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AN AMMONIA BEAM MASER ON THE 2, 2 LINE

BY

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ABSTRACT

An $N^{14}H_3$ beam maser on the 2, 2 line ($J=K=2$) was operated, using the same cavity, at different tunings, with the 3, 3 line. The oscillation characters of the 2, 2 line maser were compared with those of the 3, 3 line maser which had been obtained in our laboratory (**1**). The characters of both agreed with the same theory.

The center frequency of the 2, 2 line maser was measured on the basis of the 3, 3 line maser as a standard.

1. Introduction

The ammonia beam maser is the amplifier or oscillator in a microwave region operating on the quantum-mechanical principle. The beam is coupled to a microwave cavity in which there occurs a process of induced emission coherent with the fields in the cavity. The maser system breaks into spontaneous oscillation, when the beam flux exceeds a certain value, called starting flux. As is well known, the maser oscillator has a sufficient frequency stability and reproducibility to be used as a primary frequency standard. The 3, 3 line maser had been operated in our laboratory and the shift of the center frequency was investigated in detail (**2**). In the neighbourhood of the 3, 3 line, there exist many inversion lines based on the different rotational states. The comparison between the masers is favourable for the investigation of the oscillation behaviours. The maser oscillation on the 2, 2 line was tried, since this line is the nearest to the 3, 3 line, and it was possible to operate the maser on each line using the same cavity at different tunings. The so-called threshold voltage, $V_0(J, K)$, which menas the focuser voltage giving the starting flux, was measured *versus* the source pressure. We took the ratio of the threshold voltages on both lines for a convenient comparison with the theory, and found a good agreement. In the region above the threshold voltage, the oscillation amplitude *versus* focuser voltage characteristic of the 2, 2 line maser was compared with that of the 3, 3 line maser, and was found to be consistent with the theory, as the latter had been (**1**).

The measurement of the center frequency of the 2, 2 line maser was made, through a 100Kc quartz oscillator, on the basis of the center frequency of the 3, 3 line maser. The resulting value was compared with the values which had been obtained by the absorption method.

2. Experimental apparatus

The experimental apparatus is similar to that reported in (**1**). The block diagram of the detecting system is shown in Fig. 1. The eight-pole focuser is 355 mm in length. The cylindrical cavity consists of a copper pipe section 120 mm in length, 10 mm in inner diameter and 3 mm in thickness, which, however, has been electroplated with copper in order to finely adjust the inner diameter. This cavity is operated in TM_{010} mode and has the loaded Q value of 7000. Further, it is cooled by the liquid air trap in order to increase the Q value and is provided with an almost full-length slot to allow the tuning over a range of about 200 Mc by a movable fin. And so, it has become possible to operate the masers on the 3, 3 line (23870 Mc) and the 2, 2 line (23722 Mc) with the same

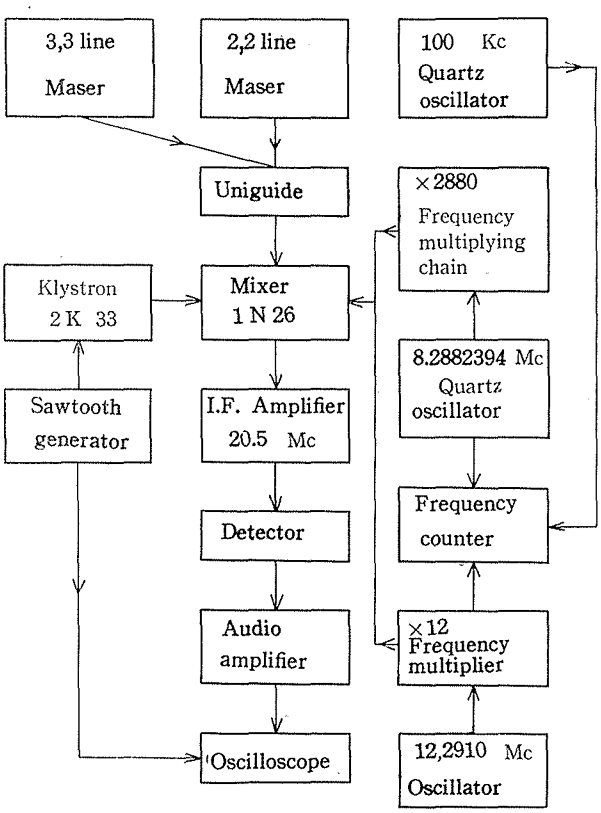

Fig. 1. Block diagram of detecting system.

cavity. Consequently, we can avoid the experimental ambiguities such as the changes in the cavity loaded Q, the coupling Q to the waveguide, the source pressure and the tank pressure, which would result, if we change from one line to the other.

