1948

A microwave polarimeter

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Recommended Citation

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A MICROWAVE POLARIMETER

BY

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A

THESIS

submitted to the faculty of the

SCHOOL OF MINES AND METALLURGY OF THE UNIVERSITY OF MISSOURI

in partial fulfillment of the work required for the

Degree of

MASTER OF SCIENCE, PHYSICS MAJOR

Rolla, Missouri.

1948

Approved by Zaboj V. Harvalik

Associate Professor of Physics

ACKNOWLEDGMENT

Grateful acknowledgment of aid in the work of this paper is due to Dr. Z. V. Harvalik, for the original idea and plan of attack, to Mr. H. A. Martin and Mr. O. C. Ellenberger, for their patience and the use of their tools and equipment, to Mr. Louis Shapiro, for his suggestions on theory, and to Mr. James Dueker, for his suggestions on construction practice and the use of his books and samples.

PREFACE

The dissertation on the following pages may read more like a construction article than an approach to a study of physical phenomena. If so, its purpose is clearly defined. This subject has been studied little from an experimental viewpoint, so one of the main objectives of this writing is to describe the instrument so others may read the article and reproduce this or an equivalent device without a great amount of reading and searching for information on just how to fabricate and mount the parts. No single book or article that I know of covers the inexpensive construction of such microwave equipment as transmitters, receivers, and power supplies. It was gratifying to find that many ideas used here have proved practical as publications under the direction of the Office of Scientific Research and Development of the National Defense Research Committee later showed. Many of these publications were released or declassified long after my designs had been made. I do deplore, however, the amount of time and labor that could have been saved if this information had been available sooner. I must say that the war surplus radio equipment available at the present time certainly expedites work in the field of microwaves and should be exploited fully by anyone working in this field.

Alfred E. Schwaneke

July 15, 1948

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A MICROWAVE POLARIMETER

Introduction

In the field of optics, polarization of light waves has been studied extensively. Much knowledge has been gained through study in the range of visible and infrared light. However, when wavelengths longer than these, i.e., radio waves, are considered, the amount of information is surprisingly small. In some cases, the equations applying to light wavelengths have been expanded into the lengths of radio waves with no ill effects. In the case of polarization equations, some in the range of light have been extended into the realm of radio but no experimental proof of the validity of these equations in the longer wavelengths has been shown.

The dearth of information and experimental study in the field of radio wave polarization is perhaps due to several reasons, some of which might be:

a. Absence of a need for this study since communication by radio, its most important phase, does not necessarily depend upon a knowledge of polarization.

b. Many obvious applications of optical work to radio waves that have been easily proved correct extend, without necessary experimental proof, the result of work with polarized light.

c. No apparatus has been extensively developed for experimental work in this field.

Although the above ideas could be supplemented with others, the first is, perhaps, most important. With the development of microwave uses in the recent war the last reason is fast disappearing.

The purpose of this paper is to describe the development of an instrument to study polarization of microwaves with an eye to extending the results of optical experiments across the narrowing but difficult gap in the electromagnetic spectrum between radio and light. With this instrument, essentially a polarimeter, a study of the effects of polarized microwave radio might be started.

Review of literature

In optics, if two nicols of a polariscope are initially crossed to obtain extinction it is found that some substances, when placed between them, simply rotate the position of the analyzer needed to produce extinction again. The resulting light is still plane polarized, the only effect being noted is the rotation of the plane of vibration shown by the new position of the analyzer. Such substances which produce this rotation of the plane of polarization are called "optically active." Some rotate the plane in one direction while others rotate the plane in the opposite direction. This left and right rotation may occur in substances of the same chemical composition. Quartz is one example of this effect. A quartz plate cut perpendicular to the optical axis, to remove the effect of double refraction, may show either right or left rotation. In many crystalline substances this rotation may be due entirely to the peculiar crystal structure, as the molten or dissolved structureless form may be inactive.

The amount of rotation by any active substance is proportional to the distance the light travels in the substance and to its density, or concentration in case of solutions. The constant of proportionality is called the "specific rotatory power." In the case of solids is is commonly expressed as degrees rotation per millimeter. The equation for specific rotatory power, as determined experimentally by Biot, is

$$\alpha = \frac{B}{\lambda^2}$$

where B is a constant for each substance. For quartz B = 7.52 when λ, the wavelength is in microns.

Other materials show rotation which does not depend on crystal form since it occurs even if the substance is dissolved or in the molten state. This seems to be the result of unsymmetrical molecular structure. It occurs in organic compounds such as sugar.

Biot's equation was determined experimentally in the range of optics, and seems to hold into infra-red and ultraviolet regions. However, Biot's equation shows no possibility of a material having a right hand rotation ever giving a left hand rotation at some wavelength.

H. E. Hollman(1) describes an experiment by K. F. Lindman in 1920 wherein artificial molecules and crystals com-

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(1) H. E. Hollman, Physik und Technik der ultrakurzen Wellen, Volume II, pp. 279-280

posed of resonant helixes, to represent atoms, could give both left and right hand rotation of the polarization plane if the wavelength were varied over a certain range around 25 centimeters. From Lindman's observations Biot's equation should probably be

$$= \frac{B\lambda_o^2\lambda_n^2(\lambda-\lambda_o)^2}{(\lambda^2-\lambda_o^2)\lambda_n^2+\lambda_n^2\lambda^2}$$

where λ_n is the wavelength of molecular resonance (resonant helixes), λ_o is the resonant wavelength of the artificial crystal system, and λ is the wavelength of the incident radiation. This shows that at $\lambda = \lambda_o$ the rotation will be zero while the rotation will be right or left depending on which side of λ_o, λ happens to be.

The instrument to be described is a result of attempts to investigate further the above mentioned work.

There are some other rather interesting investigations involving polarization of radio waves. An experiment on the polarization of down coming waves(2)(3)(4) has led to a the-

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(2) E. V. Appelton and J. A. Ratcliffe, A Method of Determining the State of Polarization of Down Coming Waves, Proc. Roy. Soc. (London) Vol. 117A pp. 576-578 March 1928

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(3) A. L. Green, The Polarization of Sky Waves in the Southern Hemisphere, Proc. I. R. E., Vol. 22 pp. 324, March 1934

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(4) W. G. Baker and A. L. Green, The Limiting Polarization

ory that the earth's magnetic field causes the received waves to be elliptically polarized. In this paper the main interest is in measuring the polarization. The method of measurement used in the above noted experiments was to use three spaced loop receivers for diversity reception. The interference fringes obtained from the three receivers as the transmitted frequency is varied decides the polarization characteristics of the received wave, in this case elliptically polarized. This system would be impractical at wavelengths of a few centimeters as would be used in a microwave polarimeter.

A method more applicable was used by J. D. Kraus(5) where the plane polarized characteristics of a dipole receiving antenna was used to explore the polarization of a helical beam antenna. A simple dipole with rectifier was rotated in the field of the transmitting antenna to show that, since the rectified current reading did not vary, the field of the antenna described was circularly polarized.

Experiments were conducted with this system using a ten centimeter wavelength transmitter feeding a dipole radiator with a parabolic reflector. The receiver was a dipole with a rectifier crystal furnishing current to a microammeter.

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of Down Coming Radio Waves Traveling Obliquely to the Earth's Magnetic Field, Proc. I. R. E., Vol 21, pp. 1103, August 1933

(5) John D. Kraus, Helical Beam Antenna, Electronics, Vol. 20, Number 4, pp. 109, April 1947

The wavelength of ten centimeters proved to be too long for accurate measurements. The problems of shielding, stray fields, reflections, and phase disturbances gave meaningless results. Also, the simple dipole was too easily influenced by adjacent materials. An array of phased dipoles would probably give sharper readings of the polarization but at ten centimeters wavelength such an array would have unreasonable dimensions considering the samples to be investigated.

The above disadvantages preclude the use of shorter wavelengths. Generators of fair efficiency and output have been developed as a result of radar investigations(6) during the war, and the information associated with these generators is being declassified and published from time to time. The generators available for this instrument consisted of several of the 723A/B series reflex klystrons which generate about 25 milliwatts of 3.2 centimeter radio frequency power. This range was selected as being applicable to the present problem. In this range antennas no longer use wires but take the shape of horns and apertures in sections of waveguide. The operation of horn antennas is covered effectively by Terman(7) giving the necessary data to calculate antennas for 3.2 cen-

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(6) C. G. Montgomery, Technique of Microwave Measurement, Chapter 2, pp. 21-58

(7) F. E. Terman, Radio Engineers' Handbook, pp. 824-833

timeter wavelengths.

A special horn radiating a circularly polarized wave has been described by G. Stavis and A. Dorne in their chapter on horns and reflectors in the publication of the Harvard Radiation Laboratory.(8) This horn makes use of a phasing section containing a dielectric sheet to retard one component of an oblique plane polarized wave to give a rotation of the phase of the emitted wave thus radiating a circularly polarized wave into space. This retardation of one component of a wave is of special interest since it allows a means of dielectric study. Also of extreme interest in this article was the method of measuring the circularity of the horn used by Stavis and Dorne. The horn under test was mounted rigid and co-axial to another sectorial horn. The tested horn was used as a source of radio frequency feeding into the sectorial horn acting as a receiver. This second horn was in a rotating mount and as it was rotated in angular steps the received signal strength was recorded. These figures when plotted on polar coordinate paper give an idea of the polarization characteristics of the emitting horn. The sectorial horn responds only to a plane polarized wave and in the case cited the circularity of polarization is evidenced by no variation of the received signal strength. This method, with slight variations, had previously been decided upon for the present

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(8) Harvard University, Radio Research Laboratory, Very High Frequency Techniques, Vol. I, Ch. 6, pp. 138-170

instrument when the ten centimeter wavelength experiment failed to produce readable results.

Further search for experiments in this field produced nothing of interest. As was stated, experiments in the field of polarimetry in radio have been few. Only in the last five years, since the widespread development of television, frequency modulation, and radar, has radio wave polarization become noticeable since only recently has the quasi-optical range of radio waves been put to use.

General circuit of the polarimeter

The essential features of the polarimeter are shown in block diagram form in figure (1), page 14. The polarizer portion consists of a type 723A/B-2K25 klystron generator coupled to a short section of waveguide which radiates energy into space through a pyramidal horn antenna. This antenna radiates a plane polarized wave(9) which is intercepted by another horn of like construction serving as the antenna of the receiver-analyzer. A special co-axial line rotating joint allows the analyzer horn to be rotated to measure the polarization characteristics of the received energy. This

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(9) The plane of polarization referred to throughout this article is that of the electrostatic lines of force. The magnetic lines are considered to exist, according to Maxwell's equations, at right angle with the plane referred to.

