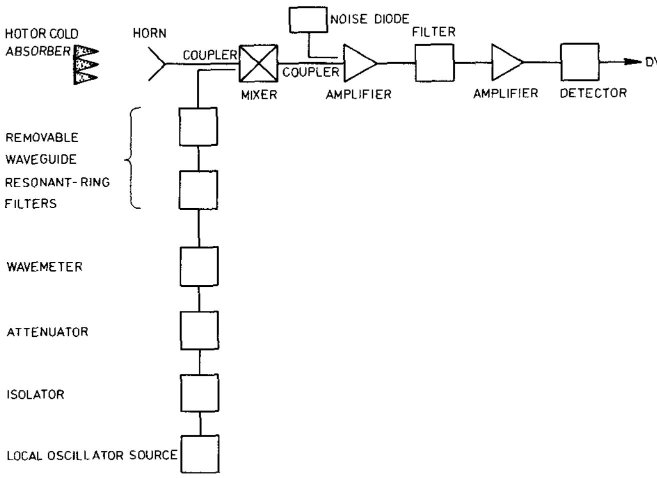

Fig. 1 IMPATT and Klystron AM noise measurement system.

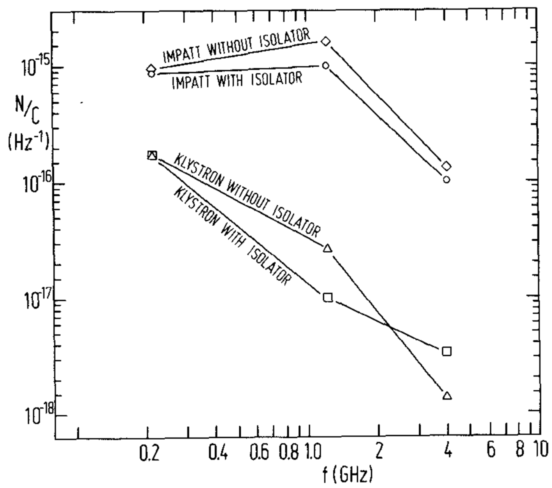

Fig. 2. Variations of double sideband AM noise-to-carrier ratio for Plessey IMPATT oscillator AT0 273 (30 mW at 94.5 GHz and 70 mA) and Varian Klystron VRB-2113 (60 mW at 89.9 GHz).

TABLE I
DOUBLE SIDEBAND AM NOISE WITHOUT AN ISOLATOR, CORRESPONDING TO RESULTS IN FIG. 2, FOR 1 mW ON MIXER

	215 MHz	1.2 GHz	4.0 GHz
IMPATT	69,000 K	122,000 K	9530 K
Klystron	13,000 K	1870 K	82 K

coupled into the IF chain in order to determine the noise contributions of the rest of the system and of the LO.

At the klystron frequency (89.9 GHz) and IMPATT frequency (94.5 GHz), insertion losses of the directional coupler and the two additional filters (which were tuned to f_{LO}) were measured at f_{LO} and $f_{LO} \pm f_{IF}$.

By operating the mixer under fixed conditions of bias, tuning, and LO power, the double sideband noise contribution of each LO was determined at three intermediate frequencies. The results are shown in Fig. 2. Table I gives the double sideband AM noise temperature corresponding to the results in Fig. 2, without an isolator, for an input power level of 1 mW on the mixer diode. The relatively poor noise performance of the IMPATT oscillator at 1.2 GHz is noteworthy but not significant; Tearle and Heath [2] also observe irregular variations of AM noise with frequency of approximately 10 dB. Chart records of radiometer output noise were similar for each LO source over periods > 90 min, with no signs of instability or excess noise.

It is noteworthy that no radical change in noise performance was observed by removing the isolator following the LO source. However, in the absence of an isolator, the IMPATT oscillator frequency was strongly dependent on load impedance.

III. CONCLUSION

These measurements indicate that the far-from-carrier AM noise of IMPATT oscillators is such that with extra filtering IMPATT's may be used as sources of local oscillator power at millimeter wavelengths without degradation of system performance.

ACKNOWLEDGMENT

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Experimental Evaluation of a Ruby Maser at 43 GHz

CRAIG R. MOORE, MEMBER, IEEE, AND DUDLEY NEFF

***Abstract*—The inversion ratio of pink ruby has been measured at several frequencies between 27 and 43 GHz for the push–pull pump angle of 54.7°. From these measurements a single-stage maser was designed which yielded 8 ± 1-dB net gain and a 3-dB bandwidth of 180 MHz at a center frequency**

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of 42.5 GHz. A multistage reflected wave maser could achieve bandwidths exceeding 1 GHz with 30-dB net gain at center frequencies near 40 GHz.

I. Introduction

Following successful introduction of *K*-band reflected-wave ruby masers into radio astronomy receiving systems, interest was generated in extending the technique to shorter wavelengths. Because of our familiarity with pink ruby and the availability of high-quality crystals free of *c*-axis wander, misorientation or dislocations, and nonuniform chromium distribution (problems encountered with other maser materials which have been used at millimeter frequencies), it was decided to determine the upper frequency limit where pink ruby could be expected to operate as a practical maser amplifier.

