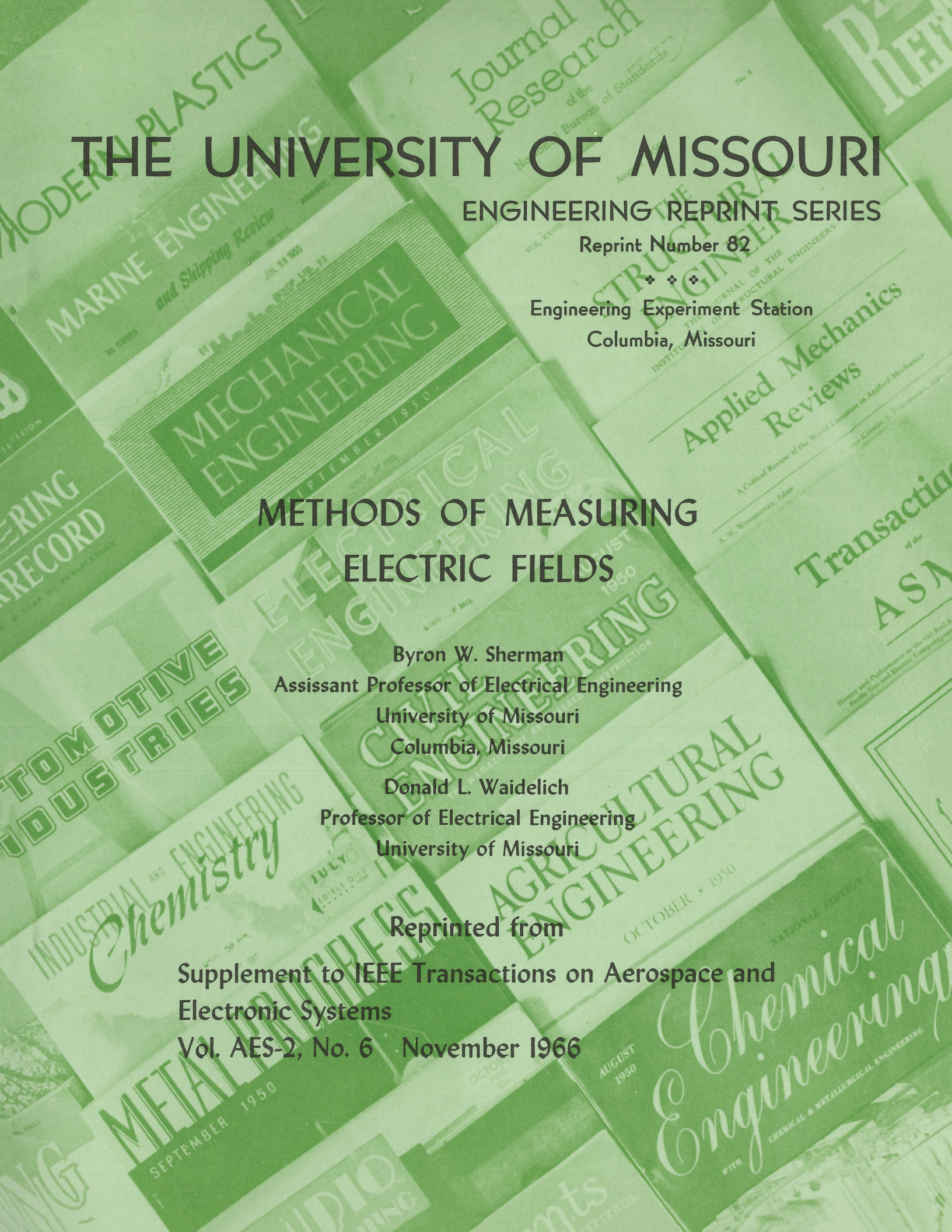

THE UNIVERSITY OF MISSOURI

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METHODS OF MEASURING ELECTRIC FIELDS

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ENGINEERING REPRINT SERIES NO. 82

METHODS OF MEASURING ELECTRIC FIELDS

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ABSTRACT

To determine the potential of a spacecraft, an electric field meter is needed to measure the field at the surface and in the neighborhood of the craft. A search was made for field measuring methods which would not involve rapidly moving parts. Several of these methods are discussed along with some experimental work performed to determine their feasibility. The use of the Stark effect in the rotational spectra of gases appears to be the most promising method considered and it is discussed in more detail.