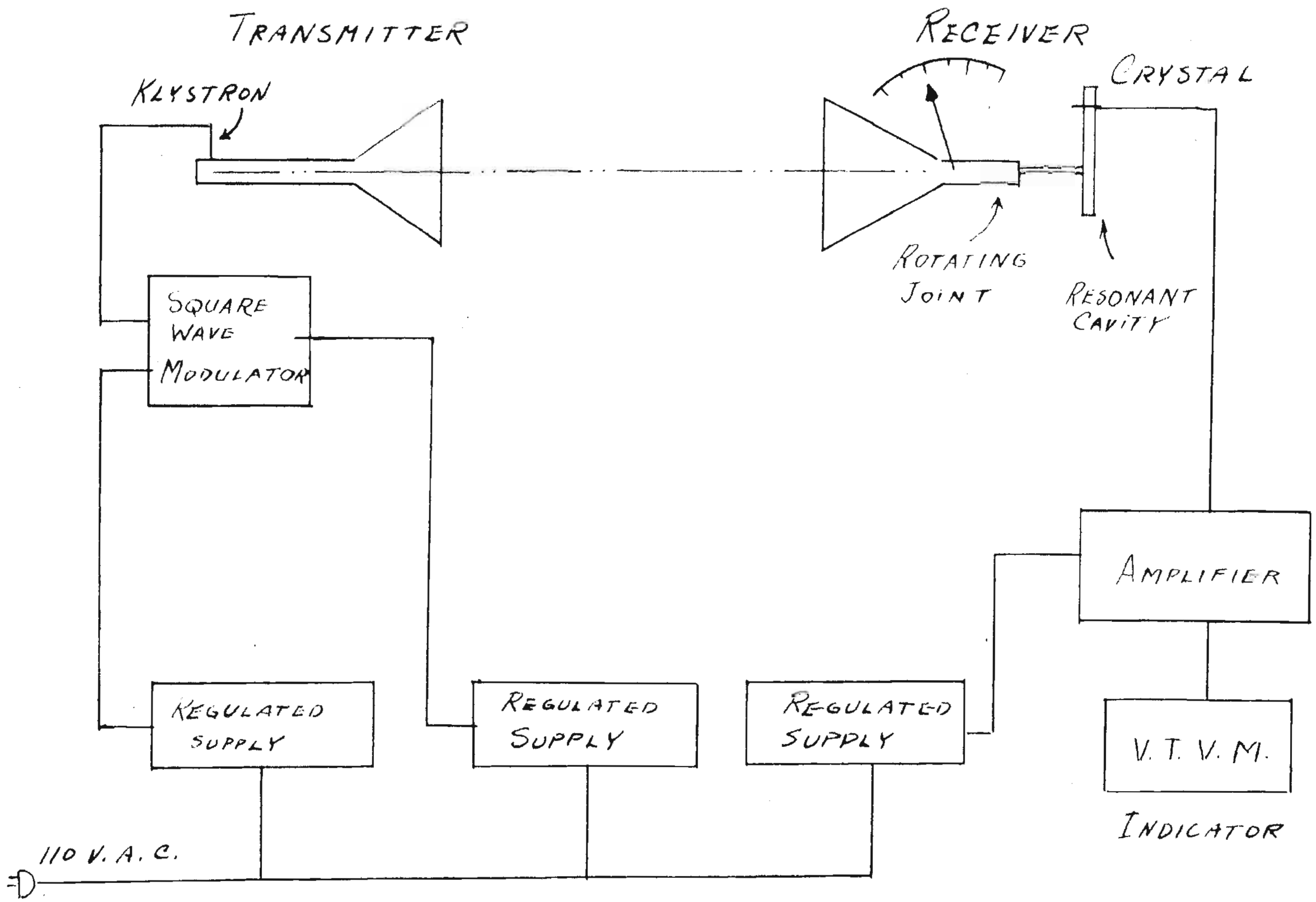


Figure (1) Block diagram of the complete polarimeter special joint couples the energy to a semi-resonant section of waveguide terminated in a silicon crystal rectifier (1N23). The output of the polarizer is amplitude modulated by a 1000 cycle per second square wave. This modulation appears as a 1000 cycle varying voltage across the crystal rectifier along with the steady direct current component of the rectified carrier. This complex current is passed through an impedance transformer, T_3 of figure (11), and the resulting 1000 cycle per second square wave is sent through the amplifier to the vacuum tube voltmeter(V.T.V.M.) to indicate the received signal strength. Any change of amplitude at the receiver is recorded by the vacuum tube voltmeter.

Variations of the line voltage would cause variations both in frequency and amplitude of currents and voltages appearing in all components of the above described system so all power furnished to these components is electronically regulated. Figure (2), page 16, and figure (3), page 17, are photographs, front view and back view, of the complete instrument set up for operation.

Power supplies

The power requirements of the 723A/B-2K25 klystron are 6.3 volts alternating current for the heater, 200 to 300 volts positive direct current for the beam voltage, 100 to 150 volts negative direct current for the repeller cap. All direct current voltages here are referred to the cathode of the klystron.

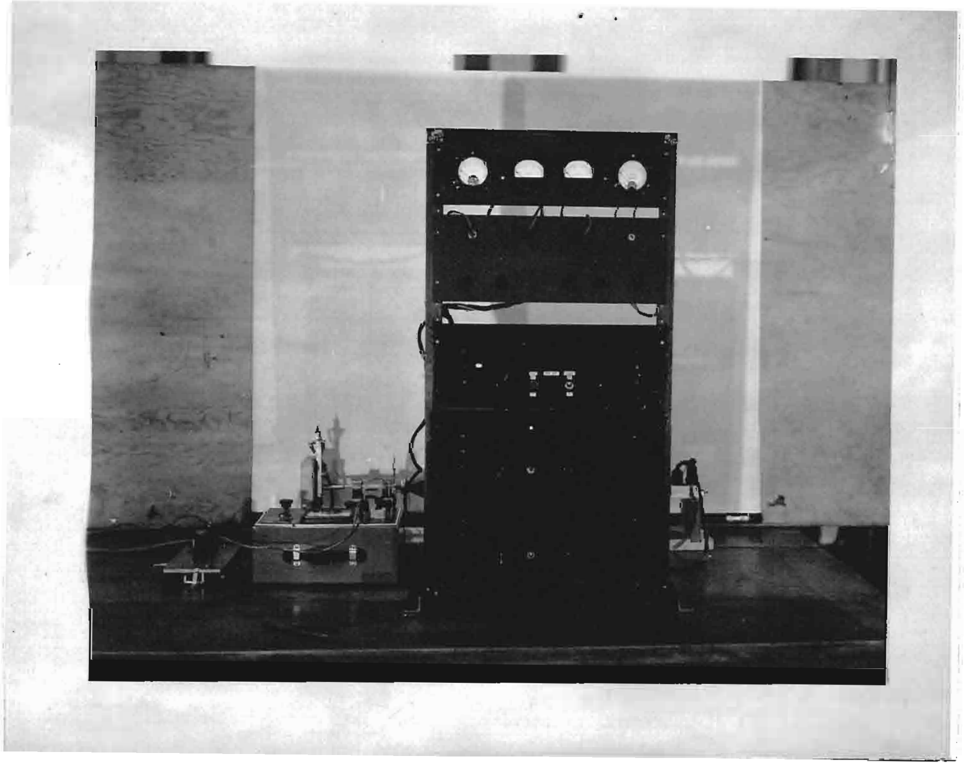


Figure (2) Front view of complete polarimeter set up for operation. At the far left is the receiver amplifier followed by the vacuum tube voltmeter. The rack contains the power supplies, modulator and voltage controls, and meters for voltage and current. The receiver-analyzer and transmitter-polarizer are behind the above indicated apparatus.

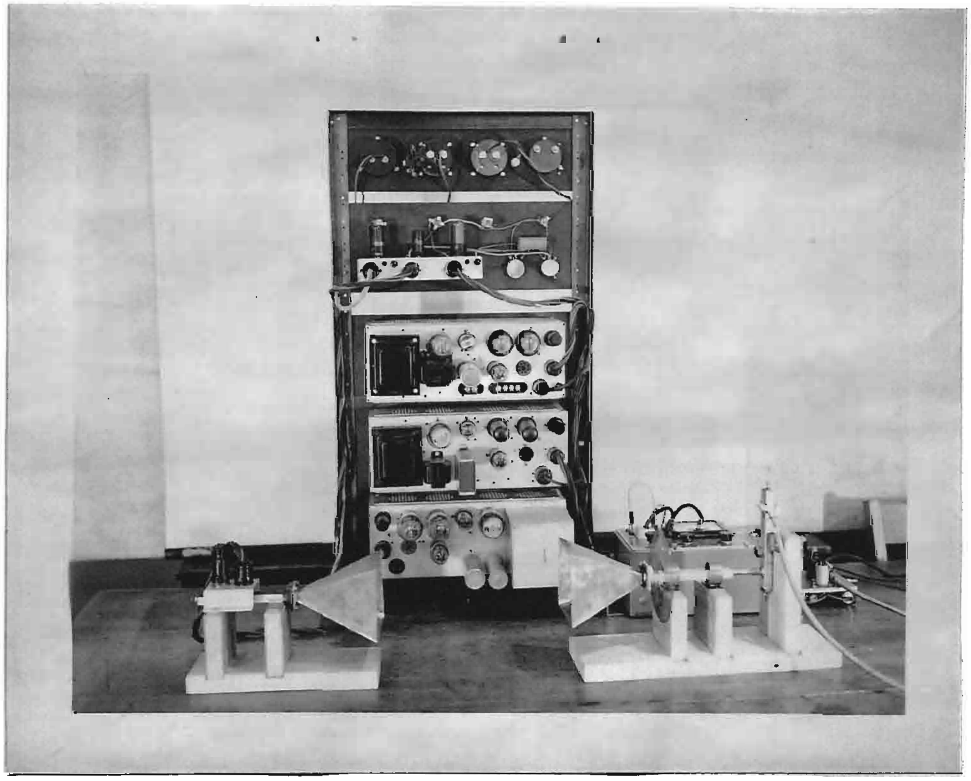
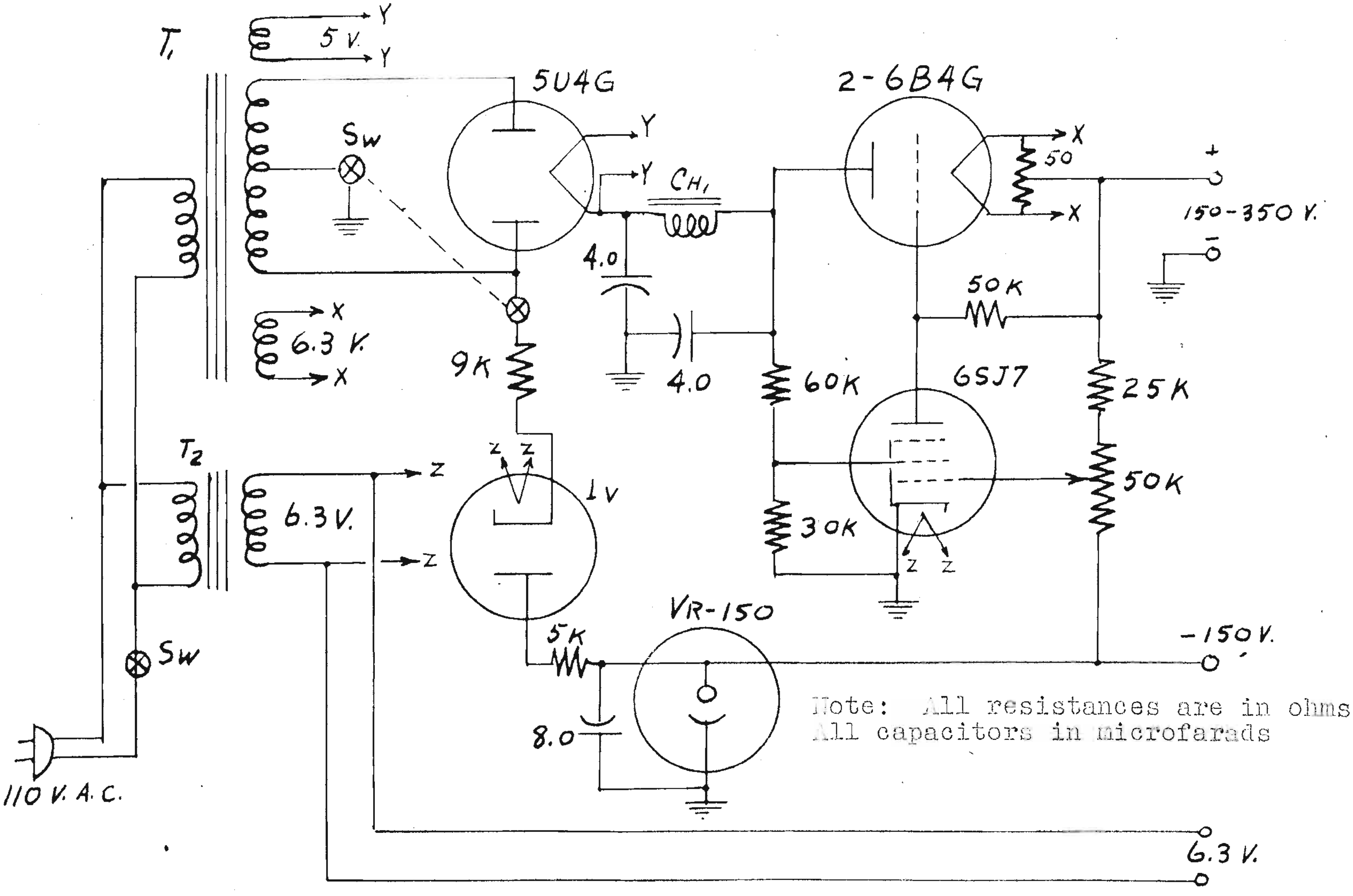


Figure (3) Rear view of complete polarimeter set up for operation. At the left foreground is the transmitter-polarizer and the right foreground the receiver-analyzer.