The present detecting system is a super-heterodyne type using a crystal mixer 1N26 and a klystron 2K33 as local oscillator.

3. Experimental results

(A) *Threshold of oscillation*

From the theory which takes into account the velocity distribution of molecules (**1, 3, 4, 5**), the focuser voltage near the threshold can be expressed as follows:

$$V^2 = \frac{mh^2\nu_0 R^2 \alpha^3}{64\,\pi^{3/2}\mu^2 QL}\left(1 + \ln\frac{2l}{\pi L}\right)^{-1}\frac{J^2(J+1)^2}{M^2K^2}\frac{1}{N\bar{\mu}^2}, \tag{1}$$

where V is the focuser voltage, m the mass of molecule, h Planck's constant, ν_0 the center frequency, μ the permanent molecular dipole moment, R the focuser radius, l the focuser length, L the cavity length, J, K, M quantum numbers, α the most probable velocity, Q the cavity loaded Q, $\bar{\mu}$ a transition matrix element of molecular dipole moment, and N the density of molecules in a particular energy state. N is considered proportional to the fractional population $f(J, K)$ (**6**). $\bar{\mu}^2$ and $f(J, K)$ are given respectively by

$$\bar{\mu}^2 = \frac{K^2\mu^2}{3J(J+1)}, \tag{2}$$

and

$$f(J, K) = g_I(2J+1)\left(\frac{B^2Ch^3}{\pi(KT)^3}\right)^{1/2}, \tag{3}$$

where B, C are the rotational constants, and g_I the statistical weight factor. Then, the theoretical value of the ratio of the threshold voltage of the 2, 2 line maser to that of the 3, 3 line maser can be obtained using (1), (2) and (3) as:

$$\left(\frac{V_0(2,2)}{V_0(3,3)}\right)_{\text{theor}} = 1.9\,. \tag{4}$$

From the experimental result shown in Fig. 2, the corresponding experimental ratio becomes

$$\left(\frac{V_0(2,2)}{V_0(3,3)}\right)_{\text{exp}} = 1.9 \pm 0.02\,, \tag{5}$$

and it will be seen that the agreement between theoretical and experimental values is satisfactory.

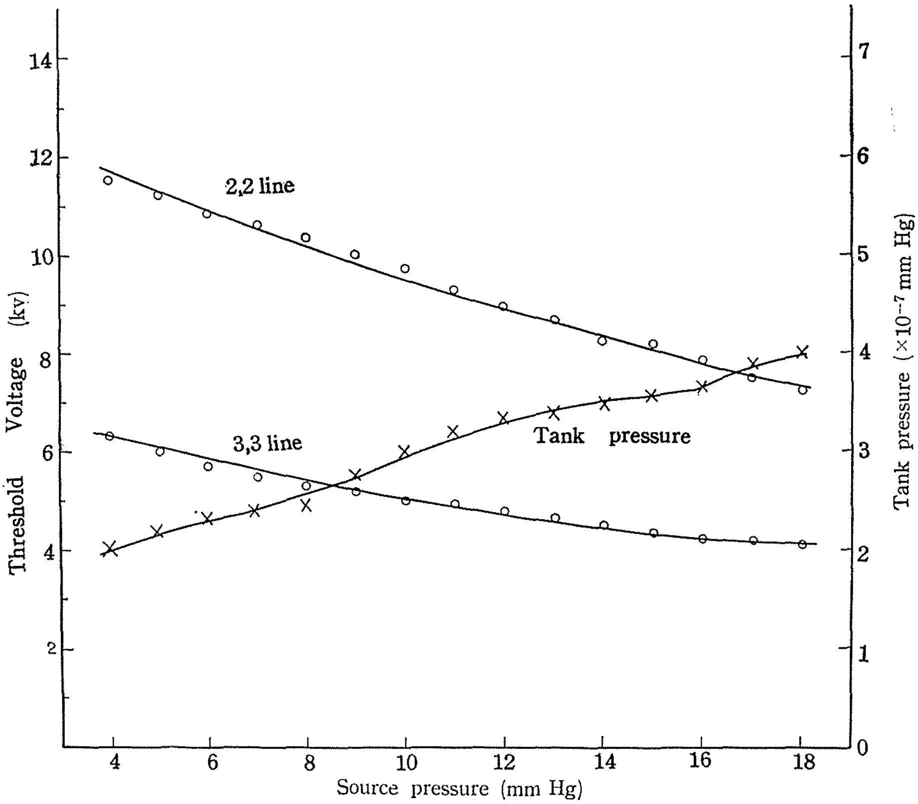

Fig. 2. Experimental threshold voltage *versus* source pressure of 2, 2 and 3, 3 line masers.

