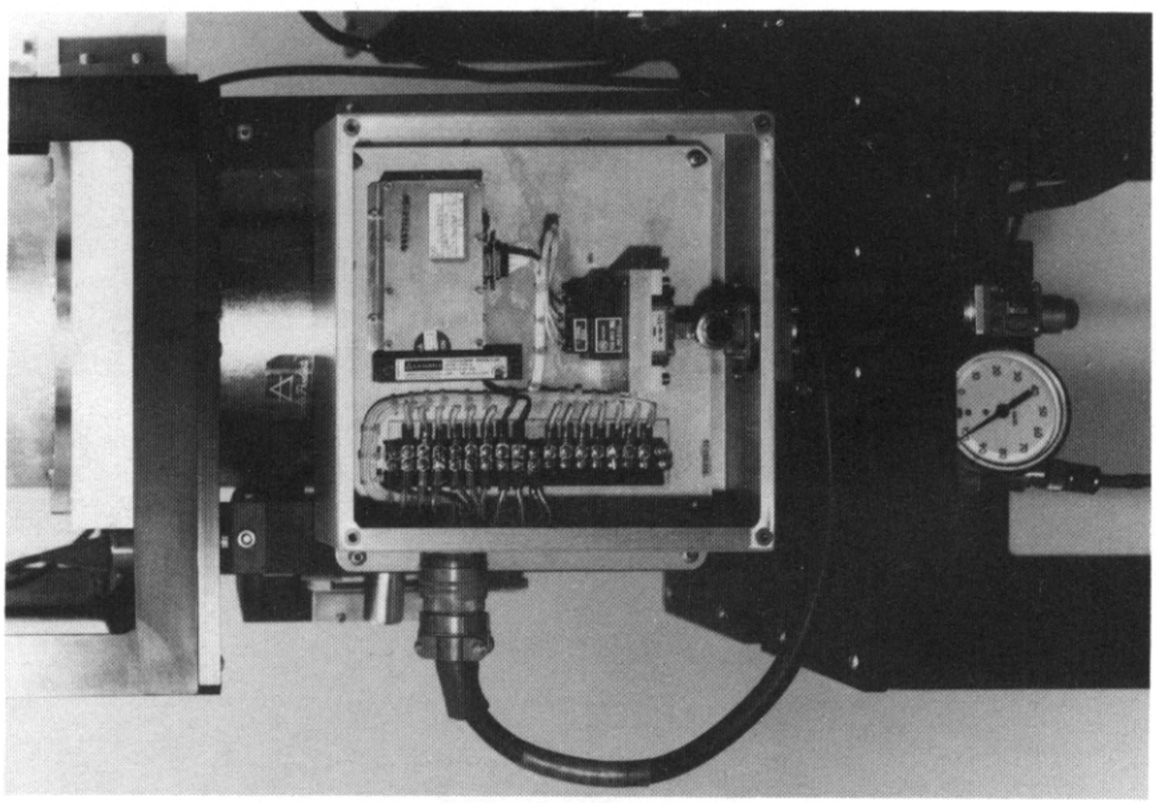

Fig. 2. Pump source assembly mounted on Block IV TWM

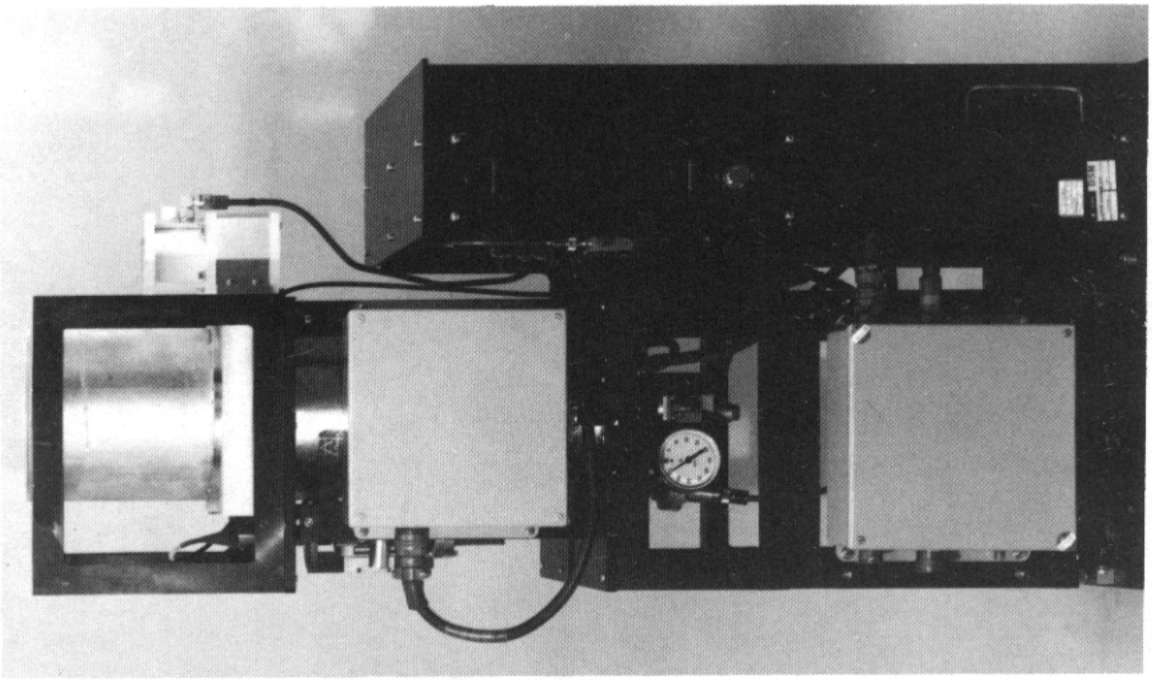

