Low Noise Receivers: Microwave Maser Development

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Microwave maser amplifiers have been used by the Jet Propulsion Laboratory in the Deep Space Network for twelve years. Pump frequency requirements have been met mainly with reflex klystron oscillators. Other microwave power sources have been tested for use as maser pump sources. Successful performance tests have been achieved with backward-wave oscillators, crystal-controlled oscillators using solid state multipliers, impatt oscillators, and an impatt noise generator. Current maser pump source requirements have a frequency range of 12.5 to 45 GHz. Power required is approximately 150 mW. Cost, availability, reliability, frequency and power stability, tunability, and power requirement considerations have resulted in the use of klystrons as pump sources for all maser amplifiers now operating in the Deep Space Network.

I. Introduction

The use of microwave maser amplifiers in the Deep Space Network (DSN) began in 1960 at Goldstone, California. A 960-MHz cavity maser was used on a 26-m-diameter antenna. A reflex klystron oscillator at 10.6 GHz was used to pump the maser. Since 1960, 44 maser systems have been installed on antennas in the DSN at L-, S-, X-, and Ku-band frequencies (960 MHz to 16.3 GHz).

Five different types of microwave power sources have been used to provide pump power for masers at the Jet Propulsion Laboratory (JPL). Many considerations led to the selection of reflex klystron oscillators as pump sources for all maser amplifiers currently in use in the DSN.

II. Maser Pump Requirements

Maser pump frequency requirements are determined by the maser signal frequency and the type and orientation of the maser material used. Ruby material oriented with $\theta = 90$ deg in comb-type traveling-wave masers is now used in all DSN maser amplifiers. Maser signal and pump frequencies used in the DSN or in tests at JPL are listed in Table 1. The pump frequency required for optimum maser performance is within 30 MHz of the value listed in Table 1. Individual masers of the same design vary in the precise pump frequency needed for optimum performance. These pump requirement variations are caused by slight differences of ruby size, orientation, microwave structure size, signal coupling circuits, and pump coupling circuits in different amplifiers. Once optimized, the pump frequency should be held constant within 1 MHz. The effects of pump frequency and amplitude changes on maser performance have been reported previously (Refs. 1 and 2). Improved maser stability achieved by pump frequency modulation (described in Ref. 2) has been implemented in some masers operating at S-, X-, and Ku-band frequencies. The optimum pump power level for these masers is between 100 and 200 mW.

The selection of pump sources for maser systems used in the DSN is influenced by many considerations. A 200-mW output power capability is desirable. 50-MHz electronic tunability is required in most applications; 200-MHz to 4-GHz tunability is advantageous in some systems. High input voltage requirements result in the use of expensive power supplies and antenna cables (systems now in use have 800-volt klystron beam voltage capability). Information about cost, availability, life expectancy, operating history, and stability is also considered in the selection of maser pump sources.

III. Pump Source Types

An impatt noise generator was used to pump an S-band maser in the laboratory. The Varian VSU-9560N produced more than 200 mW total integrated noise power between 12.63 and 12.75 GHz. The gain and noise temperature of the maser (when "noise pumped") measured the same as when the maser was pumped with a klystron. Additional tests of noise amplitude stability, load impedance change effects, environmental effects, and repeatability of the output noise spectrum in several units will be required before a determination of field worthiness can be reached.

Impatt oscillators operating between 12.5 and 13 GHz are in use for maser tests in the laboratory. These simple, easy to use oscillators are useful where maser performance can be optimized by mechanical tuning. Limitations of electronic tunability and frequency instability are reasons for not using impatt oscillators in the field at the present time.

A voltage-controlled crystal oscillator with a solid-state multiplier produced more than 200-mW power and was tunable from 12.66 to 12.72 GHz. The temperature coefficient of power measured −0.08 dB/°C between 40 and 60°C, −0.03 dB/°C from 20 to 40°C, and less than 0.01 dB/°C from 0 to 20°C. The maximum temperature coefficient of frequency was 2.4 kHz/°C at 55 to 60°C; 0.2 kHz/°C was measured between 10 and 20°C. This solid-state source was used with a 2295-MHz maser in the field for a period of one year. No degradation in maser performance was detected during the year. The oscillator/multiplier assembly is eight times the cost of a klystron which gives comparable maser performance.

