IV. MICROWAVE SPECTROSCOPY

Prof. M. W. P. Strandberg
Dr. M. Peter
S. A. Collins, Jr.
J. G. Ingersoll
B. Josephson, Jr.

J. D. Kierstead
S. Krongelb
D. Lazarus
R. D. Mattuck

W. W. McAllister
J. J. McNicholl
P. W. Sieck
H. G. R. Venkates
G. J. Wolga

A. PARAMAGNETIC RESONANCE

In previous Quarterly Progress Reports preliminary notes were given on the modifi-
cation of the paramagnetic resonance spectrograph to the higher modulation frequency
of 6 kc and 100 kc. This phase of the work is essentially completed, and exploratory
measurements were made in order to give an indication of the realized sensitivity. A
description of these measurements and of the experimental equipment follows.

1. General Description of Apparatus

The signal source is an X-band klystron (2K25 or VA-203) whose frequency is locked
to the microwave cavity resonant frequency by a feedback-stabilization circuit designed
in the Microwave Spectroscopy Laboratory. The microwave absorption is detected as
a change in reflected power from the microwave cavity. The absorption is modulated
at 6 kc (in the future it can be 100 kc) by superimposing a sinusoidally varying magnetic
field of amplitude 0-40 gauss peak-to-peak upon the dc Zeeman-splitting magnetic field.
The modulated absorption is detected in a 1N23B crystal that operates as a linear
detector. The output of the detector is amplified in a 6-kc, tuned (twin-T) amplifier
and is then synchronously detected (at 6 kc) and filtered by the 90-cycle remodulation-
demodulation scheme that is now being used in microwave spectrographs in this
laboratory. The amplification, detection, and filtering are performed with the 6-kc
amplifier and filter amplifier designed in this laboratory for microwave spectroscopy.
The filtered output is suitable for oscilloscope or recording-meter presentation. The
100-kc modulation apparatus uses a tuned amplifier and a filter amplifier similar to
those described, except for modification to pass 100-kc signals. Details of the equip-
ment follow.

2. Klystron Stabilizer

This unit uses a Foster-Seeley microwave frequency discriminator. The signal
outputs of two 1N23B crystals are superposed in proper phase to yield the discrim-
inator characteristic. Each crystal receives the microwave power reflected from
a highly dispersive microwave cavity and microwave power with frequency-insensi-
tive phase, so that the linear difference in the crystal outputs is a frequency-dis-
criminator pattern against a dc background. This signal, phased properly, is used
as the basis of a correction voltage which is applied to the reflection electrode of the

klystron. The microwave power splitting is accomplished by means of matched magic-T directional couplers. With this stabilization system, the klystron frequency variation is kept within the order of 10-20 kc, which is well within the linewidth of expected microwave absorptions.

The advantages of this stabilization system over the Pound stabilizer, previously used in the 50-cycle modulation system, are manifold. The avoidance of i-f circuitry, which is accomplished by our dc system, affords much greater simplicity in the use and maintenance of the system. The physical size and complexity of both microwave and electronic circuitry is markedly reduced.

3. Modulation

Sinusoidal amplitude modulation of the magnetic field is accomplished by two small Helmholtz coils mounted securely on the magnet pole faces on either side of the microwave cavity. The modulation field is parallel to the dc field, and both, in turn, are perpendicular to the axial microwave cavity field. The power source for the modulation is a 40-watt power amplifier which is fed by a 6-kc (100-kc) oscillator designed and built in this laboratory.

4. Microwave Cavity

The problem of introducing modulation fields of 6-kc and 100-kc frequency into a high-Q metallic cavity was solved by designing cavities of very thin (approximately 0.001 inch) metallic wall thickness. They are made of fused quartz with a thin silver coating. The 0.001-inch thickness of the silver is large with respect to the microwave skin depth but small with respect to the skin depth at the modulation frequency. The cavity used in the exploratory measurements described below operates in the TE_{011} cylindrical mode at 9408 mc and has a measured loaded Q of approximately 7800. This particular cavity has its silver coating on the outside of the cavity with some resulting losses in the quartz. Higher Q's are obtainable if the coating is put on the inside of the cavity. The cavity is iris-coupled to the waveguide from one of the flat end surfaces.