The reflex klystron type of signal generator is very sensitive to fluctuations of the beam or repeller voltages. A change in either affects the frequency of operation and also the output power. These voltages must therefore be electronically regulated.

A schematic diagram of the power supply for the transmitter-polarizer is shown in figure (4), page 19. The necessary beam voltage is furnished by the combination of T_1 and the 5U4G vacuum tube rectifier followed by the usual pi filter network of 2 4 microfarad capacitors and the filter choke, Ch_1. The output here is regulated by an electronic resistor consisting of two 6B4G triode vacuum tubes in parallel connected in series with the supply voltage to the beam electrodes. The effective resistance of these triodes presented to the circuit is controlled by their grid potential. This potential, in turn, is determined by the plate current flow of the 6SJ7 amplifier control vacuum tube. Any fluctuation of the output load voltage is felt on the grid of the 6SJ7 through the 25,000 ohm resistor in series with the 50,000 ohm potentiometer. This change immediately initiates a change in the 6SJ7 plate current which affects the 6B4G grid potential. This change in the 6B4G grid potential allows the electronic resistor to compensate for the original fluctuation in load voltage. This produces a regulated voltage output.

The 6SJ7 control amplifier must be supplied a constant negative grid bias voltage for proper operation. This is



Note: All resistances are in ohms
All capacitors in microfarads

Figure (4) Schematic diagram of power supply - Three are required.

furnished by the VR-150 gaseous regulator tube from a source rectified by the 1v half wave rectifier tube and is connected into the bottom side of the 6SJ7 grid potentiometer. The position of the potentiometer arm determines the voltage level at which the 6SJ7 takes control and thus allows a selection of the output voltage of the supply. A regulation of better than one per cent over a range of 150 to 350 volts output is thus obtained.

Since a negative potential of 150 volts is available from the VR-150 gaseous voltage regulator this is used to supply the repeller potential of the klystron.

The square wave generator-modulator and the receiver-amplifier are operated from two more identical power supplies to insure freedom from line voltage flustuations. The heater supply of 6.3 volts alternating current, also taken from the power supplies, is not regulated since a variation of one volt in the line produces less than one-twentieth volt variation in the heater potential and the time lag of heating the cathodes of the various tubes used would easily iron out these small variations.

All power supplies are built to mount in a standard relay rack for convenience and all connections to them are in the form of plugs and sockets with appropriate multi-wire cables.

Transmitter-polarizer

The transmitter-polarizer section of the polarimeter is relatively simple. A short section of waveguide 15 centimeters long, terminated in a choke flange,(10) on one end is terminated on the other end with a close fitting rectangular machined brass plug with an adjusting screw to vary the plug position over a small range of about one centimeter. Approximately 1.0 centimeters (.4 inch) away from the central region of travel of the brass plug a hole is drilled to mount a small quarter-wave choke coupling to take the co-axial output line from the klystron. The choke coupling for the co-axial line from the klystron generator is used to insulate the waveguide from the sleeve of the line since this sleeve is at the beam potential of 250 to 300 volts positive. On a small chassis placed above this hole is mounted a modified octal socket to receive the klystron. A detail of the klystron mount and waveguide connection is shown in figure (5), page 22. A male power plug is also mounted on this small chassis to furnish the various voltages to the klystron. This is not shown on the detail drawing but is an ordinary octal plug mounted beside the klystron socket. The horn antenna is attached to the choke flange at the other end of the waveguide section. A photograph of the complete transmitter-polarizer is shown in figure (6), page 23.

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(10) For a description of the choke flange and their use see: Sperry Gyroscope Company, Inc., Microwave Transmission Design Data, or C. G. Montgomery, Technique of Microwave Measurements, pp. 14-17.

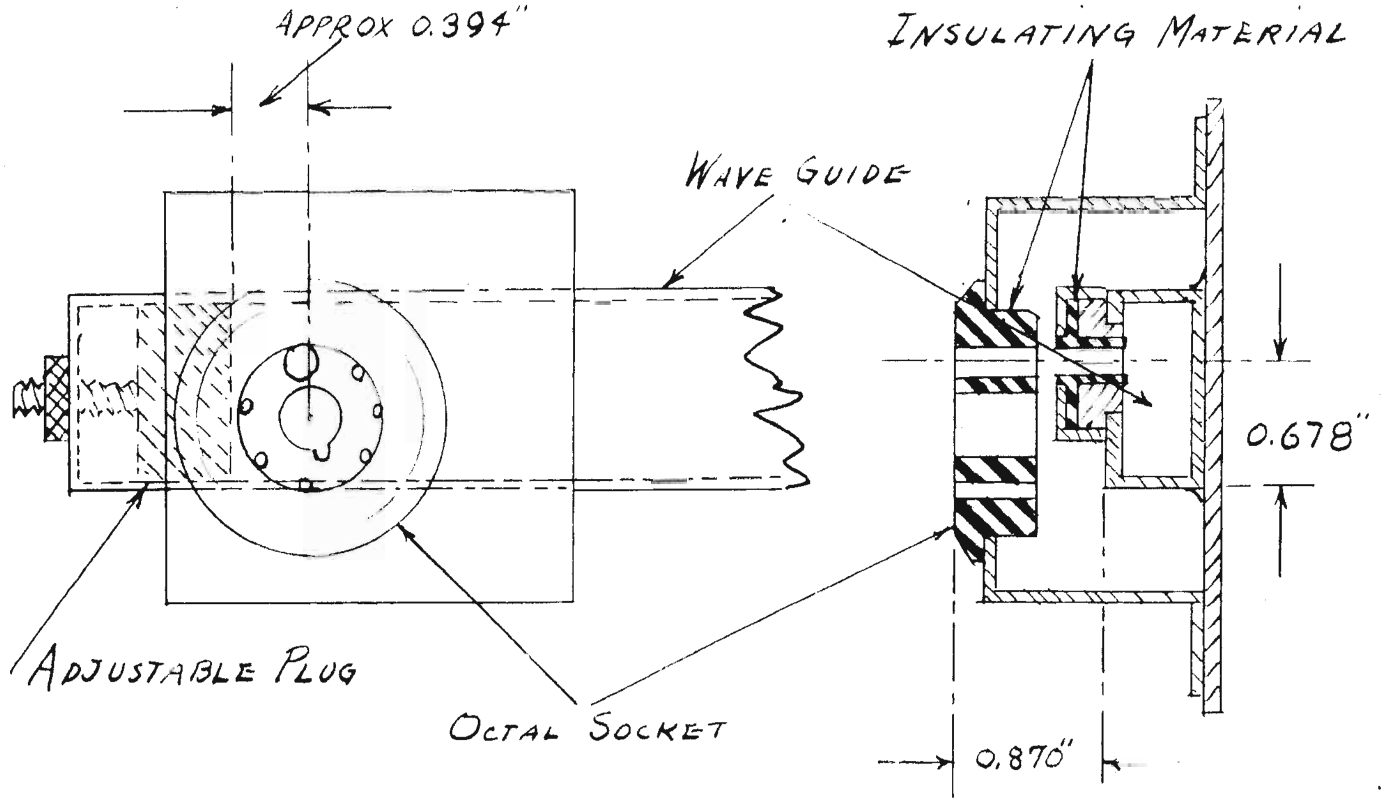

Figure (5) Detail of Klystron mount - Dimensions are in inches.

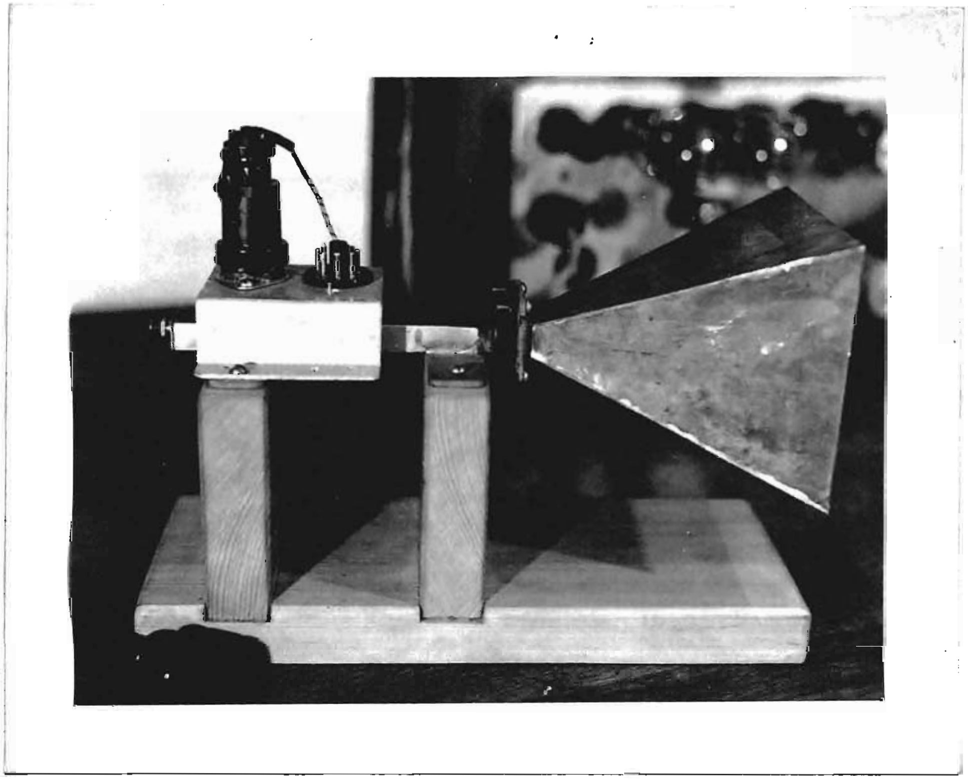

Figure (6) Close-up of Transmitter-polarizer with the klystron generator plugged in. The power socket and multi-wire cable is in the lower foreground.

This type of construction excites the waveguide in its simplest mode, namely, the TE 1,0 mode, which radiates a wave from the horn that is plane polarized parallel to the short dimension of the guide or, in this case, vertically polarized.

The whole assembly is rigidly mounted on a wood base which can be clamped to a laboratory bench to give the vertically polarized wave output.

If the reflector, or repeller, voltage of a klystron is varied sinusoidally or by a saw-toothed wave shape the resulting radio frequency output will undergo ordinary frequency modulation at the rate of the applied varying voltage. If a square-wave variation is applied to the repeller potential the result will be amplitude modulation of the klystron output power. For simplification of the receiving system the klystron here is amplitude modulated with a square-wave of approximately 1000 cycles per second.