Backward-wave oscillators have been used in the laboratory as pump sources at frequencies between 26.5 and 90 GHz. Performance characteristics and life test data to 18,000 hours have been reported by Dr. Gross in 1971 (Ref. 3). Backward-wave oscillator types used at JPL are: Siemens Model RWO 40, RWO 60, and RWO 90. High costs and high input voltage requirements (2600 V) have resulted in limited use of these tubes. Antenna installation is being considered only for the 14.3- to 16.3-GHz maser where week-to-week retuning is a requirement.

Varian VA-246E reflex klystrons are used in 14 maser systems (2270–2300 MHz signal frequency). These tubes provide more than 200 mW within an electronically tunable range of 12.66 to 12.72 GHz. The typical frequency/temperature coefficients are −70 kHz/°C. Warranted tube life is 1000 hours. Average tube life in the field is 8000 hours.

A more versatile klystron, with longer life, is now used with a tunable maser (2240–2420 MHz). The klystron (VA-287P) has a 5000-hour warranted life. Output power can be adjusted with beam voltage from 25 to 1000 mW. A long-life choke-type tuner is motor driven to cover the entire maser tuning range. The klystron tunes from 12.5 to 13.0 GHz. Resettability of the mechanical tuning system is within 5 MHz. The electronic tuning range is 70 MHz and the frequency/temperature coefficient is −50 kHz/°C. The system has been in continuous use on the 64-m antenna for 9 months. The system is tuned for signal frequencies of 2295 and 2388 MHz on a weekly basis. No degradation in maser performance has been detected during the 9-month operation. A VA-287N without a tuning motor has been operating continuously in the field without noticeable degradation for more than 2 years.

A pump package using two klystrons in push–push operation is shown in Fig. 1. A block diagram of the package is shown in Fig. 2. Figure 3 shows the loss through isolators, filters, and a power combiner as a function of frequency; the paths are as indicated by letters A, B, and C on Fig. 2. An explanation of push–push pumping and a maser description (using this technique) has been published in previous reports (Refs. 4 and 5). The klystron used in the 35- to 40-GHz range is a Varian VA-302. Three tubes of this type, presently used in the field, have demonstrated more than 5000 hours of life without noticeable degradation (warranted life is 2000 hours). The VA-302 must be mechanically retuned (at the antenna package) or replaced to accomplish a maser frequency change. The klystron used in the 25- to 28-GHz range is a Varian EM-1138. Warranted life is 5000 hours.

Figure 4 shows a pump package for a tunable X-band maser using the push–push pumping scheme. Two EM-1138 klystrons are remotely tuned to cover a 500-MHz portion of the maser's tunable range (7700–8600 MHz). The block diagram is shown in Fig. 5. Full waveguide bandwidth circulators (18.0 to 26.5 GHz) are used as isolators and as a power combiner. Total loss, from klystron to maser connections, is shown in Fig. 6.

IV. Concluding Remarks

Today the reflex klystron is used as a pump source for every maser amplifier operating in the Deep Space Network. New solid-state devices will be tested to determine future usefulness as pump sources. Extended maser tuning ranges present the most difficult requirements for pump sources of any type. A new pump device must (at reasonable cost) exceed the high-performance level achieved by today's klystrons if the device is to be used in the DSN.

References

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Table 1. Pump sources used with JPL masers

Maser frequency, MHz	Pump frequency, GHz	Pump device	Where used[a]	Number of systems
960	10.6	Klystron	Field	4
1420	11.2	Klystron	Lab	1
2270–2300	12.66–12.72	Klystron	Field	28
2270–2300	12.66–12.72	Multiplier	Field	1
2270–2300	12.66–12.72	Impatt oscillator	Lab	2
2270–2300	12.66–12.72	Impatt noise generator	Lab	1
2388	12.87	Klystron	Field	3
2295/2388	12.7/12.87	Klystron	Field	4
2240–2420	12.5–13.0[b]	Klystron	Field	1
8488	21.85	Klystron	Field	2
7700–8600	41–43.8[c]	Klystron	Field	1
7700–8600	18.4–19.4 and 22.6–24.6[b]	Klystrons	Lab	1
7600–8900	40–45	Backward-wave oscillator	Lab	1
14,300 to 16,300	25.4–27.8 and 35.4–39.3[c]	Klystrons	Lab	1
12,500 to 18,000	26.5–40 40–60 60–90	Backward-wave oscillators	Lab	1

