Low Noise Receivers: Microwave Maser Development

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A well-matched dielectrically loaded waveguide, for operation between 18 and 26.5 GHz, has been built and is being used to test the characteristics of ruby for wide-bandwidth maser applications. The unit serves a dual purpose. The initial plan was to investigate and optimize pumping techniques at 19 and 24 GHz for future use with wide-bandwidth X-band masers. Results show that an order of magnitude improvement in pumping efficiency is possible. A second use for the dielectrically loaded waveguide was found during the initial tests. The unit has excellent amplifying capability in the 18- to 26.5-GHz range when used as a reflection-type amplifier. Gains of 7.5 dB (at 4.4 kelvins) and 16 dB (at 1.9 kelvins) were measured with instantaneous bandwidth exceeding 250 MHz.

I. Introduction

A ruby-filled waveguide section has been built and is being used to investigate wide-bandwidth maser techniques. The device is used to measure pump power absorption characteristics of ruby at 19 and 24 GHz; these frequencies will be used to pump a wide-bandwidth X-band maser. The ruby-filled waveguide is well matched and has low loss across the entire 18- to 26.5-GHz range. Excellent gain and bandwidth have been achieved at 24 GHz by using the device as a reflection-type amplifier.

II. Waveguide and Matching Section

A 0.178-cm-high, 0.356-cm-wide, 4.54-cm-long waveguide, loaded with ruby, is matched to a standard WR 42 (18- to 26.5-GHz) waveguide. The matching section is a 7.62-cm-long waveguide taper partially filled with ruby. The dielectric constant (ϵ) of ruby is approximately 9. The waveguide and matching section are machined copper parts, consisting of a body and covers, which are bolted together. The body, top cover, and ruby dielectric are shown in Fig. 1. Figure 2, a cutaway drawing, shows two views which illustrate the waveguide and matching taper details. The copper waveguide matching section tapers towards the dielectric in two directions. The dielectric is tapered in only one direction, leaving a flat (0.365-cm-wide) surface with intimate contact to a flat copper surface along the entire length of the dielectric piece. No other surface of the dielectric piece needs to contact the copper waveguide. A gap of 0.003 cm between the dielectric and the copper waveguide is used so that parts may be machined and assembled with ease, and problems caused by differential thermal expansion between the dielectric and the copper waveguide are avoided. The gap across the 0.178-cm dimension affects the electric field, raising the low cutoff frequency of the loaded waveguide (about 14 GHz) about 3%. The gap does not degrade the match of the device in the 18- to 26.5-GHz range. An absorber was used at the end of the dielectric waveguide for measurement purposes; a VSWR of less than 1.2 to 1 was achieved across the 18- to 26.5-GHz range. The one-way transmission loss of the ruby-filled waveguide and matching section at room temperature is 0.6 dB. At temperatures below 20 kelvins, the one-way loss is estimated to be 0.2 dB.

III. Pump Power Considerations

X-band traveling-wave masers now in use require pump sources which produce more than 100 mW of power at both 19 and 24 GHz (Ref. 1). Refrigeration capacity measurements show that 50 to 100 mW of the applied pump power result in a heat load which is delivered from the maser to the 4.5-kelvin refrigeration station. Attempts to measure the absorption of pump power caused by the paramagnetic resonance of the maser material at the pump frequencies by thermal capacity measurements gave no detectable results. The resolution of the refrigeration capacity measurement system was about 5 mW. The conclusion, that more than 95% of applied pump power is wasted in the existing maser systems, is reinforced by test results using the ruby-filled waveguide. Application of a 5-mW test signal to the ruby-filled waveguide eliminates detectable signal absorption due to paramagnetic resonance at 19 and 24 GHz; this indicates that complete saturation of the pump transitions is possible at the 5-mW power level.

Masers with wide instantaneous bandwidth have the requirement that pump energy must also be distributed across a wide bandwidth. To achieve a 100-MHz bandwidth at X-band, the K-band pump sources must distribute energy across a 300-MHz range. Improvements in pumping efficiency will reduce pump power requirements, simplify construction and reduce the cost of pumping systems, and reduce heat loads caused by pump power at the 4.5-kelvin refrigerator station.