The modulator consists of a multivibrator, which produces essentially a square-wave voltage, a positive peak clipper tube circuit, to insure a flat-topped positive peak, and an amplifier, to produce the required power output for best modulation. The output of the square-wave amplifier is coupled to the klystron repeller through a 0.5 microfarad capacitor. A detailed schematic diagram of the modulator and associated controlls is shown in figure (7), page 25. This unit is mounted on a standard relay rack panel and is placed above the power supplies in the rack. Associated

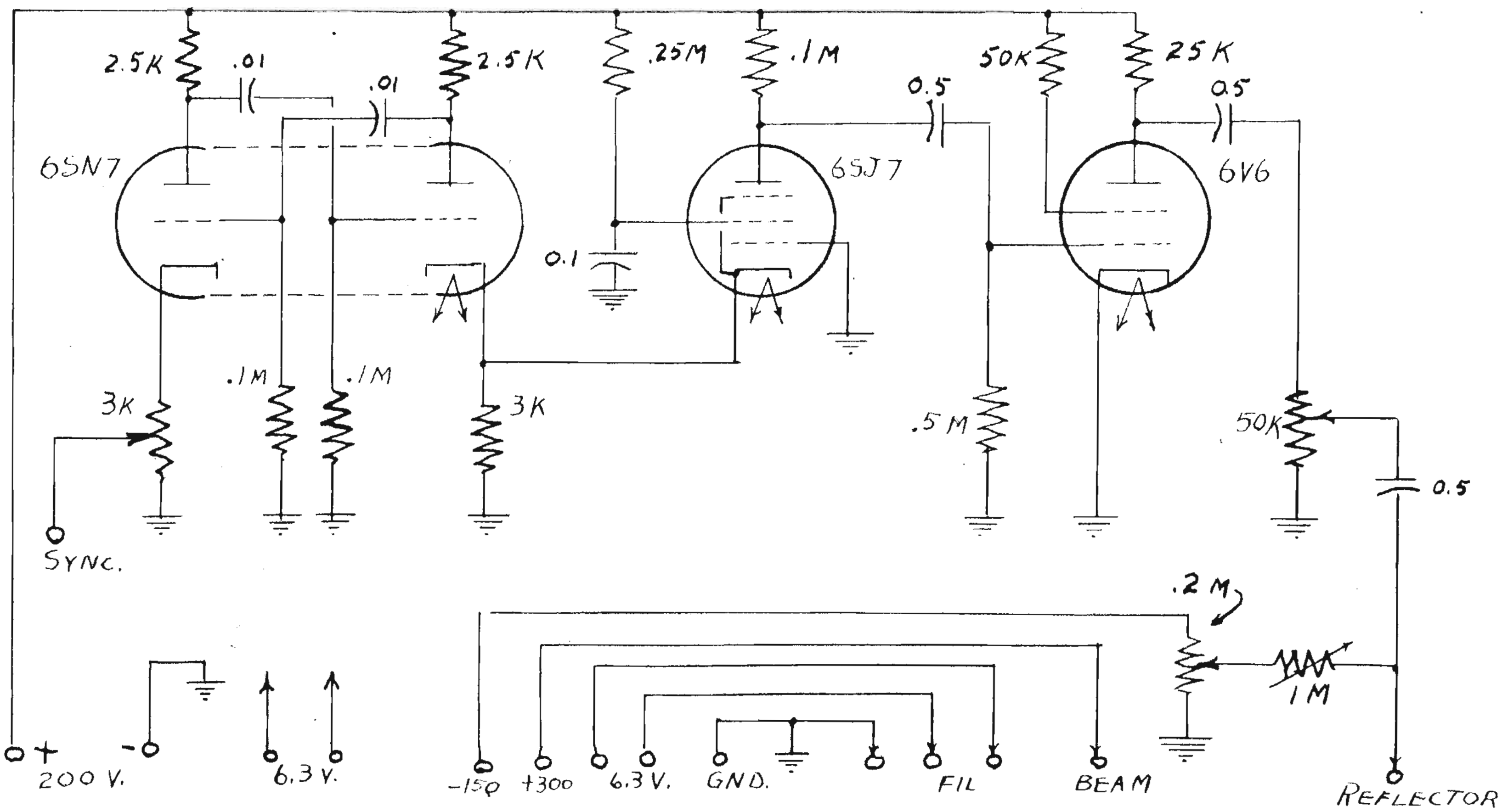

Figure (7) Schematic diagram of modulator and control panel.

with the control panel is a meter panel with voltmeters to read the beam potential and repeller potential and a milliammeter to read the beam current to the klystron. These meters are connected in at appropriate points for monitoring the necessary voltages and currents.

Receiver-analyzer

The receiver-analyzer portion of this polarimeter is decidedly unique in construction. The requirement was a receiver sensitive to only one plane of polarization that could be rotated continuously on an axis in line with the transmitted energy from the polarizer. Rotating joints for waveguide have been used extensively in radar work but a search revealed no type suitable for this requirement. All previous designs were for joints that allow lateral or azimuth rotation without a change in the plane of polarization but none for axial rotation without the change in polarization. Figure (8) is a photograph of the receiver that was developed for this instrument, page 27.

A short length of waveguide with its associated choke flange, the same as is used in the transmitter-polarizer, is mounted in lubricated bearings cast of lead with brass sleeves. These are mounted on a wood frame. This allows free axial rotation of the waveguide with the receiving horn attached to the choke flange. The opposite end of the section of waveguide supports the special rotating coupling.

A machined brass plug fits snuggly into the end of the

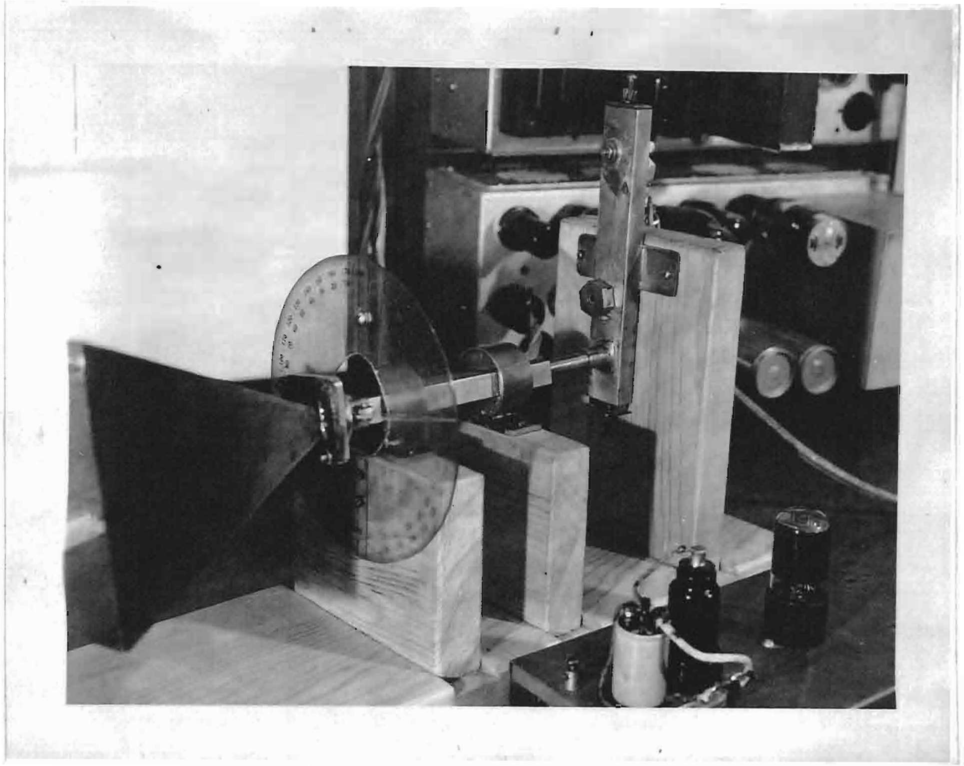

Figure (8) Close-up of the receiver-analyzer. The receiver amplifier may be seen in the lower right foreground.

waveguide. Through this plug extends a brass tube, one-eighth inch inside diameter, which serves as the outside conductor of a co-axial line centered in this tube. A wire, terminating at the inside of the brass plug in a small loop .4 centimeters in diameter, serves as the center conductor of the line. The orientation of this loop determines the response of the receiver to the plane of polarization of the energy in the waveguide. In this case the response must be limited to transverse electrostatic fields (TE 1,0) only. As all waves have associated magnetic fields at right angle to the electrostatic field the solution to obtaining a plane polarized response in the end (plug) of the guide is to mount this loop to respond only to the electromagnetic lines which are parallel to the long dimension of the guide. The use of this small loop with its axis parallel to the long dimension of the guide to link only the magnetic lines of force appearing across the long dimension of the guide allows a co-axial line to pass out the geometric center of the plug in the guide. As far as could be determined this type of coupling has not here-to-fore been used. All commercial line-to-waveguide couplings make use of a quarter wave probe placed parallel to the electrostatic lines of force in the guide. This requires a wire across the short dimension of the guide which necessitates a connection through the side of the guide which would, in this case, interfere with axial rotation of the receiving horn. A detail of this special coupling is shown in figure (9), page 29. Figure (10), page 30, is an "explo-