[a]Field use is in the DSN on 26-m or 64-m antennas; lab use is at JPL for development or test purposes.

[b]Pump range is covered by tuning motor with remote control.

[c]Pump range is covered by replacement and mechanical tuning of klystrons.

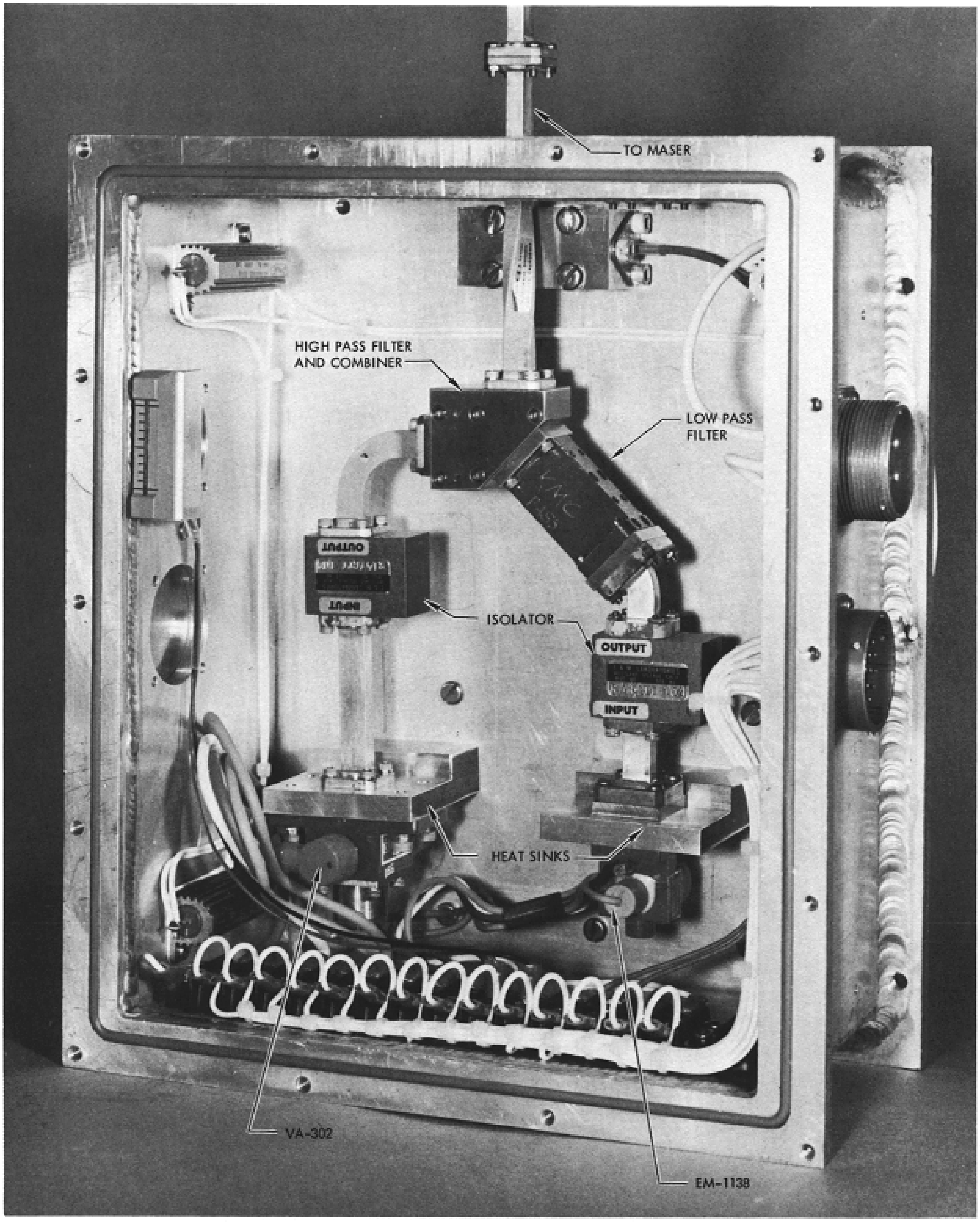

Fig. 1. Pump package for 14.3 to 16.3 GHz maser