INTRODUCTION

In determining the potential of a spacecraft, an electric field meter is needed to measure the three components or the magnitude and direction of the electric field at the surface and in the neighborhood of the craft. The first work done in the measurement of the electric field was at the surface of the earth, and later measurements were made by the use of balloons and airplanes[1]. Instruments using antennas or probes were employed to pick up a charge and then were discharged through a measuring instrument. The time for the conductors to attain their final potential was long, and so point discharges, water drops, flames, X-ray and ultraviolet sources, and radioactive sources were used to increase the conductivity of the medium and thereby accelerate the process[2].

Another instrument for measuring the electric field is the field mill[3] which consists of a rotating plate adjacent to a stationary plate. The rotating plate alternately covers and uncovers the stationary plate and thus produces an alternating voltage which may be amplified and measured. Some field mill measurements have been made on rockets and satellites[4] but difficulty has been encountered because the plasma sheath about the instrument shields it from the electric field to be measured[5]. The vibrating charged probe[6] is another method that has been used on the Gemini satellites to measure the electric field intensity. Still another method is the use of the double probe[7] in which the spacing of the probes should be great enough so that the two sheaths do not overlap and thus shield the probes from the electric field to be measured.

Both the field mill and vibrating types of meters involve motion which may cause trouble for a spacecraft on a long mission in space. The probe methods usually require a large distance between the probes and have difficulties when the potential difference associated with the electric field is the same order of magnitude as the potential drop across the sheath.

A search was made for methods of measuring electric fields that would not involve rapidly moving parts. The first method considered was that of measuring the force on a charge in an electric field. Calculations and a few simple experiments involving charged dielectric sheets and electrets quickly demonstrated that the forces involved would be too small for measurement of the expected small fields. For relatively large fields of the order of 50 volts per centimeter, this method might be quite useful.

Ferroelectric materials such as barium titanate were next investigated with the view of using one of them as the dielectric of a capacitor. The capacitance was to be measured by the use of a bridge circuit or by the change in the frequency of an oscillator. Unfortunately, the conductance of the material was so high that only transient effects could be noticed. Another possible method was to use ferroelectric materials in a manner similar to the ferromagnetic materials used in a flux-gate magnetometer[8]. Again the conductance of the materials presented a difficulty, but the major problem was that the ferroelectric material would not saturate well enough.

The next method investigated was the use of the Stark effect in the rotational spectra of gases, and this appears to be the most promising of the methods considered. Several factors made the Stark effect appear attractive as a means of measuring static fields in space. The similar technique of measuring static magnetic fields by means of the Zeeman effect had already been successful[9,10]. Also, it appeared possible that an absolute sensor could be developed whose response would depend only upon the strength of the field to be measured and the atomic constants of the gas molecules. Finally, from the considerable data available pertaining to the Stark

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effect in gases it was concluded that simple, reliable equipment could be used which would have few, if any, moving parts.

MICROWAVE ABSORPTION IN GASES

The theory of microwave absorption in gases has been developed in some detail[11, 12], and the absorption has been shown to be closely connected with the rotational motions of the gas molecules. The rotational motion of a gas molecule depends upon its physical structure which is usually described in terms of the moments of inertia about three mutually perpendicular axes, x, y, and z, which pass through its center of mass. A molecule having equal moments of inertia about two of these axes, x and y, is called a symmetric top, and this type of molecule was used in this method of field measurement. Only certain rotational energies are possible for a gas molecule, and the allowed states of rotation may be adequately described for the present application in terms of three integers or quantum numbers, K, J, and M. The quantum numbers describe the permitted angular momenta of the molecule. For example, the square of the molecule's total angular momentum, P, is given by

$$P^2 = \frac{h^2 J(J+1)}{4\pi^2} \tag{1}$$

where h is Planck's constant. The projection, P_z, of the total angular momentum on the z axis of the molecule is given by