To this end, inversion ratio measurements were made through 43 GHz for a pink ruby material [1] (0.05 percent Cr^{+3} in Al_2O_3) at 4.5 K. The ruby crystal orientation used was 54.7°, allowing the push–pull pumping technique [2], [3] where inversion ratios are increased above the value obtainable with the single-pumped three-level maser scheme.

These measurements enabled a single-stage reflected-wave maser to be designed for operation in the vicinity of 43 GHz. This single-stage maser was used to determine the pump power requirement for a multistage maser design.

II. Inversion Ratio Measurements

The inversion ratio measurements were made using a standard JPL closed-cycle refrigerator [4], [5] producing a container of liquid helium at 4.5 K (≈ 5 psi above nominal atmospheric pressure). The helium container and equipment are nonmagnetic and are mounted between the pole pieces of a large electromagnet. The test section and specimen were immersed in liquid helium within a uniform magnetic field.

The test section was mounted on a long, thin-wall, WR-28 stainless-steel waveguide to reduce heat intake to the helium bath from room temperature. The test section was fitted with two iron plates to increase the magnetic flux density in the ruby sample up to 15 000 G, as the electromagnet is limited to 10 000 G maximum.

The ruby specimens were fabricated to dimensions forming dielectric resonators at the various signal frequencies of interest. Typical dimensions were 0.24 by 0.24 by 0.178 cm thick and 0.22 by 0.22 by 0.178 cm thick. Each specimen was tested at several different positions within the test section in order to vary the coupling at both the signal and pump frequencies.

The pump signal was injected directly into the waveguide through a modified WR-28 *E*-plane bend. The ruby specimen orientation (54.7°) allows optimum performance with a single pump frequency. The frequency range tested was limited by the available pump sources (≈ 88 GHz at the 43-GHz signal frequency) and by unwanted modes above 42 GHz in the WR-28 waveguide. At least 10-mW pump power was available between 57 and 88 GHz, which was sufficient to saturate the pump transitions at the frequencies where data were taken. The pump source was frequency-modulated at 20 kHz, a rate higher than the spin-lattice relaxation rate (relaxation time ≈ 0.05 s). Frequency deviation was wide enough to "fill" the ruby specimen absorption width.

The inversion ratio was measured by adjusting the magnetic field with the pump off for ruby absorption at a specific frequency, recording the depth of absorption, and then adjusting the pump source for maximum signal amplification at this frequency. The ratio of signal amplification to absorption (in decibels) is the inversion ratio. The couplings of signal and pump frequencies are seldom optimum simultaneously; consequently, many frequencies and specimen positions (inside the test section) must be tried to obtain the peak values which indicate "ideal" or best coupling.

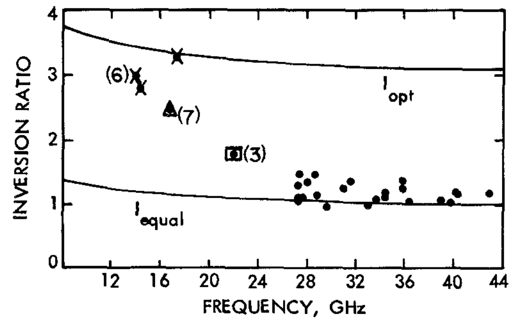

Fig. 1. Measured inversion ratios of pink ruby compared to theoretical values at $\theta = 54.7°$.

Enough data points were collected to demonstrate a definite trend in variation of inversion ratio with increasing frequency. Maximum inversion ratios ranged from 1.5 at 27 GHz to 1.25 at 43 GHz. This trend indicates that ruby will be useful well above 43 GHz. Earlier work [3], [6], [7] and the current measurements are shown in Fig. 1.

The theoretical inversion ratio [8] is determined by the ratio of the signal (f_s) and pump (f_p) frequencies and can be as high as 3.08 at 43 GHz, where

$$I_{\text{opt}} = \frac{2f_p}{f_s} - 1$$

if all relaxation times are optimum. If all relaxation times are equal, the inversion ratio is given by

$$I_{\text{equal}} = \frac{f_p}{f_s} - 1$$

which gives a value of 1.04 at 43 GHz.

III. Single-Stage Maser

The gain-bandwidth product of a maser [3], [8] can be predicted by measuring the maser material linewidth and inversion ratio and calculating magnetic Q (Q_m). Maser performance at 24 GHz, where recent NRAO masers [3], [9] have demonstrated 500-MHz bandwidth at 30-dB net gain, can be used as a starting point for prediction of higher frequency operation. It can be shown that the same length structure (15 cm) will yield bandwidths exceeding 1 GHz with 30-dB net gain at center frequencies near 40 GHz. However, the pump power requirements for such a maser cannot be predicted with any certainty. Therefore, a single-stage reflected wave maser was designed for operation at 43 GHz in order to measure experimentally the pump power required for broad-band operation.