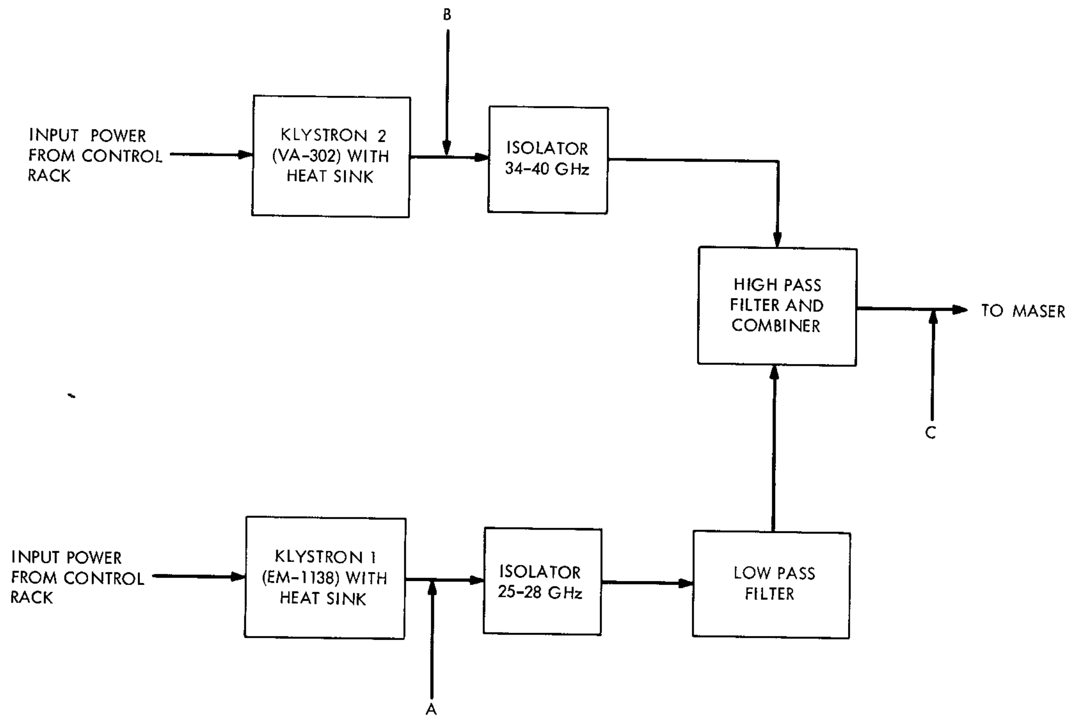

Fig. 2. Block diagram for 14.3 to 16.3 GHz maser pump package

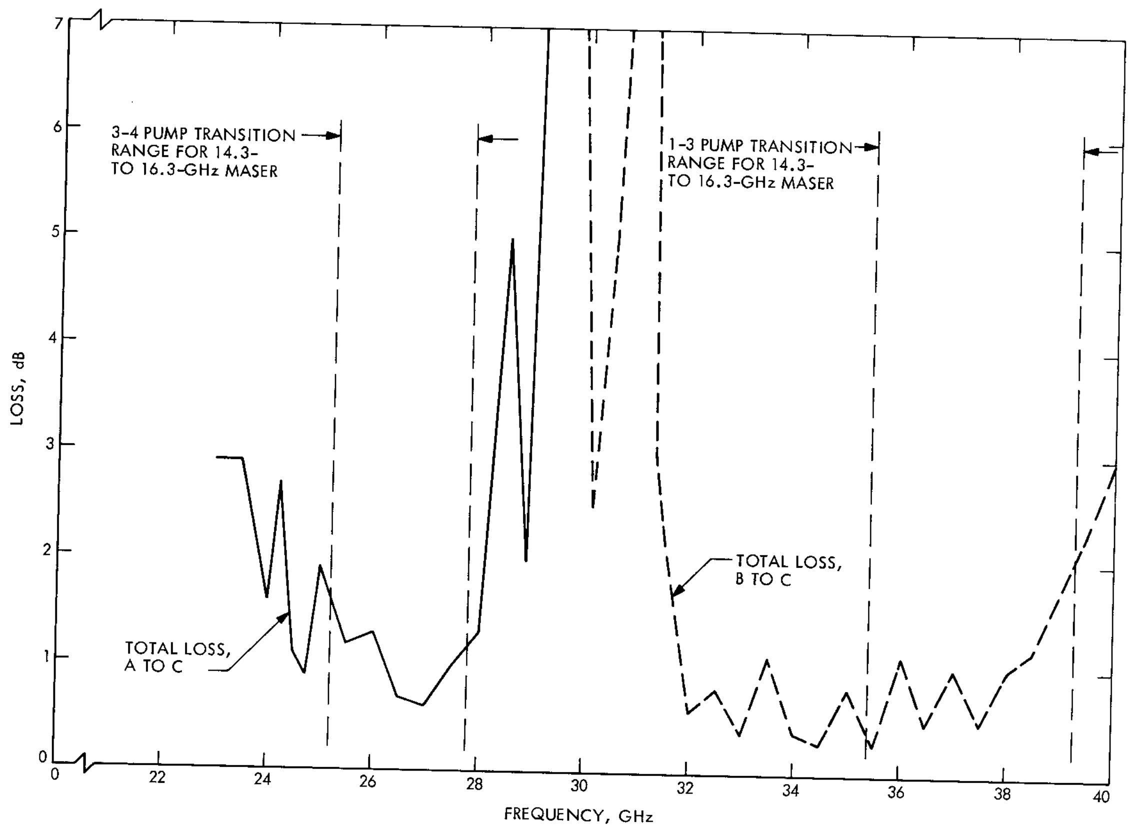

Fig. 3. Loss vs frequency for 