$$P_z = \frac{h\,K}{2\pi}. \tag{2}$$

The projection, P_Z, of the angular momentum on a polar axis, Z, fixed in space is

$$P_Z = \frac{h\,M}{2\pi}. \tag{3}$$

Since the integers, M and K, represent components of J, their magnitudes cannot exceed J. Therefore, for the symmetric top one may write

$$\begin{aligned} &J = 0, 1, 2, \ldots \\ &K = 0, \pm1, \pm2, \pm3, \ldots \pm J \\ &M = 0, \pm1, \pm2, \pm3, \ldots \pm J \end{aligned} \tag{4}$$

Absorption occurs in a gas whenever an RF electric field interacts with the dipole moment of a molecule and raises it from a given energy level to a higher one. When this occurs, the gas absorbs a photon whose frequency is given by the well-known relation, $\nu = \frac{\Delta W}{h}$, where ν is the frequency, h is Planck's constant, and ΔW is the energy difference between the two levels involved in the transition. The rotational energy of a symmetric top in a field-free region is

$$W = \frac{P_x^2}{2I_x} + \frac{P_y^2}{2I_y} + \frac{P_z^2}{2I_z} \tag{5}$$

where I_x, I_y, and I_z are the moments of inertia about the x, y, and z axes, respectively, and P_x, P_y and P_z are the corresponding angular momenta. For the symmetric top, I_x and I_y are equal and each is called I_y. Equation (5) may be written

$$W = \frac{P^2}{2I_y} + P_z^2\left(\frac{1}{2I_z} - \frac{1}{2I_y}\right). \tag{6}$$

By expressing the momenta in terms of the quantum numbers one may write

$$\frac{W}{h} = BJ(J+1) + (C-B)K^2 \tag{7}$$

where $B = \frac{h}{8\pi^2 I_y}$ and $C = \frac{h}{8\pi^2 I_z}$. The quantum number, M, does not enter into this expression because a spatial axis, Z, is not established in this zero-field situation. All of the (2J + 1) possible values of M correspond to the same energy and it is said that an M degeneracy of (2J + 1) levels exists. The symmetry of the molecule requires that $\Delta K = 0$ during an absorptive transition. This is because there is no electric dipole moment perpendicular to the z axis of a symmetric top, and so no torque along this axis can be exerted by the RF electric field.

THE STARK EFFECT

The symmetric top has an electric dipole moment, μ, along its axis of symmetry which possesses a component,

$\mu_J = \frac{\mu K}{\sqrt{J(J+1)}}$ in the direction of angular momentum. The angle, α, between the total angular momentum vector, J, and a polar axis fixed in space is given by

$$\cos\alpha = \frac{M}{\sqrt{J(J+1)}} \tag{8}$$

If the axis in space is determined by an external dc electric field of magnitude, E, then there is a change in energy of the molecule caused by the interaction of its dipole moment with the field. This change is given by

$$\Delta W_{JKM} = -\mu_J E\cos\alpha = -\frac{\mu EKM}{J(J+1)}. \tag{9}$$

From (7) and (9),

$$\frac{W_{JKM}}{h} = BJ(J+1) + (C-B)K^2 - \frac{\mu E}{h}\frac{KM}{J(J+1)}. \tag{10}$$

Thus the application of an electric field establishes a space orientation and removes the degeneracy of the energy levels. Transitions involving absorption may occur according to the rules,

$$\Delta J = +1$$

$$\Delta K = 0 \qquad (11)$$

and $\Delta M = 0, \pm 1$.