IV. Gain and Bandwidth Near 24 GHz

The ruby-filled waveguide was tested as an amplifier near 24 GHz. A block diagram of the amplifier system is shown in Fig. 3; a pump source (Siemens RWO 60 backward wave oscillator), a pump power coupling device, and a 33-GHz cutoff low-pass filter were added to the system, which had been assembled for previous pump transition saturation tests. Magnetic shims were added to the ruby-filled waveguide body to broaden the maser-material linewidth. Figure 4 shows gain between 7 and 7.7 dB across a 285-MHz bandwidth centered at 24.6 GHz. This performance was achieved at a refrigerator temperature of 4.4 kelvins. Figure 5 shows gain between 15 and 17 dB across a 250-MHz bandwidth centered at 24.4 GHz; a 1.9-kelvin refrigerator temperature was used to achieve this performance. Between 5 and 10 mW of pump energy was applied to the ruby in the above tests. Saturation of the pump level was almost complete; a 3-dB increase in pump power would cause only a 1-dB increase in gain. The pump energy supplied by the RWO 60 was distributed across a 500-MHz bandwidth near 52 GHz by frequency modulation at a 20-kHz rate.

The ruby-filled waveguide, combined with a circulator and a pump source, forms a simple maser amplifier stage which can be electronically tuned across the entire 18- to 26.5-GHz range. Combination of several stages can be used to achieve high gain with wide instantaneous bandwidth.

Reference

1. Clauss, R. C., and Quinn, R. B., "Low Noise Receivers: Microwave Maser Development," in *The Deep Space Network Progress Report*, Technical Report 32-1526, Vol. IX, pp. 128–136, Jet Propulsion Laboratory, Pasadena, Calif., June 15, 1972.

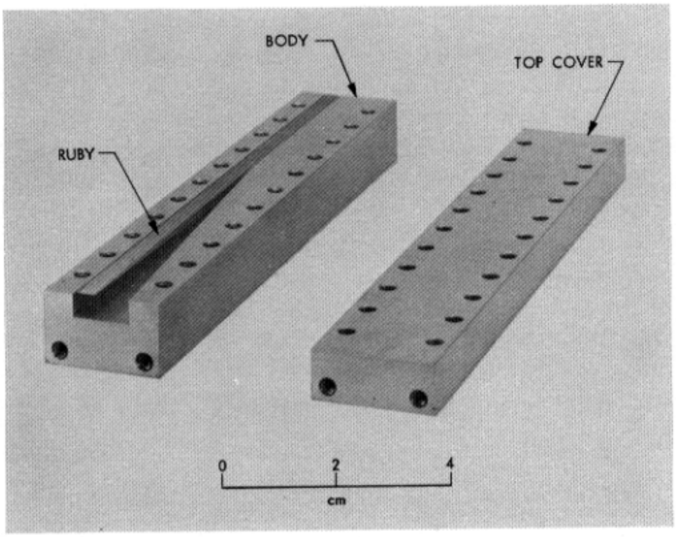

Fig. 1. Ruby-filled waveguide and matching section (covers removed)