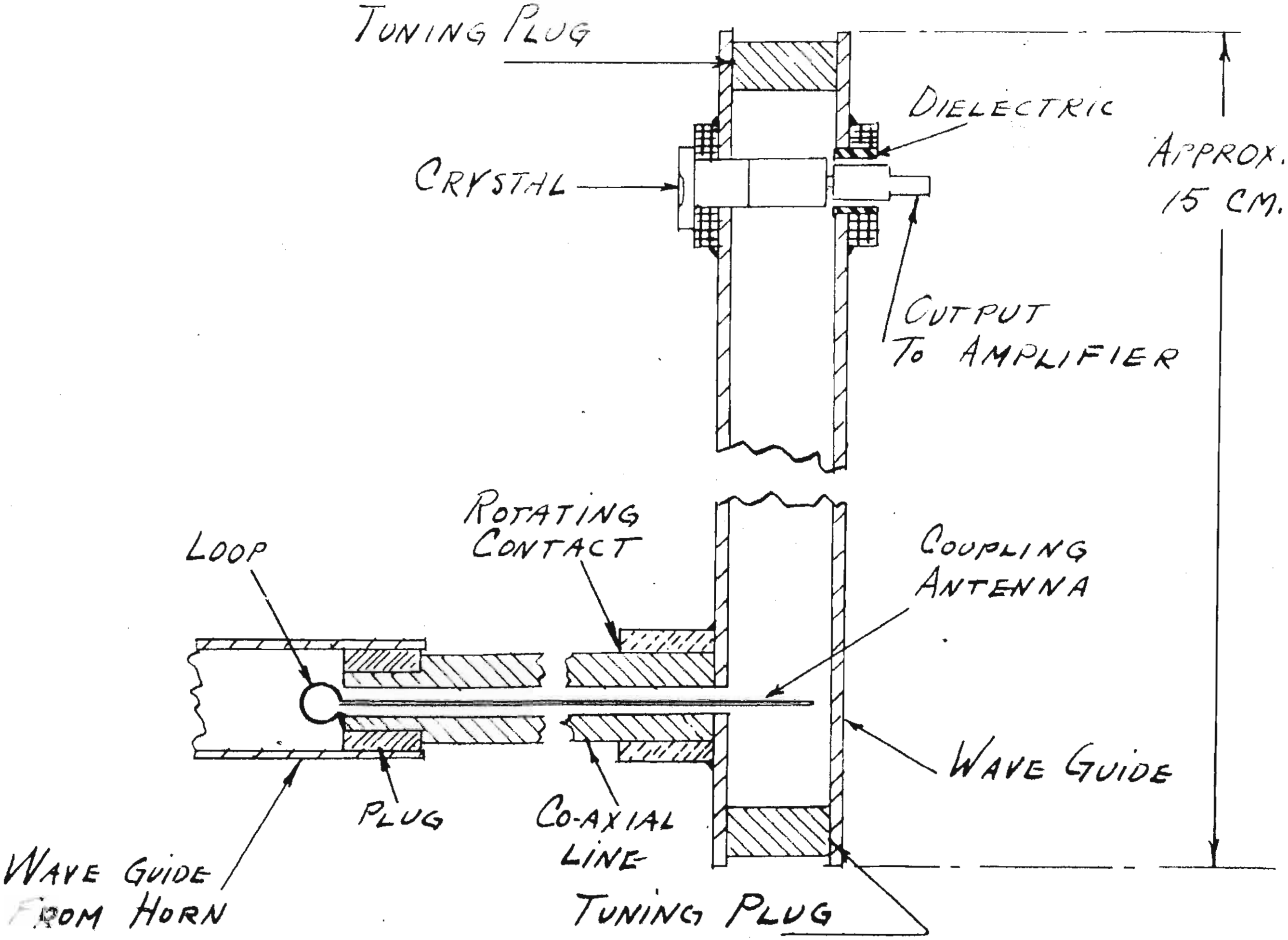

Figure (9) Detail of receiver-analyzer rotating joint and crystal mount

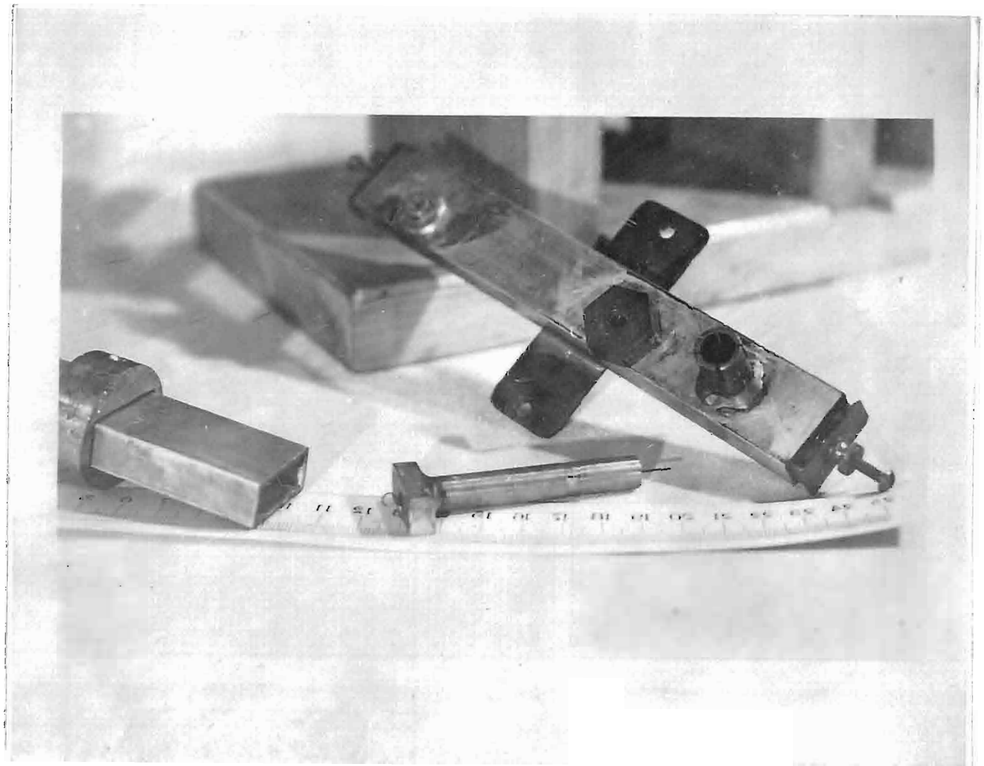

Figure (10) "Exploded" view of the special rotating joint used on the receiver-analyzer. The scale shown is a galvanometer scale and is calibrated in millimeters. The extra hexagon fitting on the wave guide is a choke joint for a klystron local oscillator in case super-hetrodyne reception is desired.

ded" view of the special rotating joint. The small loop supports the center wire of the co-axial tube by the side of the loop soldered to the plug. This makes a rigid support without the use of insulating materials.

The other end of the co-axial tube rotates in a slip ring arrangement to allow free mechanical movement with good electrical contact. A quarter-wave choke here would reflect zero resistance to the two contacting surfaces and would be an added refinement. Coupling to the waveguide semi-resonant cavity is usual through the use of the familiar quarter-wavelength probe through the side of the guide. The probe at this end of the co-axial tube is supported by a thin film of acetate glue placed at a point of low electrical impedance. The moveable tuning plug shown assures the passage of energy from the probe toward the crystal detector across the cavity at the other end. The crystal is placed slightly off center across the short dimension of the waveguide cavity to afford a better impedance match of the crystal characteristics to the guide or cavity impedance. The systems used tune with surprising ease and stability.

A microammeter attached to the crystal could be used to indicate the received signal. However, to increase sensitivity the amplitude modulation voltage appearing across the crystal is amplified and then indicated on a vacuum tube voltmeter. The vacuum tube voltmeter used in the measurements subsequently made was a Silver "Vomax", model 900. Any good instrument with a constant input impedance can be used. A circuit of the receiver amplifier appears in figure (11), page 33.

Horn antennas

The antennas used in this instrument are identical for receiver and transmitter and are of standard pyramidal form. Other types can be attached to the choke flanges whenever a special wave, such as circular polarization, is desired. The pyramidal horns are constructed of copper sheet soldered together and soldered to square flanges for attaching to the standard choke flange furnished on the waveguide sections used.

An angle of flare in the horizontal plane is 40 degrees. This angle was chosen to give greatest attenuation of other unwanted modes or planes of polarization while giving maximum gain to the transverse electrostatic plane of polarization. The length, chosen mainly for constructional ease, is five wavelengths or 16 centimeters length. The flare in the vertical plane is also 40 degrees. The flare in this plane is not absolutely necessary but was incorporated mainly to give a sharper beam of energy in the vertical plane. The angle used was selected for the same reasons as the other 40 degree angle, attenuation of unwanted modes and gain for the preferred planes of vibration. The calculated beam width with the dimensions used is approximately 20 degrees.

According to theory, the area of the opening of the horn becomes a phantom array of phased dipoles. The greater

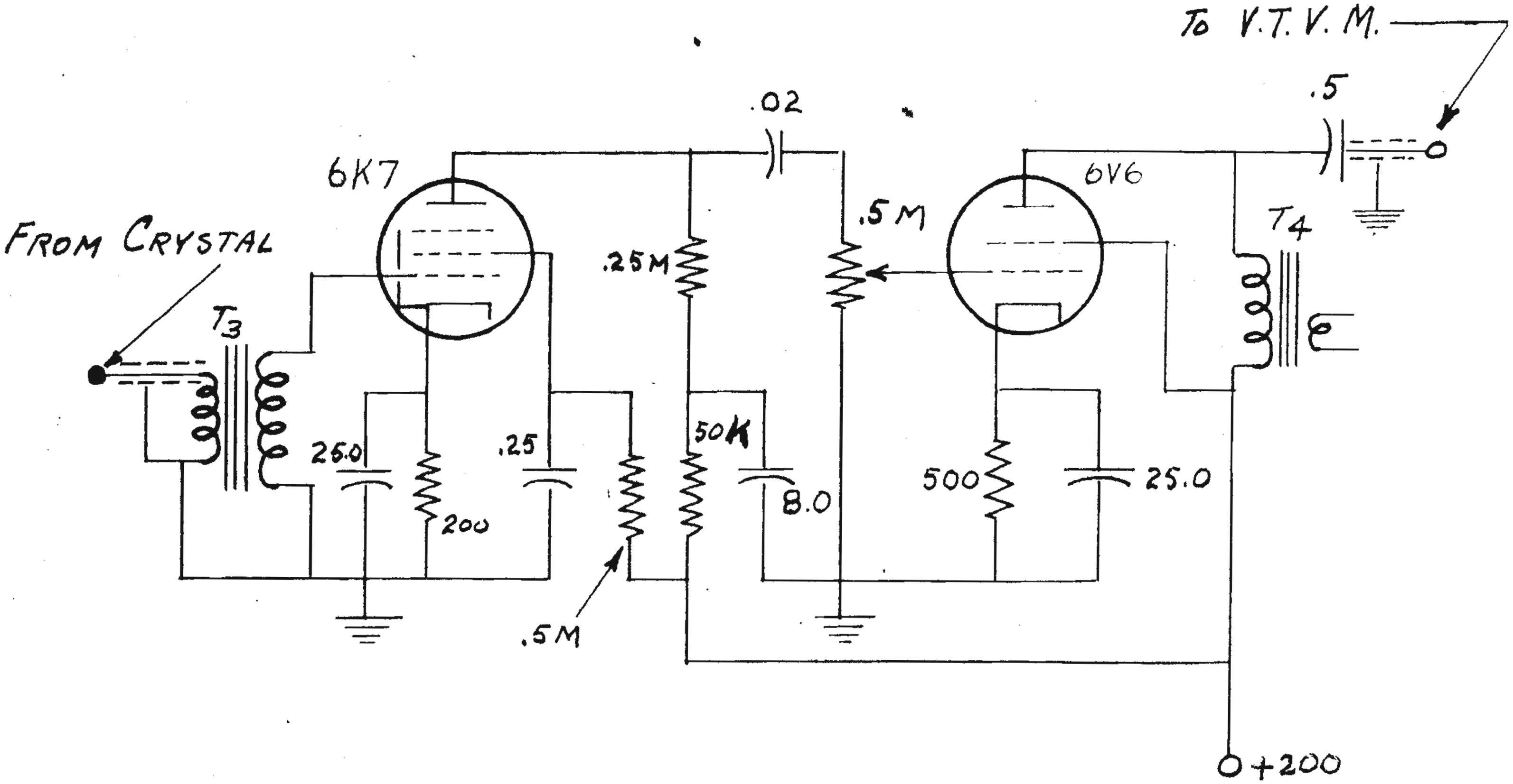

Figure (11) Schematic diagram of receiver amplifier the area, the larger the number of phased units. This accounts for the sharp response of the horn antenna.

Operation of the polarimeter

In operation the polarizer is clamped to one end of a table while the receiver-analyzer is clamped a short distance away facing the transmitter. A compass rose, made of celluloid protractors, is fixed to the base of the receiver with the rotating section of waveguide passing through its center. A pointer on the rotating part indicates the angular movement. These protractors are marked to one-half degree divisions.

With the correct voltages applied to all necessary units the receiver-analyzer horn is rotated in small angular steps as readings indicated on the vacuum tube voltmeter are recorded for graphing on polar coordinate paper. Devices and samples to influence the plane of polarization of the received energy are placed between the polarizer and analyzer with the resulting data being recorded as above in each case.

The graphs of the voltage readings are not true pictures of the polarization planes or polarization characteristics of the received waves but these characteristics may be deduced from them. If the resulting curves do not reach true nodes at two 180 degree separated settings of the horn the analyzed wave is probably elliptically polarized. The character or shape of this ellipse may be shown graphically by drawing the normals to the angular lines at the points representing the voltage for that angle. These normals will be tangent to the ellipse of the received wave. If drawing these normals does not produce an ellipse and the voltages read do show true nulls the received wave is plane polarized. The plane of polarization indicated as above is parallel to a line drawn through the nulls. Observation of the graph of readings taken to calibrate the instrument, figure (12), page 36, will clarify this point.

A further refinement of this method of taking readings is contemplated. It is planned to rotate the analyzer horn continuously about one-half revolution per second with a selsyn motor. This motor will be synchronized with a circular sweep applied to an oscilloscope with a long persistence screen, somewhat on the order of a PPI radar system. This way, the plane of polarization will appear instantaneously and any change in the polarizarion characteristics of the received wave will be easily recorded.