If the static field is parallel to the RF electric field, then $\Delta M = 0$, since the RF field cannot produce torque along the Z axis. If the static and RF electric fields are perpendicular[13], then $\Delta M = \pm 1$. For a transition from $J = J$ to $J = J + 1$, and for $\Delta M = 0$, the frequency of absorption is found from (10) to be

$$\nu = \frac{W_{(J+1)KM}}{h} - \frac{W_{JKM}}{h} = 2B(J+1) + \frac{2\mu E}{h}\frac{KM}{J(J+1)(J+2)} . \qquad (12)$$

For $\Delta M = \pm 1$ it is

$$\nu = \frac{W_{(J+1)K(M\pm1)}}{h} - \frac{W_{JKM}}{h} = 2B(J+1) + \frac{(2M \mp J)K\mu E}{hJ(J+1)(J+2)} . \qquad (13)$$

The frequency shift is a linear function of the static field in both cases. For $\Delta M = 0$ the shift is

$$\Delta\nu = \frac{2\mu KME}{hJ(J+1)(J+2)} . \qquad (14)$$

For ν in megahertz, μ in Dybye units, and E in volts per centimeter, the quantity, $\frac{2}{h}$, is equal to 1.0064. For $\mu = 1$ Debye unit, the maximum shift occurs when $K = M = J$, and it is given by

$$\Delta\nu \approx \frac{JE}{(J+1)(J+2)} \text{ megahertz.} \qquad (15)$$

For a typical case of $J = 3$ the frequency shift is

$$\Delta\nu \approx 0.15E \text{ megahertz.} \qquad (16)$$

It is interesting at this point to compare (16) with results obtained from tests where energy levels in magnetic materials were shifted by the application of dc magnetic fields. In one case[14] a shift of 2.8 megahertz per gauss was used to obtain a measure of the dc magnetic field to values as small as 10^{-7} gauss. If equal precision could be achieved in measuring frequency shifts in rotational spectra, equation (16) indicates that one could expect to measure electric fields the order of one millivolt per meter by means of the Stark effect.

THE AMMONIA ABSORPTION LINE

Ammonia was chosen as the first gas to be used in this application because it has a very strong absorption line in its microwave spectrum which exhibits a frequency shift in the presence of a dc electric field. The equation of the absorption line in the pressure range of interest is[15]

$$\gamma = K_1 \frac{\Delta}{(\nu - \nu_o)^2 + \Delta^2} \qquad (17)$$

where γ is the absorption coefficient at the frequency, ν, and is expressed in cm^{-1}. K_1 is a constant of proportionality. The frequency difference between the two half-power points of the line is 2Δ, and ν_o is the resonant frequency, or frequency of maximum absorption. Frequencies are expressed in megahertz. The expression, (17), may be written as

$$\gamma = \frac{K_2}{u^2 + 1} \qquad (18)$$

where $K_2 = \frac{K_1}{\Delta}$ and $u = \frac{\nu - \nu_o}{\Delta}$. The variable, u, is the frequency deviation from resonance expressed in units of Δ.

Ammonia is a pyramid-shaped molecule with the nitrogen atom at the apex and the three hydrogen atoms in the same plane and equidistant from the nitrogen atom. The nitrogen vibrates along the symmetry axis of the molecule and often passes through the plane of the hydrogen atoms and resumes its vibrational motion on the other side of the molecule[16]. Because of this shuttling action, the molecule in a field-free region has no average dipole moment, although it has a permanent dipole moment, μ, in either stable physical configuration. The average dipole moment is a function of the applied electric field, and so the energy of orientation is a non-linear function of this external field. The shift in frequency is a second order effect and is reported to be[17]

$$\Delta\nu = 0.5065 \frac{\mu^2 E^2}{\nu_o} \times \left[\frac{KM}{J(J+1)}\right]^2 \text{ megahertz} \qquad (19)$$

where μ is in Debye units, E is in volts per centimeter, and $\Delta M = 0$. ν_o is the resonant frequency of the unshifted line. For the line used in this work, $J = K = 3$, and M may be 0, ± 1, ± 2, or ± 3. From (19) it is seen that the amount of shift for a particular molecule depends upon the value of M describing its state. Therefore, the absorption frequency of some molecules is shifted more than others and the overall absorption line shape is changed from that described in equation (17). The behavior of this ammonia line

in a dc electric field is indicated in Figure 1.