14.3 to 16.3 GHz maser pump package

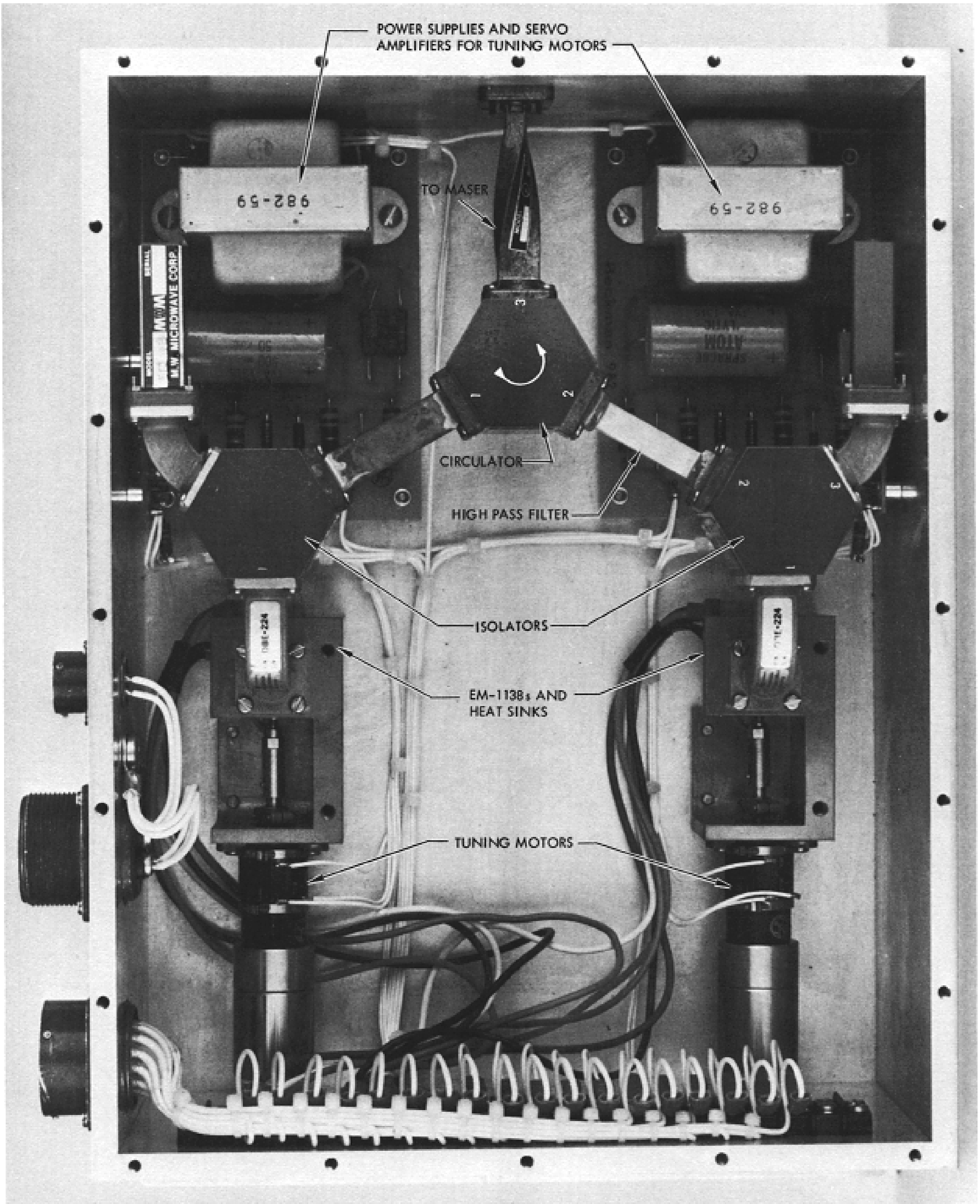

Fig. 4. Pump package for tunable X-band maser

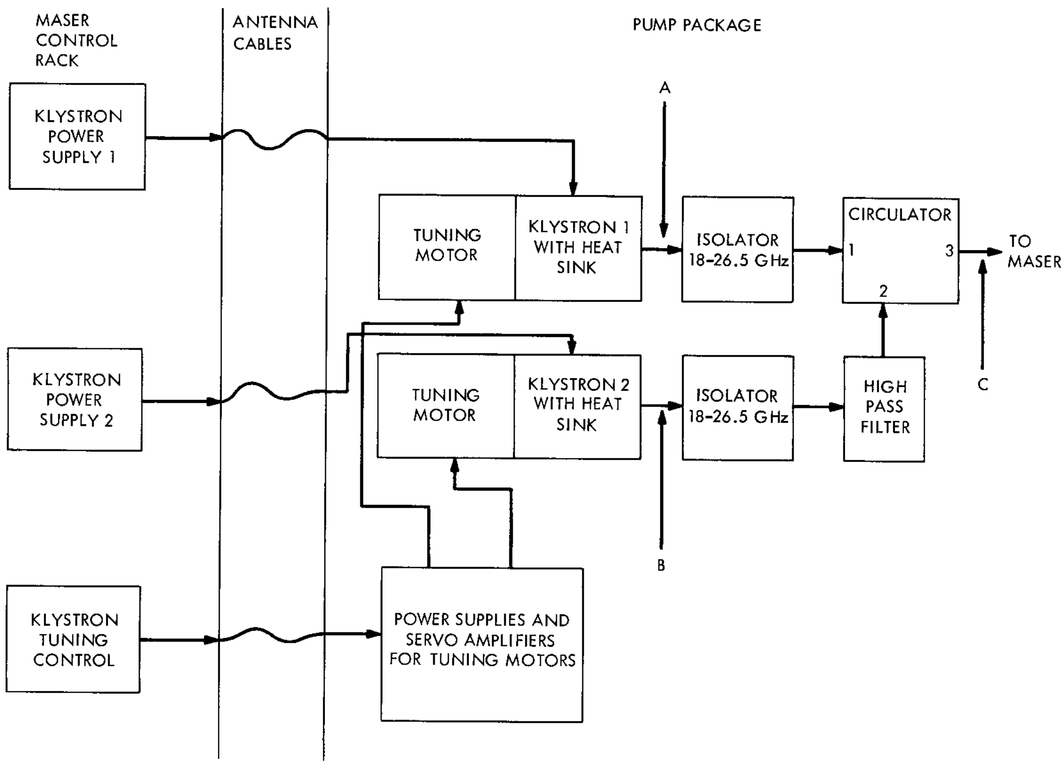