5. Exploratory Measurements

In order to determine the sensitivity of the 6-kc spectrograph, the paramagnetic resonance spectrum of oxygen at X-band has been observed, and the results were compared with results previously obtained in this laboratory by M. Tinkham. His work (Technical Report 281) gives the detailed field-dependent spectrum as well as calculated and measured line intensities. The estimate of attainable sensitivity is derived from the intensity calculations. The 1/Q increment caused by absorption in a gas-filled cavity is equal to $4\pi\chi''$ or to $(c/\omega)\alpha$, where χ'' is the imaginary part of the complex susceptibility of the gas, and α is the absorption coefficient of the gas for a plane wave. In

paramagnetic resonance the absorption is proportional to χ''; in microwave spectroscopy, where a waveguide transmission cell is used, α is the meaningful quantity. The oxygen line observed in the following calculations was the $K = 5$; $J = 6 \to 4$; $M = -3 \to -2$ line. Tinkham gives $1/Q_{ij} = 1.36 \times 10^{-8}$ for the $K = J = 1$; $M = -1 \to 0$ line. Our values will be based on this calculation. The signal-to-noise ratio observed is now, at 6 kc, $S_n^o \approx 5$, with a filter amplifier time constant of 0.01 sec. Tinkham gives 5.49 for the relative intensities of the two lines, with our line the weaker. Therefore $1/Q_{ij} = (1.36 \times 10^{-8})/5.49 = 2.48 \times 10^{-9}$. This decrement is larger than the minimum detectable decrement at 6 kc by the factor $(3/0.01)^{1/2} S_n^o = 17.3 S_n^o$, since a three-second time-constant filter is available to narrow the bandwidth, and we assume that the criterion for detectability is a signal-to-noise ratio $S_{n_{min}}^o = 1$. Thus

$$\left(\frac{1}{Q}\right)_{min} = \frac{2.48 \times 10^{-9}}{17.3 \times 5} = 2.87 \times 10^{-11}$$

at 6 kc. This corresponds to

$$\chi''_{min} = 2.3 \times 10^{-12}; \quad \alpha_{min} = 9 \times 10^{-12} \text{ cm}^{-1}$$

6. Measurements with the 100-kc System

The crystal noise power is proportional to $1/\nu$, where ν is the modulation frequency. Therefore, we should expect a gain in signal-to-noise of $(100/16)^{1/2} = 4.1$. Therefore, at 100 kc, the values given above are smaller by a factor $1/4.1 = 0.244$.

<div align="right">G. J. Wolga</div>

B. MICROWAVE EMISSION SPECTROSCOPE

A state selector added to the molecular-beam microwave spectroscope has increased the sensitivity of the device by a factor $kT/h\nu \cdot \Sigma$, where Σ is the selector efficiency. The upper and lower states of the desired transition are separated in an inhomogeneous electrostatic field, and the upper states alone remain in the beam. The field is zero in one direction normal to the beam. In this direction, the selector will therefore impose no velocity component on the molecular beam, and doppler-width reduction is still achievable.

The emission spectrum of ammonia was seen with the spectroscope (Fig. IV-1). The spectroscope is being adapted for observation of alkali halides.
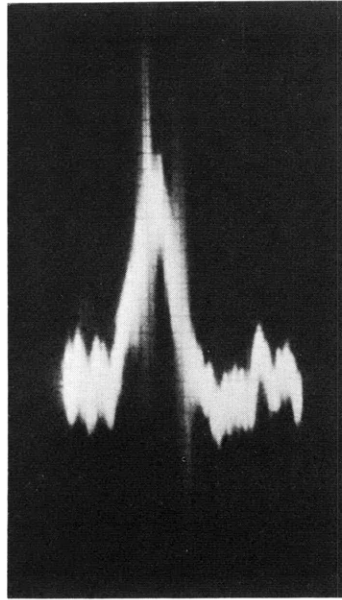
<div align="right">M. Peter</div>

Fig. IV-1. Emission spectrum of the ammonia 3-3 line.

C. SPIN ECHOES

Equipment, consisting of a double-pulse generator, a 30-mc gated oscillator, a probe circuit, an amplifier, and a detector, is being constructed to study spin echoes, especially those of nuclei. The pulse circuit was designed and constructed and it is now in working order. The gated oscillator is being constructed in accordance with a circuit described in RCA Report 185-10. The amplifier is in working order. The probe circuit has not yet been constructed.

<div align="right">D. Lazarus, W. W. McAllister</div>