Measurements and results

Preliminary calibration showed this instrument accurate enough to read planes of polarization to within 3 degrees. This is shown on a graph taken with nothing placed between the polarizer and analyzer, figure (12), page 36. The graph shown has been reduced in size for reproduction. In actual practice a large scale graph, especially through the range of the nulls, is drawn to determine the plane of

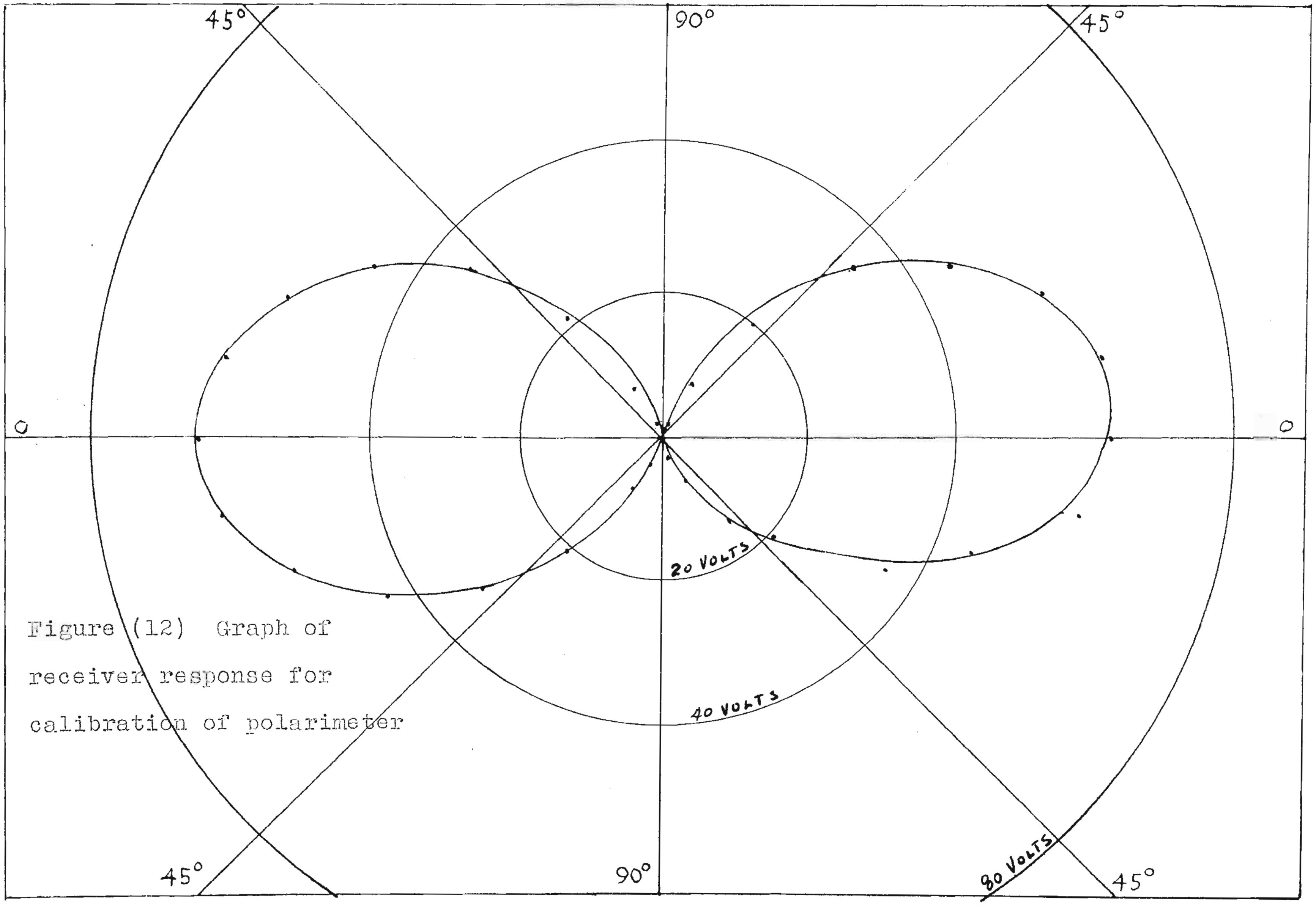

Figure (12) Graph of receiver response for calibration of polarimeter polarization. A larger graph shows the nulls to be very sharp where the voltage at these points drops to the zero reference. This reference zero is determined by allowing the receiver amplifier to operate with the transmitter and modulator turned off. The voltage indicated under these conditions represents the noise output generated in the circuit of the amplifier. In all the measurements made this reference zero was 0.8 volt or less.

The graph shown in figure (12) is one of five drawn using different amplifications to determine any variations due to the amplifier characteristics. Since all five graphs differed only in scale, only one is reproduced here. The shapes of the five curves obtained were practically identical.

Faraday effect

An attempt was made to determine if the Faraday magneto-optic effect could be measured by this instrument with the limited facilities available. The results obtained were inconclusive. It would not be correct, however, to say the results were negative. With proper equipment this effect would probably be within the measurable range of this instrument.

The pole pieces of a 110 volt direct current electromagnet, of a type similar to the Cenco number 79650,(11)

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(11) Made by Central Scientific Company, Chicago, Illinois.

were removed and replaced with iron tubing of 3.5 centimeters inside diameter, 4.7 centimeters outside diameter. The inside of the hollow pole pieces thus formed becomes a section of circular waveguide to propagate a TE 1,1 or H_1 wave.(12)

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(12) See F. E. Terman, Radio Engineers Handbook, pp. 258-260

In the space between the two hollow pole pieces was placed a plastic sample. In the cases tried, Bakelite, Tenite I, and Tenite II samples, 2.6 centimeters thick, were used.

According to Faraday's optical experiments, the plane of polarization of light rotates slightly when a refracting material is placed in a strong magnetic field and the light is passed through parallel to the magnetic lines of force. The results of the above trial failed to produce any measurable rotation. Possible reasons for the failure will include:

a. The magnetic field, though not measured, was relatively weak with the hollow pole pieces.

b. Most of the energy probably did not propagate directly through the waveguide pole pieces though shields were used.

c. The distance through the dielectric was not great enough (less than one wavelength).

d. The waveguide pole pieces were not matched to space for a traveling wave and so most energy was reflected at the discontinuities in the pole pieces. Horn terminations would probably aid impedance matching here.

The graphs obtained showed no rotation within a limit of about five degrees. The shape of the two lobes representing the receiver response were slightly distorted due to the presence of the magnet parts in the radio frequency field. The response of the analyzer was broadened to the above mentioned five degrees because the signal that did arrive at the analyzer was very weak. The graphs are not reproduced here since they show nothing of interest and were practically identical with, and without, the magnetic field.

The only conclusion to state is that further experiment with more adequate facilities for producing a strong magnetic field over a distance of dielectric filled circular wave guide with better impedance matching would prove of value.

Rotation of the plane of polarization by sheet dielectrics

While calibration tests were being made an interesting phenomenon appeared which, at the present time, is unexplained in the light of present practice. This effect was a "pseudo" optical activity showed by dielectric sheets when placed parallel to the direction of transmission from polarizer to analyzer and tilted at 45 degrees to the plane of polarization. A rotation of the plane of polarization of many degrees can be measured.

Most data on dielectric sheets in microwave applications refers to their use inside waveguides. There is some mention of measurement of dielectric constants of sheet dielectrics in free space(13) but these are only concerned with incidence of the wave on the face of the sheet. The measurements made this way involve the measurement of the phase differences in transmission through the dielectric. A thin sheet of dielectric placed across a wave guide perpendicular to the plane of polarization has no effect on the propagated wave. If a thin sheet of dielectric is placed in a wave guide parallel to the plane of polarization of the mode excited in the waveguide the result is attenuation of the transmitted wave. The attenuation depends upon the characteristic loss tangent of the dielectric involved. Actual attenuators of this form are used where the dielectric is purposely made "lossy" by application of graphite or equivalent either to the surfaces or throughout the material. These above described effects were noted to exist in the same manner when the dielectric was in free space, i.e., outside the waveguide.

In every case, above, the polarization of the wave was unaffected by the presence of the dielectric.

Another use of dielectrics inside a waveguide section has been previously described where the dielectric is used to change the polarization characteristics of the

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(13) C. G. Montgomery, Technique of Microwave Measurement, Ch. 10, The Measurement of Dielectric Constants, by R. M. Redheffer, pp. 561-672

wave. This is the work of Stavis and Dorne with a circularly polarized horn antenna described on page 12. Though many factors enter, the basic idea is that an elliptical polarization of the emitted wave results from the phase retardation of one component of the polarization vector when the plane of polarization is obliquely incident on the edge of the sheet placed in the waveguide. The circularly polarized wave is a special case of the elliptical effect.

One would naturally expect the above effect to hold in the case of a wave whose plane of polarization is obliquely incident on the edge of a sheet of dielectric in free space. With the polarimeter described, a measurement was made but the elliptical effect was absent.

The results of observations made are shown graphically in figures (13), (14), (15), (16), and (17) on pages following.

Figure (13) is a graph of the effect on the plane of polarization of a sheet of Pyralin, cellulose nitrate, 0.22 centimeters thick and 15 centimeters wide, when placed at an angle of 45 degrees with the emitted plane of polarization from the transmitter-polarizer. The sheet faces were parallel to the direction of transmission. The length of the sheet was sufficient to extend well beyond the edges of the beam transmitted from the horn antenna. As is shown on the graph, the plane of polarization is rotated 31 degrees away from the plane of the sheet at 45 de-

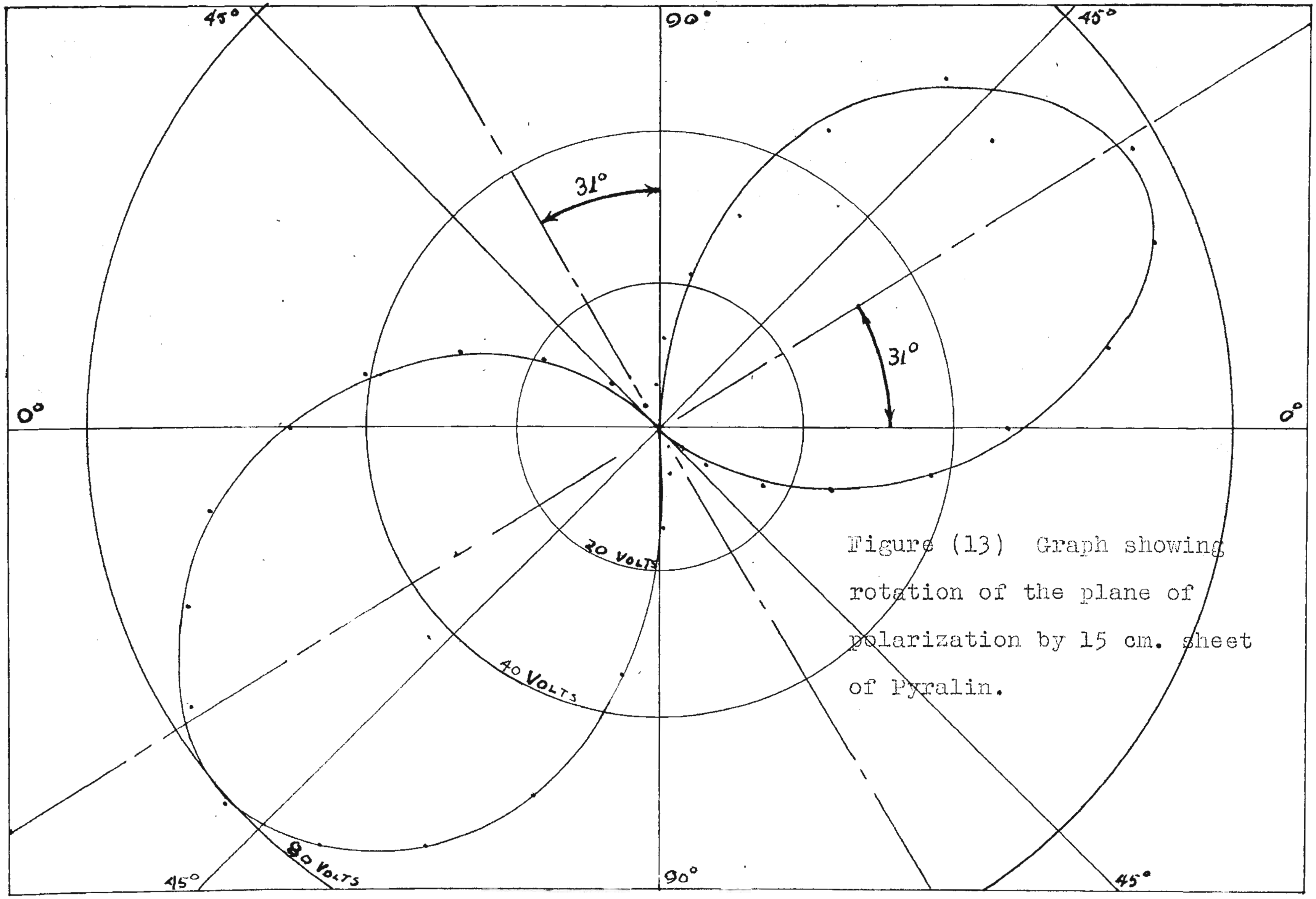

Figure (13) Graph showing rotation of the plane of polarization by 15 cm. sheet of Pyralin.