The single-stage maser was scaled dimensionally from the 24-GHz maser reported previously [9]. The ruby and microwave structure was 7.8 cm long and mounted in the center of a 20.3-cm-long Cioffi [10] superconducting magnet. A junction circulator was developed which yielded 16-dB isolation and 0.5-dB insertion loss from 42 to 49 GHz. The nickel–zinc ferrite disks were biased with rare earth permanent magnets to a flux density of 5850 G at room temperature. The circulator and ruby structure, together with the superconducting magnet, were mounted on a closed-cycle helium refrigerator which cooled the total package to 4.6 K.

The resulting maser performance is shown in Fig. 2. An electronic gain of 12 ± 1 dB and net gain of 8 ± 1 dB were achieved with a 3-dB bandwidth of 180 MHz at a center frequency

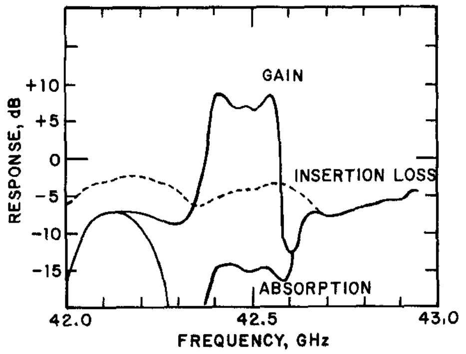

Fig. 2. Single-stage maser bandpass.

of 42.5 GHz. The observed inversion ratio was 1.2 with a pump power of 55 mW at the dewar input. The pump has a center frequency of 86.75 GHz and was distributed over 420 MHz peak to peak at a 20-kHz modulation rate. The sensitivity of gain to pump power level indicated that an increase of 4 dB in pump power was required in order to saturate the pump transitions (i.e., 0.25-dB gain change for 1-dB pump power change at saturation). When pump waveguide losses are accounted for, the pump power needed is about 6 times higher than that required for comparable performance with the 24-GHz maser. Thus, pump power on the order of 2.5 W would be required for a four-stage reflected wave maser to yield a bandwidth of 1 GHz and net gain of 30 dB at center frequencies near 40 GHz. A more modest pump power of 500 mW would yield a bandwidth of 200 MHz.

When the single-stage maser was placed ahead of a room temperature mixer receiver, a single sideband receiver noise temperature (including the contribution from a standard gain horn on the maser input) of 515 K was measured. The follow-up receiver contribution was measured as 480 K. The difference of these two measurements is the combined maser and horn noise temperature. These noise temperatures were measured at a center frequency of 42.5 GHz using ambient and liquid nitrogen temperature absorber as reference loads at the aperture of the standard gain horn. When the estimated noise contributions of the horn and input waveguide (from 300 to 4.6-K cryogenic temperature) were accounted for, the maser noise temperature at the cooled circulator input was estimated to be 14 K. The theoretical noise temperature at this point is 6.6 K, assuming 0.5-dB loss per pass in the circulator and 2.3-dB loss in the maser structure. Considering the uncertainty in the estimated maser noise temperature, any agreement between experimental and theoretical estimates is fortuitous.

IV. Conclusion

We have shown that pink ruby is useful as a maser material for frequencies in excess of 43 GHz. Pump power requirements set a limit to the bandwidth which is practical, but bandwidths exceeding 1 GHz are possible if sufficient pump power and FM deviation are available. The system temperature-bandwidth ratio should be superior to those of other devices presently operating in this frequency range.

Acknowledgment

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Automatic Permittivity Measurements in a Wide Frequency Range: Application to Anisotropic Fluids

J. P. PARNEIX, C. LEGRAND, AND S. TOUTAIN

Abstract—**In this paper a new dielectric measurements method in the range 200 MHz–18 GHz is reported. The main features of the system are the following: a) automatic determination of the sample complex permittivities for each step of frequency previously chosen by using a numerical process; b) cells requiring only a very small sample volume (typically lower than .1 cm^3); and c) cell structure allowing the dielectric characterization of anisotropic substances.**

I. Measurement Method Description

By using classical methods, the determination of the complex permittivity ($\epsilon^* = \epsilon' - j\epsilon''$) of dielectric materials is generally carried out for singular frequencies which can be very scarce in the microwave region typically one or two points for a decade range [1]. Furthermore, these methods are difficult to work out, and they often use a very large sample volume. The original method which is presented in this paper attempts to remove all these difficulties.

A. Basic Operation

Fig. 1 shows a simplified diagram of the measurement system. The basic device is a H.P. 8410 network analyzer connected to a H.P. 9825 computer. The sweep oscillator is phase locked by a Dana E.I.P 381 microwave counter. System calibration and operation is as follows.

a) The network analyzer is calibrated by using successively a calibrating short, an open circuit, and a sliding load.

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