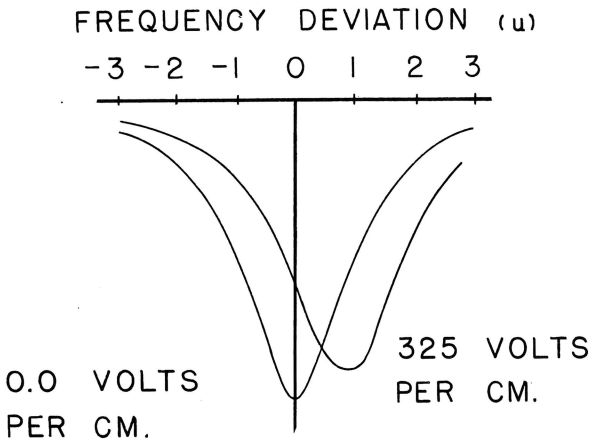


Figure 1. The Ammonia Absorption Line For Two Values of Electric Field.

THE EXPERIMENTAL SYSTEM

The simple microwave system shown in Figure 2 was constructed to demonstrate the use of the Stark effect in electric field instrumentation. It was not designed to perform precise measurements, but merely to provide some direct indication of the approximate magnitude of an applied field, and thereby justify this approach. Microwave energy at a frequency of approximately 2.4×10^{10} hertz was propagated through the absorption cell to the diode detector. When the klystron frequency was swept in synchronism with the oscilloscope trace, the absorption line shown in Figure 3 was observed on the oscilloscope. The dc electric field was established by means of an electrode within the absorption cell.

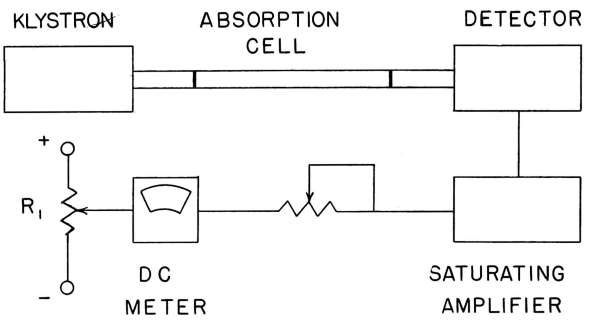
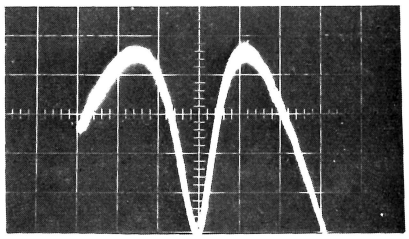
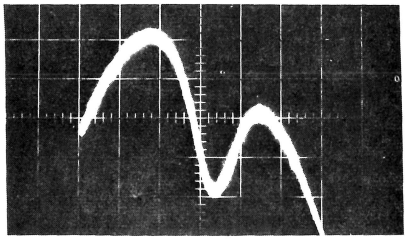


Figure 2. The Microwave System Used To Obtain a Direct Indication of the Applied Electric Field.



E = 0.0 VOLTS PER CM.

(A)



E = 140 VOLTS PER CM.

(B)

Figure 3. The Ammonia Absorption Line Superimposed Upon The Operating Mode of the Klystron for Two Values of Electric Field.

The detection system of Figure 2 was arranged to indicate a change in width of periodic pulses coming from the detector. The high-gain saturating amplifier provided a rectangular output pulse of constant amplitude whose width was a function of the width of the pulse from the detector. The dc meter provided a measure of the average value of the amplified signal. R_1 was adjusted so that the meter reading was zero when the electric field applied to the ammonia was zero.

In order to obtain a pulse which exhibited an appreciable change in width when a

dc field was applied to the absorption cell, the modulation scheme of Figure 4 was used. With this method, the frequency of the klystron oscillator was set at some value, ν_1, which was near to but

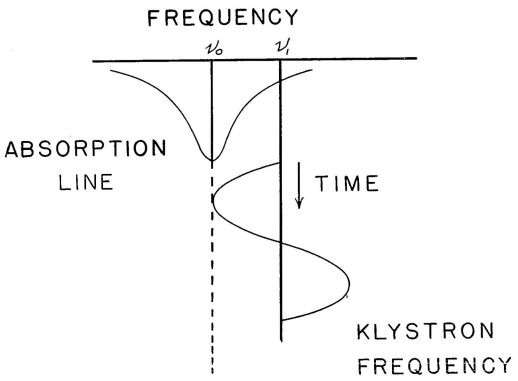


Figure 4. Klystron Frequency as a Function of Time.

higher than ν_0. The frequency was then varied sinusoidally so as to sweep one half of the absorption line twice each cycle. When the electric field modified the absorption line by changing its resonant frequency, its width, and its amplitude, the oscillator frequency swept more than one half of the line twice during each cycle. The detector output pulse then experienced a decrease in amplitude and a broadening which was caused both by line broadening and by the resonant frequency shift. This is shown in Figures 5 and 6.