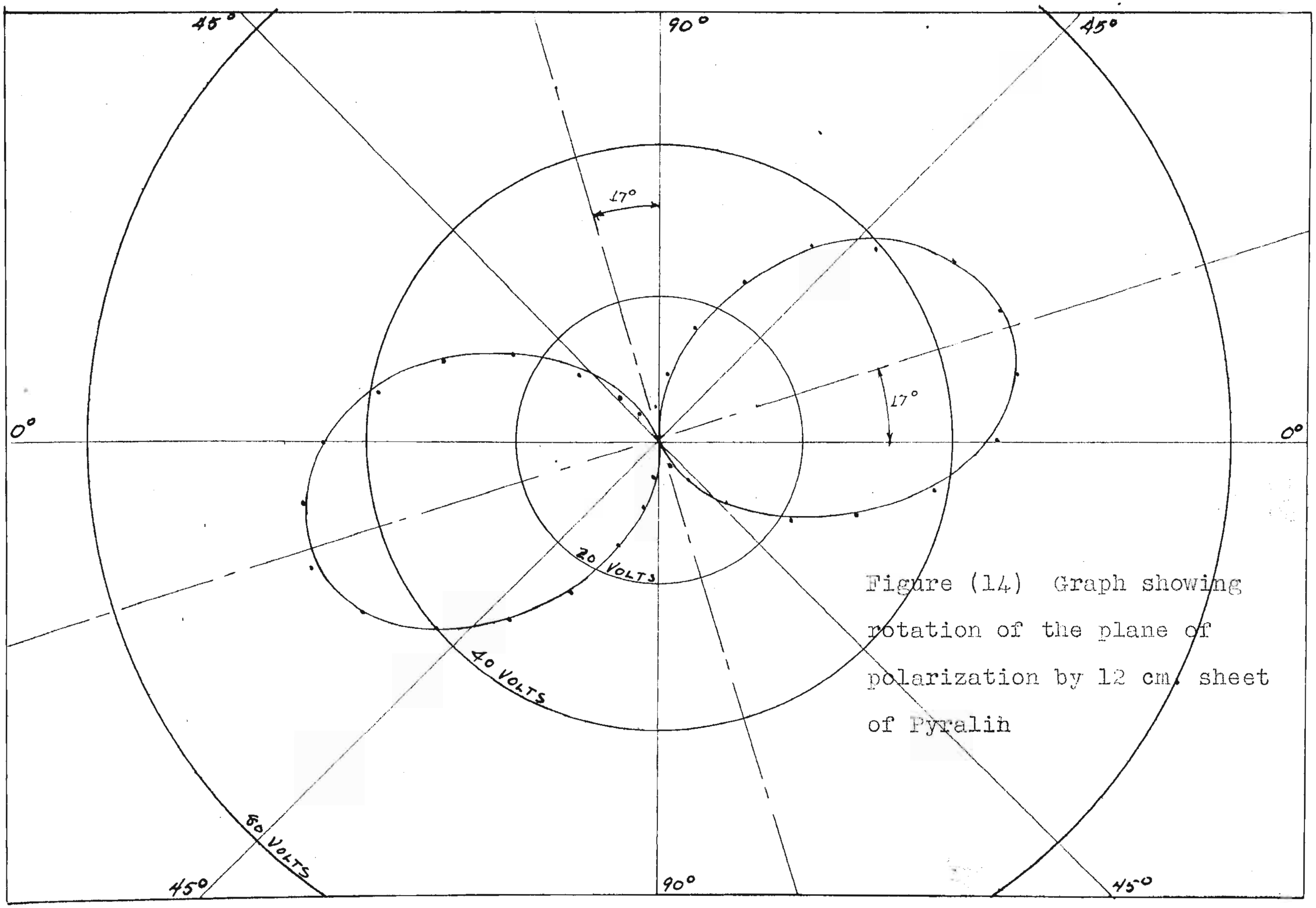

Figure (14) Graph showing rotation of the plane of polarization by 12 cm. sheet of Pyralin

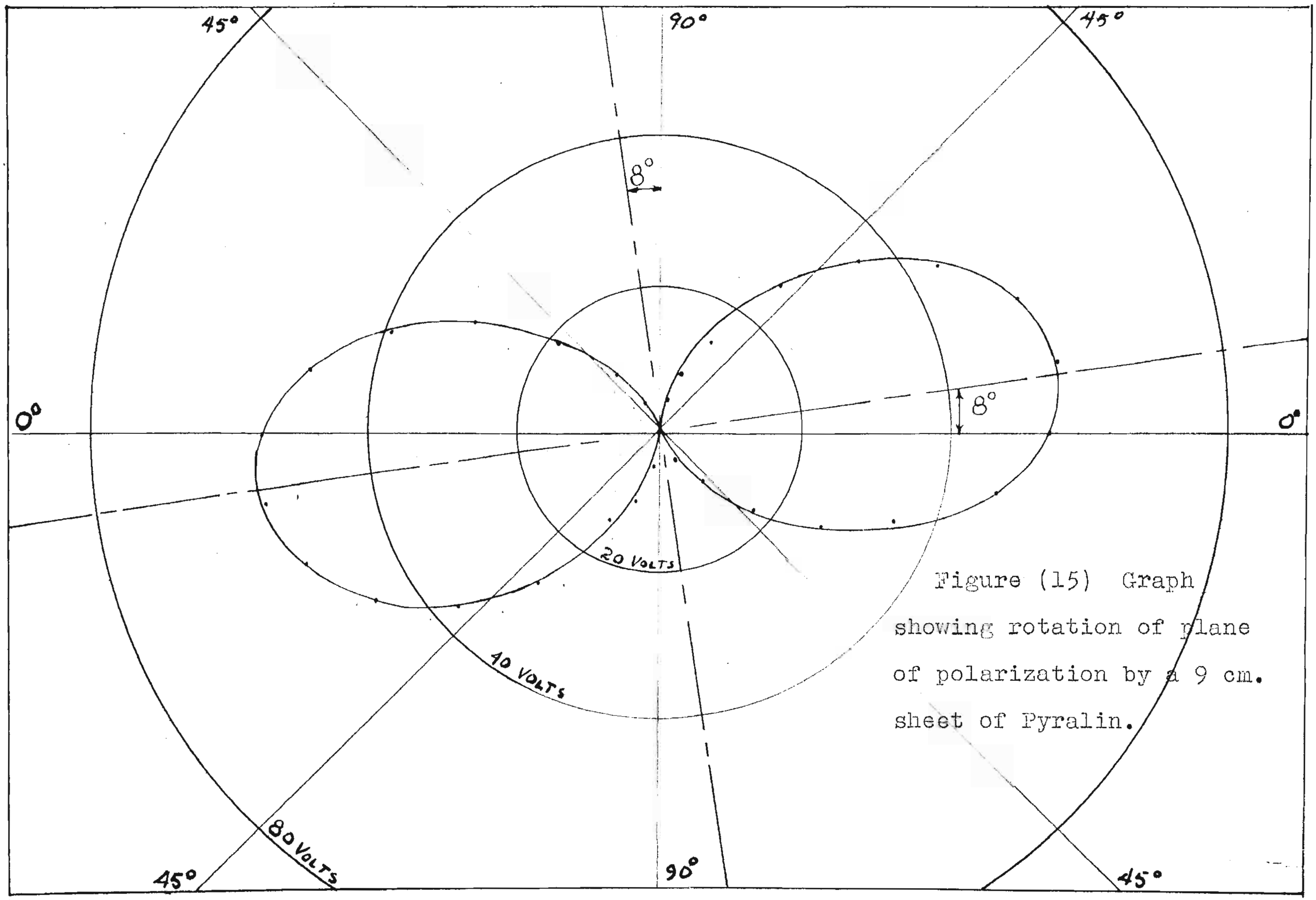

Figure (15) Graph showing rotation of plane of polarization by a 9 cm. sheet of Pyralin.

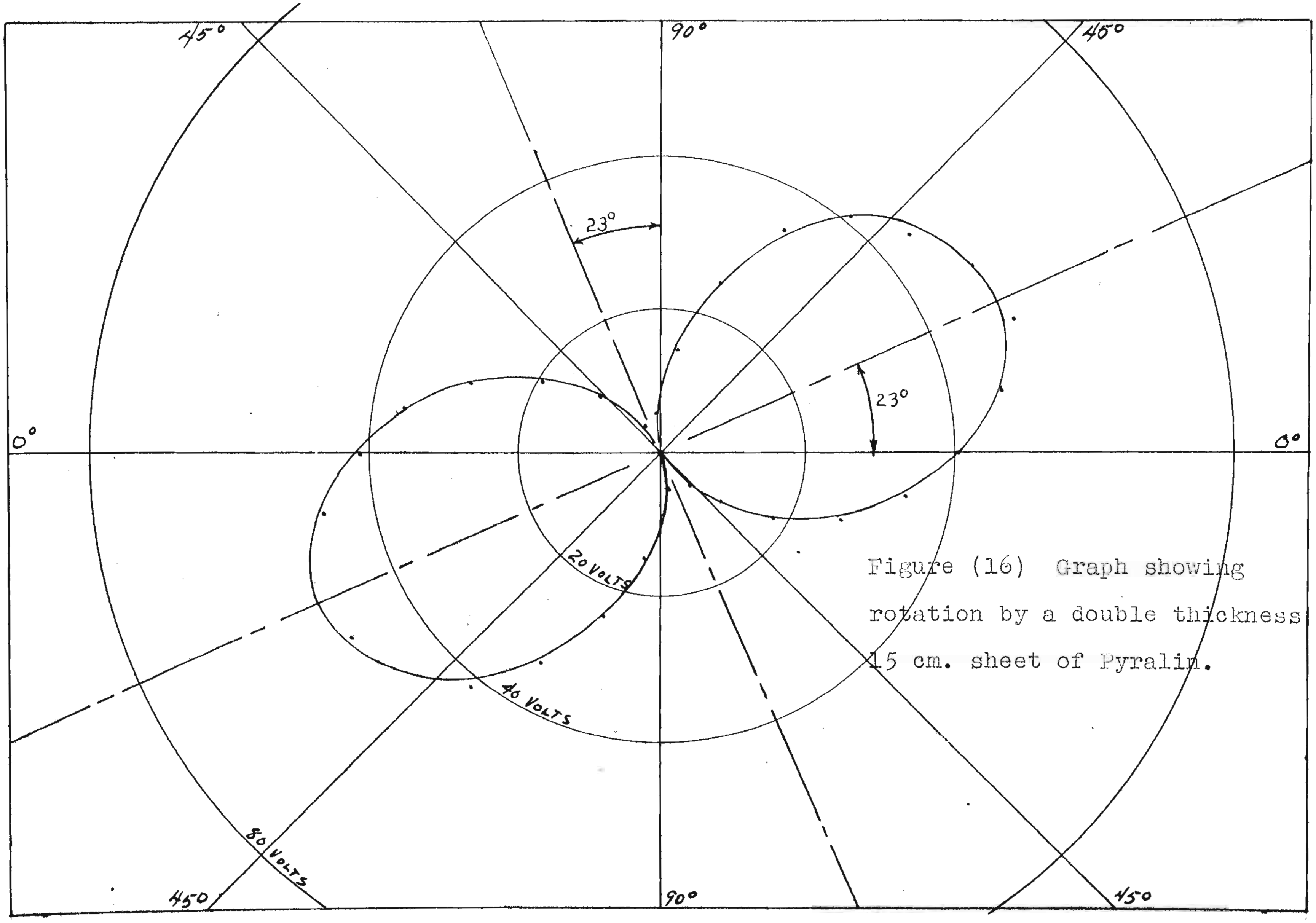

Figure (16) Graph showing rotation by a double thickness 15 cm. sheet of Pyralin.