Fig. 3. TWM/CCR and support rack assembly, front view

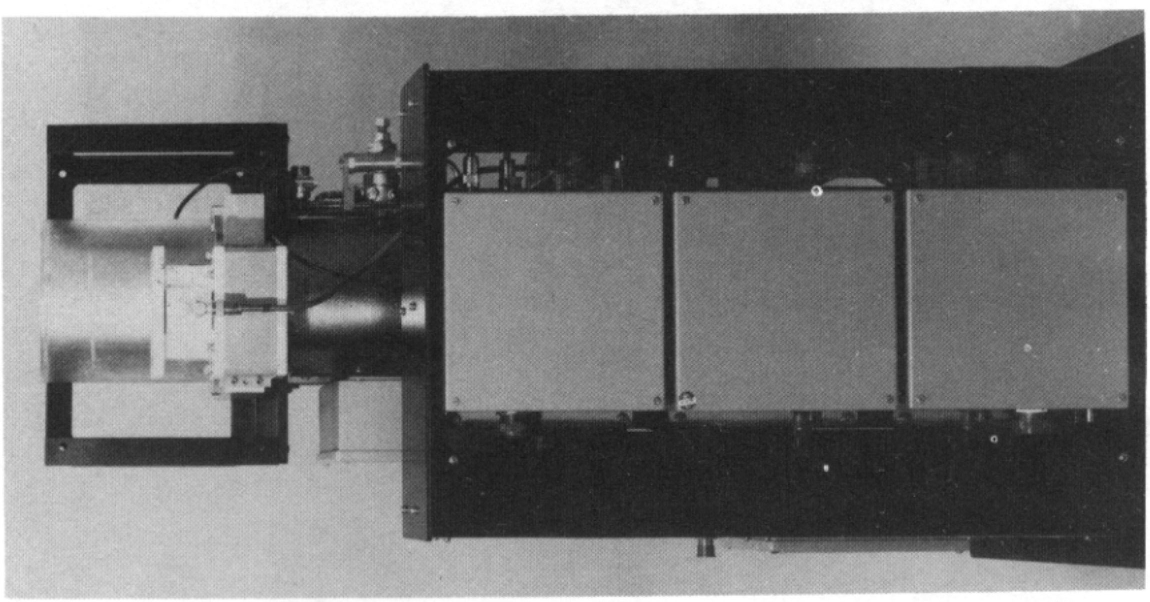

Fig. 4. TWM/CCR and support rack assembly, side view