A vacuum tube voltmeter was used to measure the output of the system. A number of factors affected the shape of the diode detector's output pulse, and, therefore affected the signal to the meter. The observed absorption line shape was distorted to some extent by the mode shape of the klystron and also by a somewhat uneven electric field distribution within the absorption cell. Also, reflections within the microwave system as well as the response of the electronic circuitry affected the output pulse shape. The

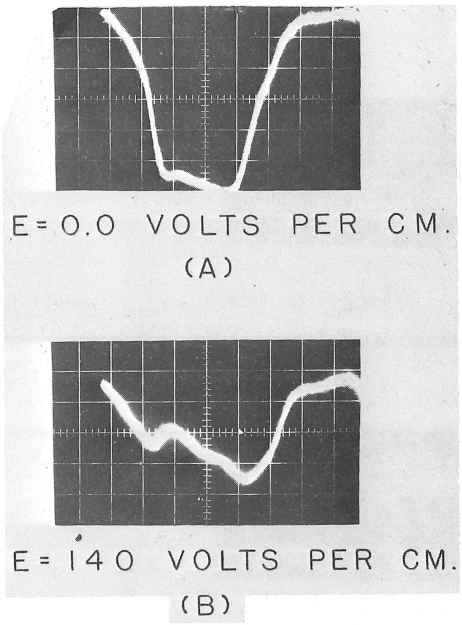


Figure 5. Detector Output of the Modulated System for Two Values of Electric Field.

observed system output as a function of the applied electric field was fitted with the computed response at the two extreme points and plotted in Figure 7 to obtain a comparison of predicted and observed results. The minimum detectable electric field in this system was estimated to be approximately fifty volts per centimeter.

CONCLUSIONS

Although this system has not been refined to the point where its ultimate sensitivity can be determined, it has demonstrated that the Stark effect can be used to measure static electric fields. Work is continuing in an effort to develop a practical Stark effect field meter. A number of significant points are being considered:

1. Arrangements are being made to measure the field external to the equipment rather than the dc field within the absorption cell as described in this paper.
2. The effect of the orientation of the instrument will be examined. In this work the dc field was always parallel to the RF electric field, a condition which resulted in the selection rule, $\Delta M = 0$.

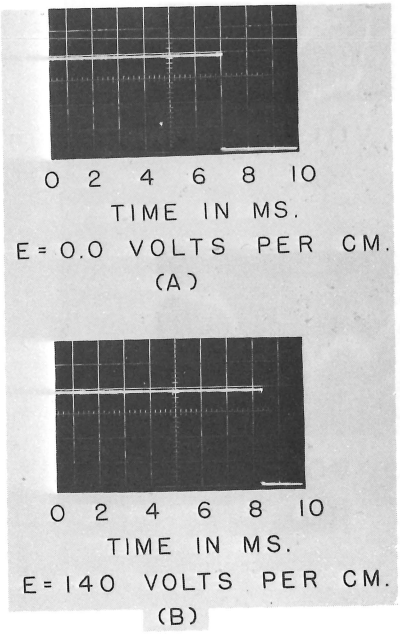


Figure 6. Amplifier Output for Two Values of Electric Field.