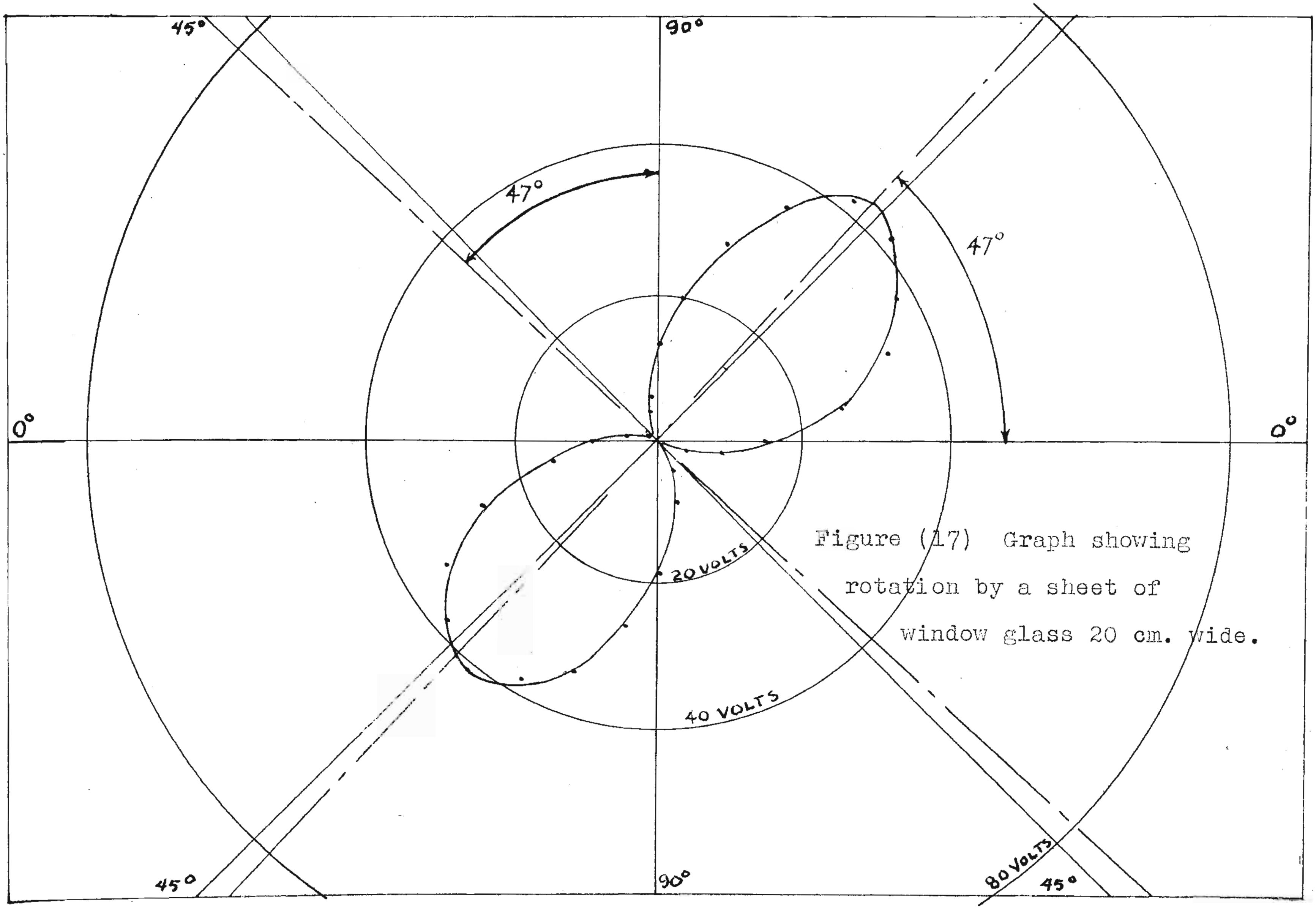

Figure (17) Graph showing rotation by a sheet of window glass 20 cm. wide.

grees. A check for the elliptical effect shows none present. The nulls drop directly to the reference zero.

Since 15 centimeters is close to 5 wavelengths in free space (3.2 centimeters wavelength, 5 wavelengths equals 16 centimeters)sheets of the same material 12 centimeters in length (4 wavelengths) and 9 centimeters in length (3 wavelengths) were tried with the results shown in figures (14) and (15) respectively. Sheets of one and two wavelengths wide were tried with an extension of the results. The 3 centimeter width gave practically no rotation. Graphs of the one and two wavelength widths are not included as they show nothing extra. The question of received amplitudes was checked and shows there is little attenuation of the received signal from normal conditions when nothing is inserted between the polarizer and analyzer. Though all the graphs shown are drawn to the same scale, the extent of the lobes is not representative of the received amplitudes since they were made with different settings of the receiver amplifier gain control.

The thick sheets of Tenite I and II, which were used in the attempt to measure the Faraday effect, being available the effect of a thick sheet of material was investigated. The 2.6 centimeter thick sheets of Tenite had no effect on the signal except a slight attenuation. The effect of thickness in the same material as tried before, Pyralin, was investigated by doubling the thickness of the 15 centimeter sheet to 0.44 centimeter. The graph obtained is shown in figure (16), page 45. Comparing this to figure (13), page 42, shows a reduction in the rotation due to the increased thickness. A paper thin (o.008 centimeter) sheet of cellulose nitrate material was tried with no rotation of the plane of polarization. Twice the thickness (0.016 centimeter) produced no measurable rotation also. The 0.22 centimeter thick sheet seems to be near an optimum for the material used.

Other dielectric materials were tried. Figure (17), page 46, is a graph of the effect of a sheet of ordinary window glass 0.231 centimeters thick and 20 centimeters wide. The rotation, though different in amount, is present with the absence of any elliptical polarization characteristics. A thick sheet of plate glass 0.62 centimeters thick gave a small rotation of the plane of polarization. Since it had a different composition from the above glass a graph is not included. The rotation measured was about eight degrees. Other materials, such as Polystyrene and celluloid, were tried as available and showed similar results to those above.

A summary shows the following:

a. The maximum effect is measured when the plane of incidence is at 45 degrees to the plane of the sheet.

b. The rotation is proportional to some function of the width of material used increasing with an increase in width.

c. The rotation is maximum at some intermediate thickness between 0.1 to 0.05 free space wavelength (for the materials tried).

d. The resulting rotated wave is still plane polarized.

e. The rotation varies for different dielectric materials.

f. Conductors of the same general dimensions have no effect on the plane of polarization.

Conclusions

The instrument described will measure the polarization planes as effected by various objects and fields within less than five degrees. A possible limit might be set at three degrees accuracy as measurements so far indicate. Since this is a different approach to the study of microwave radio and radio wave polarization and the first model of such a device, further improvements in both construction and applications will, no doubt, increase the accuracy and limiting angle of measurement. Further research along these lines is contemplated.

In the case of the measurement of optical effects in this wavelength region, such as the Faraday effect and the Kerr effect, improvements in technique and facilities will produce results. Some have been indicated in the discussion of the attempted measurement of the Faraday effect.

The plane polarized response of the dielectric sheets may be likened to the optically active materials that have been studied in optics. Attempts have been made to tie the observed effect to previous work in optics and radio waves but as yet, no key to this result has been found. There might be a possibility of measuring dielectric constants of sheet materials with this effect though all present equations for this make use of the elliptical polarization results(14) as a dielectric retards the passage of an electromagnetic wave.

It is too early to make any definite statements concerning the possibilities of the above effects and possible future applications of a study of microwave polarimetry. An investigation of transmission polarization effects has only been started while the field of reflections in this view has not even been touched.

The wavelength here is small enough to allow use of single crystals of substances which may be obtained of large size. An instrument of this same type can be built for even shorter wavelengths for which supplies are readily available. 1.25 centimeter wavelengths should be easily obtained.

Further work in this line should prove interesting and perhaps fruitful.

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(14) See appendix, page 51.

APPENDIX

An elliptically polarized wave may be obtained if two simultaneous fields are radiated in which the E vectors are at right angles to each other and are out of phase. If the fields are equal in intensity and 90 degrees out of phase the resulting wave is considered to be circularly polarized. In general, this case is not realized and the phase angle has any arbitrary value.

Let $E_1 \sin \omega t$ express the value of the electric vector in the horizontal plane or X-direction and $E_2 \sin (\omega t - \beta)$ represent the vertical or Y-direction electric vector where β represents any arbitrary value of the phase angle. The instantaneous value of the field will be the vector sum of these two quantities. The locus of the resultant, r, can be found as follows:

$$X = E_1 \sin \omega t \ldots\ldots\ldots\ldots (a)$$

$$Y = E_2 \sin(\omega t - \beta) \ldots\ldots\ldots (b)$$

$$= E_2 (\sin \omega t \cos \beta - \cos \omega t \sin \beta) \quad (c)$$

From (a): $\sin \omega t = \frac{X}{E_1} \ldots\ldots\ldots\ldots\ldots (d)$

Substituting (d) in (c) gives:

$$\frac{Y}{E_2} = \frac{X}{E_1} \cos \beta - \left(\sqrt{1 - \frac{X^2}{E_1^2}}\right) \sin \beta$$

and:

$$\frac{Y^2}{E_2^2} - \frac{2XY \cos \beta}{E_1 E_2} + \frac{X^2}{E_1^2} = \sin^2 \beta \ldots\ldots (e)$$

This is the equation of an ellipse with its center at the origin. If $\beta = 90$ degrees and $E_1 = E_2$ then equation (e) becomes the equation of a circle with center at the origin and radius E_1. E_1 and E_2 may be components of an original wave where E_2 is caused to lag by a phase angle β behind E_1 by causing E_2 to pass through a dielectric while E_1 is unaffected in its velocity.

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VITA

Alfred E. Schwaneke was born on June 3, 1916 at Kansas City, Missouri. He graduated from Central High School, Kansas City, in 1933 and attended one year, 1933 to 1934, at Kansas City Junior College. He received his amateur and commercial radio licenses in 1933 and spent the years 1934 to 1936 operating at various radio stations. From 1936 to 1939 he attended Kansas City Teachers College leaving there as a senior to attend Central Missouri State College, Warrensburg, Missouri. He received the degree of Bachelor of Science in Education, Physics Major, in the summer of 1940. 1940 to 1941 was spent teaching high school science for the Sullivan Public Schools, Sullivan, Missouri. In July, 1941, he signed aboard the SS Tidepenn as a radio officer in the United States Merchant Marine. In 1942 he joined the Missouri State Highway Patrol for seven months as a radio operator leaving in December, 1942, to teach education as an instructor at St. Louis University. In July, 1943, he became an instructor in physics at Central Missouri State College. In the fall of 1945 he went into the retail radio business at Sullivan, Missouri. The business was closed in September, 1946, to teach as an instructor in physics at the Missouri School of Mines, Rolla.