Fig. 5. Block diagram for tunable X-band maser pump package and control

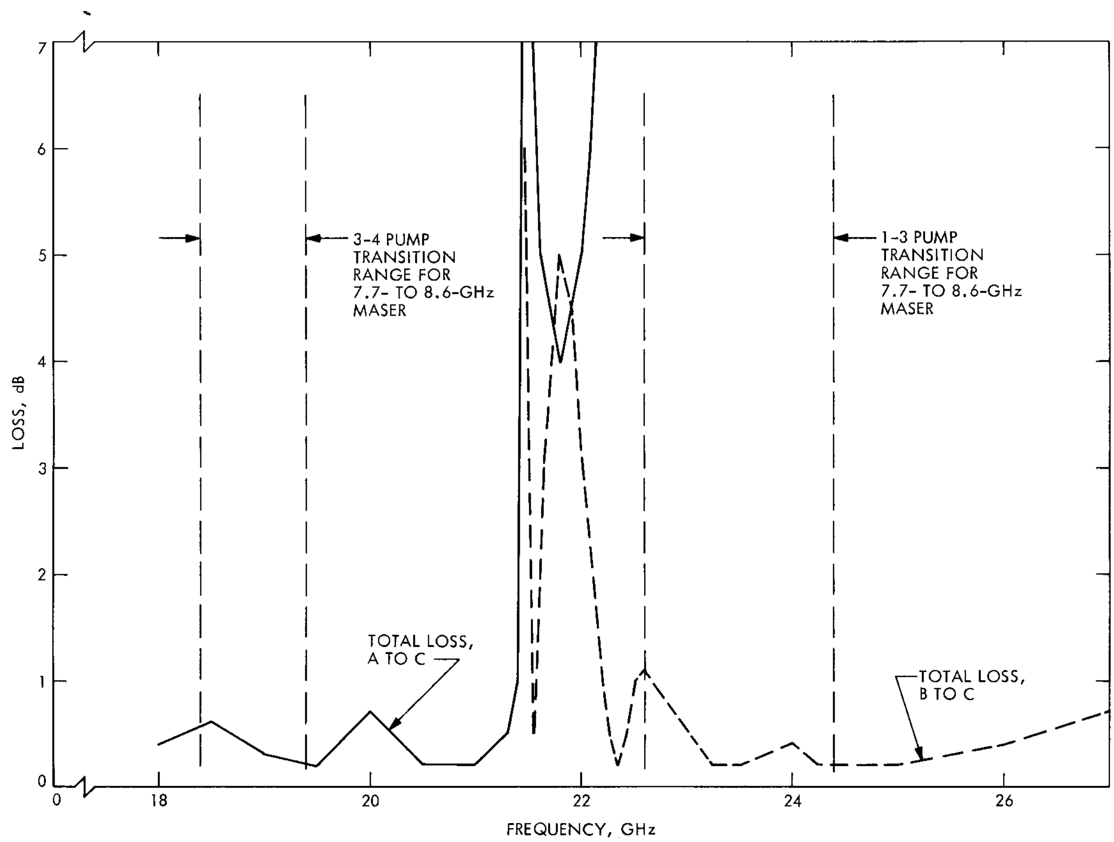

Fig. 6. Loss vs frequency for tunable X-band maser pump package