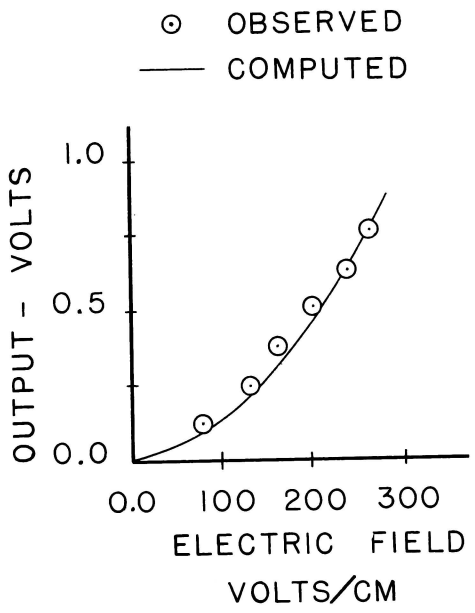


Figure 7. Output Voltage as a Function of the Electric Field.

Whenever the fields are perpendicular, the selection rule is $\Delta M = \pm 1$, and significant changes occur in the behavior of the absorption line.

3. Effort will be made to select an optimum working gas. Ammonia exhibits a strong absorption line, but its Stark shift has a square law response with respect to the applied field and causes a non-linear system response.

4. Considerable effort will be necessary in the development of the probe which senses the electric field. There are problems of the plasma environment in space, sensitivity to local magnetic fields, and electric field distortion caused by the measuring instrument. Methods being considered include the transmission of electromagnetic energy through a cloud of gas which is free in space some distance from the instrumented space vehicle. Field sensing might be done by observing the Stark shift in the absorption or by observing a Stark shift in radiation emitted spontaneously from a gas which has been excited by a pumping process.

REFERENCES

1. J. Alan Chalmers, "Atmospheric Electricity", Macmillan Co., New York, N. Y; 1957.

2. G. W. Paltridge, "Measurement of the Electrostatic Field in the Stratosphere," J. GEOPHYS. RES., vol. 69, pp. 1947-1954; May, 1964.

3. W. W. Mapleson and W. S. Whitlock, "Apparatus for the Accurate and Continuous Measurement of the Earth's Electric Field," J. ATMOS. TERR. PHYS., vol. 7, pp. 61-72; 1955.

4. G. L. Gdalevich, "Rocket Experiments Aimed at Detecting an Electric Field in the Ionosphere," in "Problems of Atmospheric and Space Electricity", Elsevier Publishing Co., pp. 566-572; 1965.

5. J. L. Wildman, "A Device for Measuring Electric Field in the Presence of Ionisation," J. ATMOS. TERR. PHYS., vol. 27, p. 417; March 1965.

6. J. M. Palmer, "A New Electrostatic Field Measuring Instrument," IEEE TRANS. ON AEROSPACE, vol. AS-3, pp. 523-527; June 1965.

7. D. W. Johnson and A. Kavadas, "A Rocket-Borne Electric Field Probe," CANADIAN J. PHYS., vol. 41, pp. 1980-1990; 1963.

8. R. Munoz, "The Ames Magnetometer," NAT. TELEMETERING CONF. PROC., pp. 77-80, Boston, Mass.; 1966.

9. L. D. Schearer, F. D. Colegrove, and G. K. Walters, "Optically Pumped Nuclear Magnetometer," REV. SCI. INSTR., vol. 34, No. 12, p. 1363; December, 1963.

10. A. R. Keyser, J. A. Rice, and L. D.

Schearer, "A Metastable Helium Magnetometer for Observing small Geomagnetic Fluctuations," J. GEOPHYS. RES., vol. 66, No. 12, 4163; December 1961.
11. B. Bak,"Elementary Introduction to Molecular Spectra," Interscience Publishers, Inc., New York; 1962.
12. C. H. Townes and A. L. Schawlow, "Microwave Spectroscopy," McGraw-Hill Book Company, Inc., New York, N. Y., ch. 1; 1955.
13. Townes and Schawlow, Ibid., p. 235.
14. Keyser, Rice, and Schearer, loc. cit.
15. Townes and Schawlow, op. cit., p. 343.
16. E. Merzbacher, "Quantum Mechanics," John Wiley and Sons, Inc., New York, N. Y., pp. 64-77; 1961.
17. W. Gordy, W. V. Smith, and R. F. Trambarulo,"Microwave Spectroscopy," John Wiley and Sons, Inc., New York, N. Y., p. 158; 1953.

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