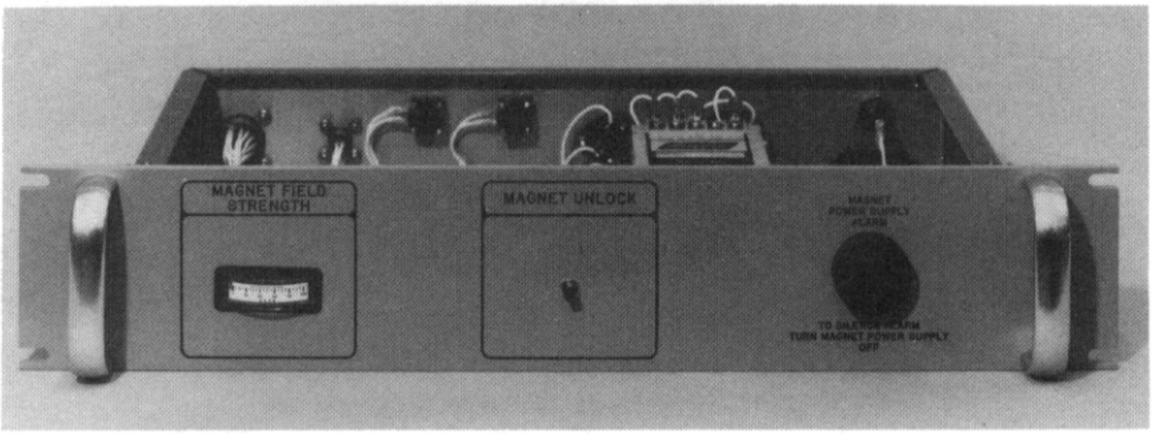


Fig. 5. Superconducting magnet control

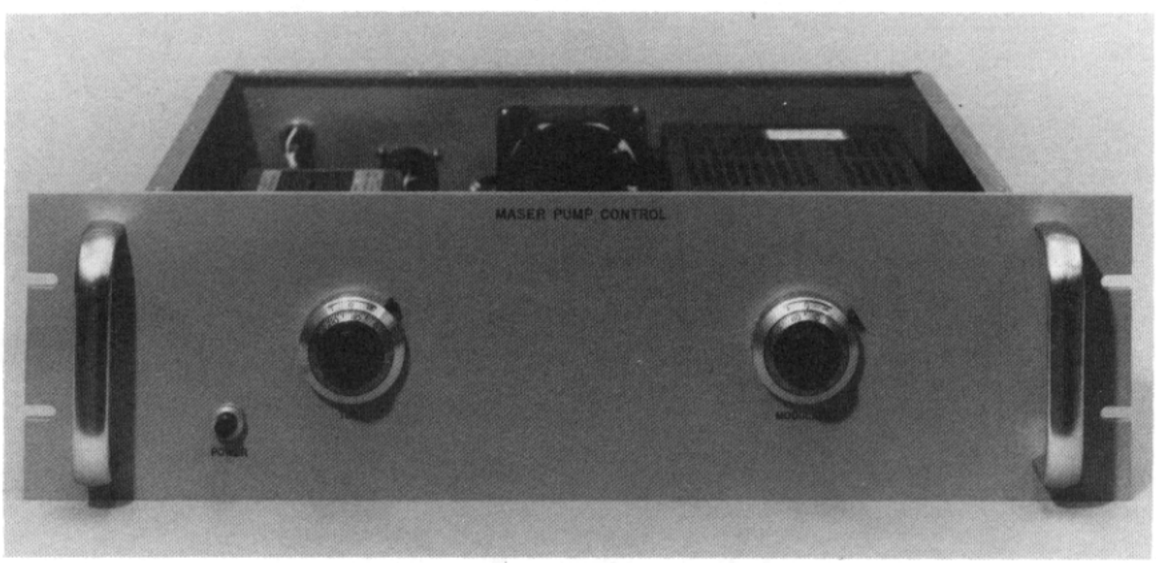


Fig. 6. Maser pump control