(B) *Amplitude characteristic*

The oscillation amplitude *versus* focuser voltage characteristic of each maser is shown in Fig. 3, where the curve and experimental points for the 3, 3 line are reproduced from the previous report (**1**). The curve for the 2, 2 line has been plotted relative to that for the 3, 3 line, since in the present case the oscillation amplitude has been measured only relatively. Thus, the experimental points for the 2, 2 line well lie on the curve, showing the agreement between the experiment and the theory for the present case.

(C) *Frequency measurement*

The center frequency of the 3, 3 line maser had been measured, using two 3, 3 line masers in our laboratory, to be 23870. 12953 Mc (**2**) to an accuracy of $\pm 1\times 10^{-9}$. We could in this case produce the above frequency only to an accuracy of $\pm 1\times 10^{-8}$, at the cavity tuning giving the maximum oscillation

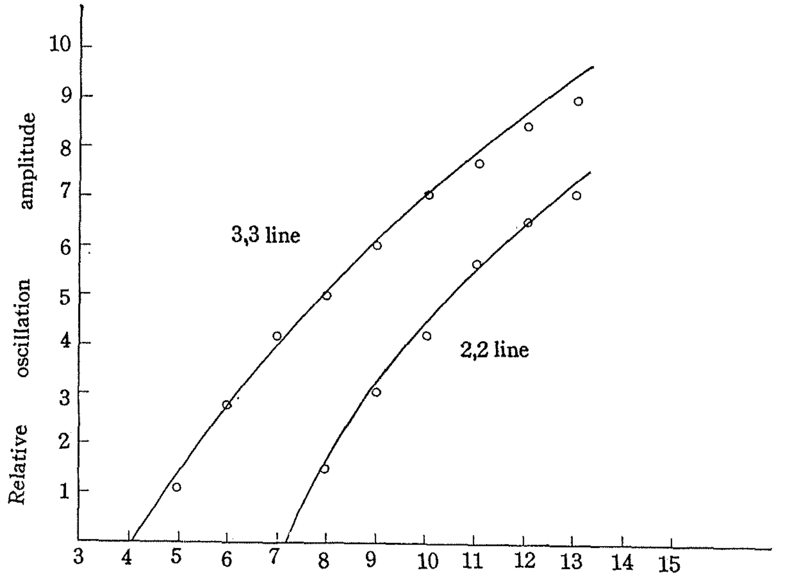

Fig. 3. Relative oscillation amplitude *versus* focuser voltage of 2, 2 and 3, 3 line masers at the source pressure of 18 mmHg: small circles show the experimental points.

amplitude, since a single maser was used.

The frequency counter had the time scale determined by the 100 Kc quartz oscillator, which was calibrated to have an accuracy of $\pm 1\times 10^{-8}$, in the following way. The process of determination and calibration was done by counting the fundamental frequency of another quartz oscillator which is variable about 8.2882394 Mc, when its 2880 th harmonic makes the zero beat with the center frequency of the 3, 3 line maser, which is observed on the oscilloscope screen. Then, the center frequency of the 2, 2 line maser was measured at the cavity tuning giving the maximum oscillation amplitude, just as that of the 3, 3 line maser, as follows. We observed on the oscilloscope screen the zero beat of the frequency to be measured with the difference frequency between the 2880 th harmonic of the 8.2882394 Mc oscillator and the 12 th harmonic of the 12.2910 Mc oscillator which was varied, and counted both frequencies of 8.2882394 Mc and 12.2910 Mc. The result is shown in Table 1 together with the results obtained by the absorption method.

Table 1.

W. Good *et al.* (7)	M. Strandberg *et al.* (8)	I. Takahashi *et al.* (9)	Present authors
23,722.63±0.02 Mc	23,722.59±0.05 Mc	23,722.62±0.024 Mc	23,722.636±0.005 Mc

The direct comparison of the 2, 2 line maser with the 3, 3 line maser is now in progress.

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