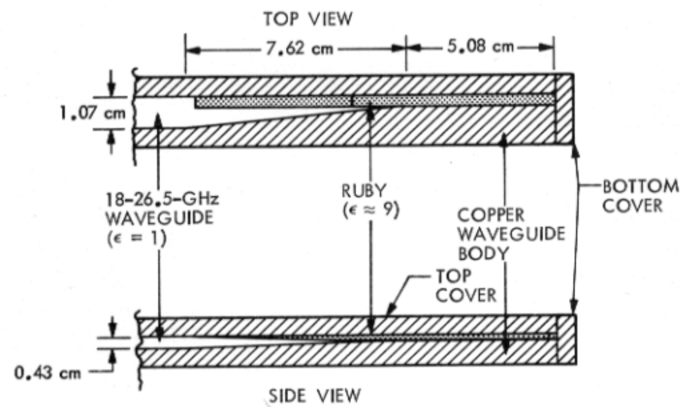

Fig. 2. Cutaway drawing of ruby-filled waveguide and matching section

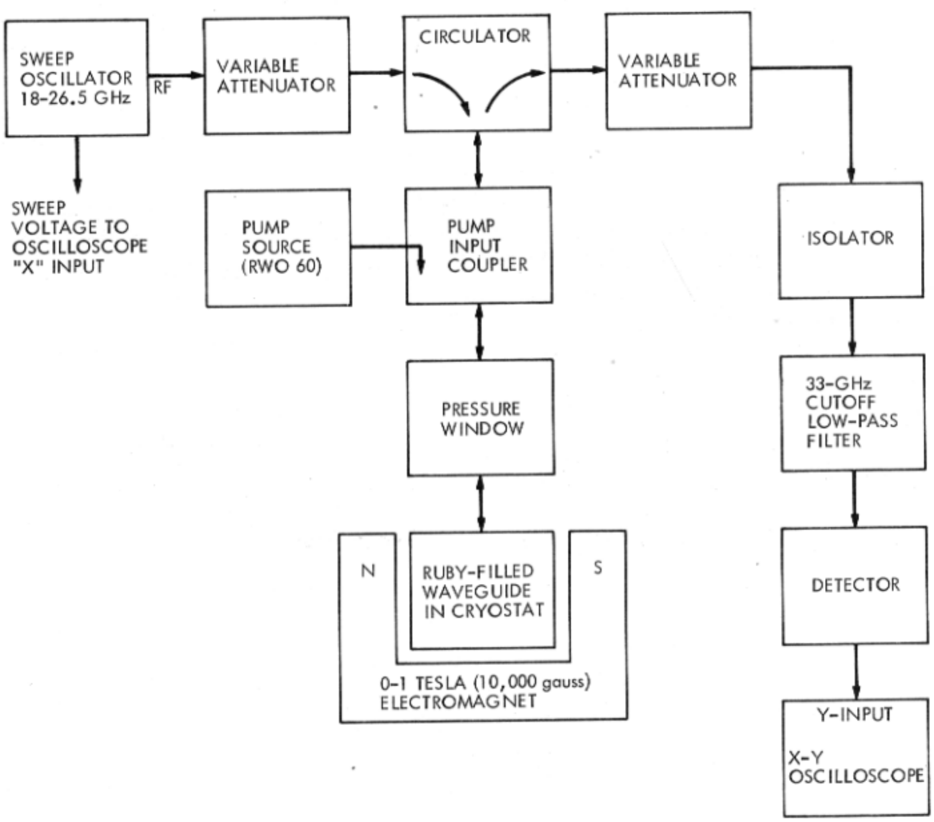

Fig. 3. 24-GHz maser amplifier system

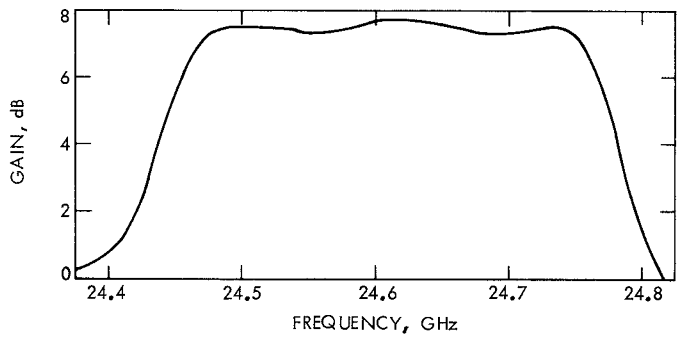

Fig. 4. Maser gain and bandwidth: refrigerator at 4.4 kelvins

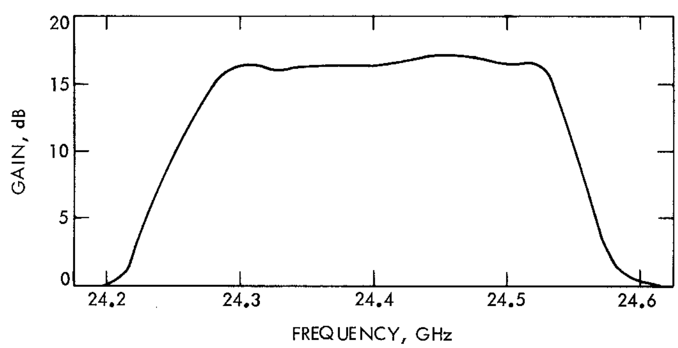

Fig. 5. Maser gain and bandwidth: refrigerator at 1.9 kelvins